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Technical Brief

Number 22

Environmental Cleaning for the Prevention of Healthcare-Associated Infections

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Preface

The Agency for Healthcare Research and Quality (AHRQ), through its Evidence-based Practice Centers (EPCs), sponsors the development of evidence reports and technology assessments to assist public- and private-sector organizations in their efforts to improve the quality of health care in the United States. The reports and assessments provide organizations with comprehensive, science-based information on common, costly medical conditions and new health care technologies and strategies. EPCs systematically review the relevant scientific literature on topics assigned to them by AHRQ and conduct additional analyses when appropriate before developing their reports and assessments.

This EPC evidence report is a Technical Brief. A Technical Brief is a rapid report, typically on an emerging medical technology, strategy, or intervention. It provides an overview of key issues related to the intervention—for example, current indications, relevant patient populations and subgroups of interest, outcomes measured, and contextual factors that may affect decisions regarding the intervention. Although Technical Briefs generally focus on interventions with limited published data and too few completed protocol-driven studies to support definitive conclusions, the decision to request a Technical Brief is not solely based on the availability of clinical studies. The goals of the Technical Brief are to provide an early objective description of the state of the science, a potential framework for assessing the applications and implications of the intervention, a summary of ongoing research, and information on future research needs. In particular, through the Technical Brief, AHRQ hopes to gain insight on the appropriate conceptual framework and critical issues that will inform future research.

AHRQ expects that the EPC evidence reports and technology assessments will inform individual health plans, providers, and purchasers as well as the health care system as a whole by providing important information to help improve health care quality.

We welcome comments on this Technical Brief. They may be sent by mail to the Task Order Officer named below at: Agency for Healthcare Research and Quality, 540 Gaither Road, Rockville, MD 20850, or by email to epc@ahrq.hhs.gov.

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Key Informants

In designing the study questions, the EPC consulted a panel of Key Informants who represent subject experts and end users of research. Key Informant input can inform key issues related to the topic of the Technical Brief. Key Informants are not involved in the analysis of the evidence or the writing of the report. Therefore, in the end, study questions, design, methodologic approaches, and/or conclusions do not necessarily represent the views of individual Key Informants.

Key Informants must disclose any financial conflicts of interest greater than $10,000 and any other relevant business or professional conflicts of interest. Because of their role as end users, individuals with potential conflicts may be retained. The Task Order Officer (TOO) and the EPC work to balance, manage, or mitigate any conflicts of interest.

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Before publication of the final evidence report, EPCs sought input from independent Peer Reviewers without financial conflicts of interest. However, the conclusions and synthesis of the scientific literature presented in this report does not necessarily represent the views of individual reviewers.

Peer Reviewers must disclose any financial conflicts of interest greater than $10,000 and any other relevant business or professional conflicts of interest. Because of their unique clinical or content expertise, individuals with potential nonfinancial conflicts may be retained. The TOO and the EPC work to balance, manage, or mitigate any potential nonfinancial conflicts of interest identified.

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Environmental Cleaning for the Prevention of Healthcare-Associated Infections

Structured Abstract

Background: The cleaning of hard surfaces in hospital rooms is essential for reducing the risk of healthcare-associated infections. Many methods are available for cleaning and monitoring cleanliness, but their comparative effectiveness is not well understood.

Purpose: This Technical Brief summarizes the evidence base addressing environmental cleaning of high-touch surfaces in hospital rooms and highlights future research directions.

Methods: A systematic search for published and gray literature since 1990 was performed using PubMed, EMBASE, CINAHL, the Cochrane Library, and other resources. Clinical studies examining the cleaning and disinfection of high-touch surfaces in adult inpatient hospital rooms were included. Primary outcomes of interest were patient infection, colonization, or surface contamination with Clostridium difficile, methicillin-resistant *Staphylococcus aureus*, or vancomycin-resistant *enterococci*. Additionally, 12 Key Informants were interviewed, representing environmental services management, hospital infection control, and clinical infectious diseases.

Findings: Eighty studies were included. Forty-nine studies examined cleaning modalities, including chemical agents, self-disinfecting surfaces, and no-touch technologies. Fourteen studies evaluated monitoring strategies, including visual inspection, microbiological cultures, assays, and ultraviolet light. Seventeen studies addressed challenges or facilitators to implementation. Sixty-five studies used nonrandomized concurrent or historical controls. The outcome of surface contamination was reported in 57 studies; infection rates were reported in 25.

Conclusions: Comparative-effectiveness studies directly comparing disinfection modalities and monitoring strategies are limited. Future research should examine and compare newly emerging strategies, such as peracetic acid, hydrogen peroxide wipes, enhanced coatings, and microfiber cloths as cleaning strategies, and adenosine triphosphate and ultraviolet light technologies as monitoring strategies. Patient colonization and infection rates should be included as outcomes when possible. Other challenges to be addressed include identification of surfaces posing the greatest risk of pathogen transmission, developing standard thresholds for defining cleanliness, and using methods to adjust for confounders such as hand-hygiene practices when examining the impact of disinfection modalities.

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Background

Introduction

Environmental cleaning (EC) is a fundamental principle of preventing infection in the hospital setting. Both porous surfaces (e.g., mattresses) and nonporous surfaces (e.g., bed rails) in patient rooms are highly susceptible to bacterial contamination with dangerous pathogens, including *Clostridium difficile,* and antibiotic-resistant organisms such as methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *enterococci* (VRE), and multiple species of *Acinetobacter* (*Acinetobacter* spp). Hard, nonporous surfaces, which include common items such as furniture, bed rails, and medical equipment, as well as fixed spaces like floors and bathroom facilities, form part of the environmental reservoir that can lead to significant microbial contamination. The potential for these contaminated environmental surfaces contributing to transmission of pathogens has been most clearly established for certain key health-care-associated pathogens, including MRSA, VRE, *C. difficile*, and *Acinetobacter* spp.[1-4] These nosocomial pathogens can survive on inanimate surfaces for prolonged periods. For example, gram-positive organisms such as MRSA and VRE have been shown to persist on dry surfaces for several weeks to months.[5-7] *C. difficile* spores have been shown to survive in the environment for as long as 5 months.[8] Appropriate cleaning of these surfaces is an important part of an overall strategy to reduce the risk of health-care-associated infections (HAIs). However, little consensus exists for optimal approaches to EC. Both the physical action of cleaning surfaces and applying a disinfectant are critical in reducing microbial burden on surfaces. In this report, we use "cleaning" to refer to removal of general surface debris and "disinfection" to refer to use of agents or technologies designed to kill microbial organisms. The term "environmental cleaning" refers broadly to the organized processes employed by hospitals for cleaning, disinfecting, and monitoring.

A wide variety of cleaning agents and disinfection technologies are commercially available, each with potential benefits and disadvantages. Additionally, hospitals often monitor the quality of room cleaning and disinfection to ensure that surfaces have been treated appropriately. Several monitoring strategies exist, which range from simple visual inspection, to microbiologic testing of surface contamination, to technologic innovations that measure the adequacy of surface cleaning. As the variety of options for cleaning, disinfecting, and monitoring grow, hospitals are faced with many choices, but limited evidence exists on the comparative effectiveness of these interventions, especially related to HAI rates within the hospital. This Technical Brief is designed to summarize and map the current evidence base addressing EC to prevent HAIs and highlight future research needs.

Disinfection Strategies

A wide variety of chemical disinfectants have been approved for use in the hospital setting. The most commonly used surface disinfectants are quaternary ammonium compounds (QACs, often referred to as "quats") and sodium hypochlorite (commonly known as bleach). Other agents that have been introduced for surface disinfection include peracetic acid and accelerated liquid hydrogen peroxide. The effectiveness of chemical disinfectants can depend upon both the antimicrobial activity of the disinfectant and appropriate application, including adequacy of cleaning, contact time, and concentration of the disinfectant. In addition to these manually applied chemicals is the use of "no-touch" modalities for hospital room disinfection, including

application of ultraviolet light (UV-C)[9-11] or fogging with hydrogen peroxide vapor or mist.[12-14] These processes can be used only for terminal disinfection when patient rooms are empty and must be preceded by adequate room cleaning. Another strategy is the adoption of "self-disinfecting" surfaces that are impregnated or coated with copper, silver, germicides, or other antimicrobial-releasing agents.[15,16] These surfaces are designed to resist contamination and augment routine cleaning processes.

Assessing Disinfection Following Environmental Cleaning

In addition to selecting effective cleaning and disinfection methods, hospitals also assess how effectively such processes are being implemented. Visual inspection is the simplest method for evaluating cleanliness, but concerns about the adequacy of visual inspection alone[17-19] have fostered the development of technology-based approaches. Several strategies have emerged that may improve the quality of visual assessment but introduce additional expense and other potential disadvantages. One such alternative is to collect specimens from surfaces and measure aerobic colony counts, which is a culture-based method for assessing surface microbial contamination. Another technique is the use of invisible fluorescent markers placed on room surfaces before cleaning and disinfection, with UV light inspection afterward. This approach provides immediate, direct feedback. Bioluminescence-based adenosine triphosphate (ATP) assays have been developed as another alternative that offers direct, rapid feedback and provides a quantitative measure of cleanliness. However, the detected presence of ATP does not necessarily indicate viable pathogens on the tested surface. In addition, universal cutoffs for ATP levels and "cleanliness" have not been established. Lastly, some studies have shown that certain disinfectants can interfere with ATP readings.[20-22]

A related and important consideration is the desire to establish standardized criteria for determining "clean" surfaces on the basis of each monitoring modality. While routine cleaning and enhanced disinfection strategies will not result in a sterile environment, consensus is lacking on the threshold of contamination below which pathogen transmission is minimized and can be considered safe. Establishing an evidence-based benchmark for defining a surface as clean will depend on the patient population, current cleaning and disinfection processes, and specific pathogen(s) being targeted.

Programmatic Monitoring of Environmental Services Personnel

Monitoring the operational processes associated with environmental services (EVS) and properly training and managing the staff charged with these duties are also necessary for preventing transmission of HAIs. Strategies for assessing compliance may include use of checklists, direct observation (open or covert), and surveys of personnel and patients. Process evaluation and improvement may also consider important human factors and logistical concerns, including workflow, staffing, staff training and supervision, collaboration between support services and clinical staff, institutional leadership, and patient preferences. Finally, sustaining long-term improvement is a critical but challenging goal as EVS personnel are continuously faced with pressure to clean occupied rooms and turn over terminal rooms.

Clinical Settings and High-Touch Surfaces

EC can be examined very broadly. Concern about HAIs extends far beyond acute care hospital patient rooms. Routine cleaning is necessary to ensure patient safety in every health care setting, including surgical suites and other procedure areas, diagnostic testing sites, long-term care facilities, rehabilitation centers, outpatient physician offices, and others. This Technical Brief's scope of interest, however, is limited to rooms that house hospitalized adult patients. Preventing infections during hospitalization is a primary goal of current initiatives by hospitals, clinicians, payers, regulators, and patient advocates. Additionally, hospital inpatient wards are complex settings, clinically and logistically, and merit consideration apart from other sites.

Similarly, the environmental reservoir that carries infection risk encompasses much more than a few surfaces in a patient room. Vectors for disease transmission may include medical instruments like endoscopes, fabric surfaces such as linens and patient privacy/room curtains, and the many people a patient encounters daily, including health care providers, ancillary services, visitors, and other patients. This Technical Brief is limited to cleaning and disinfection techniques used on the hard surfaces that form a fixed part of the patient room environment and are frequently touched by the patients and providers, which are often categorized as "high-touch surfaces" or "high-touch objects" (HTOs). Examples include bed rails, trays, call buttons, intravenous (IV) poles, doorknobs, floors, and bathroom facilities. Much of the available research on EC focuses on these types of surfaces, and strategies for ensuring their cleanliness differ from how soft fabrics are laundered or invasive instruments are sterilized.

Primary Pathogens

Hospitals serve as hosts to a wide array of diseases and pathogens. This Technical Brief focuses on evidence for strategies that may prevent transmission of three of the most common pathogens causing HAIs and for which there is significant evidence for surface contamination: *C. difficile*, MRSA, and VRE. Many studies of surface disinfection and monitoring have concentrated on removing and/or killing these organisms.

Guiding Questions

Guiding Question 1. Overview of Modalities Currently Used To Clean, Disinfect, and Monitor Cleanliness of Patient Rooms

- What are the options for cleaning, disinfecting, and monitoring the patient-care environment to reduce surface contamination and prevent HAIs?
- What approaches are currently in use, and what strategies have recently emerged?
- How do cleaning, disinfection, and monitoring strategies interact?
- What advantages and disadvantages may be associated with each option?
- Do current benchmarks exist for defining "clean" surfaces? If so, could they serve as useful surrogate measures for HAI transmission? If not, what approaches could be used to establish benchmarks?

Guiding Question 2. Context in Which Cleaning, Disinfecting, and Monitoring Modalities Are Implemented

- What contextual factors interact with and affect implementation of cleaning and monitoring?
- What equipment is necessary to support EVS operations?
- What other resources are required?
- What are important considerations when training EVS staff?
- What current U.S. Food and Drug Administration (FDA) and Occupational Safety and Health Administration (OSHA) regulations govern disinfection interventions?
- What role do outside contractors serve in the selection and implementation of strategies and staff training and monitoring?

Guiding Question 3. Current Evidence for Each Cleaning, Disinfecting, and Monitoring Modality

- What data exist for the effectiveness of different cleaning/disinfecting/monitoring options, including for specific pathogens and surfaces, and where are the gaps?

Guiding Question 4. Future Directions for Research on Environmental Cleaning, Disinfecting, and Monitoring of Cleanliness in Patient Rooms

- What outcomes are relevant?
  - HAI rate
  - Colonization rate
  - Surface pathogen bioburden
  - Pathogen/infection-specific data versus composite of common pathogens
  - Patient satisfaction
  - Cost analysis
- How can studies control for important confounders?
  - Multicomponent HAI reduction interventions
  - Movement of pathogens across surfaces and hospital areas
  - Exposure to diverse sources of colonization/infection (e.g., patients, visitors, staff)
  - Length of data-collection follow-up
- How can research be designed in the context of innumerable combinations of pathogen(s), method(s), and surface type(s) or location(s)?
  - Combining or collapsing categories to streamline data and yield more generalizable conclusions
  - Representative strategies that can be adapted

Methods

We conducted systematic searches of published and gray literature sources and completed interviews with Key Informants (KIs) representing multiple stakeholder groups.

Data Collection

Discussions With Key Informants

We selected KIs with expertise in each of the following areas: infectious disease and infection control, environmental disinfection, hospital epidemiology, microbiology, and managing and implementing EVSs in health care settings. Twelve KIs were interviewed, individually or in pairs.

We asked KIs with expertise in infection control about the advantages and disadvantages of cleaning and disinfecting agents and monitoring strategies, the outcomes most important to infection preventionists and patients, challenges to conducting research on EC, and knowledge gaps that future research should address. We asked KIs with experience in EC processes to discuss operational factors that facilitate or impede cleaning procedures, factors that influence decisionmaking around the selection of cleaning agents and monitoring approaches, training and evaluation of front-line personnel, and other elements that are critical to implementation and sustainability. One KI representing the Centers for Medicare & Medicaid Services (CMS) was asked about federal regulations and hospital oversight, coverage decisions and payment policy, and measures of hospital quality and effectiveness. We sought feedback from the topic nominator about the study protocol (http://effectivehealthcare.ahrq.gov/protocol), research design, guiding questions, inclusion and exclusion criteria, and overall project goals.

We used KI input to refine the systematic literature search, identify gray literature sources, provide information about ongoing research, confirm evidence limitations, and recommend approaches to help fill these gaps. We also sought KI input to inform our findings for Guiding Questions 2 and 4.

Gray Literature Search

Gray literature includes reports, studies, articles, and monographs produced by federal and local government agencies, private organizations, educational facilities, consulting firms, and corporations that typically do not appear in the peer-reviewed journal literature. For this report, we searched gray literature sources to identify clinical practice guidelines, white papers or position statements, descriptions and evaluations of emerging disinfection technologies and monitoring strategies, and influential perspectives on real-world facilitators and barriers to implementation.

Websites and databases associated with the following institutions were searched using text words: AHRQ, Centers for Disease Control and Prevention (CDC), U.S. Environmental Protection Agency (EPA), OSHA, ECRI Institute Healthcare Standards, Medscape, and the National Guideline Clearinghouse™. To locate ongoing clinical trials of EC to prevent HAIs, we searched ClinicalTrials.gov.

We also searched the websites of relevant professional organizations, including the American Organization for Nurse Executives, Association for the Healthcare Environment, Healthcare Infection Society, Institute for Healthcare Improvement, Society for Healthcare Epidemiology of America, Society of Hospital Medicine, University HealthSystem Consortium, and the American

Nurses Credentialing Center's Magnet Recognition Program. We searched conference abstracts published since 2013 by the Association for Professionals in Infection Control and Epidemiology (APIC) and the Infectious Diseases Society of America.

Published Literature Search

Medical librarians in the EPC Information Center performed systematic literature searches, following established systematic review protocols. We searched the following databases using controlled vocabulary and text words: EMBASE (including EMBASE and MEDLINE records), Cumulative Index to Nursing and Allied Health (CINAHL), the Cochrane Library, and PubMed (unprocessed records only). Searches covered the literature published from January 1, 1990, through February 4, 2015. This time frame was selected because we intended to include contemporary disinfection technologies and monitoring approaches while excluding strategies no longer in use. Additionally, significant advances in hand hygiene and other infection control protocols have emerged during approximately the past 25 years. Older studies may not reflect these important improvements in the clinical environment. Appendix A presents a sample search strategy.

We performed literature screening in duplicate using the database Distiller SR (Evidence Partners, Ottawa, Canada) and screened results for relevancy, with relevant abstracts screened in duplicate. Studies that appeared to fit the scope of the brief were retrieved in full and screened again in duplicate. An independent reviewer randomly verified abstracted data.

We included studies if they addressed a guiding question; examined any inpatient wards (such as general medicine, surgery, critical care, oncology); addressed "high-touch" surfaces; evaluated colonization, infection, or environmental contamination with *C. difficile*, MRSA, or VRE or included multiple unspecified pathogens that were likely to include the above; and were English-language studies. Studies were excluded if they occurred exclusively in pediatric, ambulatory, operating room, or long-term care settings; addressed only transmission routes that are not inherent to the environmental reservoir (e.g., caregiver hands or stethoscopes, patient and guest personal items, linens) or were in vitro studies that did not collect samples from actual patient rooms. We recognize that by restricting our review's scope to three pathogens and hard surfaces we have omitted other important organisms (e.g., gram-negative pathogens) and vectors of transmission (e.g., curtains). However, based on limitations inherent to writing a technical brief, especially the need to focus the scope as narrowly as possible, we consulted with the KIs to develop inclusion and exclusion criteria (see Table 1).

Table 1. Inclusion and exclusion criteria

Topic	Inclusion	Exclusion
Setting	Patient rooms and isolation rooms in acute care hospital wards in the United States, Canada, Western Europe, and Australia	• Ambulatory care settings • Long-term care facilities or physical rehabilitation centers • Surgical suites • Pediatric hospital wards
Language	English	Non-English
Literature	Systematic reviews, clinical practice guidelines, randomized controlled trials, nonrandomized studies with concurrent or historical controls, observational studies, descriptive studies	In vitro or laboratory studies without specimen selection or testing in patient rooms
Surfaces	High-touch objects with hard, nonporous surfaces	• Soft surface, porous objects • Linens or curtains • Invasive medical devices
Pathogens	Infection or contamination with *C. difficile*, MRSA, VRE; or unspecified pathogens where *C. difficile*, MRSA and VRE were not explicitly excluded in study	Studies not evaluating *C. difficile*, MRSA, or VRE
Technology	Products or processes currently available in the United States or undergoing investigational studies	Products or processes not available in the United States or not undergoing investigation
Multi-component strategies	Multicomponent interventions if change in cleaning, disinfection, or monitoring was a primary or prominent component	Multicomponent interventions if cleaning, disinfection, and monitoring were unchanged or secondary to other components

Data Organization and Presentation

Descriptive characteristics and outcomes from published studies and gray literature were abstracted and detailed in tables. Relevant data included study design; patient population; hospital characteristics; hand-hygiene policies and similar concurrent infection control procedures; pathogen type; high-touch surfaces cleaned; type of cleaning, disinfection, or monitoring modality; focus and scope of outcome measure and implementation strategy; and analytic technique used to evaluate outcomes. Clinical practice guidelines and systematic reviews were detailed in tables separately from primary studies.

A project team member documented KI interviews during each call. Investigators reviewed and discussed notes to evaluate how KI input confirmed or varied from published evidence. KI discussions also provided insight on emerging disinfection and monitoring strategies, evidence gaps, and human and system factors that affect implementation. These insights were incorporated into the findings.

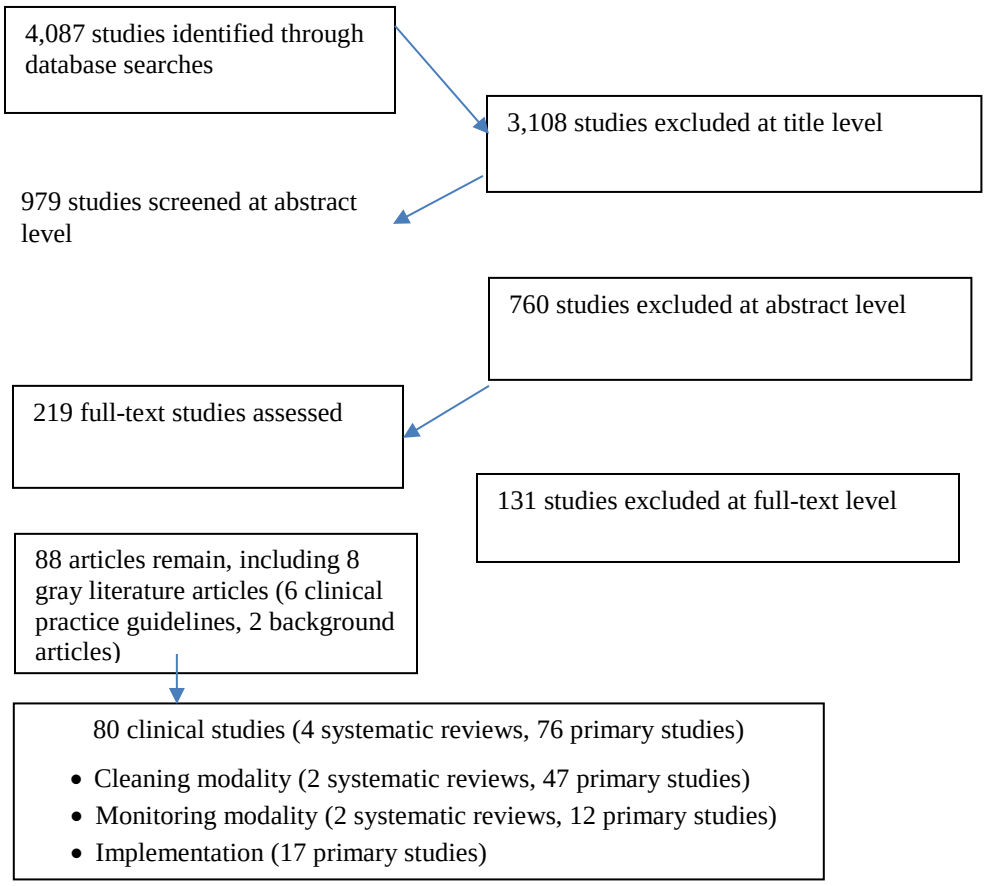
Findings were organized into an evidence map that chronicles the scope and depth of existing research on cleaning, disinfecting, and monitoring processes, while highlighting important gaps in the evidence base. Published studies, gray literature, and KI perspectives and insights informed the evidence map.

Findings

Our search of the published literature identified 4,087 potentially relevant studies. We excluded 3,868 studies during title and abstract screening. These studies were not relevant to the Guiding Questions or did not meet our criteria for publication type. This resulted in full-text screening of 219 articles. We excluded 131 studies at the full-text level. See Appendix B for a list of studies organized by reason for exclusion.

Of the 88 remaining documents, 2 were used for background information and 6 were identified as clinical practice guidelines. Information on 63 other clinical practice guidelines (many provided in the Topic Triage documentation) or guidance documents (e.g., tool kits) identified in the gray literature are summarized in Appendix D. Figure 1 presents a PRISMA flow diagram of our study screening.

Figure 1. PRISMA flow diagram of study screening



Our searches identified 4 systematic reviews and 76 published studies that fit our inclusion criteria and addressed modalities for cleaning, disinfecting, assessing cleanliness, or implementing EC processes. We did not identify for inclusion any conference abstracts presented within the past 2 years. A search of ClinicalTrials.gov identified three clinical trials categorized as “currently recruiting,” “ongoing, but not recruiting,” and “not yet open for participant recruitment,” respectively. We also identified one trial (NCT00566306) completed in

August 2008. No outcome data were reported, and no publications are available from this trial. For more information on the ongoing trials, see Table D-2 in Appendix D.

Overview of Cleaning and Disinfection Modalities (Guiding Question 1)

Three distinct modalities exist for routine disinfection of hard surfaces in patient rooms: chemical disinfectants, self-disinfecting surfaces, and no-touch technologies.

Chemical Disinfectants

Five categories of chemical agents are currently used in hospitals. These disinfectants are usually applied with a spray, wipes soaked in a disinfectant-filled bucket, textile or microfiber cloth, or premoistened wipe; some formulations can also be used as a liquid for mopping floors. Selecting a chemical agent for routine disinfection of the patient room environment can be a complex process that includes careful consideration of its advantages and drawbacks.

For an effective disinfection protocol, consideration should be given to the microorganisms being targeted, type of surface, the characteristics of a specific disinfectant (e.g., compatibility on various surfaces/materials), cost and ease of use, and safety of EVS personnel. Thus, selecting specific disinfectants commonly involves input of multiple stakeholders (e.g., infection control committees, EVS personnel) and can often be institution-dependent.

Importantly, the effectiveness of all disinfectants, regardless of category, is significantly affected by how it is used in the real-world hospital environment (e.g., sufficient contact time, temperature, concentration).[23] For example, manufacturer-recommended dwell times are established in the laboratory setting, but in the hospital environment, where there is often pressure to turn rooms around quickly, allowing for appropriate dwell times can be challenging. Lastly, as opposed to newer disinfection technologies such as hydrogen peroxide vapor, use of these chemical disinfectants are not recommended in preparations for spraying or fogging application.

Quaternary Ammonium

QACs are widely used EPA-registered health care disinfectants and are generally regarded as effective, surface-compatible agents with some persistent antimicrobial activity when left undisturbed on surfaces. These compounds frequently are used for routine cleaning and disinfection of noncritical environmental surfaces (e.g., floors, HTOs such as bed rails and tray tables, medical equipment that contacts intact skin [such as blood pressure cuffs]). These agents are bactericidal, virucidal against enveloped viruses (e.g., HIV), and fungicidal.

However, they are not sporicidal and generally not mycobactericidal or virucidal against nonenveloped viruses. High water hardness and materials such as cotton towels and cloths can diminish microbicidal activity.[24-26] Finally, case reports of occupational asthma have been documented due to use of benzalkonium chloride.[27,28]

Hypochlorite

Hypochlorites are EPA-registered surface disinfectants and the most commonly used of the chlorine disinfectants. For example, commercially available concentrations of 4% to 6% sodium hypochlorite solutions are formulated as concentrated household bleach, which are typically diluted by a factor of 10 for a final-use concentration of 0.4% to 0.6%. Hypochlorites are

bactericidal, fungicidal, virucidal, mycobactericidal, and sporicidal. They are commonly used for disinfecting surfaces in bathrooms and surfaces used in food preparation and are generally included in recommendations for disinfecting surfaces or objects contaminated with hepatitis viruses, HIV, and *C. difficile*. Hypochlorites are also used to disinfect blood spills in the hospital setting. Depending on the surface being cleaned and the pathogens targeted, instructions for specific formulations, concentrations, and contact times must be followed. Hypochlorites must be freshly prepared when diluting from higher concentrations and proper dilution protocols must be followed to reduce chemical irritation or decreased efficacy. Hypochlorites are unaffected by water hardness, relatively stable and fast-acting, and generally safe with a low incidence of serious toxicity.[29,30]

However, sodium hypochlorite (i.e., household bleach) may cause skin and eye irritation, as well as oropharyngeal, esophageal, and gastric burns.[31-33] Hypochlorites also are corrosive to metals in high concentrations (>500 ppm) and can discolor fabrics. Finally, given that their activity is significantly reduced by organic matter (e.g., blood, fecal matter), surfaces must be precleaned before disinfection.[29,30]

Accelerated Hydrogen Peroxide

Accelerated hydrogen peroxide products are recently introduced EPA-registered surface disinfectants; they are bactericidal, virucidal, fungicidal, sporicidal, and mycobactericidal. These products have a generally short contact time, with some products having a 30-second to 1-minute bactericidal and virucidal claim, and a 5-minute mycobactericidal claim.[34] Lower-level concentrations are used for disinfecting hard surfaces, while higher-level concentrations (2%) are used for high-level disinfection. These compounds are commonly used, considered safe for EVS staff (i.e., lowest EPA toxicity category IV), surface compatible, noncorrosive, and unaffected by organic material.[34] In addition, accelerated hydrogen peroxide products are generally considered benign for the environment. However, they are more expensive than other disinfectants such as quaternary ammonium.

Phenolics

Phenolics are EPA-registered and bactericidal, mycobactericidal, fungicidal, and virucidal and are used for surface disinfection (e.g., bedrails, tables) and for disinfecting noncritical medical devices.[35] While inexpensive, they are less commonly used because of several disadvantages, including absorption by porous materials, ability for residual product to irritate tissue, and depigmentation of skin. In addition, phenolics are not sporicidal and can cause hyperbilirubinemia in infants when they are not prepared per manufacturers' recommendations.[36,37]

Peracetic Acid

Peracetic acid preparations are EPA-registered disinfectants with rapid activity against microorganisms and are bactericidal, fungicidal, virucidal, mycobactericidal, and sporicidal. Peracetic acid generally remains active in the presence of organic material and lacks harmful decomposition materials (e.g., oxygen, hydrogen peroxide). Disadvantages include lack of stability, particularly following dilution, and potential to corrode metals such as copper and brass. Peracetic acid is most commonly used in automated machines designed to sterilize medical instruments (e.g., endoscopes, dental instruments), and in a formulation with hydrogen peroxide, to disinfect hemodialyzers.

Self-Disinfecting Surfaces

Coating surfaces with heavy metals may protect against bacterial contamination and render items "self-disinfecting." Copper and silver have been investigated for self-disinfecting properties in hospital settings. Many surfaces can be coated with copper or silver, including bed rails, trays, call buttons, IV poles, and other objects.

Copper

High levels of copper ions are toxic to most microorganisms due to generation of reactive oxygen species, resulting in damage of nucleic acids, proteins, and lipids and, ultimately, cell death. In the health care setting, copper has been used to control *Legionella* spp. in water supplies and, more recently, incorporated into self-disinfecting surfaces used in hospital rooms. Given its bactericidal properties, contact with copper has been examined as a mechanism to kill many clinically important pathogens, including MRSA, *Escherichia coli*, *Enterococcus* spp., and *Mycobacterium tuberculosis*.

However, no standardization exists as to type of alloy and selection of specific surfaces. The effectiveness of copper-containing surfaces in reducing the risk of HAIs is under active investigation, and real-world experience remains limited to date. A study performed in three hospitals demonstrated a significant reduction in the microbial burden of certain intensive care unit (ICU) surfaces following installation of copper-impregnated surfaces.[38] Furthermore, a recent randomized controlled trial (RCT) evaluating the use of copper alloy-coated surfaces for several HTOs (e.g., bed rails, tray tables) in the ICU demonstrated decreased rates of HAIs and MRSA and VRE colonization.[39]

Silver

Silver ions have the greatest level of antimicrobial activity of all the heavy metals. While its mechanism of action has not been completely elucidated, its bactericidal properties likely involve binding of disulfide and sulfhydryl groups present in the proteins of microbial cell walls. The use of silver-impregnated environmental surfaces has recently been studied and shown to reduce experimental surface contamination, but the clinical impact of this modality has not been evaluated.[39,40]

Altered Topography

Materials with altered surface topography to inhibit bacterial biofilm formation are currently under investigation. An example of this design is Sharklet AF (Sharklet Technologies, Alachua, FL), which uses topography similar to shark skin and has been shown to reduce biofilm formation and growth of *S. aureus* on molds utilizing Sharklet technology.[41] However, no data exist on use in the real-world hospital environment, and disadvantages include potential difficulty in retrofitting surfaces with these materials, as well as lack of microbicidal properties.

Light-Activated Antimicrobial Coatings

Light-activated antimicrobial coatings have been recently studied for self-disinfection of surfaces. Irradiation of certain compounds (e.g., titanium dioxide, photosensitizers) with visible or UV light results in the production of reactive radicals that nonselectively target microorganisms. These surfaces may provide a less toxic approach than the use of chemical disinfectants and are broadly microbicidal.[42-44] However, a constant source of photoactivation is

required, and it is unclear whether these surfaces are sporicidal. Studies are still required on long-term disinfecting properties of these surfaces in the real-world hospital environment.

No-Touch Modalities

Two kinds of devices have been developed and commercially produced to disinfect hospital rooms. One type of device emits UV light, and another produces a mist or vapor of hydrogen peroxide. These devices are often referred to as no-touch or automated modalities because they disinfect via a stand-alone machine instead of manual application of chemical agents. Experts indicate that no-touch modalities should be used only as adjunctive infection control measures.

Ultraviolet Light

The use of a UV wavelength light as a no-touch, automated modality for hospital room disinfection has received significant recent attention. The UV-C wavelength of 200 to 270 nanometers is germicidal and involves breaking of molecular bonds in DNA, resulting in microorganism death. Advantages of UV-C technology include its microbicidal activity against a wide range of health-care-associated pathogens, including *C. difficile,* and the ability for more rapid room decontamination compared to hydrogen peroxide systems. Automated UV-C systems have most commonly been tested for postdischarge terminal disinfection in hospital rooms of patients with C. difficile infection.

This technology's disadvantages include the requirement for the room to be vacated and disinfected before decontamination, its use only for terminal disinfection (vs. daily disinfection), and its significant cost. Also, equipment and furniture must be moved away from walls to prevent shadowing because UV-C systems cannot disinfect areas without a direct or indirect line of sight. Finally, these units require significant time for effective disinfection and can therefore adversely affect bed turnover time. While dependent on many factors (e.g., system being used, dose, organism being targeted), the turnaround time for these devices can range from approximately 15 to 20 minutes for vegetative bacteria to approximately 50 to 100 minutes for C. *difficile* spores. A recent study utilizing a UV-reflective wall coating resulted in significantly decreased decontamination times, from ~25 minutes to ~3 minutes for MRSA, and from ~43 minutes to ~9 minutes for C. difficile spores.[45]

Hydrogen Peroxide-Producing Systems

The use of hydrogen peroxide-producing systems for disinfecting hospital room surfaces and objects has been recently studied. Several systems that produce hydrogen peroxide using differing methods are available (e.g., dry mist, hydrogen peroxide vapor). Advantages of these include reliable microbicidal activity against a variety of pathogens associated with HAIs, including *C. difficile,* as well as uniform distribution in the room via an automated dispersal system, such that furniture and equipment do not need to be moved away from walls.

However, as with UV-C devices, all patients and health care staff must leave the room before decontamination, and these devices are used for terminal room disinfection (i.e., not for daily disinfection). Costs of these devices can also be substantial, and a lot of time is required for effective disinfection. High-level training is required to operate these devices. Air vents, doors, and windows must be isolated and sealed, and active monitoring with sensors is necessary to monitor for leaks and ensure that the room is safe for personnel to enter. A safety concern with improper use is airway and mucous membrane irritation. As with UV-C devices, hydrogen

peroxide–producing systems are a relatively recent disinfection technology and, pending further studies, are not yet routinely used for disinfecting hospital rooms.

Overview of Monitoring Modalities (Guiding Question 1)

Visual Inspection

Visual inspection of hospital room surfaces is often used to assess adequacy of routine cleaning and disinfection practices. However, direct visual inspection can assess only visible cleanliness (e.g., removal of organic debris, dust, moisture) from surfaces and not microbial contamination.[46-48] Covert visual monitoring of EVS staff during actual cleaning and disinfection provides an objective assessment of an individual staff member's adherence to protocols, particularly when in conjunction with direct feedback and educational interventions. This method is straightforward, easy to implement in hospitals, and often performed by EVS managers.

Visual inspection can also occur following completion of room cleaning and disinfection by EVS staff; while assessing the subjective cleanliness of surfaces, this method precludes the ability to determine whether these surfaces were actually cleaned. Furthermore, adequacy of cleaning and disinfection as assessed by visual inspection may increase patients' perceptions of cleanliness and therefore satisfaction levels. However, limitations of this monitoring method include interobserver variability and biases secondary to the Hawthorne effect (when the presence of observation affects observed behavior).

Microbiologic Methods

Microbiologic methods have been used to evaluate microbial contamination of environmental surfaces. Methods typically utilize swab cultures, in which a moistened sterile swab is used to sample a surface and then inoculate agar, often with broth enrichment. Swab cultures are easy to use and are often used to sample irregular surfaces, medical equipment, and health care workers' hands. Swab cultures are most often used to identify specific pathogens during epidemiologic investigation of an outbreak. Importantly, the use of aerobic culture (with or without enumerating colony counts) is the only method that can provide information about the viability of our pathogens of interest (e.g. MRSA, VRE).

Another method for sampling is the use of Rodac contact plates, which are small petri plates filled with agar. Sampling of flat environmental surfaces is performed via direct application of the plate to the surface, with the surface area typically measuring 25 cm^2. Advantages of contact plates include ease of use and standardization of an approach for quantitative measurement (e.g., results are often expressed as colony-forming units per cm^2). However, contact plates can be expensive and allow for sampling of only a small area per plate.

A less commonly used method is the agar slide culture, in which an agar-coated slide with finger holds is used for sampling of flat, hard surfaces. These systems are often used in conjunction with aerobic colony counts (ACCs), a microbiologic method used to quantify microbial contamination of environmental surfaces. The sensitivity of these techniques for recovery of microorganisms depends on many factors, including the type of surface being sampled, specific pathogen, and user technique. For example, a study comparing a swab technique to Rodac plates demonstrated that the sensitivity of swabs for recovery of gram-positive cocci was lower than that of Rodac plates (54% vs. 70%). In contrast, the sensitivity of

the swab technique for recovery of gram-negative bacteria was 74% compared to 43% with Rodac plates.[49]

An overall limitation of methods utilizing ACCs is the lack of accepted criteria for defining a surface as "clean" using ACCs. Additional limitations include the cost of processing (e.g., identifying isolates in the microbiology laboratory), delay in results, small sample area per swab or slide, and the need to determine precleaning levels of microbial contamination for each object or surface being evaluated. In addition, clinical microbiology laboratories do not always perform quality-control assessments in use of ACCs, including maintenance of certification for environmental microbiologic testing. As such, testing using microbiologic methods for environmental monitoring in the hospital setting could benefit from oversight by a certified environmental microbiology laboratory.

UV-Visible Surface Marker

Fluorescent markers can be used in powder or gel form to mark high-touch surfaces before room cleaning and disinfection. Following cleaning and disinfection, UV light inspection is used to determine adequate removal of the fluorescent markers on these surfaces. Fluorescent gel is the most commonly used formulation because it dries to a transparent finish on surfaces, is abrasion-resistant, and unlike powder, is not easily disturbed. For these reasons, the fluorescent gel formulation has been the most well-studied method to assess surface disinfection and to quantify the impact of educational interventions.

Advantages of UV-visible surface markers include relative low cost of use and ease of implementation, including as a feedback tool for EVS staff. Importantly, because fluorescent markers are designed to correlate with physical removal of an applied substance, surfaces that are effectively disinfected (i.e., decreased microbial contamination) but less effectively "cleaned" may be noted as failing to meet quality standards of cleaning. An additional limitation of this assessment method is that unlike ACCs, fluorescent gel cannot be used to detect the presence of a specific organism; therefore, its utility during a pathogen-specific outbreak may be adjunctive.

ATP Assays

ATP bioluminescence assays are commonly used in the hospital setting. ATP assays detect the presence of organic debris on surfaces, are easy to use, and can provide direct, rapid feedback to EVS staff. A special swab is used to sample the surface of interest and placed in a reaction tube. The reaction tube is subsequently entered into a device luminometer, with results expressed in relative light units (RLUs). However, ATP assays detect the presence of both viable and nonviable bioburden on surfaces, so the presence of ATP does not necessarily indicate viable pathogens on the tested surface.

Along these lines, a few studies have shown poor agreement between ATP readings and ACCs in regard to defining surfaces as "clean."[48,50] Furthermore, some studies have shown that certain disinfectants can interfere with ATP readings. Nevertheless, ATP assay measurements can serve as a general measure of cleanliness, and given their ease of use, have utility as teaching and monitoring tools.

A cutoff level that can be used as a surrogate measure of an increased risk of HAIs has not yet been validated. Cutoffs used to classify surfaces as "clean" by ATP assays depend on the assay system used, and universal cutoffs for ATP levels and "cleanliness" have not been

established. The sensitivity and specificity of different luminometers/assay systems can differ significantly.

Polymerase Chain Reaction–Based Technology

Polymerase chain reaction (PCR)–based assays for assessing EC are currently investigational. PCR-based assays offer rapid turnaround time for detecting the presence of specific organisms (e.g., MRSA, *C. difficile*) and are performed in the microbiology laboratory following sampling of surfaces, usually via swabs.

However, these assays currently do not differentiate between the presence of viable versus nonviable microorganisms. As these technologies become less expensive, they may have a larger role in assessing effectiveness of cleaning and disinfection, particularly in the outbreak setting.

Interaction of Cleaning, Disinfecting, and Monitoring Strategies (Guiding Question 1)

The integration of cleaning, disinfecting, and monitoring strategies is important in reducing environmental contamination and the risk of transmission of nosocomial pathogens. The physical action of cleaning removes foreign material from environmental surfaces and HTOs. Disinfection is needed to eliminate many pathogens following the cleaning process. Finally, implementing systems to monitor the appropriateness of cleaning and disinfection is critical in optimizing the effectiveness of these processes on a regular basis. Integration of cleaning, disinfection, and monitoring strategies requires a multidisciplinary approach and often depends on the surface type, patient population, hospital environment, and pathogen(s) being targeted.

Defining “Clean” Surfaces (Guiding Question 1)

Despite the importance of EC and disinfection in reducing microbial contamination on hospital surfaces, no current benchmarks exist to define “clean.” While microbiologic and chemical tools provide a more objective assessment of cleanliness than visual inspection, a lack of consensus still exists on how to correlate results from these monitoring modalities to the “cleanliness” of a surface.

It is clear that an appropriate benchmark for defining a surface as “clean” is needed for effective monitoring of cleaning and disinfection processes. This benchmark should be defined using an evidence-based approach and should indicate whether the “cleanliness” of a surface will lead to a reduction in important patient-level outcomes, including acquisition of hospital pathogens and HAI rates. Benchmarks for “cleanliness” likely will need to be adapted to the patient population, type of surface under study, and specific pathogen(s) being targeted. Lastly, establishment of such benchmarks and integration into EC strategies will allow for more standardized and evidence-based monitoring of cleaning and disinfection processes.

Overview of the Context in Which Cleaning, Disinfection, and Monitoring Modalities Are Implemented (Guiding Question 2)

Key Points

- Implementation of environmental control strategies is highly influenced by appropriate preparation, application, and contact time of disinfectants; adherence to best practices

(e.g., checklists); proper education and training; and clearly defined roles for cleaning HTOs.

- Key Informants suggested that institutional leaders should place less importance on room turnover time and more importance on the value of EVS staff.
- Despite pressures on compliance with evidence-based policies and procedures from various health care organizations (e.g., CDC), only one study reported on the influence of external factors in EC.
- Institutional collaboration between Infection Prevention and Control and EVS Management is critical while developing EC programs. Five studies described participation in planning and processes by individuals (e.g., infection prevention nurses), committees, and departments.
- Educational tools, training tools, and protocols should be language-appropriate and written in a manner commensurate with education level. Twenty-four (32%) studies reported integrating implementation and management tools into their EC strategies; educational tools were the most commonly integrated tool.
- Understanding local hospital culture is key when outsourcing EC services.

We present below insight from KIs on the influence of context on implementation followed by a description of a conceptual or analytic framework for identifying high-priority contexts. Lastly, we present contextual factors relevant for implementation of EC from all 76 studies followed by detailed information on the 17 studies primarily focused on implementation.[51-67]

Key Informant Feedback

Key Informants frequently emphasized the impact of contextual factors on the effectiveness of EC and monitoring. Several KIs suggested that selecting any particular disinfecting agent or monitoring modality versus another was less important than implementation processes at the local level. A common sentiment was that "it's not what you use, it's how you use it."

Key Informants identified several aspects of implementation that can influence the effectiveness of EC. One important concern is basic compliance with appropriate preparation and application of disinfectants. Some agents must be diluted before use, and one KI noted that "if you have 20 EVS personnel, you have 20 ways to dilute bleach." After preparation, a disinfectant must remain in contact with a surface for the labeled contact time for optimal effectiveness, but in daily practice contact time may fall short of labeled instructions.

A related challenge described by KIs is the inconsistency of workflow, especially during daily room cleaning and disinfection, as EVS personnel must respect patients' personal needs and preferences while working around clinical staff interventions, meal delivery, linen services, visitors, and other routine "interruptions."

Terminal room cleaning and disinfection, after a patient has been moved or discharged, has its own challenges. Many KIs expressed concern that hospital leaders may place too great a premium on room turnover time, resulting in suboptimal adherence to cleaning and disinfection protocols. Pressure to achieve rapid room turnover may also discourage use of technologies that require more time to implement, such as no-touch modalities.

Key Informants cited training as vital to ensure that EVS staff recognize the clinical significance of adhering to proper work procedures and guiding them on how to manage routine workflow. Staff in some hospitals undergo extensive initial and ongoing education, including training on how to foster a "customer service" atmosphere when interacting with patients.

Institutions may also use simulation to map workflow and design systems that are less user-dependent and more intuitive.

Several KIs also regarded checklists used by EVS personnel as a useful tool to standardize procedures and encourage adherence to best practices. The impact of these training strategies may be lower in work environments where staff turnover is high. Additionally, one KI noted that while many EVS staff may not speak English as their primary language, training materials and protocols are rarely available in other languages.

Another related factor that KIs discussed is the individual hospital patient safety culture. A positive culture can foster collaboration and respect among clinical and support services staff and nurture supportive relationships between supervisors and frontline personnel. Conversely, failure to build a positive culture can contribute to suboptimal work performance. Institutional leadership and the value that executives place on EVS are important contributing factors in organizational culture. KIs described examples of hospitals whose leadership embraced and emphasized EC's importance, resulting in better compliance with best practices. Alternatively, a few KIs cautioned that when faced with financial challenges, some hospital executives may view room cleaning and disinfection as low priority and resort to reducing staff and supplies.

An important aspect of the work culture is how clinical and administrative professionals in the hospital perceive the role of EVS staff. Almost every KI indicated that staff are often underappreciated despite playing a critical role in the infection prevention community. Some KIs suggested that hospitals consider EVS staff as "environmental cleaning technicians" or use a similar title that reflects the technical complexity of their responsibilities (e.g., preparing and applying an array of disinfection agents, operating newer technological modalities) and the important contribution of their work to effective infection prevention. Others described the importance of sharing HAI rates with EVS departments to reaffirm the importance of EVS staff.

Conceptual Framework for Contextual Factors

The influence of contextual factors on implementation was a major theme of the March 2013 AHRQ report, "Making Health Care Safer II: An Updated Critical Analysis of the Evidence for Patient Safety Practices."[68] In earlier work, "Assessing the Evidence for Context-Sensitive Effectiveness and Safety of Patient Safety Practices: Developing Criteria," Shekelle et al. laid out a framework for assessing evidence for context-sensitive interventions.[69] The report recommends assessing the "high-priority contexts" of four domains: (1) structural organizational characteristics (e.g., size, location, financial status); (2) external factors (e.g., regulatory requirement, pressure from penalties such as pay-for-performance); (3) patient safety culture (e.g., teamwork and leadership at the unit level); and (4) availability of implementation and management tools (e.g., staff education and training, dedicated time for training, use of internal audit and feedback).

Structural Organizational Characteristics

An important approach some hospitals have adopted is outsourcing EVS. Environmental support services provided by outside contractors can include training and development programs, designing of comprehensive protocols, competency testing, and participation on infection prevention teams.[70,71] While supporting a large EVS department (over 650 employees) at Mount Sinai Hospital (New York, NY), one supplier implemented multiple interventions, including retraining staff (e.g., chemical dilution and use), updating departmental processes (e.g., hospitality training), and introducing new technologies (e.g., a UV irradiation device).[71] One

study, Brakovich et al. 2013,[57] indicated that followup disinfection of rooms formerly occupied by patients with *C. difficile* infection was outsourced to a company that provided hydrogen peroxide vapor devices and services.

Outsourcing has grown in recent years, according to several KIs, although national economic patterns may partly drive cycles of expansion and decline in use of outsourced service companies. One KI felt that while outsourcing may be cost-effective, better guidance is needed on process monitoring and standardization. Some KIs discouraged outsourcing because outside contractors may not understand local hospital culture, which is a major component of any patient safety program. Lastly, one KI commented that how EVS is organized in a hospital (e.g., location of EVS in the administrative hierarchy) is an important structural factor that can affect the success of EC processes.

External Factors

Compliance with "evidence-based policies and procedures" from organizations such as CDC, EPA, CMS, Joint Commission, FDA, and OSHA are important external factors. In its 2008 "Guideline for Disinfection and Sterilization in Healthcare Facilities," CDC notes that health care workers need to understand requirements pertaining to them when applying disinfectants and sterilants as well as the relative roles of CDC, EPA, FDA and others in regulating these agents. EPA plays a particularly important role as the agency charged with setting national regulations for the safety and appropriate use of many of the disinfection agents reviewed in this Technical Brief (http://www2.epa.gov/pesticide-registration/antimicrobial-pesticide-registration). For a list of EPA and OSHA regulations related to sterilants and disinfectants, see Table 2.[72]

CMS reimbursement policies will begin to shape EC efforts in the near future. Beginning in 2017, payment penalties under the Hospital Value-based Purchasing Program will be linked to National Quality Forum-endorsed measures of MRSA and *C. difficile* infection.[73]

Table 2. EPA and OSHA regulations for disinfectants

Organization	Topic	Regulation
EPA	Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)	Provides EPA with the authority to oversee the registration, distribution, sale, and use of pesticides. FIFRA applies to all types of pesticides, including antimicrobials, which includes sterilants, disinfectants, and other cleaning compounds that are intended to control microorganisms on surfaces. FIFRA requires users of products to follow the labeling directions on each product explicitly (go to FIFRA page). EPA regulates most of the disinfectants discussed in this Technical Brief.
OSHA	Hazard Communication Standard (HazCom)	Requires that information concerning any associated health or physical hazards be transmitted to employees via comprehensive hazard communication programs (Go to HERC HazCom page). The programs must include: o **Written Program.** A written program that meets the requirements of the Hazard Communication Standard (HazCom). o **Labels.** In-plant containers of hazardous chemicals must be labeled, tagged, or marked with the identity of the material and appropriate hazard warnings. o **Safety Data Sheets** (formerly called Material Safety Data Sheets). Employers must have a [Safety Data Sheet] for each hazardous chemical which they use and which must be readily accessible to employees when they are in their work areas during their work shifts. o **Employee Information and Training.** Each employee who may be "exposed" to hazardous chemicals when working must be provided information and be trained before initial assignment to work with a hazardous chemical and whenever the hazard changes.
	Employee protection	Depending on the ingredients contained in a sterilant or disinfectant and its manner of use, employee protection may be required, including ventilation controls, personal protective equipment, clothing or gloves, and other applicable precautions. The employer should make this assessment based on the unique conditions of use of the product at that establishment.
	Exposure to injurious corrosive materials	Where the eyes or body of any person may be exposed to injurious corrosive materials, **employers must provide** suitable mechanisms for quick drenching or flushing of the eyes and body within the work area for immediate emergency use [1910.151(c)].

EPA=Environmental Protection Agency; HERC=Healthcare Environmental Resource Center, an on-line compliance assistance center funded by a grant from EPA to the National Center for Manufacturing Sciences, with the cooperation of the American Hospital Association, the American Nurses Association, and EPA; OSHA=Occupational Safety and Health Administration.

Patient Safety Culture

Institutional culture has been described as "the accumulation of invisible, often unspoken ideas, values, and approaches that permeate organizational life."[74] Clarke et al. 2006[75] adds that culture may be partially formed by leadership decisions that ultimately result in cultural norms. Five (7%) studies reported on this domain; three recently published studies (2013–2014) described participation in planning and managing of EC processes by leaders from Infection Control,[54] Quality and Safety,[57] and EVS.[58] Two earlier studies reported the influence of project directors[64] and the Department of Infection Control.[66]

Collaboration between infection prevention and control and EVS management during implementation phases (both planning and ongoing) is one of several key components presented by CDC in a two-level program to evaluate EC. The 2010 toolkit, "Options for Evaluating Environmental Cleaning,"[76] presents context (specific to terminal room cleaning) to assist

hospitals in developing programs to improve HTO cleaning. The toolkit recommends that institutions start with a basic program that is consistent with previously issued guidelines.[23,77] It stresses the importance of the two disciplines working together to set expectations for staff, to develop metrics for competency evaluation and educational programs for hospital and EVS staff.

Administrative leadership is also "critical in managing outbreak situations," according to APIC's "Guide to Preventing Clostridium difficile Infections."[78] The administrator's responsibilities include ensuring staff have sufficient time to thoroughly clean (including adequate contact time for cleaning agents) and working with EVS and infection prevention staff to develop a monitoring program that provides desired information and timely feedback.

Implementation and Management Tools

Another component of CDC's program is the development of a hospital-specific program (consistent with CDC standards[23,77]) and use of a checklist for cleaning "objects in the patient zone." Cleaning checklists for HTOs were used in five studies;[52,54,56,57,60] one study used a 43-point room cleaning checklist.[54] CDC also specifies that the responsibilities for cleaning HTOs should be clearly defined to avoid miscommunication among staff. One KI noted that roles are not usually clearly defined—for example, nursing staff believe that EVS personnel are responsible for cleaning an undesignated area of a patient's room and vice versa, which may result in inadequate room cleaning.

Next, CDC encourages "structured education for EVS staff" and outlines educational elements for EVSs frontline personnel such as:

- Provide an overview of the importance of HAIs in a manner commensurate with their educational level.
- Review specific terminal room cleaning practice expectations.
- Discuss the manner in which their practice will be monitored.
- Repeatedly reinforce the importance of their work.

Of the 24 (32%) studies that integrated implementation tools, 23 (96%) studies reported education as a key component while five studies specifically reported on training staff.[54,57,79-81] Smith et al. 2014[56] reported integrating educational interventions such as hands-on education with ATP devices and use of the "Clean Sweep" electronic game in which users rank three high-touch surfaces (from cleanest to least clean) from a drop-down menu, then submit the data for feedback. In 2007, Whitaker et al. provided education for staff, patients, and visitors,[82] while other studies used a training DVD, competency-based training,[79] training on preparation, use and storage of products,[80] and training on the use of chemicals.[57]

Next, CDC recommends developing measures for monitoring staff competency and performance that may include evaluations and utilize patient satisfaction surveys. One approach to evaluate skill acquisition is the Dreyfus model.[83] This model describes five levels of expertise from novice to expert level and can be used "(a) to provide a means of assessing and supporting progress in the development of skills or competencies, and (b) to provide a definition of an acceptable level for the assessment of competence or capability." Five studies (all published since 2012) described audits.[58-60,80,84] One study included a UV monitoring audit tool,[59] while another integrated monthly EC audits.[80] Ramphal et al. 2014[53] implemented "blinded monitoring with transparent reporting of the results in a positive, engaging manner," while Hota et al. 2009[62] utilized "intensified" monitoring "providing immediate, specific feedback." One KI recommended leveraging organizations such as APIC (http://www.apic.org/) and Infection Control and Prevention-Canada (http://www.ipac-canada.org/) to inform and encourage

"translation of knowledge" to frontline staff. Another KI emphasized the importance of identifying those who can best communicate to EVS staff, particularly when staff knowledge deficits or other concerns are identified.

According to CDC, each "cycle of evaluation" should be followed by feedback to EVS staff, with results "shared widely within and beyond the institution." Distinct methods of feedback described in primary studies were weekly electronic feedback (e.g., unit rates, rankings) to EVS, hospital leadership, and unit administrators;[85] feedback of UV-powder and gel surveillance results to EVS staff, hospital leadership, and unit administrators,[85] feedback from staff focus groups;[86] and feedback to EVS staff (monthly meetings, small group meetings, and individual meetings).[87] To optimize the thoroughness of terminal room cleaning and disinfection, CDC recommends discussing the results of monitoring programs and interventions as "a standing agenda item for the Infection Control Committee."

One acute care hospital used patient satisfaction surveys to measure patient satisfaction after the introduction of a pulsed xenon ultraviolet (PX-UV) device.[88] Satisfaction scores were measured on the Hospital Consumer Assessment of Healthcare Providers and Systems survey on a quarterly basis over 13 quarters. Forwalt and Riddell noted that "after the introduction of the PX-UV system, the score for cleanliness and the overall rating of the hospital rose from below the [50th] to the [99th] percentile," which ultimately resulted in financial benefits to the hospital.

Evidence of the Effectiveness of Strategies for Implementing Cleaning, Disinfection, and Monitoring Modalities (Guiding Question 2)

Key Points

- Seventeen implementation studies were conducted primarily in the United States and were designed as before-and-after studies.
- Fourteen (82%) studies implemented single-component strategies to prevent HAIs due to multiple pathogens. Infection rate was the primary outcome for two (14%) studies. Surface contamination-related outcomes were the primary focus of 12 (86%) studies.
- Three (18%) studies reported positive results from implementing multicomponent strategies to prevent *C. difficile* infections.
- Five studies reporting on sustainability of preventive strategies described ongoing education, direct feedback, and commitment and flexibility of administrative leaders as key components to successful implementation.

Primary Studies

We next present detailed information on the studies focused specifically on implementing infection control interventions and contextual factors. Seventeen studies were published between 2006 and September 2014; nine (53%) studies were published since 2012. Most studies were conducted in the United States, and others were conducted in Australia[58] and Canada.[59,60] Complete information on these studies is available in Appendix C.

Study Characteristics

Thirteen studies used historical controls, including before-and-after study designs (9), and interrupted time series (4).[52,53,57,63] Three studies used nonrandomized concurrent controls,[56,59,61] and one was an uncontrolled, descriptive study.[55] Study length ranged from 8 weeks to 4 years. Three studies implemented multicomponent strategies.[52,53,57] One study implemented an infection prevention bundle that included contact precautions for patients with diarrhea and sign placement for patients with confirmed/suspected *C. difficile* infection.[52] Other studies incorporated hand hygiene[53] and antibiotic stewardship[57] with their EC strategies.

The unit of analysis in order of most to least common were patient rooms, HTOs, hospital units, hospitals, beds, and patients. The primary setting for six studies was the ICU.[55,60-63,89] Other settings included burn units,[52] telemetry units,[52] long-term acute care hospitals,[57] general medical wards,[59] respiratory step-down units,[65] and a surgical ward.[66] Wards were not specified in three studies.[51,53,58]

C. difficile was the primary focus of three studies.[52,57,59] VRE was the primary focus of two studies.[62,67] The remaining studies focused on at least two of the three pathogens of interest. Five studies reported cleaning and disinfection of more than 15 HTOs.[52,53,55,56,65] One study's sole focus was the bathroom.[59] Most commonly reported HTOs included bed rails, call buttons, light switches, tray tables, and toilets, but there was substantial variety in selection of HTOs across studies.

Use of ATP bioluminescence and fluorescent/UV markers was widely integrated into implementation strategies as monitoring and educational tools. Cleaning and disinfection methods reported by some studies included hypochlorite-based disinfectant,[52] QAC,[56,61,62] hydrogen peroxide vapor, and microfiber mops.[57]

Study Outcomes

Primary outcomes for most studies were variants of surface contamination (e.g., surfaces cleaned, positive cultures, compliance with room cleaning and disinfection protocols). Acquisition of pathogens was reported as a primary outcome in two studies.[61,67] Infection rate was reported as a primary outcome in three studies[57,61,67] and as a secondary outcome in two studies.[52,53]

All three studies implementing multicomponent preventive strategies reported positive results. Koll et al. 2014[52] reported significant reductions in hospital-onset *C. difficile* infection rates at 35 participating New York metropolitan regional hospitals. Ramphal et al. 2014[53] reported statistically significant improvements in cleaning rates due to repeated training, while Brakovich et al. 2013[57] reported success in decreasing *C. difficile* incidence.

Of the remaining 14 implementation studies, the study length of 6 studies was 6 months or fewer. Two studies (2 months in duration)[51,60] reported that use of ATP and fluorescent markers as monitoring tools resulted in "rapid improvements in cleaning thoroughness"[60] and "enhanced collaboration, communication and education."[51] One 4-month trial (Rupp et al. 2014)[55] identified a subgroup of housekeepers or "optimum outliers" who were significantly more efficient and effective than their coworkers. The authors hoped to use their exemplary performance to increase overall performance improvement. Three studies described various monitoring methods (e.g., swab cultures,[66] fluorescent markers,[58] UV markers[59]) as useful tools to audit and educate staff.

One recently conducted 4-year study (Rupp et al. 2014)[54] concluded that monthly feedback and face-to-face meetings with frontline staff were crucial to EC success. Hayden et al.[67] demonstrated that a multimodal intervention to improve EC and hand hygiene reduced VRE

acquisition in an endemic setting. Datta et al. 2011[61] concluded that enhanced cleaning (bucket immersion of cloths into QAC) may reduce MRSA and VRE transmission and eliminate risk of MRSA acquisition from a room previously occupied by a patient colonized with MRSA. Results from three studies demonstrated improvements in cleaning rates,[63,65] with an expectation that the decrease in environmental contamination would help control spread of multi-drug-resistant organisms (MDROs).[67]

Lastly, Hota et al. 2009[62] purported that VRE contamination is caused by poor adherence to procedures and use of products "rather than to a faulty cleaning procedure or product." Carling et al. 2008[64] conducted the largest study (a collaborative of 36 hospitals) and concluded that an EC program's success relies on support by administrative leadership and institutional flexibility.

Several studies reported on the sustainability of their preventive strategies. Ramphal et al. 2014[53] reported sustaining gains for 6 months. Trajtman et al. 2013[59] described use of graphs posted on the wards and in the EVS office to assist in "sustained improvement in cleaning compliance." In 2011, Murphy et al.[58] reported unsustainable gains without ongoing education. In 2008, Carling et al.[64] reported results of collaborative efforts by 36 hospitals to improve cleaning practices. Eight hospitals that had participated for over 2 years in the program reported data on sustainability. They found that the thoroughness of cleaning decreased by 10% to 20% within 6 to 18 months of the last feedback session. Of the remaining 59 studies, only 1 study reported sustainability of its EVS strategy and reported "prolonged benefits" from 12-week use of fluorescent markers combined with regular feedback of results.[85]

Evidence of the Effectiveness of Strategies for Environmental Cleaning and Disinfection (Guiding Question 3)

Key Points

- Study designs for primary studies focusing on cleaning and disinfection were mostly limited to nonrandomized concurrent or historical controls.
- Use of QAC, chlorine-based disinfectants, and UV or hydrogen peroxide vapor devices were well studied, while use of peracetic acid/hydrogen peroxide wipes, enhanced coatings, or microfiber cloths were not.
- *C. difficile*, MRSA, and VRE were most to least well studied, respectively.
- Primary outcomes included variants of surface contamination (40 studies), infection rate (13 studies), and colonization (3 studies).
- Studies examining chemical disinfectants reported mixed findings. Results from six studies examining chlorine-based products reported improvements in infection rates with bleach (4 studies);[82,90-92] ineffectiveness of Difficil-S in reducing infection rates (1 study)[80] and no difference in reducing microbial burden when comparing Virex with QAC (1 study).[93] One study reported that use of a potassium monopersulfate-based product was ineffective in reducing *C. difficile* spores.[94]
- Six studies integrating wipes into preventive strategies[81,84,95-98] reported positive outcomes, including significant and sustained reductions in *C. difficile* infection rates (2 studies).[81,97]
- Seventeen studies implementing no-touch modalities such as UV light and hydrogen peroxide vapor reported positive findings; three studies reported reductions in infection rates.[99-101]

- Seven (88%) studies examining enhanced coatings reported positive findings.[38,102-107]

We identified 4 systematic reviews and 59 primary studies that met the inclusion criteria for this question. The focus of 2 systematic reviews[108,109] and 47 primary studies[9,38,79-82,84,86,87,90-107,110-129] was cleaning and disinfection.

Systematic Reviews

Two systematic reviews addressed this topic. First, Falagas et al. 2011[108] reviewed the effectiveness of airborne hydrogen peroxide (vapor and dry mist formulations) in hospital settings in 10 studies published before December 2009. Seven studies evaluated the delivery of hydrogen peroxide in the form of vapor while three studies evaluated delivery of hydrogen peroxide in the form of a dry-mist system or "dry fog." Pathogens addressed included MRSA (5 studies) and *C. difficile* (3 studies). Settings included surgical wards, "ward side rooms," and bathrooms. Results indicated significant reductions in contamination of sampled environmental sites after use of hydrogen peroxide compared with standard terminal cleaning and disinfection (39.0% [range 18.9% to 81.0%] baseline, 28.3% [range 11.9% to 66.1%] after standard terminal cleaning, 2.2% [range 0% to 4.0%] after addition of airborne hydrogen peroxide). Two studies reported on effectiveness of hydrogen peroxide on infection rates. One study (conducted in a 20-bed surgical ward) indicated "eradication of MRSA," while the other study (conducted in a 500-bed hospital) indicated "significant reductions in *C. difficile*-associated disease." Despite favorable results for the use of airborne hydrogen peroxide for disinfection and infection control, the authors called for additional studies to "assess the effectiveness, safety, costs, and applicability of this novel method against other available cleaning methods."[108]

Second, Dettenkofer et al. 2004[109] evaluated the effects of disinfection compared with cleaning with "detergent only" of environmental surfaces on HAI rates. The review included four clinical trials published through 2001. Settings included tertiary hospitals, medical units, and ICUs. Disinfectants included QAC, orthobenzyl-parachlorophenol, 0.5% aldehyde, and a 1:10 hypochlorite solution. Three studies indicated no significant difference in the rates of nosocomial infections. Results from the fourth study indicated a significant decrease in HAI rates in bone marrow transplant patients but no decrease in rates in patients in the neurosurgical ICU or a general medicine unit. The authors concluded that targeted disinfection is an "established component of hospital infection control," but future research will require well-designed studies due to the "complex, multifactorial nature of nosocomial infection."[109] The two systematic reviews are summarized in Appendix C.

Primary Studies

Of the 47 primary studies addressing this topic, 27 (57%) were conducted in the United States. The remaining 20 (43%) studies were conducted in the United Kingdom,[80,81,104,105,107,111,119,122,126,129] Australia,[79,84,86,117,123] Sweden,[94,106] Canada,[120] Norway,[121] and Italy.[92] Studies were published between 1998 and September 2014, but 28 (59%) were published since 2012, reflecting recently growing interest in EC. Cleaning and disinfection methods were generally categorized as surface cleaning and disinfection, automated processes, or enhanced coatings or surfaces. Two studies examined steam vapor[116] and mopping methods.[92] Of the remaining studies, 33 focused solely on either surface cleaning/disinfection (21 studies), automated technologies (8 studies), or enhanced coatings (4 studies), while 12 studies reported on a combination of methods.

Reported touch modalities included QAC, chlorine-based disinfectants (e.g., Chlor-Clean, Difficil-S, Oxivir, Virex, bleach), wipes (e.g., accelerated hydrogen peroxide wipes, disposable V-wipes, peracetic acid wipes), other detergents (e.g., potassium monopersulfate), and neutral electrolyzed water.[129] Seventeen studies evaluated the effectiveness of no-touch modalities, including automated UV light, hydrogen peroxide vapor, or steam vapor to reduce microbial burden. Ten studies (published since 2010) examined UV-C devices such as Tru-D [87,112,118,122,124,125,128] or PPX-UV.[9,99,100] Seven studies evaluated use of hydrogen peroxide vapor systems such as BioQuell[79,101,111,114,117,124] or steam vapor using the VaporJet PC 2400.[116] Enhanced coatings or surfaces included copper,[38,102-105,107] organosilane antimicrobial,[127] and "Appeartex," an antimicrobial coating.[106] Lastly, two distinct studies compared cleaning methods (i.e., mopping methods,[121] quaternary ammonium delivery by spray or bucket[110]). Table 3 summarizes key characteristics of the primary studies identified by our search. Further information about the primary studies is presented in Appendix C. The systematic reviews are summarized in Table C-1.

Table 3. Summary of cleaning and disinfection primary studies

Modality	QAC	Chlorine-based	Peracetic Acid or HP Wipes	Ultraviolet Light Emitting	Hydrogen Peroxide Vapor	Coatings	Microfiber	Electrolyzed Water	All Studies
N, Studies	10	13	4	10	6	8	4	1	47
Pathogen: *C. difficile*	5	8	2	8	4	4	2	--	29
Pathogen: VRE	5	3	1	4	2	4	2	--	17
Pathogen: MRSA	6	1	--	5	2	5	2	1	20
Study Design: RCT	3	1	--	--	--	1	1	--	6
Study Design: Non-randomized Concurrent Controls	2	4	--	3	3	4	1	--	14
Study Design: Before-After	4	6	3	5	2	3	2	1	22
Study Design: Interrupted Time Series	1	2	1	2	1	--	--	--	5
Outcome: Surface Contamination	9	6	3	8	3	7	4	1	31
Outcome: Patient Colonization	1	1	1	--	--	1	--	--	3
Outcome: Patient Infection	1	8	1	3	4	--	--	--	13

HP=hydrogen peroxide; MRSA=Methicillin-resistant *Staphylococcus aureus;* QAC=quaternary ammonium compound; RCT=randomized controlled trial; VRE=Vancomycin-resistant *enterococci.*

Study Characteristics

Five studies were RCTs, and one was a randomized crossover study. Fourteen studies used nonrandomized concurrent controls, while 27 used historical controls, including 22 before/after study designs and 5 interrupted time series. Study length ranged from 4 weeks to 43 months. Three studies implemented multicomponent strategies (i.e., integrated an additional non-EC-related strategy).[79,119,123] The multicomponent strategies in one study included monitoring of hand-hygiene compliance and antimicrobial usage, additional active MRSA surveillance with more rapid turnaround of laboratory results, and implementation of isolation precautions.[79] Preventive strategies in another study included hand-hygiene education and enforcement of an antibiotic policy.[119] The third study integrated modified protocols to rely on alcohol-based hand hygiene and sleeveless aprons in place of long-sleeved gowns and gloves.[123] One study (Byers et al. 1998)[110] was a description of disinfection practices in the context of an outbreak.

The units of analysis were most commonly patient rooms or microbiologic samples. Numbers of rooms ranged from 4[121] to 11,389.[100] Numbers of samples ranged from 142[112] to 20,736.[119] The primary setting for most studies was the ICU or general medical or surgical wards. Other settings included cancer wards,[84,123] "intensive therapy unit,"[122] transplant ward,[123] and a long-term care ward.[116]

Monitoring methods used in these studies were categorized as swab cultures (13 studies), contact plates (9 studies), agar slide cultures (8 studies), fluorescent/UV markers (5 studies), and visual observation (3 studies). Other monitoring methods were described as sponge/wipe cultures, agar contact plates for aerobic bacteria, surface contact plates and seeded petri dishes, wipes, glove and hand plate cultures, and wipe/swatch cultures.

C. difficile was the primary focus of 13 studies.[80,81,87,90,91,94,97,99,101,111,118,120,126] VRE was the primary focus of four studies,[84,110,117,123] and MRSA was the focus of two studies.[9,79] The remaining studies focused on at least two pathogens, including one of the three pathogens of interest (*C. difficile*, MRSA, VRE). Most commonly reported HTOs were bed rails, side/tray tables, toilets, and floors. Table 3 includes the modalities by type of pathogen.

Study Outcomes

The primary outcome for 31 (66%) studies was surface contamination (e.g., bacterial burden, number of surfaces cleaned, positive cultures).[9,38,80,84,86,87,92-94,96,98,103-107,111-113,115-118,120-122,124,125,127-129] Sixteen (34%) studies reported infection rate (e.g., incidence rate expressed per 1,000 patient-days)[9,79,81,82,90,91,97,99-101,111,114,126] or colonization[80,102,123] as a primary outcome. Eight studies reported on *C. difficile*, two studies reported on MRSA, one study reported VRE infection rates, and three studies reported overall HAI rates. Other reported primary outcomes included compliance with room cleaning protocol,[98] contamination rates for health care worker gowns/gloves,[95] and number of bed areas where target pathogens were isolated during a sampling day.[119]

Secondary outcomes of interest included *C. difficile* ribotypes,[111] cleaning time,[9,98] adverse effects,[96] hospital-acquired *C. difficile* infection–attributable deaths/colectomies,[99] ease of use of ATP and Tru-D device,[121,128] and recontamination.[129]

Studies examining chemical disinfectants reported mixed findings. Grabsch et al. 2012[123] found marked reductions in new VRE colonization after implementing the Bleach-Clean program (a multicomponent strategy). Four studies examining bleach[82,90-92] reported reduced *C. difficile* rates. One study examining the effectiveness of accelerated hydrogen peroxide versus

stabilized hydrogen peroxide suggested that the accelerated hydrogen peroxide formulation was significantly better.[120]

Other studies, however, reported no difference or identified strategies that were ineffective. One study reported that use of Difficil-S, a chlorine-based product, was ineffective in reducing *C. difficile* contamination and *C. difficile* infection rates.[80] Sjoberg et al. 2014[94] reported a "moderate spread of *C. difficile* spores despite use of a potassium monopersulfate-based disinfectant (Virkon™)."[94] One randomized trial by Schmidt et al. 2012[93] reported no difference in "mean relative reduction of microbial burden" after use of Virex soaked on a washcloth or quaternary ammonium as a microdroplet from the PureMist system. Lastly, Stewart et al.[129] reported that while electrolyzed water significantly reduced microbial counts (including MRSA) 1-hour postcleaning, microbial counts exceeded original levels at 24 hours.

Studies integrating wipes into their cleaning and disinfection regimens reported positive findings. Friedman et al. 2013[84] studied the application of a QAC (Viraclean) or V-wipe against VRE contamination. The authors reported significantly lower residual levels of VRE compared with earlier levels using a benzalkonium chloride-based product for disinfection. Other studies integrating wipes into a surface-cleaning routine reported a nonsignificant reduction in contamination of health care worker gowns and gloves after routine patient care activities,[95] a significant reduction in *C. difficile* rates,[81] effectiveness as a surface disinfectant,[96] and sustained reductions in hospital-acquired *C. difficile* infection.[97] They supported the use of ready-to-use wipes over a traditional bucket method.[98]

Authors of the 10 studies examining UV light devices[87,112,118,122,124,125,128] or PPX-UV devices[9,99,100] as adjunctive infection control measures, concluded that the devices effectively reduced bacterial bioburden,[87,112,118,122,125,128] significantly reduced hospital-acquired *C. difficile* infection rates,[99] significantly decreased overall hospital-acquired MDRO rates,[100] or was superior to manual disinfection.[9] One study stated that integration of education, monitoring, feedback, a dedicated daily disinfection team, and implementation of a standardized process played a role in improved thoroughness.[87] One study comparing UV-C to hydrogen peroxide vapor[124] indicated effectiveness of both devices in reducing bacterial bioburden, but indicated that hydrogen peroxide vapor was significantly more effective due to UV-C's ineffectiveness "for sites out of direct line of sight."

Of the six remaining studies evaluating hydrogen peroxide vapor[79,101,111,114,117] or steam vapor,[116] investigators reported reductions in MRSA contamination from a multicomponent strategy,[79] significant reductions in *C. difficile*-associated diarrhea rates,[101] reduced environmental contamination and risk of acquiring MDROs compared with standard cleaning/disinfection,[114] and >90% or highly effective reduction in bacterial levels.[111,116,117]

Of the eight studies examining enhanced coatings or surfaces, authors indicated significantly lower rates of incident HAI and/or colonization compared with patients in standard rooms;[102] that the integration of copper reduced[103,104] or significantly reduced[38,105-107] surface bacterial bioburden, and no sustained impact on antimicrobial activity for organosilane products tested.[127]

Anderson et al. 2009[121] compared various modes of mopping and indicated that wet, moist, and dry mopping more effectively reduced bacterial burden on the floor than spray mopping. Lastly, Byers et al. 1998[110] indicated that the "new bucket method" of delivering quaternary ammonium resulted in "uniformly negative cultures."

Evidence of the Effectiveness of Strategies for Monitoring of Cleanliness (Guiding Question 3)

Key Points

- Two recent reviews[130,131] reported ATP as a quick and objective monitoring method that was poorly standardized[130] with low specificity and sensitivity to detect bacteria.[131]
- Fluorescent/UV markers and ATP bioluminescence were well-studied monitoring methods, while visual observation, agar slide cultures, and swab cultures were not.
- Ten (83%) studies were designed with nonrandomized concurrent or historical controls.
- Most commonly reported primary outcomes were percent of targets cleaned[17,132-134] or cleaning rate.[18,85,135,136]
- Findings from six studies mainly focusing on fluorescent/UV markers were positive.[85,132-136]
- Visual observation was reported as inferior compared to various monitoring methods in six studies.[17,18,137-140]

Of the 4 systematic reviews and 59 primary studies that met the inclusion criteria for this question, the focus of 2 systematic reviews[130,131] and 12 primary studies was monitoring.[17,18,85,132-140]

Systematic Reviews

Two systematic reviews examined monitoring tools for cleaning and disinfection. The sole focus of one systematic review (Amodio and Dino 2014)[130] was ATP bioluminescence. The other review (Mitchel et al. 2013)[131] took a broader approach and addressed visual inspection, fluorescent gel markers, ATP bioluminescence, and microbiological sampling.

Amodio and Dino 2014[130] included 12 studies published from 2000 to 2011 and conducted in the United Kingdom (8 studies), the United States (3 studies), and Brazil (1 study). Surfaces were monitored after cleaning and disinfection (4 studies), before and after (6 studies), or time of monitoring was not reported (2 studies). No study included concurrent surface cultures to correlate with microbial burden. ATP thresholds for RLUs ranged from 100 to 500. One study evaluated two thresholds (250 and 500 RLUs). Reported ATP threshold failure rates before cleaning ranged from 21.2% to 93.1% while after cleaning ranged from 5.3% to 96.5%. The authors concluded that while ATP was a quick and objective method for evaluating hospital cleanliness, it appeared to be poorly standardized at both the national and international level.

Mitchel et al. 2013[131] reviewed 124 articles for inclusion in the review (the final number of studies included was not reported). Findings from six studies evaluating visual inspection indicated "poor performance at identifying microbial load with 17% to 93% more surfaces identified as clean compared with other monitoring methods." Findings from seven clinical trials evaluating fluorescent markers indicated a frequent lack of attention to "high-risk surfaces in the near-patient zone." For ATP, Mitchel et al. 2013 described the low specificity and sensitivity in detecting bacteria. Lastly, microbiological sampling was recommended only in certain situations (e.g., ongoing outbreak investigations) since the process typically takes at least 2 days and requires technical expertise and laboratory capacity. For routine EC evaluation, the authors called for "fast, reproducible, cost-effective and reliable methods" to predict "timely clinical risk." These systematic reviews are summarized in Table C-1 in Appendix C.

Primary Studies

Of the 12 primary studies focused on monitoring, seven (58%) studies were conducted in the United States. Other settings included the United Kingdom (3 studies) and Canada (1 study); one location was unspecified. Studies were published from 2003 to 2013; three (25%) studies were published since 2012. Fluorescent/UV markers and ATP bioluminescence were the most commonly evaluated monitoring methods and were included in eight (67%) and five (42%) studies, respectively. Other monitoring methods evaluated were visual observation (5 [42%]) studies), agar slide cultures (3 [25%]) studies), and swab cultures (1 [(8%]) study). Al-Hamad and Maxwell evaluated agar slide cultures and the wipe-rinse method and assays. Six studies[85,132-136] focused on fluorescent/UV markers, and six other studies[17,18,137-140] evaluated several monitoring methods. Information on cleaning and disinfection methods and implementation factors associated with these studies were mostly unreported. Table 4 summarizes the primary studies on monitoring modalities identified in our literature searches. Additional information on these studies is available in Appendix C. The systematic reviews are summarized in Table C-1.

Table 4. Summary of modalities examined and study designs used in primary monitoring studies

Modality	ATP	UV	ACC	Visual Inspection	All Studies
N, Studies	5	8	4	5	12
RCT	--	--	--	--	--
Nonrandomized Concurrent Controls	5	2	3	5	5
Before-and-After	--	2	1	--	3
Interrupted Time Series	--	1	--	--	1
Descriptive	--	3	--	--	3

ACC=aerobic colony counts; ATP=adenosine triphosphate; RCT=randomized controlled trial; UV=ultraviolet light.

Study Characteristics

Five studies used nonrandomized concurrent controls, four used historical controls, and three studies did not have comparison arms. One study (Al-Hamad and Maxwell 2008)[139] was also designed to study the "correlation of two monitoring methods." Study length ranged from 4 weeks to 8 months (4 studies did not report study length). All the studies implemented a single-component EC strategy. The reported units of analysis were rooms (7 studies) or microbiologic samples (6 studies). Numbers of rooms ranged from 10 to 1,119. Numbers of microbiologic samples ranged from 90 to 3,532. Other units of analysis included surfaces (3 studies), hospitals (1 study reported, including 27 hospitals),[132] patients (1 study), and hospital wards (1 study). The unit of analysis in one study (Carling et al. 2008)[136] was 13,369 high-risk objects. Of the studies reporting setting (4 did not), four studies were set in the ICU and one was set in a general medical and surgical ward. Four studies focused on a single pathogen.[18,133,135,139] The most commonly reported HTOs were bed rails, tray/side table, toilet, call buttons, light switches, and door knobs.

Study Outcomes

Primary outcomes for eight studies were reported as percent of targets cleaned[17,132-134] or cleaning rate.[18,85,135,136] Two studies[138,140] reported air or surface microbial burden counts (RLUs

or colony-forming units [CFUs]), while other studies reported sensitivity to detect pathogens[137] or number of positive cultures[139] as the primary outcome of interest.

Six studies mainly focusing on fluorescent/UV markers[85,132-136] reported positive results. The technologies were reported as useful, inexpensive, simple, highly objective surface targeting methods[85,132,134] that helped achieve significant improvements [132,136] in cleaning and disinfection practices at their respective institutions. Blue et al. 2008[133] reported that the fluorescent chemical GlitterBug was "superior to previous visual inspection methods."

Results from the six studies[17,18,137-140] evaluating various monitoring methods mostly described the inferiority of visual observation compared to other monitoring methods. Of the six studies, five had nonrandomized controls.[17,18,137,138,140] Luick et al. 2013[137] reported that fluorescent marker and ATP assay "demonstrated better diagnosticity" than visual inspection. Smith et al. 2013[138] reported that despite measuring different aspects of environmental contamination, quantitative microbiology and ATP both "generally agree in distinguishing clean from dirty surfaces." Snyder et al. 2013[17] reported poor correlation between ATP/fluorescent markers and a microbiologic comparator. One study[18] proposed an ATP benchmark value of 100 RLUs since it would offer the closest correlation with microbial growth levels <2.5 CFU/cm^2. A 2003 study[140] recommended assessing effectiveness of hospital disinfection with internal audit and rapid hygiene testing. Lastly, results from a before/after study (Al-Hamad and Maxwell 2008)[139] indicated a "poor correlation between the findings of total aerobic count and MRSA isolation." See Appendix C for further details on the outcomes and conclusions reported in these studies.

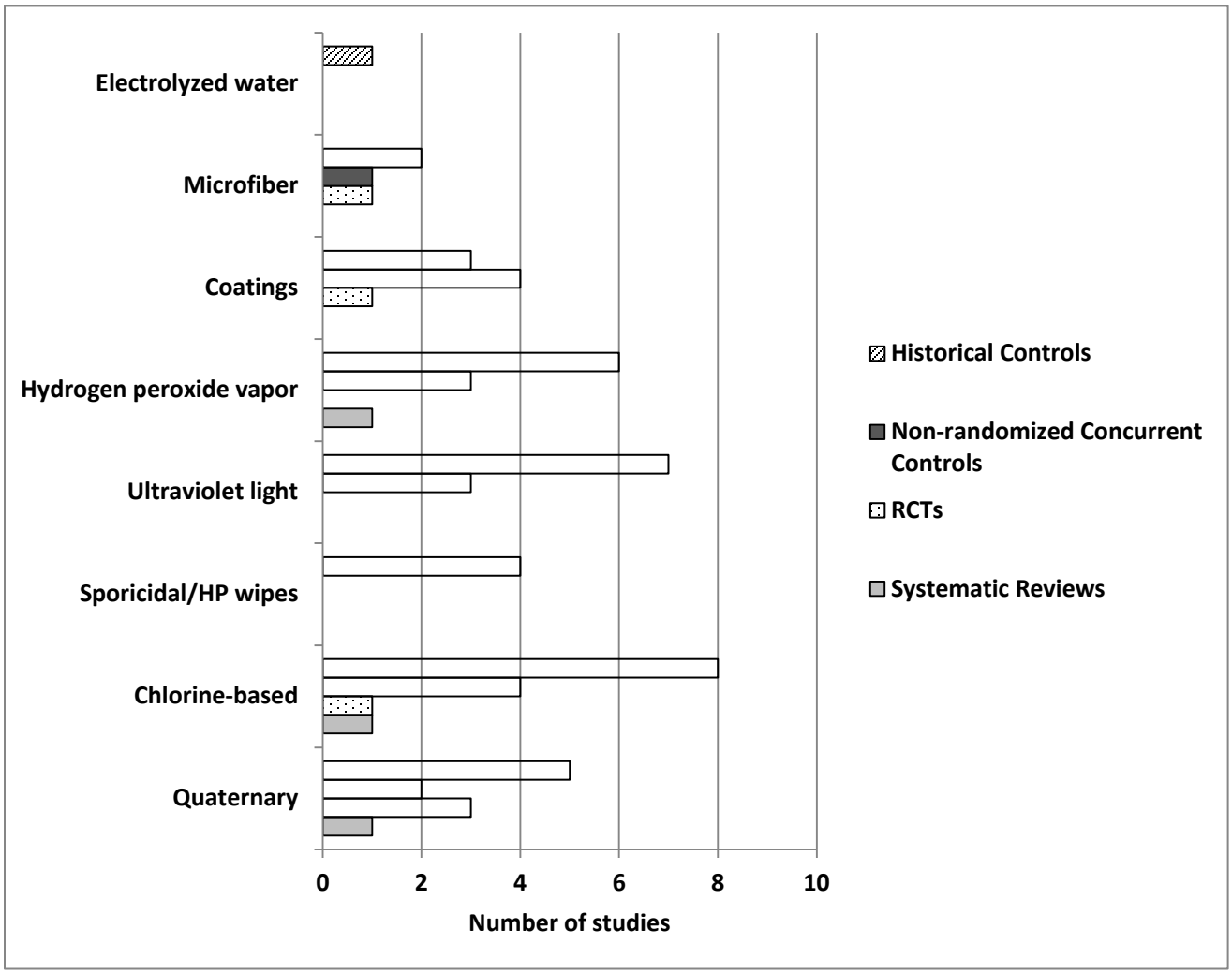
Evidence Map (Guiding Questions 3 and 4)

The evidence map that follows is designed as a concise, visual summary of the evidence base and major evidence gaps on EC for preventing HAIs.

Figure 2 shows the number and research design of published studies that address major categories of cleaning and disinfection strategies. Figure 3 presents the number and research design of studies of monitoring modalities. Figure 4 and Figure 5 provide snapshots of how many studies address critical outcomes and major pathogens, respectively, from among articles that evaluate cleaning, disinfection, monitoring, or implementation of these strategies. Figure 6 depicts evidence gaps that suggest high-impact areas for future research, as recommended by our Key Informants or indicated by our analysis of the current evidence base. The interventions in Figure 6 are organized in a framework adapted from McDonald and Arduino's recently proposed "evidence hierarchy" for environmental infection control.[141] This framework represents the progression of evidence for the effectiveness of EC interventions, from laboratory studies that measure surface contamination, to clinical studies that assess contamination in real-world settings, to studies of pathogen colonization and infection in patients.

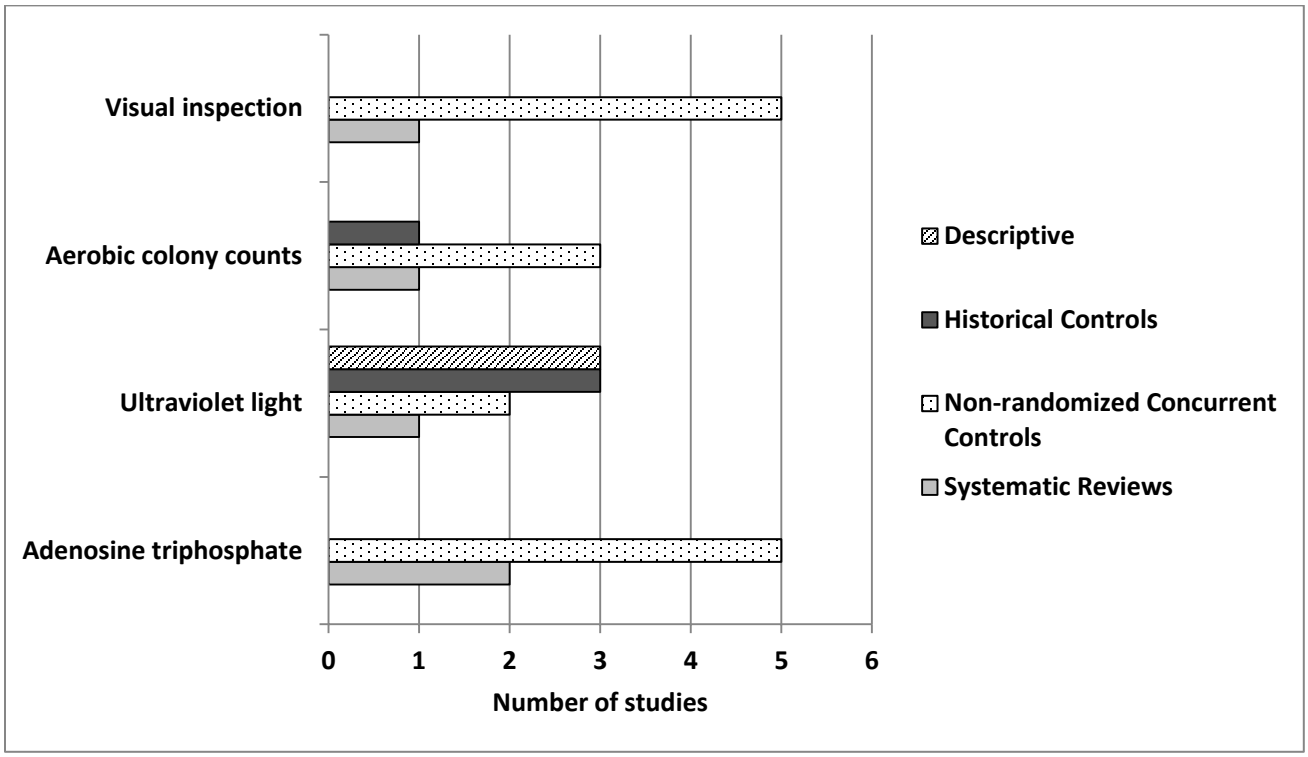
Summary of Published Evidence

Figure 2. Cleaning modalities: number of studies by study design
2 systematic reviews, 47 primary studies*



*Some studies evaluated more than one modality.

Figure 3. Monitoring modalities: number of studies by study design
2 systematic reviews, 12 primary studies*



*Some studies evaluated more than one modality.

Figure 4. Outcomes reported in all primary studies of disinfection, monitoring, and implementation

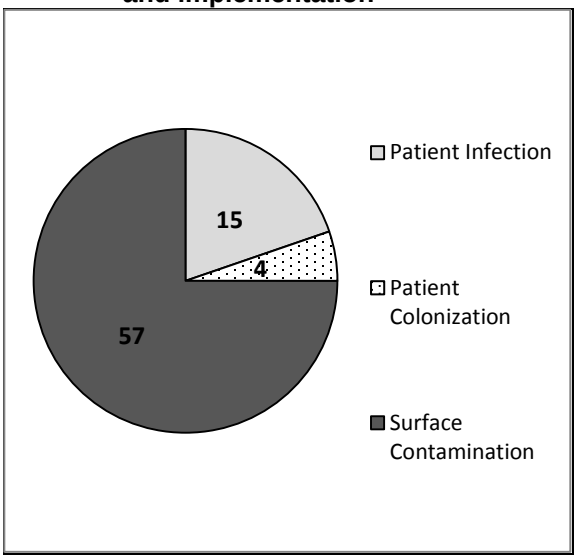


Figure 5. Pathogens studied in all primary studies of disinfection, monitoring, and implementation

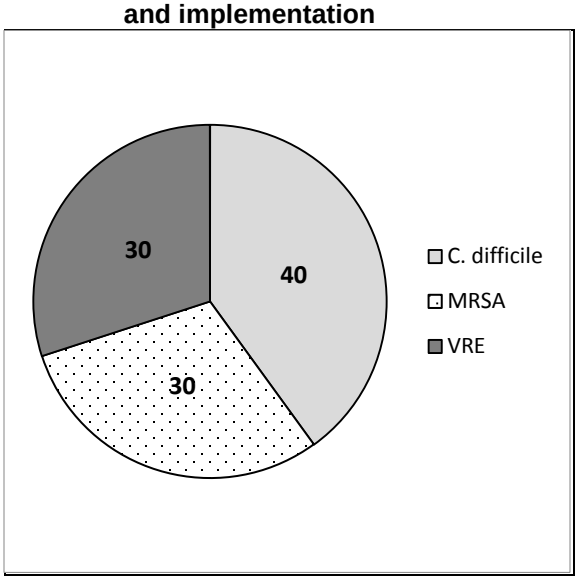
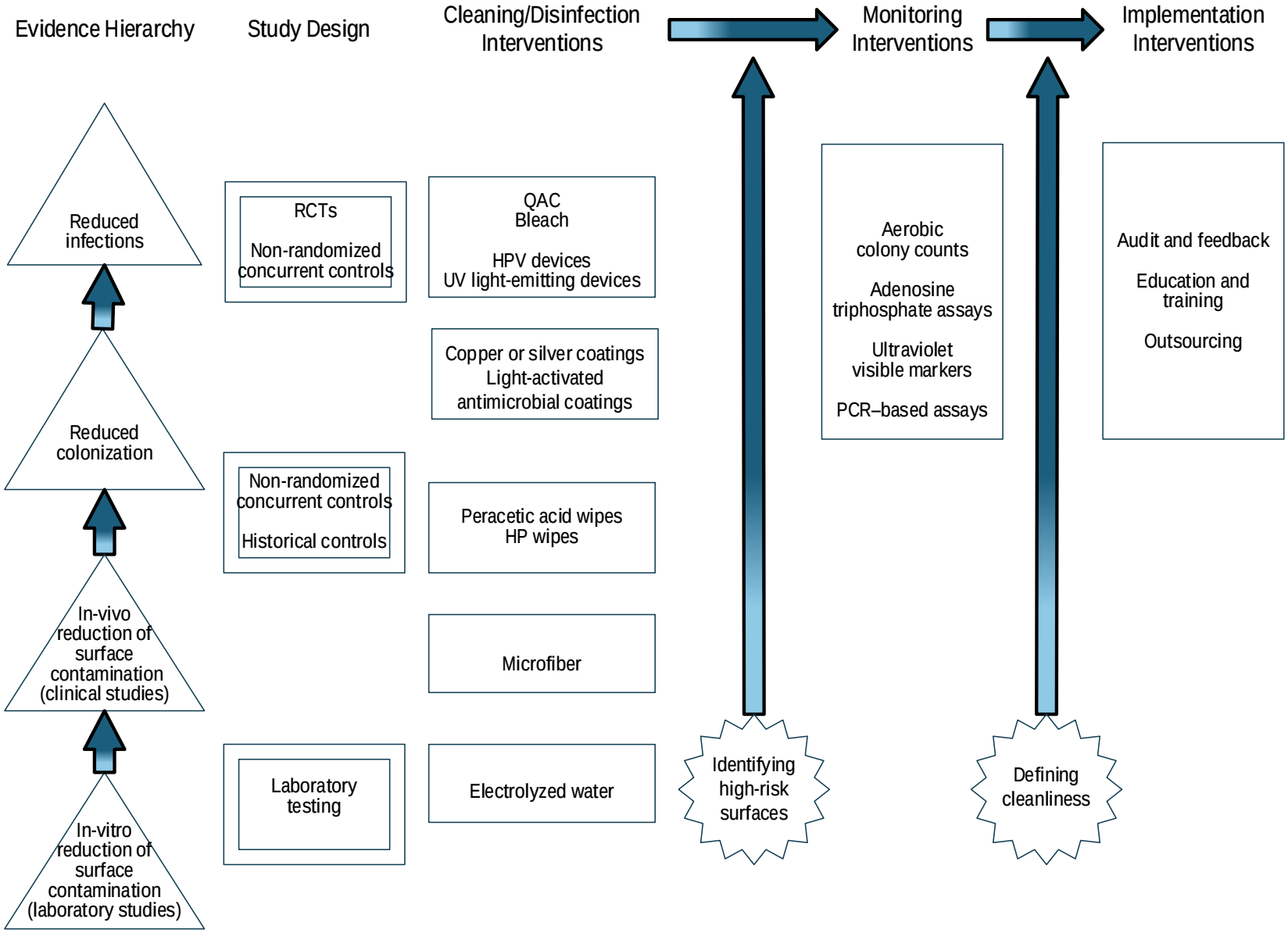


Figure 6. Evidence needs



HP=hydrogen peroxide; HPV=Hydrogen peroxide vapor; PCR=Polymerase chain reaction; QAC=quaternary ammonia compounds; RCTs-randomized controlled trials; UV=ultraviolet

Adapted from McDonald and Arduino. Climbing the Evidence Hierarchy for Environmental Infection Control[141]

Summary and Implications

A wide variety of studies have been published examining strategies for environmental cleaning (EC,) including 47 studies of surface cleaning/disinfection modalities, 12 studies of strategies for monitoring cleanliness, and 17 studies addressing implementation of best practices. Many surface disinfection techniques were evaluated, including well-established products such as quaternary ammonium and bleach, recently emerging technologies such as UV-C light, hydrogen peroxide vapor, and copper coatings, and less frequently used approaches, including sporicidal wipes and microfiber cleaning instruments. Multiple studies assessed several different monitoring techniques, including ATP, UV light, microbiologic colony counts, and visual inspection. Analyses of implementation studies demonstrated that numerous factors, such as culture, leadership, use of process standardization and feedback to staff, and organizational structure, can serve as facilitators or barriers to improving EVS practices. Challenges were also highlighted, including regulatory requirements, use of outsourcing to provide cleaning services, and sustaining improvement over time.

Cleaning and Disinfection Modalities

Surface cleaning and disinfection products and technologies have been widely studied, but the evidence base and current expert opinion have yielded consensus favoring only the value of quaternary ammonium and chlorine-based products. These chemical agents are the primary disinfectants used for routine disinfection of hospital rooms, with hypochlorites often recommended for rooms of patients infected with *C. difficile*. Use of wipes soaked in peracetic acid or hydrogen peroxide may be an alternative to QAC and bleach for manual surface disinfection, but studies supporting their effectiveness have only recently emerged.

Augmentation of manual surface cleaning and disinfection with automated disinfection technologies has been examined increasingly in recent years. Nine studies of UV light and seven studies of hydrogen peroxide vapor machines demonstrate their potential value, but product, maintenance, and staff training costs may deter hospitals from acquiring these devices. Coating surfaces with copper or silver is another approach that has recently begun to generate interest, and seven studies of coated surfaces have been published.

A major limitation of the evidence base, which KIs highlighted frequently, is the gap between appropriate use of surface cleaning/disinfection agents in studies and practical implementation in real-world settings. While surface disinfectants work best when applied properly to all relevant surfaces for a sufficient contact time, factors such as the consistency of chemical concentration and the effect of hard water on the disinfectants play a role in the products' efficacy. In addition, manufacturers typically provide recommendations for proper use of their products, but most studies do not report thoroughness of cleaning or adherence to disinfectant contact time; this information also remains largely unknown in daily practice. If studies do not ensure adequate application and contact time of chemical agents, results may be biased against a given product or in favor of an alternative, newer modality. Conversely, if study results reflect a product's optimal use, failure to adhere to appropriate product application and contact time in practice may lead to suboptimal outcomes. An important related concern, voiced by KIs and peer reviewers, is uncertainty by end users about the applicability of some manufacturer recommendations. Guidance that accompanies products may be based on laboratory testing under ideal conditions rather than clinical settings. Recommendations may also

be developed based on certain types of pathogens, but users may choose to implement a product or technology for broader effects.

Another challenge to interpreting the results of EC studies is the role of many confounding factors, including patient factors, hand hygiene, and other direct patient care practices that affect the risk of HAIs. Infection prevention within the hospital setting comprises many critical components in addition to hard surface cleaning, including sterilization of instruments, laundering of linens, implementation of appropriate isolation precautions, and proper hand washing/hygiene. These and other elements may sometimes be included as interventions within a larger multicomponent infection prevention strategy, limiting the ability to discern the specific impact of any single disinfection approach. These factors also have the potential to modify the effectiveness of EC interventions. Almost every KI emphasized that proper hand hygiene is the most important step for preventing HAIs and that failure to achieve good hand-hygiene practices can minimize the value of surface cleaning and disinfection techniques.

Monitoring Modalities

Visual inspection was the traditional method employed by EVS personnel and supervisors to ensure that rooms were cleaned adequately. Recently emerging monitoring modalities such as ATP and UV detection of fluorescent markers were examined in 5 studies and 8 studies, respectively. Aerobic colony counts (ACCs) were also used to evaluate surface microbial contamination in 4 studies.

As with cleaning and disinfection modalities, lack of direct comparisons between techniques is a major limitation of the evidence base for monitoring strategies. None of the studies identified by the literature searches for monitoring modalities was an RCT, and fewer than half used any comparative study design. Hospitals are therefore reluctant to adopt ATP and UV, according to several KIs, because these strategies have not been compared head-to-head.

An additional limitation of these studies is the lack of consensus for thresholds of cleanliness. Studies of bioluminescent markers typically report results in RLUs, but benchmarks for RLU levels have not been established. Similarly, thresholds for ACCs are not clearly delineated. This problem is not relevant for studies of UV light, where a threshold of total marker removal is widely accepted. Without commonly agreed-upon measures of key outcomes, selection of optimal approaches is difficult. Inclusion of feedback from various stakeholders, especially EVS management, is also key when deciding appropriate measures to use.

Additional Considerations

Two important limitations of this review should be noted. One is the restriction of this Technical Brief to studies of *C. difficile*, MRSA, and VRE. These pathogens have high incidence rates, cause significant patient morbidity, and are frequently targeted in studies of EC. By excluding studies that focused on gram-negative or other organisms to limit the scope of the Brief, our findings may not be fully generalizable to interventions aimed at reducing other types of infections. Future research should seek to review the evidence base for other pathogens. Further, many of the studies included in this review were undertaken during outbreaks and may not be representative of the effect of cleaning/disinfection and monitoring during routine periods of patient care.

Additionally, the limited breadth of evidence does not provide clear guidance on where and when to implement many of these interventions. For example, hospitals may seek to determine whether and how to prioritize the deployment of no-touch technologies (e.g., terminal cleaning

after discharge of a patient with *C. difficile*), but the studies reviewed in this Technical Brief do not provide direct evidence on the effectiveness of competing strategies in different settings. Similarly, the results of a study that examined terminal cleaning after discharge may not be generalizable to routine cleaning of nondischarge rooms, and vice versa. The evidence base provides important insights into the potential effectiveness of numerous EC strategies, but further research is needed to clarify the optimal context for their use.

Next Steps (Guiding Question 4)

Several important gaps in the current evidence base limit efforts to improve infection prevention programs and reduce HAI rates. Four important questions shape the evidence needs we have identified: (1) What surfaces should be cleaned and disinfected? (2) How should surfaces be cleaned and disinfected? (3) How should cleaning and disinfection be monitored and measured? and (4) How should interventions be implemented?

1. What Surfaces Should Be Cleaned and Disinfected?

A limitation of the overall evidence base on EC is uncertainty regarding which surfaces should be targeted during cleaning and disinfection. The scope of this Technical Brief was limited to HTOs. Focusing on surfaces that most frequently come into contact with both patients and health care workers is practical, but consensus is weak on which specific objects have the highest risk of transmitting HAIs. Studies of cleaning, disinfection, and monitoring modalities vary widely when selecting surfaces to evaluate, and some studies focus only on 2 or 3 surfaces while others assess 15 or more, thus making it difficult to determine which surfaces are at greatest risk of microbial contamination and infection transmission. KIs also expressed concern that almost no evidence exists to clarify whether any one specific surface presents greater risk of pathogen transmission to patients than another, and that further work was necessary to establish which objects and surfaces were “high-risk,” rather than merely “high-touch.” Future research should identify which objects and surfaces pose the greatest risk of transmission of pathogens and determine how risk varies by type of pathogen. Studies that correlate surface contamination with patient colonization or infection will be important for clarifying which surfaces require the greatest attention from EVS personnel.

2. How Should Surfaces Be Cleaned and Disinfected?

Certain chemical-based cleaning and disinfecting agents, including QAC and bleach, are widely used and have been studied in many settings. However, most studies have employed historical controls and have focused on documenting removal of surface contamination. Head-to-head comparisons that measure patient-centered outcomes, such as colonization or infection rates, are necessary to provide data on their comparative effectiveness. Similarly, numerous studies have examined no-touch devices that employ hydrogen peroxide vapor or emit ultraviolet light, but most studies have not compared them directly to each other, or to various touch modalities. In addition to these approaches, there are several emerging technologies that require further research to establish their efficacy for removing or preventing surface contamination, as well as evaluating their effectiveness for reducing pathogen transmission and patient infection. These include enhanced surface coatings, peracetic acid or hydrogen peroxide wipes, microfiber mops and cloths, and electrolyzed water. Future research should assess these approaches with

consideration of the limitations we have described throughout this Technical Brief and EPA regulations for registering products (http://www.epa.gov/pesticides/regulating/laws.htm).

3. How Should Cleaning and Disinfection Be Monitored and Measured?

Similarly, more studies are needed that examine how cleanliness is monitored. Future research should evaluate the comparative effectiveness of ATP, ultraviolet light, and ACCs, as compared to each other as well as the standard practice of visual observation. RCTs that provide head-to-head comparisons of patient-centered outcomes may be difficult to implement, but nonrandomized comparative studies examining surrogate outcomes can provide valuable data. Additionally, without validated benchmarks or widespread consensus on what thresholds of surface contamination are safe or acceptable, interpreting and comparing studies on the effectiveness of cleaning, disinfection, and monitoring tools will be difficult. Further research is necessary to correlate the cleanliness metrics that are measured by these modalities with clinical outcomes such as patient colonization or infection. Finally, the use of polymerase chain reaction (PCR)-based assays for assessing surface contamination is an emerging field for future study.

4. How Should Interventions Be Implemented?

Factors that affect real-world implementation are crucial but are rarely studied systematically or in depth. While previous studies have addressed organizational culture, staff training, and feedback cycles, there remains little understanding about the effect of these factors on HAIs. Important considerations of implementation, including how programs are sustained and the frequency and impact of EVS outsourcing, also require study.

Table 5 summarizes the additional evidence needed to optimize environmental cleaning of standard inpatient hospital rooms. It is based on the PICOTS structure, but the population and setting are not explicitly noted, because they are the same for each intervention listed: inpatient rooms in general medical and surgical units, as described in the Methods section. For each intervention described in the report, we have identified research needs that are not adequately met in the current literature, and categorized them by the following criteria: Comparator, which indicates which standard or alternative interventions would be appropriate for comparison; Outcomes, which identifies which of three primary outcomes (surface contamination, patient colonization, or patient infection) are needed for evaluating the effectiveness of an intervention; Timing, which indicates whether the intervention should be tested for routine, daily cleaning of hospital rooms, or terminal cleaning; and Study Design, which suggests what types of studies are necessary to assess each comparison and outcome.

Table 5. Evidence needs for environmental cleaning of standard inpatient hospital rooms

Intervention Category	Intervention	Comparator	Outcomes	Timing	Study Design
Cleaning and Disinfection: Touch Modalities	Quaternary ammonia compounds (QAC)	Detergents/ Chlorine-based disinfectants	Colonization/ Infection	Routine/ Terminal	RCTs/ Nonrandomized concurrent controls
	Chlorine-based disinfectants	Detergents/ QAC	Colonization/ Infection	Routine/ Terminal	RCTs/ Nonrandomized concurrent controls
Cleaning and Disinfection: Touch Modalities (continued)	Peracetic acid or HP wipes	Standard care	Contamination	Routine	Historical controls
		All other touch modalities	Contamination/ Colonization/ Infection	Routine	Any
	Microfiber	Standard mops/towels	Contamination	Routine	Historical controls
		Other touch modalities	Contamination/ Colonization/ Infection	Routine	Any
	Electrolyzed Water	Standard care	Contamination	Routine	Historical controls/ Laboratory testing
Cleaning and Disinfection: No-Touch Modalities	Ultraviolet light emitting	Touch modalities	Colonization/ Infection	Terminal	RCTs/ Nonrandomized concurrent controls
		Hydrogen peroxide vapor	Contamination/ Colonization/ Infection	Terminal	RCTs/ Nonrandomized concurrent controls
	Hydrogen peroxide vapor	Touch modalities	Colonization/ Infection	Terminal	RCTs/ Nonrandomized concurrent controls
		Ultraviolet light emitting	Contamination/ Colonization/ Infection	Terminal	RCTs/ Nonrandomized concurrent controls
	Coatings	All touch and non-touch modalities	Contamination/ Colonization/ Infection	Routine/ Terminal	Any
Cleaning and Disinfection: Additional Considerations	Identifying “high-risk” surfaces	Comparisons between high-touch surfaces	Contamination/ Colonization/ Infection	Routine	Nonrandomized concurrent controls/ Laboratory testing

Table 5. Evidence needs for environmental cleaning of standard inpatient hospital rooms (continued)

Intervention Category	Intervention	Comparator	Outcomes	Timing	Study Design
Monitoring	ATP	Visual inspection	Colonization/ Infection	Terminal	Nonrandomized concurrent controls
		Ultraviolet light/ Aerobic colony counts	Contamination/ Colonization/ Infection	Terminal	RCTs/ Nonrandomized concurrent controls
	Ultraviolet light	Visual inspection	Colonization/ Infection	Terminal	Nonrandomized concurrent controls
		ATP/ Aerobic colony counts	Contamination/ Colonization/ Infection	Terminal	RCTs/ Nonrandomized concurrent controls
	Aerobic colony counts	Visual inspection	Colonization/ Infection	Terminal	Nonrandomized concurrent controls
		ATP/ Ultraviolet light	Contamination/ Colonization/ Infection	Terminal	RCTs/ Nonrandomized concurrent controls
Monitoring: Additional Consideration	Setting thresholds for "cleanliness"	Contamination measures	Colonization/ Infection	Routine/ Terminal	Nonrandomized concurrent controls
Implementation: Structural Characteristics	Outsourcing	In-house staff	Adherence to standards/ Contamination/ Colonization/ Infection	Routine/ Terminal	Nonrandomized concurrent controls/ Historical controls
Implementation: Management Tools	Training and educational interventions	N/A	Adherence to standards/ Contamination/ Colonization/ Infection	Routine/ Terminal	Nonrandomized concurrent controls/ Historical controls
	Feedback cycles	N/A	Adherence to standards/ Contamination/ Colonization/ Infection	Routine/ Terminal	Nonrandomized concurrent controls/ Historical controls

ATP=adenosine triphosphate; N/A=not applicable; QAC=quaternary ammonia compounds; RCT=randomized controlled trial

Additional Considerations for Future Research

As represented in Table 5 and Figure 6, there are two additional factors that must be considered in designing and prioritizing future research efforts: selection of appropriate patient-centered outcomes, and designing research studies that are practical and useful.

Patient-Centered Outcomes

The current evidence base does not demonstrate strong correlation between cleaning, disinfection, monitoring, and HAIs. Surface contamination is the most common outcome reported in studies of cleaning/disinfection and monitoring strategies. Patient infection rates are

less frequently measured, although they were reported in 15 studies. Patient colonization measures were rarely recorded, but a few KIs suggested that pathogen acquisition is a useful surrogate outcome that should be measured and reported in studies of EC. Among the potential advantages of measuring acquisition is that it is a more clinically meaningful outcome than surface contamination and a more frequent outcome than infection and thus provides studies with more power to detect meaningful differences between interventions. Baseline infection rates within the study populations are also important factors for understanding the evidence. Since many of the studies in this review occurred during outbreaks, the effect size of interventions may have been overestimated.

Patients also have preferences in addition to clinical outcomes. KIs reported that patients often expect their room to "look and smell clean." Although these preferences are imprecise and may not correlate with scientific measures of cleanliness, patients may express concerns to hospital staff or management or through satisfaction surveys when expectations are not met.

Research Design

Most studies do not directly compare the effectiveness of different techniques. Instead, most used historical controls, such as before-and-after or interrupted time-series study designs, to assess the impact of a single disinfection modality. Although such studies are valuable for establishing baseline measures of effectiveness, they do not demonstrate which approaches might be optimal. Direct comparative-effectiveness data are necessary to guide optimal selection of cleaning/disinfection agents and technologies. Second, RCTs are not always feasible for studying EC interventions.[141] Patient-centered outcomes such as HAI rates often do not occur with enough frequency to be easily detected by modest-sized RCTs. This is further complicated by the complex environment of pathogen transmission and the interaction of disinfection strategies with many other factors such as hand hygiene. Given these challenges, well-designed observational studies may provide crucial evidence to guide EC practices.

It is also important to control for confounders and multicomponent interventions in these studies. Innovative approaches for designing or analyzing studies are necessary to discern the specific impact of EC strategies within the larger context of infection prevention programs and hand-hygiene compliance for preventing HAIs. This Technical Brief did not identify any specific published models or strategies that might guide efforts to control for confounding by other infection prevention strategies.

Funding Future Research

Studies of EC are most often funded by manufacturers of cleaning agents or disinfection technologies, creating potential conflicts of interest. These conflicts introduce real or perceived biases into the evidence base and may lead to skepticism by EVS professionals and infection control experts about the results of these studies. Our KIs indicated that concerns about industry funding of published research may deter adoption of disinfection and monitoring technologies. While it is reasonable to expect that manufacturers should be the primary source of funding for early studies of newly emerging technologies, it is important for less conflicted funders to assume a major role in comparative-effectiveness research in this domain.

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Appendix A. Literature Search Methods

Electronic Database Searches

ECRI Institute information specialists searched the following databases for relevant information. Search terms and strategies for the bibliographic databases appear below.

Table A-1. Electronic database searches

Database	Date Limits	Platform/Provider
ClinicalTrials.gov	Through February 3, 2015	U.S. National Institutes of Health
The Cochrane Central Register of Controlled Trials (CENTRAL)	1990 through 2015. Issue 2	Wiley
The Cochrane Database of Methodology Reviews (Methodology Reviews)	1990 through 2015, Issue 2	Wiley
The Cochrane Database of Systematic Reviews (Cochrane Reviews)	1990 through 2015, Issue 2	Wiley
Cumulative Index to Nursing and Allied Health Literature (CINAHL)	1990 through 2015, Issue 2	EBSCO*host*
Database of Abstracts of Reviews of Effects (DARE)	1990 through 2015, Issue 2	Wiley
EMBASE (Excerpta Medica)	1990 through February 2, 2015	Elsevier
Health Technology Assessment (HTA)Database	1990 through 2015, Issue 2	Wiley
Healthcare Standards Directory (ECRI Institute)	Through February 3, 2015	ECRI Institute
MEDLINE (via EMBASE)	1990 through February 2, 2015	Elsevier
PubMed (In-process, Publisher, and PubMedNotMedline records)	1990 through February 2, 2015	U.S. National Library of Medicine
Scopus*	Through February 4, 2015	Elsevier
U.K. National Health Service Economic Evaluation Database (NHS EED)	1990 through 2015, Issue 2	Wiley
U.S. National Guideline Clearinghouse™ (NGC)	Through February 3, 2015	Agency for Healthcare Research and Quality (AHRQ)

*Scopus was utilized for citation tracking and searching trade publications

Hand Searches of Journal and Non-journal Literature

Journals and supplements maintained in ECRI Institute's collections were routinely reviewed. Non-journal publications and conference proceedings from professional organizations, private agencies, and government agencies were also screened. Other mechanisms used to retrieve additional relevant information included review of bibliographies/reference lists from peer-reviewed and gray literature. (Gray literature consists of reports, studies, articles, and monographs produced by federal and local government agencies, private organizations, educational facilities, consulting firms, and corporations. These documents do not appear in the peer-reviewed journal literature. See the *Methods* section, *B. Gray Literature Search*, for a list of gray literature resources searched.)

Bibliographic Database Searches

EMTREE Index Terms, CINAHL Headings, and Text Words

The search strategies employed combinations of free-text keywords as well as controlled vocabulary terms, including the concepts shown in the Topic-specific Search Terms table.

Table A-2. Topic-specific search terms

Concept	Controlled Vocabulary	Text Words
Population (admitted, adult patients in hospital settings)	**EMTREE (EMBASE)** Patient **CINAHL** Patients	Inpatient/s Patient/s
Setting (physical location) (patient rooms and common areas in hospitals and hospital-like settings)	**EMTREE** Health care facility Hospital Hospital discharge **CINAHL** Academic medical centers Health facilities Hospital units Hospitals Patients' rooms+ Patient discharge	Acute care Burn unit/s Common area/s Critical care General ward/s Health care facility/ies Healthcare facility/ies Health care setting/s Healthcare setting/s Hospital/s Hospitals/hospitalization ICU Institution/s Intensive care Medical facility/ies Medical ward/s Patient care area/s Patient room/s Patient ward/s
Setting (types of surfaces) (high-touch surfaces)	**EMTREE** Fomite Hospital bed Hospital equipment **CINAHL** "beds and mattresses" portable equipment	Bathroom* Bed rail/s Bedrail/s Cart/s Chair/s Clinical surfaces Commode/s Environmental surfaces Fomes Fomite/s Environmental réservoir/s High-contact High-touch

Concept	Controlled Vocabulary	Text Words
		Hospital bed/s Hospital surface/s Mobile equipment Portable equipment Railing/s Shared medical equipment Surface contamination Surface microbes Toilet* Wheelchair/s
Infections (broad terms)	**EMTREE** Healthcare associated infection Hospital infection **CINAHL** Cross infection	HAI/s Health care acquired infection/s Health care acquired pathogen/s Health care associated infection/s Health care associated pathogen/s Health care acquired infection/s Health care acquired pathogen/s Health care associated infection/s Health care associated pathogen/s Hospital acquired infection/s Hospital associated infection/s Hospital associated pathogen Health care acquired pathogen Healthcare acquired pathogen Hospital acquired pathogen/s Hospital associated pathogen/s
Infections (specific terms) (Clostridium difficile, methicillin-resistant Staphylococcus aureus, and vancomycin-resistant enterococci)	**EMTREE** Clostridium difficile Clostridium difficile infection Enterococcal infection Methicillin resistant staphylococcus aureus Methicillin resistant staphylococcus aureus infection Vancomycin resistant enterococcus **CINAHL** Clostridium difficile Clostridium infections Enterococcus Enterococcal infections Methicillin resistance Methicillin-resistant staphylococcus aureus	Antibiotic resistance Antibiotic-resistant CDI Difficile Methicillin-resistance Methicillin –resistant MRSA Multi-drug resistance Multi-drug-resistant Multidrug resistance Multidrug-resistant Vancomycin resistance Vancomycin-resistant VRE VRE

Concept	Controlled Vocabulary	Text Words
	Staphylococcal infections Vancomycin resistance	
General hospital cleaning	**EMTREE** Cleaning disinfection environmental sanitation Infection control **CINAHL** Decontamination, hazardous materials Infection control Sterilization and disinfection	Cleaning Aseptic technique/s Cleaning method/s Cleaning practice/s Cleaning protocol/s Cleaning regimen/s Cleaning routines Cleaning technique/s Discharge cleaning Discharge room cleaning Enhanced cleaning Environmental cleaning Environmental decontamination Environmental disinfection Environmental sanitation Hospital hygiene Housekeeping Precleaning Pre-cleaning Room cleaning Room decontamination Routine cleaning Surface cleaning Surface decontamination Surface disinfection Terminal cleaning Terminal disinfection Terminal room
Disinfection agents	**EMTREE** Bleaching agent Disinfectant agent Quaternary ammonium derivative **CINAHL** Cleaning compounds Disinfectants Quaternary ammonium compounds Sodium hypochlorite	Accelerated hydrogen peroxide Aldehyde/s Alcohol/s Benzalkonium chloride Biocidal Biocide/s Bleach/ing Calcium hypochlorite Chemical agent/s Chemical disinfection Chlorhexidine digluconate Cleaning agent/s Disinfectant/s

Concept	Controlled Vocabulary	Text Words
		Disinfecting Disinfection agent/s Germicidal Germicide/s Glutaraldehyde Guanidine hydrochloride Hypochlorite/s Ortho-phthalaldehyde Orthophthalaldehyde Peracetic acid Phenol Phenols Phenolic/s QAC/s Quaternary ammonium Sodium dichloroisocyanurate Sporicidal Sporicide/s Vinegar
Automated devices	**EMTREE** Disinfection system Hydrogen peroxide Ultraviolet irradiation Ultraviolet radiation Vapor Water vapor **CINAHL** Hydrogen peroxide Ultraviolet rays	Aerosol Automated cleaning Automated device/s Automated decontamination Automated disinfection Automated surface Fogging Hydrogen peroxide H2O2 Mist No-touch Non-touch Pulsed ultrasound Pulsed xenon Room sterilisation Room sterilization Self-disinfecting Self disinfection Steam Superoxidis/zed water Ultraviolet disinfection Ultraviolet irradiation Ultraviolet light Ultraviolet radiation

Concept	Controlled Vocabulary	Text Words
		UV disinfection UV irradiation UV light UV radiation Vapor/ization Vapour/isation 405-nm 405nm
Enhanced coatings and surfaces	**EMTREE** Copper Material coating **CINAHL** Copper	Antimicrobial coating/s Antimicrobial-impregnated Antimicrobial surface/s Coated Coating/s Copper-coated Copper-impregnated Copper surface/s Silver-coated Silver-impregnated Silver surface/s
Cleaning personnel and training	**EMTREE** Hospital service Housekeeping Staff training **CINAHL** Education Housekeeping department Staff development	Cleaning personnel Cleaning service/s Cleaning staff Cleaning worker/s Environmental services Environmental technician/s Housekeeper/s Housekeeping Service worker/s Staff
Measuring and monitoring cleanliness	**EMTREE** Adenosine triphosphate Bioluminescence Hospital hygiene **CINAHL** Adenosine triphosphate Luminescent measurements	Adenosine triphosphate ATP Bioluminescence Cleanliness Fluorescent marker/s Glo-germ Glogerm Hospital hygiene Surface hygiene

Search Strategies

The strategy below is presented in EMBASE syntax; the search was simultaneously conducted across EMBASE and MEDLINE. A similar strategy was used to search the databases comprising CINAHL, the Cochrane Library, and PubMed.

Table A-3. EMBASE/MEDLINE strategy

Set #	Concept	Search Statement
1	Infections (broad terms, healthcare-associated)	(“healthcare associated infection” OR “hospital infection”)/de
2		((“health care acquired” next/1 (infection* OR pathogen*)) OR (“healthcare acquired” next/1 (infection* OR pathogen*)) OR (“hospital acquired” next/1 (infection* OR pathogen*)) OR (“health care associated” next/1 (infection* OR pathogen*)) OR (“healthcare associated” next/1 (infection* OR pathogen*)) OR (“hospital associated” next/1 (infection* OR pathogen*))):ti,ab
3		(HAI OR HAIs):ti
4	Infections (specific terms-bacterial)	(“clostridium difficile” OR “clostridium difficile infection” OR “methicillin resistant staphylococcus aureus” OR “methicillin resistant staphylococcus aureus infection” OR enterococcus OR “vancomycin resistant enterococcus” OR “enterococcal infection”)/de
5		((antibiotic OR “multi-drug” OR multidrug OR methicillin OR vancomycin) next/1 resistan*):ti,ab OR difficile:ti,ab OR (“methicillin resistant” next/2 aureus):ti,ab OR (“vancomycin resistant” next/1 enterococc*):ti,ab
6		(CDI OR MRSA OR VRE):ti
7	Limit to patients	(#4 OR #5 OR #6) AND (patient/exp OR (inpatient* OR patient*):ti,ab)
8	Combine infection sets	#1 OR #2 OR #3 OR #7
9	Setting (hospitals, inpatient facilities, patient rooms)	(“health care facility” OR “hospital discharge”)/de OR hospital/exp
10		(“acute care” OR “burn unit” OR “burn units” OR “common area” OR “common areas” OR “critical care” OR “healthcare facility” OR “healthcare facilities” OR “health care facility” OR “health care facilities” OR “healthcare setting” OR “healthcare settings” OR “health care setting” OR “health care settings” OR hospital OR hospitalis* OR hospitaliz* OR ICU OR institution OR institutions OR “intensive care” OR “patient care area” OR “medical facility” OR “medical facilities” OR “patient care areas” OR “patient room” OR “patient rooms” OR “patients rooms” OR ward OR wards):ti,ab
11	Setting (high-touch surfaces)	(fomite OR “hospital bed” OR “hospital equipment”)/de
12		(fomes OR fomite* OR “environmental reservoir” OR “environmental reservoirs” OR “surface contamination” OR “surface microbes”):ti,ab
13		(bathroom* OR “bed rail” OR “bed rails” OR bedrail* OR cart OR carts OR chair OR chairs OR “clinical surfaces” OR commode* OR “environmental surfaces” OR “high contact” OR “high-touch” OR “hospital bed” OR “hospital beds” OR “hospital surfaces” OR “mobile equipment” OR “portable medical equipment” OR railing OR railings OR toilet* OR “shared medical equipment” OR wheelchair*):ti,ab
14	Combine setting sets	#9 OR #10 OR #11 OR #12 OR #13
15	Combine sets (any infection or setting)	#8 OR #14

Set #	Concept	Search Statement
16	General cleaning	(cleaning OR disinfection OR “environmental sanitation”)/de OR “infection control”/mj
17		(“cleaning method” OR “cleaning methods” OR “cleaning practice” OR “cleaning practices” OR “cleaning protocol” OR “cleaning protocols” OR “cleaning regimen” OR “cleaning regimens” OR “cleaning routines” OR “cleaning technique” OR “cleaning techniques” OR “discharge cleaning” OR “discharge room cleaning” OR “enhanced cleaning” OR “environmental cleaning” OR “environmental decontamination” OR “environmental disinfection” OR “environmental sanitation” OR “hospital cleaning” OR “pre cleaning” OR precleaning OR “room cleaning” OR “room decontamination” OR “routine cleaning” OR “surface cleaning” OR “surface disinfection” OR “surface decontamination” OR “terminal cleaning” OR “terminal disinfection” OR “terminal room”):ti,ab
18		(cleaning OR decontamination OR disinfect* OR “infection control”):ti
19	Disinfectants	“disinfectant agent”/exp OR (“bleaching agent” OR “quaternary ammonium derivative”/de)
20		(biocidal OR biocide* OR “chemical agent” OR “chemical agents” OR “chemical disinfection” OR “cleaning agent” OR “cleaning agents” OR disinfectant* OR “disinfecting agent” OR “disinfecting agents” OR “disinfection agent” OR “disinfection agents” OR germicidal OR germicide* OR sporicidal OR sporicide*):ti,ab
21		(“accelerated hydrogen peroxide” OR aldehyde* OR alcohol OR alcohols OR bleach OR bleaching OR “benzalkonium chloride” OR “calcium hypochlorite” OR “chlorhexidine digluconate” OR glutaraldehyde OR “guanidine hydrochloride” OR hypochlorite* OR “ortho-phthalaldehyde” OR orthophthalaldehyde OR “peracetic acid” OR phenolic* OR phenol OR phenols OR “quaternary ammonium” OR QACs OR “sodium dichloroisocyanurate” OR “sodium hypochlorite” OR vinegar):ti,ab
22	Limit to disinfectant studies to cleaning	(#19 OR #20 OR #21) AND (clean* OR decontaminat* OR disinfect* OR housekeep*):ti,ab
23	Automated devices	(“disinfection system” OR “ultraviolet irradiation” OR “ultraviolet radiation”)/de OR (“hydrogen peroxide” AND (vapor OR “water vapor”))/de
24		(automated next/2 (cleaning OR device* OR decontamination OR disinfection)):ti,ab OR ((“no touch” OR “non touch”) next/1 disinfect*):ti,ab OR (“room sterilisation” OR “room sterilization” OR “self disinfecting”):ti,ab
25		((405nm OR “405 nm” OR “pulsed ultrasound” OR “pulsed xenon” OR ((ultraviolet OR UV) next/1 (disinfection OR light OR irradiation OR radiation))):ti,ab) AND (clean* OR decontaminat* OR disinfect* OR room OR rooms):ti,ab
26		“superoxidised water”:ti,ab OR “superoxidized water”:ti,ab OR ((“hydrogen peroxide” OR H2O2) AND (aerosol* OR fogging OR mist OR steam OR system OR systems OR vapor* OR vapour*)):ti,ab
27	Enhanced coatings and surfaces	(copper AND “material coating”)/de
28		“self disinfecting”:ti,ab OR ((antimicrobial OR copper OR silver) NEAR/2 (coated OR coating* OR impregnated OR surface*)):ti,ab
29	Cleaning personnel and training	(“hospital service” OR housekeeping OR “staff training”)/de
30		(“cleaning personnel” OR “cleaning service” OR “cleaning services” OR “cleaning staff” OR “cleaning workers” OR “environmental services” OR “environmental technician” OR “environmental technicians” OR housekeeper* OR housekeeping OR “service worker” OR “service workers”):ti,ab

Set #	Concept	Search Statement
31	Measuring and monitoring cleanliness	(“adenosine triphosphate” AND bioluminescence)/de OR (“hospital hygiene”)/de
32		(((“adenosine triphosphate” OR ATP) next/1 bioluminescen*) OR cleanliness OR “fluorescent marker” OR “fluorescent markers” OR “glo germ” OR glogerm OR “hospital hygiene” OR “surface hygiene”):ti,ab
33	Combine sets (any cleaning concept)	#16 OR #17 OR #18 OR #22 OR #23 OR #24 OR #25 OR #26 OR #27 OR #28 OR #29 OR #30 OR #31 OR #32
34	Combine sets (any infection or setting AND any cleaning concept)	#15 AND #33
35	Limit to English-language publications	#34 AND [english]/lim
36	Remove undesired publication types	#35 NOT (‘conference paper’/exp OR (‘case report’ OR book OR erratum OR letter OR note OR ‘short survey’)/de OR (book OR conference OR erratum OR letter OR note OR ‘short survey’):it OR (book OR ‘conference proceeding’):pt)
37	Limit to publications with abstracts	#36 AND [abstracts]/lim
38	Remove animal and in vitro studies	#37 NOT ([animal cell]/lim OR [animal experiment]/lim OR [animal model]/lim OR [animal tissue]/lim OR “in vitro study”/de)
39	Remove pediatric studies	#38 NOT (adolescen* OR babies OR child* OR fetal OR infant OR infants OR neonat* OR newborn* OR NICU OR paediatric* OR pediatric* OR school OR schools OR teen* OR youth*):ti
40	Remove undesired geographic locations	#39 NOT (africa/exp OR asia/exp OR mexico/de OR “oceanic regions”/exp OR “south and central america”/exp)
41	Limit by publication date	#40 AND [1990-2015]/py
42	Limit to meta-analyses and systematic reviews published	#41 AND (“meta analysis”/de OR “systematic review”/de OR (“evidence base” OR “evidence based” OR “meta analysis” OR methodologic* OR pooled OR “quantitative analysis” OR “quantitative review” OR “research synthesis” OR search* OR “systematic review”):ti,ab)
43	Limit to clinical studies	#41 AND ((“comparative study” OR “controlled study” OR “experimental study” OR “field study” OR “in vivo study” OR methodology OR model OR “observational study” OR “pilot study” OR “prevention study” OR “quasi experimental study” OR “trend study” OR “validation study”)/exp OR (analysis OR “case control” OR clinical OR cohort OR comparison OR “matched controls” OR random* OR study OR trial):ti,ab OR article/de OR article:it OR “article in press”:it OR “priority journal”/de)
44	Limit to narrative reviews published from 2009 onward	#41 AND (review/de OR review:it OR (overview OR review):ti) AND [2009-2015]/py
45	Limit to clinical practice guidelines	#41 AND (practice guideline/exp OR (“best practice” OR “best practices” OR consensus OR guidance OR guideline* OR recommendation* OR standard* OR statement):ti)
46	Combine sets	#42 OR #43 OR #44 OR #45

EMBASE Syntax:

*	=	truncation character (wildcard)
NEAR/*n*	=	search terms within a specified number (*n*) of words from each other in any order
NEXT/*n*	=	search terms within a specified number (*n*) of words from each other in the order specified
/	=	search as a subject heading
exp	=	"explodes" controlled vocabulary term (e.g., expands search to all more specific related terms in the vocabulary's hierarchy)
mj	=	denotes a term that has been searched as a major subject heading
/de	=	search in the descriptors field (controlled terms and keywords)
:lnk	=	floating subheading
:it,pt.	=	source item or publication type
:ti.	=	limit to title
:ti,ab.	=	limit to title and abstract fields

Appendix B. Excluded Studies Based on Review of Full-Length Articles

Not a location or setting of interest

Aiken ZA, Wilson M, Pratten J. Evaluation of ATP bioluminescence assays for potential use in a hospital setting. Infect Control Hosp Epidemiol. 2011 May;32(5):507-9. PMID: 21515983

Alfa MJ, Lo E, Olson N, et al. Use of a daily disinfectant cleaner instead of a daily cleaner reduced hospital-acquired infection rates. Am J Infect Control. 2015 Feb 1;43(2):141-6. http://dx.doi.org/10.1016/j.ajic.2014.10.016. PMID: 25534117

Ali S, Moore G, Wilson AP. Effect of surface coating and finish upon the cleanability of bed rails and the spread of Staphylococcus aureus. J Hosp Infect. 2012 Mar;80(3):192-8. PMID: 22264495

Allen G. Implementing AORN recommended practices for environmental cleaning. AORN J. 2014 May;99(5):570-82. PMID: 24766919

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Berendt AE, Turnbull L, Spady D, et al. Three swipes and you're out: How many swipes are needed to decontaminate plastic with disposable wipes? Am J Infect Control. 2011 Jun;39(5):442-3. PMID: 21306797

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Bradley CR, Fraise AP. Heat and chemical resistance of enterococci. J Hosp Infect. 1996 Nov;34(3):191-6. PMID: 8923273

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Appendix C. Clinical Evidence

Table C-1. Characteristics of systematic reviews

Citation	Objective	Search Strategy	Key Inclusion/ Exclusion Criteria	Evidence Base	Interventions	Relevant Findings	Authors' Conclusions
Amodio and Dino 2014[1] Use of ATP bioluminescence for assessing the cleanliness of hospital surfaces: A review of the published literature (1990–2012)	To systematically review the evidence on ATP bioluminescence	Searches were completed in PubMed and Scopus. Bibliographies of articles retrieved were also searched. 31 articles were considered for inclusion.	Articles were excluded for not pertaining to hospital surfaces, being an experimental design, or being published before 1990.	Studies: 12 studies published from 2000 to 2011 were included. Studies were conducted in the United Kingdom (8), United States (3), and Brazil (1) Methods: Surfaces were monitored after cleaning (4 studies), before and after cleaning (6 studies), or not reported (2) Pathogens were not described.	ATP devices were provided by 3M (5), Biotrace (4) and Hygiena (3). ATP thresholds (RLUs): 100: 2 (16.7%) 250: 5 (41.7%) 500: 4 (33.3%) Both 250 and 500: 1 (8.3%)	ATP measurements before cleaning (RLUs): Ranged from 0 to >500,000 ATP measurements after cleaning (RLUs): Ranged from 3 to 500,000 Failure rates before cleaning: 21.2% to 93.1% Failure rates after cleaning: 5.3% to 96.5%	"Although the use of ATP bioluminescence can be considered a quick and objective method for assessing hospital cleanliness, it appears to be still poorly standardized at both the national and international level."

Citation	Objective	Search Strategy	Key Inclusion/ Exclusion Criteria	Evidence Base	Interventions	Relevant Findings	Authors' Conclusions
Mitchell et al. 2013[2] Methods to evaluate environmental cleanliness in healthcare facilities	To describe monitoring methods used in environmental cleaning	Searches in MEDLINE, CINAHL, and PubMed for English language publications. A search of the gray literature included infection-control professional organization Web sites, Australian state government sites, and international guidelines.	Article addressing the efficacy of cleaning. Environmental cleanliness was categorized as process evaluation (visual inspection, use of fluorescent gel marker) and outcome evaluation (use of ATP or microbial cultures).	124 articles were reviewed. Number of articles included not reported.	Visual inspection, fluorescent gel marker, ATP, microbial cultures	Visual inspection (6 studies): Poor performance at identifying microbial load with 17%–93% more surfaces identified as "clean" than other assessment methods. Fluorescent gel marker (7 studies): Frequently demonstrates a "lack of attention to high-risk surfaces in the near-patient zone." ATP: ATP measurements have low specificity and sensitivity in detecting bacteria (1 study reported sensitivity/specificity of 57%). Factors that may affect ATP readings include residual detergents or disinfectants, including sodium hydrochlorite, eroded surfaces, plasticizers found in microfiber cloths or ammonium compounds found in laundry products. Microbiological sampling: Sampling to detect specific bacteria is "generally only recommended as part of an ongoing outbreak investigation, as a research study, or as part of a policy or process evaluation" since the process may take at least 2 days, requires expertise and lab access.	"Methods that evaluate cleaning performance are useful in assessing adherence to cleaning protocols, whereas methods that sample bio-burden provide a more relevant indication of infection risk. Fast, reproducible, cost-effective and reliable methods are needed for routine environmental cleaning evaluation in order to predict timely clinical risk."

Citation	Objective	Search Strategy	Key Inclusion/ Exclusion Criteria	Evidence Base	Interventions	Relevant Findings	Authors' Conclusions
Falagas et al. 2011[3] Airborne hydrogen peroxide for disinfection of the hospital environment and infection control: a systematic review	To review the effectiveness of airborne hydrogen peroxide in a clinical setting	Searches were completed in PubMed through December 2009. Bibliographies of relevant articles were also searched.	Included studies focused on the effectiveness of airborne hydrogen peroxide for reducing bacterial burden in the hospital setting and discussed pathogens naturally dispersed in this setting.	Studies: 10 studies were included. Pathogens addressed were MRSA (5), *C. difficile* (3), and multiple pathogens (2). Settings: Surgical wards, ward side rooms, single isolation rooms, multiple-bed ward bays, bathrooms, and other utility rooms. High-touch areas: Chairs, bed frames, control panels, bedside tables, remote controls, door handles, bed rails, telephones, sink taps, toilet seats, and sites handled by HCWs. Pathogens: MRSA, *C. difficile*, and others	7 studies evaluated the BioQuell HPV system BioQuell Ltd., Andover, Hampshire, UK) 3 studies evaluated a hydrogen peroxide dry-mist system or "dry fog" (Gloster Sante Europe, Labège Cedex, France)	Disinfection: Contamination of sampled environmental sites Before cleaning (9 studies): 39.0% (range: 18.9%–81.0%) After terminal cleaning (6 studies): 28.3% (range: 11.9%–66.1%) After airborne hydrogen peroxide (10 studies): 2.2% (range: 0%–4.0%) Infection Control 1 study indicated eradication of MRSA in 1 20-bed surgical ward. Another study indicated significant reductions in *C. difficile*-associated disease in a 500-bed university-affiliated hospital.	"Data from several relevant studies indicate that disinfection of the hospital environment using airborne hydrogen peroxide in vapour or dry mist formulations, appears to provide additional benefits to currently used cleaning regimens, including inactivation of bacterial spores. Few studies have evaluated the use of airborne hydrogen peroxide disinfection as an adjunctive infection control measure in actual hospital practice. These limited relevant data are favourable, but further studies are needed to assess the effectiveness, safety, costs, and applicability of this novel method against other available cleaning methods."

Citation	Objective	Search Strategy	Key Inclusion/ Exclusion Criteria	Evidence Base	Interventions	Relevant Findings	Authors' Conclusions
Dettenkofer et al. 2004[4] Does disinfection of environmental surfaces influence nosocomial infection rates?	To review evidence for the effects of disinfection of environmental surfaces on hospital-acquired infection rates	Biological Abstracts/BIOSIS Previews (1980–1988/ 1989–2001); Cochrane Library (2001, Issue 4) Cochrane Clinical Trials Register; HECLINET: Health Care Literature Information Network (1969–2000); Medline (Ovid, 1966–2001); Science Citation Index (1991–1996); SwetScan (1997–2001); Web of Science (Science Citation Index Expanded, 1997–2001); EMBASE (1974–2001) and EMBASE alert; and Somed (1978–2000). General internet search was also undertaken.	Randomized controlled trials, cohort, case-control, and observational studies in English, German, French, Italian, and Spanish evaluating use of disinfectant or detergent for "inanimate surfaces" in health care settings were included.	4 trials discussed impact of disinfectant vs. detergent on environmental surfaces. Dharan study compared NI rates in 2 different wings of a medical unit over 4 months. Danforth study used a crossover design to examine NI rates in 8 wards in a tertiary care teaching hospital over 3 months. Daschner study examined NI rates in ICU units over 12 months. Mayfield study examined use of 2 disinfectants on incidence of *C. difficile* in bone marrow transplant patients and patients in neurosurgical ICU and general medicine units. High-touch areas: Floors, furniture, bathrooms, toilets, and isolation rooms (Dharan) Floor (Danforth) Floor, patient care equipment, bedside tables, and bed frame (Daschner) Not described (Mayfield) Pathogens: MRSA, *C. difficile*, and others	Dharan study QAC, an active oxygen-based compound, and an alcohol solution Danforth study Disinfectant orthobenzyl parachlorophenol or detergent Daschner study Disinfectant (0.5% aldehyde) and detergent Mayfield study QAC or 1:10 hypochlorite solution	Dharan study *Detergent only:* Increase in bacterial surface counts *QAC:* No reduction in bacterial counts *Active oxygen-based compound, the alcohol solution, and the dust-attracting floor mop:* Significant reduction of bacterial counts. Dharan, Danforth and Dashner studies *Occurrence of NI:* No significant difference Mayfield study: *CDAD incidence:* Significant decrease in rates in bone marrow transplant patients, no reduction in patients on neurosurgical ICU or general medicine unit	"Disinfectants may pose a danger to staff, patients, and the environment and require special safety precautions. However, targeted disinfection of certain environmental surfaces is in certain instances an established component of hospital infection control. Given the complex, multifactorial nature of nosocomial infections, well-designed studies that systematically investigate the role of surface disinfection are required."

ATP=adenosine triphosphate; CDAD=Clostridium difficile-associated diarrhea; *C. difficile=Clostridium difficile*; HCW=health care workers; HPV=hydrogen peroxide vapor; ICU=intensive care unit; MRSA=methicillin-resistant staphylococcus aureus; NI=nosocomial infection; QAC=quaternary ammonium compound; RLU=relative light unit.

Table C-2. Study characteristics of cleaning and disinfection studies

Author	Country	Study Design	General Cleaning Method	Study Length	Sample Size	Primary Setting	Pathogens	High-Touch Objects
Best et al. 2014[5]*	United Kingdom	Before/after	SC and AC	20 weeks	342 sites	Rehabilitation ward	*C. difficile*	Bed, curtain track, wall trunking, patient line boxes, tops of hoist rail
Boyce et al. 2014[6]*	United States	Before/after	EC	4 weeks	9 rooms 1,155 samples	Ward not specified	NR	Bed rail, remote control, toilet, tray table, telephone, doorknob, sink
Haas et al. 2014[7]**	United States	Before/after	AC	2 years	11,389 rooms	Ward not specified	*C. difficile*, MRSA, VRE	NR
Jinadatha et al. 2014[8]*	United States	Nonrandomized controlled	SC and AC	2 months	20 rooms (10 per arm)	Ward not specified	MRSA	Bed rail, call buttons, toilet, tray table, bathroom handrail
Mitchell et al. 2014[9]	Australia	Interrupted time series	SC and AC	6 years	3,600 discharge cleans	Ward not specified	MRSA	Bed, vent, sink, console, chair, table, locker, mattress, pillow
Sjöberg et al. 2014[10]**	Sweden	Before/after	SC	8 months	10 rooms 150 samples	NR	*C. difficile*	Bed rail, call button, side table, toilet, doorknob
Stewart et al. 2014[11]*	United Kingdom	Before/after	SC	4 months	30 bed spaces	Elderly care	MRSA and MSSA	Bedside locker, left/right cotside, overbed table
Wiemken et al. 2014[12]*	United States	Randomized controlled	SC	1 month	9 rooms	Ward not specified	Hardy pathogens	Side table, toilet, sink
Anderson et al. 2013[13]*	United States	Prospective cohort	AC	15 months	27 rooms 142 samples	Ward not specified	Various pathogens including: *C. difficile*, VRE	Bed rail, floor, side table, toilet, chair arm, overbed table, sink counter
Boyce and Havill 2013[14]*	United States	Before/after	SC	NR	72 rooms	Ward not specified	NR	Bed rail, remote control, toilet, tray table, phone, bedside panel, chair arm, blood pressure cuff, grab bar, and faucet handle
Friedman et al. 2013[15]**	Australia	Interrupted time series	SC	10 days	21 rooms 1,026 samples	Cancer ward	VRE	Floor, remote control, toilet, tray table, phone, locker drawer handle, bathroom tap
Gillespie et al. 2013[16]	Australia	Before/after	SC	3 months	10 rooms 200 samples	General medical ward, residential aged care ward	*C. difficile*, VRE	Not specified
Hess et al. 2013[17]*	United States	Randomized controlled	SC	10 months	132 rooms 4,444 samples	ICU, surgical ward	Various pathogens including: MRSA	Bed rail, call button, light switch, tray table, bed control, desk, intravenous poles and infusion pumps, phone, room sink, supply cart, and others

Author	Country	Study Design	General Cleaning Method	Study Length	Sample Size	Primary Setting	Pathogens	High-Touch Objects
Levin et al. 2013[18]**	United States	Interrupted time series	AC	1 year	NR	ICU, contact precaution and other rooms	*C. difficile*	Patient room, including bathroom
Mahida et al. 2013[19]*	United Kingdom	Before/after	AC	NR	6 rooms 32 locations	Intensive therapy unit, OR, and ward isolation room	Various pathogens including: MRSA, VRE	Not specified
Manian et al. 2013[20]**	United States	Before/after	SC and AC	3 years	870 rooms 1,123 rounds of cleaning	Ward not specified	*C. difficile*	Bed rail, call button, light switch, telephone, doorknob, sink
Passaretti et al. 2013[21]*	United States	Prospective cohort	SC and AC	30 months	1,039 rooms 6,607 patients	ICU	Various pathogens including: *C. difficile*, MRSA, VRE	Bed rail, computer keyboard, electronic monitoring equipment
Salgado et al. 2013[22]	United States	Randomized controlled	SC and EC	11 months	16 rooms (8 copper, 8 standard) 614 patients (294 cared for in rooms with copper)	ICU	*C. difficile*, MRSA, VRE	Bed rail, overbed table, bed footboard, intravenous poles and arms of the visitors chair
Schmidt et al. 2013[23]	United States	Nonrandomized controlled	AC and EC	3 months	75 beds	ICU	Various pathogens	Bed rail
Sigler and Hensley 2013[24]	United States	Before/after	SC	NR	10 rooms	Rooms occupied by patients with Staph infections (usually MRSA)	Various pathogens including: MRSA	Bed rail, call button, floor, tray table, sink, TV button, telephone
Sitzlar et al. 2013[25]	United States	Interrupted time series	SC and AC	21 months	NR	General medical ward, surgical ward	*C. difficile*	Bed rail, call button, toilet, tray table, telephone
Goldenberg et al. 2012[26]	United Kingdom	Before/after	SC	4 months	13 wards	General medical ward, surgical ward, plastic surgery, orthopedics, elderly care, acute admissions	*C. difficile*	Bed rail, call button, floor, remote control, toilet, telephone, locker, chair, sluice room, side room, mop bucket, and others
Grabsch et al. 2012[27]	Australia	Interrupted time series	SC	24 months	NR	ICU, cancer ward, liver transplant, renal	VRE	Call button, curtain, locker handle, chair, chart, supplies trolley, phone
Havill et al. 2012[28]*	United States	Non-randomized controlled	AC	NR	15 rooms	Ward not specified	Various pathogens including: *C. difficile*	Bed rail, remote control, toilet, tray table
Karpanen et al. 2012[29]*	United Kingdom	Crossover	EC	24 weeks	19 rooms	General medical ward	*C. difficile*, MRSA, VRE	14 HTOs including toilet seat, grab rail and door handle

Author	Country	Study Design	General Cleaning Method	Study Length	Sample Size	Primary Setting	Pathogens	High-Touch Objects
Kundrapu et al. 2012[30]*	United States	Randomized controlled	SC	NR	70 patients	Ward not specified	*C. difficile*, MRSA	Bed rail Call button Side table Toilet telephone, chair, wall mounted vital signs equipment, IV medication stand, door knobs and handles,
Schmidt et al. 2012[31]*	United States	Randomized controlled	SC and AC	3 months	NR	Ward not specified	Various pathogens including: MRSA, VRE	Bed rail
Schmidt et al. 2012[32]	United States	Before/after	SC and EC	43 months	1,587 rooms 9,522 objects	ICU	*C. difficile*, MRSA, VRE	Bed rail, call button, tray table, intravenous stand, visitor chair, computer mouse, data input device
Boyce et al. 2011[33]*	United States	Before/after	AC	NR	25 rooms	Ward not specified	*C. difficile*	Bed rail, toilet, tray table, television remote
Carter and Barry 2011[34]**	United Kingdom	Before/after	SC	18 months	NR	NR	*C. difficile*	Light switch, toilet, furniture, bed frame, intravenous pump
Chan et al. 2011[35]*	Australia	Nonrandomized controlled	SC and AC	NR	NR	Ward not specified	VRE	Call button, side, toilet, arm rest, cotside
Orenstein et al. 2011[36]*	United States	Before/after	SC	2 years	NR	General medical ward	*C. difficile*	Not specified
Sexton et al. 2011[37]*	United States	Before/after	Steam vapor	2 days	8 rooms	Long-term care wing	Various pathogens including: *C. difficile*, MRSA	Bed rail, side table, guest chair arm, sink, door push panel
Wilson et al. 2011[38]*	United Kingdom	Randomized crossover	SC and “enhanced cleaning”	1 year	20,736 samples 1,152 bed days	ICU	Various pathogens including: *C. difficile*, MRSA, VRE	Bed rail, drawer handle, chart, keyboard, syringe driver, nurses hand, monitor
Alfa et al. 2010[39]*	Canada	Before/after	SC	19 months	243 patients 714 samples	Ward not specified	*C. difficile*	Toilet
Casey et al. 2010[40]*	United Kingdom	Non-randomized controlled	EC	10 weeks	NR	General medical ward, common area	Various pathogens including: *C. difficile*, MRSA, VRE	Toilet, sink, door push plate

Author	Country	Study Design	General Cleaning Method	Study Length	Sample Size	Primary Setting	Pathogens	High-Touch Objects
Hacek et al. 2010[41]**	United States	Before/after	SC	3 years	All rooms occupied by patients with *C. difficile* in 3 hospitals; # not specified	Ward not specified	*C. difficile*	Bed, bed rail, bed control, floor, side table, toilet, tray table, doorknob, sink, wall
Hamilton et al. 2010[42]*	United Kingdom	Non-randomized controlled	SC	7 weeks	NR	Ward not specified	NR	Bed, floor, tray table
Hedin et al. 2010[43]	Sweden	Non-randomized controlled	EC	3 weeks	12 rooms 36 samples	infectious disease ward	Various pathogens including: MRSA	Side table
Nerandzic et al. 2010[44]	United States	Before/after	AC	NR	66 rooms, 261 sites	Ward not specified	*C. difficile*, MRSA, VRE	Call light, bedside table, telephone and bed rail
Rutala et al. 2010[45]*	United States	Before/after	AC	8 months	8 rooms	Ward not specified	*C. difficile*, MRSA	Bed rail, floor
Andersen et al. 2009[46]	Norway	Non-randomized controlled	SC	NR	4 rooms 192 samples	Geriatric ward	Various pathogens including: *C. difficile*, MRSA, VRE	Floor
McMullen et al. 2007[47]**	United States	Non-randomized controlled	SC	2.5 years	Entire medical and surgical ICUs included for 2 1/2 years	ICU, common area	*C. difficile*	Not specified
Whitaker et al. 2007[48]**	United States	Before/after	SC	2 years	NR	Ward not specified	*C. difficile*	"Every lateral surface"
De Lorenzi et al. 2006[49]**	Italy	Non-randomized controlled	Mopping methods	5 days	2 rooms	Surgical ward	NR	Floor
Wilcox et al. 2003[50]	United Kingdom	Non-randomized controlled	SC	2 years	1,128 samples	2 "elderly medicine wards"	*C. difficile*	Bed rail, floor, toilet
Byers et al. 1998[51]***	United States	Before/after	SC	NR	10 conventional rooms, 4 bucket method; 376 conventional samples, 135 bucket samples	Ward not specified	VRE	Bed rail, floor, side table, intravenous pole, phone, blood pressure cuff, wall panel control

* Manufacturer-funded (i.e., sponsoring institution reported receiving equipment and/or monetary funding from the manufacturer for execution of the study.)

** Funding not reported

***Described an outbreak situation

AC=automated cleaning; *C. difficile=Clostridium difficile*; EC=enhanced coating; ICU=intensive care unit; MRSA=methicillin-resistant *staphylococcus aureus*; MSSA=methicillin-susceptible *staphylococcus aureus*; NR=not reported; OR=operating room; SC=surface cleaning; VRE=vancomycin-resistant enterococci.

Table C-3. Methods of cleaning and disinfection reported in studies*

Author	Cleaning Method	Monitoring Method	Implementation Tools
Best et al. 2014[5]	Chlor-Clean disinfectant (Gues Medical Ltd., Aylesford, UK), Deprox hydrogen peroxide decontamination unit (Hygiene Solutions, Kings Lynn, UK)	Sponge/wipe cultures	NR
Boyce et al. 2014[6]	Organosilane antimicrobial coatings (Eco Antimicrobial; Micro-Texpur, Conover, NC; and Bio-Protect AM500; PureShield, Inc., Jupiter, FL)	Agar slide cultures	NR
Haas et al. 2014[7]	Pulsed xenon ultraviolet light (PPX-UV) (Xenex Corp., Austin, TX)	NR	NR
Jinadatha et al. 2014[8]	Dispatch bleach solution, PPX-UV (Xenex Healthcare Services, San Antonio, TX)	Contact plates	NR
Mitchell et al. 2014[9]	ph neutral detergent, dry hydrogen vapor room decontamination system (Nocospray, EquipMed, North Ryde, New South Wales, Australia)	Swab cultures	Competency-based training, staff feedback
Sjöberg et al. 2014[10]	Potassium monopersulfate-based disinfectant Virkon (Antec International Ltd., Sudbury, UK)	NR	NR
Stewart et al. 2014[11]	Electrolyzed water (Salvesan; Aqualution)	Dip slides	NR
Wiemken et al. 2014[12]	Sodium hypochlorite cleaner/disinfectant solutions (ready-to-use wipes versus bucket method)	Fluorescent/UV markers	Employee productivity and compliance
Anderson et al. 2013[13]	Ultraviolet-C (UV-C) emitter (Tru-D Smart UVC, Lumalier, Memphis, TN).	Contact plates	NR
Boyce and Havill 2013[14]	Hydrogen peroxide disinfectant wipe (Activated Hydrogen Peroxide; Clorox Healthcare)	ATP bioluminescence, Agar contact plates for aerobic bacteria	NR
Friedman et al. 2013[15]	Benzalkonium chloride-based product, Viraclean (Whiteley Industrial PTY LTD, Tomago, New South Wales, Australia) or disposable V-wipes	Swab cultures	Audits
Gillespie et al. 2013[16]	Ultramicrofiber cloths** (Johnson Diversey, Racine, WI) and steam (UMF/steam) technology	ATP bioluminescence, Fluorescent/UV markers, visual observation, swab cultures	Education, infection control sessions for cleaning staff, feedback from staff focus groups
Hess et al. 2013[17]	Enhanced cleaning (cleaning targeted at frequently touched, frequently contaminated surfaces), with wipes saturated with quaternary ammonium	Fluorescent/UV markers, swab cultures	NR
Levin et al. 2013[18]	PPX-UV device (Xenex Healthcare Services, San Antonio, TX)	NR	NR
Mahida et al. 2013[19]	UV-C (Tru-D™; manufacturer not specified)	Surface contact plates and seeded petri dishes	NR
Manian et al. 2013[20]	Bleach, hydrogen peroxide vapor decontamination (Bioquell, Andover, UK)	NR	NR
Passaretti et al. 2013[21]	Quaternary ammonium compound (QAC; 3M, St Paul, Minnesota). Oxivir disinfectant (Johnson Diversity, Sturtevant, Wisconsin), and hydrogen peroxide vapor (Bioquell, Horsham, PA)	Swab cultures	NR
Salgado et al. 2013[22]	Virex 256 (Johnson-Diversey), Dispatch (Caltech Industries), and Cavicide (Metrex); copper-enhanced surfaces	NR	NR
Schmidt et al. 2013[23]	Virex II 256 dispensed from an automated dilution system (Use Solution, Johnson Diversey); copper enhanced surfaces	Wipes	NR
Sigler and Hensley 2013[24]	QAC, microfiber cloths** and mops	Visual observation	NR

Author	Cleaning Method	Monitoring Method	Implementation Tools
Sitzlar et al. 2013[25]	Clorox Germicidal Wipes, UV-C (Tru-D, Lumalier, Memphis, TN)	ATP bioluminescence, fluorescent/UV markers	Education and feedback to staff (monthly meeting, small group meetings, and for individuals); a dedicated daily disinfection team and implementation of a process requiring supervisory assessment and clearance of terminally cleaned CDI rooms
Goldenberg et al. 2012[26]	A chlorine dioxide-based disinfectant, Difficil-S (Clinimax Ltd, Bury St Edmunds, UK).	Swab cultures	Training on preparation, use, and storage of the product; monthly environmental cleaning audits
Grabsch et al. 2012[27]	Bleach-Clean, a bleach-based disinfection program	Swab cultures	Employment of cleaning supervisors; new verbal and written training program for cleaners; new system of performance appraisal and benchmarking; regular monthly screening of standardized sites
Havill et al. 2012[28]	Hydrogen peroxide vapor (Bioquell, Horsham, PA) vs. UV-C (Tru-D, Lumalier, Memphis, TN)	Agar slide cultures	NR
Karpanen et al. 2012[29]	Copper surfaces	Swab cultures	NR
Kundrapu et al. 2012[30]	Daily cleaning of high-touch surfaces vs. cleaning only when soiled	Glove and hand plate cultures	NR
Schmidt et al. 2012[31]	Virex 256 soaked on a washcloth, QAC as a microdroplet from the PureMist system (PureCart Systems, Green Bay, WI)	Agar slide cultures	NR
Schmidt et al. 2012[32]	Virex 256 (Johnson-Diversey), Dispatch (Caltech Industries), and Cavicide (Metrex); copper-enhanced surfaces	Swab cultures	NR
Boyce et al. 2011[33]	Mobile UV-C (Tru-D; Lumalier, Memphis, TN)	Contact plates	NR
Carter and Barry 2011[34]	Peracetic acid-releasing sporicidal wipes	NR	Training, infection prevention, and control awareness days, ward visits by nurses included feedback with staff; flyers and newsletters were disseminated.
Chan et al. 2011[35]	A neutral detergent (HC90, Agar Cleaning Systems, Preston, Victoria, Australia) two hypochlorite-based products Bleach (Agar Cleaning Systems, Preston, Victoria, Australia) and Det-Sol 500 (Eucalip Bio Chemicals, Dandenong South, Victoria, Australia) ; and hydrogen peroxide vapour (Nocospray, EquipMed, North Ryde, NSW, Australia)	Contact plates	NR
Orenstein et al. 2011[36]	Germicidal bleach wipes	ATP bioluminescence, visual observation	NR
Sexton et al. 2011[37]	Steam vapor (VaporJet PC 2400 Steam Vapor System with the TANCS component from Advanced Vapor Technologies (Seattle, WA).)	Wipe/swatch cultures	NR
Wilson et al. 2011[38]	Detergent, alcohol spray, Actichlor Plus (Ecolab, Swindon, UK), steam cleaning, enhanced cleaning using microfiber cloths (Johnson Diversey Northampton, Northants, UK)	Agar slide cultures, contact plates, hand cultures	NR
Alfa et al. 2010[39]	Oxivir accelerated hydrogen peroxide (Diversey, Sturtevant, WI) vs. PerDiem stabilized hydrogen peroxide (SHP) (Diversey)	Fluorescent/UV markers, contact plates	NR
Casey et al. 2010[40]	Copper surfaces	NR	NR

Author	Cleaning Method	Monitoring Method	Implementation Tools
Hacek et al. 2010[41]	Bleach	NR	NR
Hamilton et al. 2010[42]	Ultramicrofiber cloths and mops, copper biocide	Agar slide cultures	NR
Hedin et al. 2010[43]	"Appeartex," an antimicrobial coating (Appeartex AB, Göteborg, Sweden)	Swab cultures, Agar slide cultures	NR
Nerandzic et al. 2010[44]	UV-C light emitting (Tru-D; Lumalier Corporation, Memphis, TN)	Swab cultures	NR
Rutala et al. 2010[45]	UV-C light emitting (Tru-D; Lumalier Corporation, Memphis, TN)	Agar slide cultures	NR
Andersen et al. 2009[46]	4 floor-mopping methods (dry, spray, moist and wet)	ATP bioluminescence, contact plates	NR
McMullen et al. 2007[47]	Bleach	NR	NR
Whitaker et al. 2007[48]	Bleach	NR	Education for staff, patients, and visitors
De Lorenzi et al. 2006[49]	Floor cleaning by dry, then wet mopping versus wet, then dry mopping	Agar slide cultures	NR
Wilcox et al. 2003[50]	Bleach	Swab cultures	NR
Byers et al. 1998[51]	Quaternary ammonium spray vs. bucket method (drenching surface)	Swab cultures	NR

* None of the studies discussed patient safety culture or sustainability of programs. For external factors, Mitchell et al. 2014[9] discussed the external quality control process undertaken by the manufacturer.

** The linear density of microfibers and ultramicrofibers are less than one denier per thread and less than 0.5 denier per thread, respectively. A strand of silk is approximately one denier.

ATP=adenosine triphosphate; CDI=*Clostridium difficile* infection; HT=high touch; IPC=infection protection and control; NR=not reported; UV=ultraviolet; UV-C=ultraviolet light.

Table C-4. Outcomes and conclusions of cleaning/disinfection studies

Author	Primary Outcome	Secondary Outcome of Interest	Authors Conclusions
Best et al. 2014[5]	Sites positive for *C. diff*[a] CDI incidence[b]	*C. diff* ribotypes	"HPD, after deep cleaning with a detergent/chlorine agent, was highly effective for removing environmental C. difficile contamination. Long-term follow-up demonstrated that a CDI-symptomatic patient can rapidly recontaminate the immediate environment. Determining a role for HPD should include long-term cost-effectiveness evaluations."
Boyce et al. 2014[6]	Mean ACC [a]	NR	"Cultures of surfaces obtained before daily cleaning with a quaternary ammonium disinfectant showed no significant residual antimicrobial activity of the organosilane products, although a modest reduction could not be excluded."
Haas et al. 2014[7]	Incidence rate of HAIs[b]	NR	"During the time period UVD was in use, there was a significant decrease in overall hospital-acquired MDRO plus CD in spite of missing 24% of opportunities to disinfect contact precautions rooms. This technology was feasible to use in our acute care setting and appeared to have a beneficial effect."
Jinadatha et al. 2014[8]	ACC, [a] total MRSA[b]	Individual surface counts, cleaning time in minutes	"PPX-UV technology appears to be superior to manual cleaning alone for MRSA and HPC. Incorporating 15 minutes of PPX-UV exposure time to current hospital room cleaning practice can improve the overall cleanliness of patient rooms with respect to selected micro-organisms."
Mitchell et al. 2014[9]	Incidence of MRSA[b]	NR	"Use of HP disinfection led to a decrease in residual MRSA contamination in patient rooms compared with detergent. It may also have encouraged the reduction in patient MRSA acquisition despite several confounders including staff feedback on terminal cleaning, additional MRSA screening and quicker laboratory methods. Infection control is best served by concurrent interventions targeting both the patient and healthcare environment."
Sjöberg et al. 2014[10]	Sites positive for culture [a]	NR	"We demonstrated a moderate spread of CD spores to the environment despite routine cleaning procedures involving Vikron."
Stewart et al. 2014[11]	CFU [a]	Recontamination	"Cleaning with electrolyzed water reduced ACC and staphylococci on surfaces beside patients. ACC remained below precleaning levels at 48 hours, but MSSA/MRSA counts exceeded original levels at 24 hours after cleaning. Although disinfectant cleaning quickly reduces bioburden, additional investigation is required to clarify the reasons for rebound contamination of pathogens at near patient sites."
Wiemken et al.[12]	Compliance with room protocol [a]	Time needed to clean	"In conclusion, this study supports the use of RTU CD wipes over the traditional bucket method. Enhancing environmental processes may reduce the environmental bioburden, leading to reductions in HAIs because of environmentally hardy pathogens."
Anderson et al. 2013[13]	Total number of CFU, median number of CFUs per sample [a]	NR	"Our data confirm that automated UV-C-emitting devices can decrease the bioburden of important pathogens in real-world settings such as hospital rooms."
Boyce and Havill 2013[14]	CFU [a]	RLU, adverse effects	"The activated hydrogen peroxide wipe product evaluated in our study proved to be an effective surface disinfectant, as reflected by ACC and ATP bioluminescence assays. ATP bioluminescence assays can be used as a tool to monitor the effectiveness of cleaning practices while using an activated hydrogen peroxide disinfectant. Additional studies are warranted to determine whether ATP and ACC cutoff points used to classify surfaces as clean should vary depending on the surface sampled."

Author	Primary Outcome	Secondary Outcome of Interest	Authors Conclusions
Friedman et al. 2013[15]	VRE-positive samples [a]	VRE colonization rates, rate per 1,000 patient days	"During use of a chlorine-based, 3-staged protocol, significantly higher residual levels of VRE contamination were identified, compared with levels detected during use of a benzalkonium chloride based product for disinfection. This reduction in VRE may be due to a new disinfection product, more attention to the thoroughness of cleaning, or other supplementary efforts in our institution."
Gillespie et al. 2013[16]	RLU[d]	NR	"Our pilot study supports using ultramicrofiber cloth and steam technology as an alternative to cleaning with chemicals."
Hess et al. 2013[17]	Contamination rates for health care worker gowns and gloves[d]	NR	"Intense enhanced daily cleaning of ICU rooms occupied by patients colonized with MRSA or MDRAB was associated with a nonsignificant reduction in contamination of HCW gowns and gloves after routine patient care activities. Further research is needed to determine whether intense environmental cleaning will lead to significant reductions and fewer infections."
Levin et al. 2013[18]	Hospital-associated CDI rate per 10,000 patient days[b]	HA-CDI attributable deaths, HA-CDI attributable colectomies	"In 2010, the HA-CDI rate was 9.46 per 10,000 patient-days; in 2011, the HA-CDI rates was 4.45 per 10,000 patient-days (53% reduction, P = .01). The number of deaths and colectomies attributable to hospital-associated C difficile infection also declined dramatically."
Mahida et al. 2013[19]	CFU [a]	Disinfection times	"UV-C is an emerging decontamination technology that is effective in reducing bacterial contamination in the clinical environment. There are significant advantages to using UV-C, and, based on the results of this study we would recommend using Tru-D at the higher reflected dose setting of 22,000 mWs/cm^2 for terminal room disinfection in most healthcare settings."
Manian et al. 2013[20]	*C. diff*-associated diarrhea rate per 1,000 patient days[b]	NR	"Implementation of an enhanced hospital-wide terminal cleaning program revolving around HPV decontamination of targeted hospital rooms was practical, safe, and associated with a significant reduction in the endemic rate of CDAD at our hospital. Further studies are needed to delineate better the role of HPV decontamination in reducing the endemic rate of transmission of other pathogens with significant environmental presence in hospitals."
Passaretti et al. 2013[21]	Adjusted incidence rate ratio[b]	Proportion of contaminated rooms, MDRO matches/differs from the current room occupant	"HPV decontamination reduced environmental contamination and the risk of acquiring MDROs compared with standard cleaning protocols."
Salgado et al. 2013[22]	Rate of colonization[c]	Length of stay, mortality	"Patients cared for in ICU rooms with copper alloy surfaces had a significantly lower rate of incident HAI and/or colonization with MRSA or VRE than did patients treated in standard rooms. Additional studies are needed to determine the clinical effect of copper alloy surfaces in additional patient populations and settings."
Schmidt et al. 2013[23]	Bacterial burden [a]	NR	"Copper, when used to surface hospital bed rails, was found to consistently limit surface bacterial burden before and after cleaning through its continuous antimicrobial activity."
Sigler and Hensley 2013[24]	PCR positive for staph [a]	NR	"Overall, genetic markers for several staphylococci known to colonize and infect humans remained ubiquitous in each room following daily disinfection practices."
Sitzlar et al. 2013[25]	Percent of targets cleaned [a]	Disinfection as measured by cultures	"An intervention that included education as well as monitoring and feedback improved thoroughness of cleaning but did not significantly improve CDI room disinfection. The use of an automated UV device improved disinfection, but 35% of rooms remained culture positive after use. Disinfection was dramatically improved through formation of a dedicated daily disinfection team and implementation of a standardized process for clearing CDI rooms."
Goldenberg et al. 2012[26]	Number of contaminated sites [a]	CDI rate	"The prevalence of environmental contamination was unaffected with a rate of 8% (9/120) before and 8% (17/212) following the change. Rates of patient infection were also unchanged during these periods."

Author	Primary Outcome	Secondary Outcome of Interest	Authors Conclusions
Grabsch et al. 2012[27]	VRE colonization[c]	Newly recognized VRE colonization, total burden of inpatient VRE colonization	"The Bleach-Clean programme was associated with marked reductions in new VRE colonizations in high-risk patients, and VRE bacteraemia across the entire hospital. These findings have important implications for VRE control in endemic healthcare settings."
Havill et al. 2012[28]	ACC[a]	NR	"Both HPV and UVC reduce bacterial contamination, including spores, in patient rooms, but HPV is significantly more effective. UVC is significantly less effective for sites that are out of direct line of sight."
Karpanen et al. 2012[29]*	CFU[a]	NR	"Copper alloys (greater than or equal to 58% copper), when incorporated into various hospital furnishings and fittings, reduce the surface microorganisms. The use of copper in combination with optimal infection-prevention strategies may therefore further reduce the risk that patients will acquire infection in healthcare environments."
Kundrapu et al. 2012[30]	CFU[a]	Frequency of health care worker hand contamination	"In a randomized nonblinded trial, we demonstrated that daily disinfection of high-touch surfaces in rooms of patients with Clostridium difficile infection and methicillin-resistant Staphylococcus aureus colonization reduced acquisition of the pathogens on hands after contacting high-touch surfaces and reduced contamination of hands of healthcare workers caring for the patients."
Schmidt et al. 2012[31]	CFU[a]	Overall microbial burden	"There was no difference in effectiveness, with a mean relative reduction of microbial burden of 84% for the traditional method versus 88% for the PureMist method."
Schmidt et al. 2012[32]	CFU[a]	NR	"The introduction of copper surfaces to objects formerly covered with plastic, wood, stainless steel, and other materials found in the patient care environment significantly reduced the overall MB on a continuous basis, thereby providing a potentially safer environment for hospital patients, health care workers (HCWs), and visitors."
Boyce et al. 2011[33]	Mean ACC (CFU per plate)[a]	Proportion of surfaces yielding a positive culture result (more than 1 CFU); number of surfaces yielding >2.5 CUs/cm^2 for the ACC	"The mobile UV-C light unit significantly reduced aerobic colony counts and C. difficile spores on contaminated surfaces in patient rooms."
Carter and Barry 2011[34]	CDI rate per 1,000 patients, overall rate of *C. diff* infection[b]	NR	"The introduction of sporicidal wipes resulted in a significant reduction in C. difficile rates. This supports the need to review and enhance traditional environmental cleaning regimens for preventing and controlling C difficile in acute settings."
Chan et al. 2011[35]	CFU[a]	NR	"These results showed that dry hydrogen peroxide vapour room decontamination is highly effective on a range of surfaces, although the cleanliness data obtained by these methods cannot be easily compared among the different surfaces as recovery of organisms is affected by the nature of the surface."
Orenstein et al. 2011[36]	*C. diff* incidence rates[b]	NR	"We found that daily room cleaning with 0.55% germicidal bleach wipes led to a sustained reduction in hospital-acquired CDI on units with high endemic incidence of CDI. Targeting the use of daily bleach wipe cleaning to units with an increased C. difficile colonization pressure is an effective method to wipe out healthcare-acquired CDI."
Sexton et al. 2011[37]	CFU[a]	Log(10) reduction	"The steam vapor system reduced bacterial levels by >90% and reduced pathogen levels on most surfaces to below the detection limit. The steam vapor system provides a means to reduce levels of microorganisms on hospital surfaces without the drawbacks associated with chemicals, and may decrease the risk of cross-contamination."

Author	Primary Outcome	Secondary Outcome of Interest	Authors Conclusions
Wilson et al. 2011[38]	Number of bed areas from which target pathogens were isolated at least once during a sampling day[d]	Unpooled results of screening for the target pathogens in bed/communal areas, total ACC	"Enhanced cleaning reduced environmental contamination and hand carriage, but no significant effect was observed on patient acquisition of methicillin-resistant Staphylococcus aureus."
Alfa et al. 2010[39]	CFU [a]	NR	"Our data indicate that the AHP formulation evaluated that has some sporicidal activity was significantly better than the currently used SHP formulation. This AHP formulation provides a one-step process that significantly lowers the C. difficile spore level in toilets during non-outbreak conditions without the workplace safety concerns associated with 5,000 ppm bleach."
Casey et al. 2010[40]	Median CFU/cm^2 [a]	NR	"The results of this trial clearly demonstrate that copper-containing items offer the potential to significantly reduce the numbers of micro-organisms in the clinical environment. However, the use of antimicrobial surfaces should not act as a replacement for cleaning in clinical areas, but as an adjunct in the fight against HCAI."
Hacek et al. 2010[41]	*C. diff* cases per 1,000 patient days[b]	NR	"The implementation of a thorough, all-surface terminal bleach cleaning program in the rooms of patients with CDI has made a sustained, significant impact on reducing the rate of nosocomial CDI in our health care system."
Hamilton et al. 2010[42]	Total viable bacterial counts[a]	NR	"Cleaning with UMF reduces TVC in the hospital environment and this effect is significantly enhanced (about two-fold) with additional CuWB50. The copper-based biocide has two beneficial effects: (i) a residual effect that requires 2-3 weeks of cleaning to establish, and (ii) an immediate effect on reducing TVC that is most evident shortly after cleaning."
Hedin et al. 2010[43]	Total ACC [a]	NR	"Significantly fewer bacteria were found on Appeartex-treated surfaces compared with untreated surfaces."
Nerandzic et al. 2010[44]	Positive cultures [a]	Ease of use	"The Tru-D Rapid Room Disinfection device is a novel, automated, and efficient environmental disinfection technology that significantly reduces *C. difficile*, VRE and MRSA contamination on commonly touched hospital surfaces."
Rutala et al. 2010[45]	Total CFUs per site [a]	NR	"This UV-C device was effective in eliminating vegetative bacteria on contaminated surfaces both in the line of sight and behind objects within approximately 15 minutes and in eliminating C. difficile spores within 50 minutes."
Andersen et al. 2009[46]	CFU [a]	CFU in air, ease of use of ATP	"Wet, moist and dry mopping seemed to be more effective in reducing bacteria on the floor, than the spray mopping (P=0.007, p=0.002 and p=0.011, respectively). The burden of bacteria in air increased for all methods just after mopping. The overall best cleaning methods seemed to be moist and wet mopping."
McMullen et al. 2007[47]	Cases of *C. diff*-associated diarrhea per 1,000 patient days[b]	NR	"These findings are further evidence that use of sodium hypochlorite solution may be an effective means of reducing the occurrence of CDAD in acute care facilities where the disease is epidemic or hyperendemic."
Whitaker et al. 2007[48]	*C. diff* infection rate per 1,000 patient days[b]	NR	"A combination of automated daily isolation reports, use of a standardized methodology for isolation rounds, as well as development of a 10% hypochlorite disinfection protocol resulted in a dramatic decrease in health care-associated C difficile cases. Weekly nursing director reports and daily rounds by nursing leadership keep the direct line supervisors abreast of infection control issues on their respective nursing units. The addition of the dual-chamber bleach container ensured that the proper dilution was achieved when disinfecting reusable equipment."

Author	Primary Outcome	Secondary Outcome of Interest	Authors Conclusions
De Lorenzi et al. 2006[49]	ACC [a]	NR	"Dry wiping followed by damp washing did not produce any significant reduction in the average bacterial load. However, damp washing followed by dry wiping reduced the bacterial load for both types of flooring. The difference was statistically significant."
Wilcox et al. 2003[50]	Incidence rate of *C. diff* infection[b]	Surface colonization	"Our results provide some evidence that hypochlorite environmental cleaning may significantly reduce CDI incidence, but also emphasize the potential for confounding factors."
Byers et al. 1998[51]	Number of colonized sites[c]	Cost of labor and supplies, cost of keeping room empty	"Sixteen percent of hospital room surfaces remained colonized by VRE after routine terminal disinfection. Disinfection with a new "bucket method" resulted in uniformly negative cultures. Conventional cleaning took an average of 2.8 disinfections to eradicate VRE from a hospital room, while only one cleaning was required with the bucket method."

ACC=aerobic colony counts; AHP=accelerated hydrogen peroxide; ATP=adenosine triphosphate; CD=cleaning and disinfection; CDAD=Clostridium difficile-associated diarrhea; CDI=Clostridium difficile infection; CFU=colony-forming unit; C diff=Clostridium difficile; HA-CDI=hospital-associated Clostridium difficile infection; HAI=hospital-associated infection; HCAI=healthcare-associated infection; HCW=healthcare worker; HP=hydrogen peroxide; HPC=heterotrophic plate counts; HPD=hydrogen peroxide decontamination; HPV=hydrogen peroxide vapor; ICU=intensive care unit; MB=microbial burden; MDRAB= multidrug-resistant *Acinetobacter baumannii*; MDRO=multiple-drug-resistant organisms; MRSA=methicillin-resistant staphylococcus aureus; MSSA=methicillin-susceptible *staphylococcus aureus*; PPX-UV=pulsed xenon ultraviolet light; RLU=relative light unit; RTU=ready-to-use; SHP=stabilized hydrogen peroxide; TVC= total viable (bacterial) counts; UMF=ultramicrofiber; UVD= ultraviolet environmental disinfection; VRE=vancomycin-resistant enterococci.

Primary outcome focused on surface contamination[a], infection rate[b], colonization[c], or other outcomes.[d]

Table C-5. Characteristics of monitoring studies

Author	Country	Study Design	Monitoring Method	Study Length	Sample Size	Primary Setting	Pathogens	High Touch Object(s)
Luick et al. 2013[52]	United States	Nonrandomized controlled	ATP bioluminescence, fluorescent/UV markers, visual observation	2 months	50 rooms, 250 total surfaces	Ward not specified	NR	Bed rail, call button, toilet, tray table, telephone
Smith et al. 2013[53]	United States	Nonrandomized controlled	ATP bioluminescence, visual observation, swab cultures	Not reported	10 rooms	Ward not specified	Various pathogens including *C. diff*, MRSA, VRE	Bed rail, call button, light switch, side table, toilet, sink, telephone, door handle
Snyder et al. 2013[54]	United States	Nonrandomized controlled	ATP bioluminescence, fluorescent/UV markers, visual observation	3 months	20 rooms, 290 surfaces	Ward not specified	NR	Bed rail, call button, light switch, side table, toilet, tray table, door knob, telephone, sink
Mulvey et al. 2011[55]	United Kingdom	Nonrandomized controlled	ATP bioluminescence, visual observation, Agar slide cultures	4 weeks	90 samples	General medical and surgical wards	MRSA	Bed, bed rail, floor, tray table
Munoz-Price et al. 2011[56]	United States	ITS	Fluorescent/UV markers	20 weeks	284 rooms, 2,292 surfaces	ICU	Various pathogens	Bed rail, bed control, call button, light switch, monitor control panel, remote control, side table, toilet, tray table
Carling et al. 2010[57]	United States	Before/after	Fluorescent/UV markers	Not reported	260 rooms, 3,532 samples, 27 hospitals	ICU	NR	NR
Alfa et al. 2008[58]	Not specified	Descriptive	Fluorescent/UV markers	8 months	20 patients, 201 samples	Ward not specified	*C. diff*	Toilet
Alhamad and Maxwell 2008[59]	United Kingdom	Before/after and correlation of 2 monitoring methods	Agar slide cultures, "wipe-rinse method," used an assay	4 weeks	130 samples	Intensive care unit and "high dependency unit"	MRSA	Bed rail, monitor control panel, cabinet, door handle, telephone, keyboard
Blue et al. 2008[60]	Canada	Before/after	Fluorescent/UV markers	4 months	364 samples	Ward not specified	VRE	Bed rail, call buttons light switch, toilet, tray table, doorknob
Carling et al. 2008[61]	United States	Descriptive study of UV fluorescent monitoring	Fluorescent/UV markers	12 weeks	1,119 rooms, 13,369 "high risk-objects"	ICU and other units	NR	Bed rail, call button, light switch, side table, toilet, tray table, sink, telephone, doorknob
Carling et al. 2006[62]	United States	Descriptive study of fluorescent marker monitoring	Fluorescent/UV markers	Not reported	157 rooms, 1,404 samples	Ward not specified	NR	Bed rail, call button, side table, toilet, tray table, sink, doorknob, telephone
Malik et al. 2003[63]	United Kingdom	Nonrandomized controlled	ATP bioluminescence, visual observation, Agar slide cultures	Not reported	8 hospital wards	Ward not specified	NR	Not specified

ATP=adenosine triphosphate; C-diff=Clostridium difficile; HTO=high touch object; ICU=intensive care unit; ITS=interrupted time series; MRSA=methicillin-resistant staphylococcus aureus; NR=not reported; UV=ultraviolet; VRE=vancomycin-resistant enterococci.

Table C-6. Methods for monitoring studies*

Author	Monitoring Methods	Implementation Tools	Discusses Sustainability
Luick et al. 2013[52]	ATP bioluminescence, fluorescent/UV markers, visual observation	Not reported	No
Smith et al. 2013[53]	ATP bioluminescence, visual observation, swab cultures	Not reported	No
Snyder et al. 2013[54]	ATP bioluminescence, fluorescent/UV markers, visual observation	Not reported	No
Mulvey et al. 2011[55]	ATP bioluminescence, visual observation, Agar slide cultures	Not reported	No
Munoz-Price et al. 2011[56]	Fluorescent/UV markers	Feedback of UV-powder surveillance to environmental services, hospital leadership, and unit administrators.	Yes
Carling et al. 2010[57]	Fluorescent/UV markers	Feedback and education to staff	No
Alfa et al. 2008[58]	Fluorescent/UV markers	Not reported	No
Alhamad and Maxwell 2008[59]	Agar slide cultures, "wipe-rinse method," uses an assay	Not reported	No
Blue et al. 2008[60]	Fluorescent/UV markers	Includes regular feedback to EVS personnel	No
Carling et al. 2008[61]	Fluorescent/UV markers	Not reported	No
Carling et al. 2006[62]	Fluorescent/UV markers	Not reported	No
Malik et al. 2003[63]	ATP bioluminescence, visual observation, Agar slide cultures	Not reported	No

Cleaning methods, external factors, and patient safety culture were not reported.
ATP=adenosine triphosphate; CDI=*Clostridium difficile* infection; EVS=environmental services.

Table C-7. Outcomes and conclusions for monitoring studies

Author	Primary Outcome	Secondary Outcome of Interest	Authors' Conclusions
Luick et al. 2013[52]	Sensitivity to detect pathogens	Specificity of tests, PPV, NPV	"In a simultaneous assessment of 250 environmental surfaces after terminal cleaning using aerobic cultures as a gold standard, both fluorescent marker and an adenosine triphosphate bioluminescence assay system demonstrated better diagnosticity compared with subjective visual inspection."
Smith et al. 2013[53]	RLU/cm^2; CFU/cm^2	NR	"Although quantitative microbiology and ATP detection measure somewhat different aspects of environmental contamination, they both generally agree in distinguishing clean from dirty surfaces."
Snyder et al. 2013[54]	Percent of targets cleaned	Test characteristics of UV, ATP, and visual inspection	"In assessing the effectiveness of PDC, there was poor correlation between the two most frequently studied commercial methods and a microbiologic comparator. Visual inspection performed at least as well as commercial methods, directly addresses patient perception of cleanliness, and is economical to implement."

Author	Primary Outcome	Secondary Outcome of Interest	Authors' Conclusions
Mulvey et al. 2011[55]	Cleaning rate	Surface contamination (measured by ATP and dipslides)	"Microbiological and ATP monitoring confirmed environmental contamination, persistence of hospital pathogens and measured the effect on the environment from current cleaning practices. This study has provided provisional benchmarks to assist with future assessment of hospital cleanliness. Further work is required to refine practical sampling strategy and choice of benchmarks."
Munoz-Price et al. 2011[56]	Cleaning rate	NR	"We found that regular surveillance using an inexpensive technology coupled with regular feedback of results produced sustained improvements in environmental cleaning, which may explain the coincident reduction in hospital-acquired infections. The ability of this brief (12 weeks) intervention to produce rapid benefits (within 4 weeks) and prolonged benefits (more than 20 weeks) speaks to its efficacy. Further studies aimed at optimizing reintroduction of the intervention to optimize cleaning rates should be considered."
Carling et al. 2010[57]	Percent of targets cleaned	NR	"Significant improvements in intensive care unit room cleaning can be achieved in most hospitals by using a structured approach that incorporates a simple, highly objective surface targeting method and repeated performance feedback to environmental services personnel."
Alfa et al. 2008[58]	Cleaning rate	NR	"Our data demonstrated the value of UVM for monitoring the compliance of housekeeping staff with the facility's toilet cleaning protocol. In addition to providing good physical cleaning action, agents with some sporicidal activity against C. difficile may be needed to effectively reduce the environmental reservoir."
Alhamad and Maxwell 2008[59]	Number of samples with positive culture	Overall CFU/cm^2	"There was no direct correlation between the findings of total aerobic count and MRSA isolation. We suggest, however, that combining both standards will give a more effective method of assessing the efficacy of cleaning/disinfection strategy. Further work is required to evaluate and refine these standards in order to assess the frequency of cleaning required for a particular area, or for changing the protocol or materials used."
Blue et al. 2008[60]	Percent of targets cleaned	VRE infection rate	"The GlitterBug product is an effective tool to evaluate environmental cleaning and adherence to policies and procedures and this method was superior to previous visual inspection methods. The use of GlitterBug potion improved physical cleaning and enhanced staff contribution. The Brevis GlitterBug product was incorporated into the CSS environmental cleaning program at Hamilton Health Sciences as a quality indicator to monitor environmental cleaning practices."
Carling et al. 2008[61]	Cleaning rate	NR	"We identified significant opportunities in all participating hospitals to improve the cleaning of frequently touched objects in the patient's immediate environment. The information obtained from such assessments can be used to develop focused administrative and educational interventions that incorporate ongoing feedback to the environmental services staff, to improve cleaning and disinfection practices in healthcare institutions."
Carling et al. 2006[62]	Percent of targets cleaned	NR	"The use of a novel target compound to evaluate housekeeping practices confirmed high rates of cleaning of traditional sites but poor cleaning of many sites that have significant potential for harboring and transmitting microbial pathogens. This methodology has the potential for being used to evaluate objectively the cleaning/disinfecting activities in various health care settings."
Malik et al. 2003[63]	RLU, CFU/cm^2	NR	"The data suggest that visual assessment is a poor indicator of cleaning efficacy and that the ACE audit gives a better assessment of cleaning programs compared with the other 2 audit methods in relation to microbial surface counts. It is recommended that hospital cleaning regimes be designed to ensure that surfaces are cleaned adequately and that efficacy is assessed with use of internal auditing and rapid hygiene testing."

ACC=aerobic colony count; ACE=audit for cleaning efficacy; ATP=adenosine triphosphate; CDI=Clostridium difficile infection; CFU=colony-forming unit; CSS=infection control and customer support services; MRSA=methicillin-resistant *staphylococcus aureus*; NPV=negative predictive value; NR=not reported; PDC=postdischarge cleaning; PPV=positive predictive value; RLU=relative light unit; UVM=ultraviolet visible marker.

Table C-8. Characteristics of implementation studies

Author	Country	Study Design	Study Length	Single or Multicomponent Strategy	Sample Size	Primary Setting	Pathogen(s) Described	High Touch Object(s)
Branch-Elliman et al. 2014[64]	United States	Before/after	2 months	Single	820 surfaces, 210 rooms	Ward not specified	MRSA, VRE	Side rail, over-bed rail, toilet seat
Koll et al. 2014[65]	United States	ITS	22 months	Multicomponent/infection prevention bundle, including contact precautions for patients with diarrhea and sign placement for patients with confirmed/suspected CDI	35 hospitals	Burn, telemetry and medical surgical unit	*C. diff*	Over 20 HTOs, including bed, bed rail, call button, floor, toilet, tray table, over 20 HTOs
Ramphal et al. 2014[66]	United States	ITS	14 months	Multicomponent/hand hygiene, improved kits for line-changing procedures	3,185 HTOs	Ward not specified	Various pathogens, including *C. diff*	20 HTOs, including bed rail, call button, remote control, and tray table
Rupp et al. 2014[67]	United States	Before/after	4 years	Single	90 rooms, 1,117 surface measurements	Medical/surgical critical care units	NR	Bed rail, tray table, room door handle, thermometer, monitor, bed rail, release button, nurse call monitor, and other items
Rupp et al. 2014[68]	United States	Observation-al	4 months	Single	292 rooms, 17 housekeepers	Surgical/medical ICU	NR	18 HTOs, including bed rail, call button, light switch, and toilet
Smith et al. 2014[69]	United States	Non-RCT	20 months	Single	13,345 sites	5 units, including telemetry, ICU, medical/surgical, and cardiac	*C. diff*, MRSA, VRE	16 HTOs, including toilet seat, light switch, call light, mattress, and bedrail
Brakovich et al. 2013[70]	United States	ITS	7 months	Multicomponent/a tiered approach that included environmental cleaning and disinfection, diagnostics and surveillance, and infection control measures, including antibiotic stewardship	50 beds	Long-term acute care hospital	*C. diff*	Not specified
Trajtman et al. 2013[71]	Canada	Non-RCT	24 weeks	Single	7,680 sites	General medical ward	*C. diff*	Bathroom
Ragan et al. 2012[72]	Canada	Before/after	8 weeks	Single	823 HTO	ICU	*C. diff*, MRSA, VRE	Light switch, toilet, tray table, IV pole, drawer handle, door knob and other items

Author	Country	Study Design	Study Length	Single or Multicomponent Strategy	Sample Size	Primary Setting	Pathogen(s) Described	High Touch Object(s)
Datta et al. 2011[73]	United States	Retro-spective cohort	19 months	Single	17,652 patients	ICU	MRSA, VRE	Not specified
Murphy et al. 2011[74]	Australia	Before/after	17 weeks	Single	37 rooms, 986 HTOs	Ward not specified	MRSA, VRE	Light switch, toilet, bedroom door handle, bedroom soap dispenser, bedroom tap handle, paper towel dispenser
Hota et al. 2009[75]	United States	Before/after	25 weeks	Single	2,901 sites for thoroughness of cleaning, 1,472 sites for contamination	ICU	VRE	Bed rail, tray table, infusion pump; countertop; soap dispenser, and other items
Po et al. 2009[76]	United States	ITS	9 months	Single	16 bed	ICU	*C. diff*, VRE	Computer keyboard on wheels
Carling et al. 2008[77]	United States	Before/after	NR	Single	20,646 HTOs	General medical ward, special care areas	*C. diff*, MRSA, VRE	14 HTOs including bed rail, toilet, and tray table
Goodman et al. 2008[78]	United States	Before/after	8 months	Single	85 rooms, 1,121 surfaces	Respiratory step-down unit	MRSA, VRE	15 HTOs, including bed rail, curtain, light switch, and toilet
Eckstein et al. 2007[79]	United States	Before/after	16 weeks	Single	17 rooms	Surgical ward	*C. diff*, VRE	Bed rail, call button, side table, toilet, and door knob
Hayden et al. 2006[80]	United States	Before/after	255 days	NR	485 cleaning episodes	ICU	VRE	Bed rail, infusion pump, countertop, door handle, telephone, and other items

CDI=*Clostridium difficile* infection; C. diff=*Clostridium difficile*; HTO=high touch object; ICU=intensive care unit; ITS=interrupted time series; IV=intravenous; MRSA=methicillin-resistant staphylococcus aureus; non-RCT=nonrandomized controlled trial; NR=not reported; VRE=vancomycin-resistant enterococci.

Table C-9. Methods for implementation studies

Author	Cleaning Methods	Monitoring Methods	External Factors	Patient Safety Culture	Implementation Tools	Discusses Sustainability
Branch-Elliman et al. 2014[64]	NR	ATP bioluminescence	NR	NR	Education, monitoring, feedback	Yes
Koll et al. 2014[65]	Hypochlorite-based disinfectant	NR	NR	NR	Cleaning checklists	NR
Ramphal et al. 2014[66]	NR	Fluorescent/UV markers	NR	NR	Education, training, "blinded monitoring with transparent reporting of the results in a positive, engaging manner"	Yes

Author	Cleaning Methods	Monitoring Methods	External Factors	Patient Safety Culture	Implementation Tools	Discusses Sustainability
Rupp et al. 2014[67]	NR	Fluorescent/UV markers	NR	Department of infection control	43-point room-cleaning checklist, housekeeper educational program, training DVD, face-to-face meetings with housekeeping	Yes
Rupp et al. 2014[68]	Routine	ATP bioluminescence	NR	NR	NR	NR
Smith et al. 2014[69]	Quaternary ammonium	ATP bioluminescence	NR	NR	Educational interventional activities such as hands-on training and education with ATP devices, education via "Clean Sweep" electronic game, laminated pocket-size cleaning order, and high-touch surface lists in both English and Spanish.	Yes
Brakovich et al. 2013[70]	Microfiber mops, HPV	NR	Outside contractor provided HPV devices and services for followup decontamination of rooms formerly occupied by patients with CDI	IP Registered Nurse, members of the Quality and Safety Committee, Clinical Quality Outcomes Coordinator	Lipstick challenge, checklists, training on use of chemicals, color-coded microfiber cloths, database output of quarterly reports	Yes
Trajtman et al. 2013[71]	NR	Fluorescent/UV markers	NR	NR	Feedback and UVM audit tool	Yes
Ragan et al. 2012[72]	NR	Fluorescent/UV markers	NR	NR	Audit and feedback, check list for HTOs	NR
Datta et al. 2011[73]	Quaternary ammonium, change in application of disinfectant to bucket immersion of cloths	Fluorescent/UV markers	NR	NR	Education	NR
Murphy et al. 2011[74]	NR	Fluorescent/UV markers	NR	EVS management from 2 participating hospitals were given advice to better understand and improve cleaning	Audit and feedback, education to EVS staff, survey of EVS staff	Yes
Hota et al. 2009[75]	Quaternary ammonium	Swab cultures	NR	NR	Education, intensified monitoring	NR
Po et al. 2009[76]	NR	Fluorescent/UV markers	NR	NR	Education and feedback, process improvement interventions (e.g., assigned 1 specific individual to clean COWS), modification to cleaning protocols	Yes

Author	Cleaning Methods	Monitoring Methods	External Factors	Patient Safety Culture	Implementation Tools	Discusses Sustainability
Carling et al. 2008[77]	NR	Fluorescent/UV markers	NR	Hospital directors at all participating hospitals reviewed evaluation of terminal room cleaning practices with EVS management and subsequently presented this information to frontline staff; active interhospital networking	Audit and feedback	Yes
Goodman et al. 2008[78]	Quaternary ammonium (change from pour bottles to immersing cloth in bucket)	ATP bioluminescence, swab cultures	NR	NR	Education, monitoring, and feedback	NR
Eckstein et al. 2007[79]	NR	Swab cultures	NR	Infection Control Department meets monthly with housekeeping to provide feedback on culture results and to reconfirm importance of housekeeping in controlling pathogens	Audit and feedback, education, housekeeping staff asked for input on additional resources needed to perform job well	NR
Hayden et al. 2006[80]	Quaternary ammonium	Visual observation, VRE cultures	NR	NR	Educational in services, increased monitoring, audit, and feedback	NR

ATP=adenosine triphosphate; CDI=Clostridium difficile infection; COW=computer on wheels; EVS=environmental services; HPV=hydrogen peroxide vapor; HTO=high touch objects; IP=Infection prevention; NR=not reported; UVM=ultraviolet visible marker; VRE=vancomycin-resistant enterococci.

Table C-10. Outcomes and conclusions for implementation studies

Author	Primary Outcome	Secondary Outcome of Interest	Authors' Conclusions
Branch-Elliman et al. 2014[64]	Proportion of surfaces cleaned	NR	"We successfully implemented a quality improvement and education project to improve environmental cleaning in our hospital. Our study demonstrates that quality-assessment tools, such as the ATP luminometer, can be used at the point of cleaning to improve cleaning performance. Use of the tool in a positive feedback loop directly with front-line EMS staff resulted in enhanced collaboration, communication, and education among services."
Koll et al. 2014[65]	Compliance with room cleaning protocol	CDI rates	"The use of a collaborative model to implement a multifaceted infection prevention strategy was temporally associated with a significant reduction in hospital-onset CDI rates in participating New York metropolitan regional hospitals."

Author	Primary Outcome	Secondary Outcome of Interest	Authors' Conclusions
Ramphal et al. 2014[66]	Percent of targets cleaned	*C. diff* rate per 1,000 patient days	"The percentage of cleaned surfaces improved incrementally between the three trials—with values of 20%, 49%, and 82%—showing that repeat training favorably changed behavior in the staff (P = 0.007). During the study period, during which other infection control interventions were also introduced, there was a decline from 0.27 to 0.21 per 1000 patient days for Clostridium difficile infection, 0.43 to 0.21 per 1000 patient days for ventilator-associated infections, 1.8% to 1.2% for surgical site infections, and 1.2 to 0.7 per 1000 central venous line days for central line–associated bloodstream infections."
Rupp et al. 2014[67]	Compliance with room cleaning protocol	NR	"Over a 4-year period, we observed that monthly feedback of performance data in face-to-face meetings with frontline personnel was crucial in maintaining environmental-cleaning effectiveness in adult critical care units."
Rupp et al. 2014[68]	Housekeeper efficiency and effectiveness based on RLUs	NR	"A subgroup of housekeepers was identified who were significantly more effective and efficient than their coworkers. These optimum outliers may be used in performance improvement to optimize environmental cleaning."
Smith et al. 2014[69]	Cleaning score measures over time	Trends in HAIs	"The ATP detection device combined with educational feedback for EVS workers resulted in significant improvement in cleaning efficacy of the hospital room environment."
Brakovich et al. 2013[70]	Incidence rate of CDI	Cost	"This program was successful in decreasing the incidence of CDI in the LTACH creating a safe and cost-effective environment for patients, families, and the community."
Trajtman et al. 2013[71]	Compliance with room cleaning protocol	NR	"The use of UVM as an audit tool combined with weekly feedback of results to housekeeping staff resulted in significant, sustained improvement in the overall level of cleaning compliance of housekeeping staff."
Ragan et al. 2012[72]	Percent of targets cleaned	NR	"We demonstrate that auditing with fluorescent targeting can be implemented in both the ward and intensive care unit settings using only modest resources, resulting in rapid improvements in cleaning thoroughness."
Datta et al. 2011[73]	Infection rate: MRSA and VRE	Acquisition by prior occupant status	"Enhanced intensive care unit cleaning using the intervention methods may reduce MRSA and VRE transmission. It may also eliminate the risk of MRSA acquisition due to an MRSA-positive prior room occupant."
Murphy et al. 2011[74]	Compliance with room cleaning protocol	Percent of targets cleaned	"The [fluorescent marker] was useful to assess HTO cleaning thoroughness. It facilitated relevant feedback and education and motivated staff to strive for continual improvements in environmental cleaning. Without on-going education, preliminary improvements were unsustained. However, investigators better understood flaws in cleaning and policy/procedure conflicts."
Hota et al. 2009[75]	Percent of targets cleaned	Contamination of sites postcleaning, VRE prevalence	"These findings suggest that surface contamination with VRE is due to a failure to clean rather than to a faulty cleaning procedure or product."
Po et al. 2009[76]	Cleaning rate	NR	"Following a series of educational and programmatic interventions, we were able to improve the thoroughness of cleaning to 100%."
Carling et al. 2008[77]	Percent of targets cleaned	NR	"Significant improvements in disinfection cleaning can be achieved in most hospitals, without a substantial added fiscal commitment, by the use of a structured approach that incorporates a simple, highly objective surface targeting method, repeated performance feedback to environmental services personnel, and administrative interventions. However, administrative leadership and institutional flexibility are necessary to achieve success, and sustainability requires an ongoing programmatic commitment from each institution."

Author	Primary Outcome	Secondary Outcome of Interest	Authors' Conclusions
Goodman et al. 2008[78]	Positive cultures	Number of rooms with positive culture	"Increasing the volume of disinfectant applied to environmental surfaces, providing education for Environmental Services staff, and instituting feedback with a black-light marker improved cleaning and reduced the frequency of MRSA and VRE contamination."
Eckstein et al. 2007[79]	Percent of positive cultures	NR	"Our findings provide additional evidence that simple educational interventions directed at housekeeping staff can result in improved decontamination of environmental surfaces. Such interventions should include efforts to monitor cleaning and disinfection practices and provide feedback to the housekeeping staff."
Hayden et al. 2006[80]	Colonization with VRE	Time to clean, antibiotic use	"Decreasing environmental contamination may help to control the spread of some antibiotic resistant bacteria in hospitals."

ATP=adenosine triphosphate; CDI=*Clostridium difficile* infection; EVS=environmental services; HAI=hospital-associated infection; HTO=high touch object; LTACH=long-term acute care hospital; MRSA=methicillin-resistant staphylococcus aureus; RLU=relative light unit; UVM=ultraviolet visible marker; VRE=vancomycin-resistant enterococci.

Appendix D. Clinical Practice Guidelines and Ongoing Clinical Trials

Table D-1. Clinical practice guidelines

Organization	Reference	Country	Methods (Evidence-based or Consensus/narrative-based)
American College of Gastroenterology	Surawicz CM et al. Guidelines for diagnosis, treatment, and prevention of Clostridium difficile infections. Am J Gastroenterol. 2013 Apr;108(4):478-98.[81]	USA	Evidence-based
Association for the Healthcare Environment (AHE), formerly known as the American Society for Healthcare Environmental Services (ASHES) (part of the American Hospital Association)	Association for the Healthcare Environment. Practice guidance for healthcare environmental cleaning, 2nd edition. Chicago (IL): American Hospital Association; 2010.[82]	USA	Evidence-based
Association for Healthcare Research and Quality (AHRQ)	Collins AS. Chapter 41. Preventing health care–associated infections. In: Hughes RG, editor. Patient safety and quality: An evidence-based handbook for nurses. Rockville (MD): Agency for Healthcare Research and Quality (AHRQ); 2008. p. 547-75. http://www.ncbi.nlm.nih.gov/books/NBK2683/pdf/ch41.pdf.[83]	USA	Evidence-based
Association for Professionals in Infection Control and Epidemiology (APIC)	Association for Professionals in Infection Control and Epidemiology (APIC). APIC position on mandatory public reporting of HAIs. Washington (DC): Association for Professionals in Infection Control and Epidemiology (APIC); 2005 Mar 14. 3 p. http://www.apic.org/Resource_/TinyMceFileManager/Position_Statements/MandRpt_posnPaoper_2005.pdf.[84]	USA	Consensus/narrative
APIC	Greene LR et al. APIC Position Paper: The importance of surveillance technologies in the prevention of healthcare-associated infections (HAIs). Washington (DC): 2009 May 29. 7 p.[85]	USA	Evidence-based
APIC	Cardo D et al. Moving toward elimination of healthcare-associated infections: a call to action. [White paper]. Am J Infect Control. 2010 Nov;38(9):671-5.[86] "a joint white paper between APIC, Society for Healthcare Epidemiology of America (SHEA), Infectious Diseases Society of America (IDSA), Association of State and Territorial Health Officials, Council of State and Territorial Epidemiologists, Pediatric Infectious Diseases Society, and the Centers for Disease Control and Prevention."	USA	Consensus/narrative
APIC	Friedman C et al. APIC/CHICA-Canada infection prevention, control, and epidemiology: Professionals and practice standards. Washington (DC): Association for Professionals in Infection Control and Epidemiology (APIC); 2008. 5 p.[87]	Canada	Consensus/narrative
APIC	Association for Professionals in Infection Control and Epidemiology, Inc. Guide to preventing Clostridium difficile infections. Washington (DC): Association for Professionals in Infection Control and Epidemiology, Inc.; 2013 Feb. 100 p. http://www.apic.org/Resource_/EliminationGuideForm/59397fc6-3f90-43d1-9325-e8be75d86888/File/2013CDiffFinal.pdf.[88]	USA	Consensus/narrative

Organization	Reference	Country	Methods (Evidence-based or Consensus/narrative-based)
APIC	Association for Professionals in Infection Control and Epidemiology, Inc. Guide to the elimination of methicillin-resistant Staphylococcus aureus (MRSA) transmission in hospital settings, 2nd edition. Washington (DC): Association for Professionals in Infection Control and Epidemiology, Inc.; 2010. 65 p. http://www.apic.org/Resource_/EliminationGuideForm/631fcd91-8773-4067-9f85-ab2a5b157eab/File/MRSA-elimination-guide-2010.pdf.[89]	USA	Evidence-based
APIC	Infection Control and Epidemiology, Inc. Guide to the elimination of methicillin-resistant Staphylococcus aureus (MRSA) transmission in hospital settings. California supplement 2009. Washington (DC): Association for Professionals in Infection Control and Epidemiology, Inc.; 2009 Apr 3. 12 p. http://www.apic.org/Resource_/EliminationGuideForm/16c7a44f-55fe-4c7b-819a-b9c5907eca72/File/APIC-MRSA-California.pdf.[90]	USA	Consensus/narrative
APIC	Association for Professionals in Infection Control and Epidemiology, Inc. Guide to the elimination of methicillin-resistant Staphylococcus aureus (MRSA) in the long-term care facility. Washington (DC): Association for Professionals in Infection Control and Epidemiology, Inc.; 2009. 74 p. http://www.apic.org/Resource_/EliminationGuideForm/08b12595-9f92-4a64-ad41-4afdd0088224/File/APIC-MRSA-in-Long-Term-Care.pdf.[91]	USA	Evidence-based
Association of periOperative Registered Nurses (AORN)	Association of periOperative Registered Nurses (AORN). Recommended practices for environmental cleaning. In: 2014 perioperative standards and recommended practices. Denver (CO): Association of perioperative Registered Nurses (AORN); 2013 Sep. p. 255-76.[92] NGC summary.	USA	Evidence-based
AORN	Allen G. Implementing AORN recommended practices for environmental cleaning. AORN J. 2014 May;99(5):570-82. See: http://dx.doi.org/10.1016/j.aorn.2014.01.023.[93]	USA	Evidence-based
Australasian Society for Infectious Diseases (ASID)	Stuart RL et al. ASID/AICA position statement: Infection control guidelines for patients with Clostridium difficile infection in healthcare settings. Healthc Infect. Mar 2011;16(1):33-9. http://dx.doi.org/10.1071/HI11011.[94]	Australia	Consensus/narrative
ASID	Cheng AC et al. Australasian Society for Infectious Diseases guidelines for the diagnosis and treatment of Clostridium difficile infection. Med J Aust. 2011 Apr 4;194(7):353-8.[95]	Australia	Evidence-based
Center for International Blood and Marrow Transplant Research (CIBMTR)	Tomblyn M et al. Guidelines for preventing infectious complications among hematopoietic cell transplantation recipients: A global perspective. Biol Blood Marrow Transplant. 2009 Oct;15(10):1143-238.[96]	Multinational	Evidence-based
Centers for Disease Control and Prevention (CDC), including the Healthcare Infection Control Practices Advisory Committee (HICPAC)	Rutala WA, Weber DJ, Healthcare Infection Control Practices Advisory Committee. Guideline for disinfection and sterilization in healthcare facilities, 2008. Atlanta (GA): Centers for Disease Control and Prevention; 2008. 158 p. http://www.cdc.gov/hicpac/Disinfection_Sterilization/17_00Recommendations.html.[97] See also: Recommendations for disinfection and sterilization in health-care facilities.	USA	Evidence-based

Organization	Reference	Country	Methods (Evidence-based or Consensus/narrative-based)
CDC, including HICPAC	Centers for Disease Control and Prevention (CDC). Antibiotic resistance threats in the United States, 2013. Atlanta (GA):Centers for Disease Control and Prevention (CDC); 2013. 114 p. http://www.cdc.gov/drugresistance/threat-report-2013/pdf/ar-threats-2013-508.pdf.[98]	USA	Evidence-based
CDC, including HICPAC	Guh A. Carling P, Environmental Evaluation Workgroup. Division of Healthcare Quality Promotion; National Center for Emerging, Zoonotic and Infectious Diseases. Options for evaluating environmental cleaning. [Toolkit]. 2010. Atlanta (GA): Centers for Disease Control and Prevention (CDC); 2010 Dec.15 p. http://www.cdc.gov/HAI/pdfs/toolkits/Environ-Cleaning-Eval-Toolkit12-2-2010.pdf.[99] Note: Additional resources.	USA	Consensus/narrative
CDC, including HICPAC	McGKibben L et al. Guidance on public reporting of healthcare-associated infections: Recommendations of the Healthcare Infection Control Practices Advisory Committee. Am J Infect Control. 2005 May;33(4):217-26.[100]	USA	Consensus/narrative
CDC, including HICPAC	Recommendations for Preventing the Spread of Vancomycin Resistance Recommendations of the Hospital Infection Control Practices Advisory Committee (HICPAC). MMWR Recomm Rep. 1995 Sep 22;44(RR-12):1-13.[101]	USA	Consensus/narrative
CDC, including HICPAC	Sehulster L et al. Guidelines for environmental infection control in healthcare facilities. Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC) [Published errata appear in MMWR Recomm Rep 2003 Oct 24;52(42):1025-6]. MMWR Recomm Rep. 2003 Jun 6;52(RR-10):1-42.[102]	USA	Evidence-based
CDC, including HICPAC	Siegel J et al. Guideline for isolation precautions: preventing transmission of infectious agents in healthcare settings. Atlanta (GA): Centers for Disease Control and Prevention (CDC); 2007 Jun. 219 p.[103]	USA	Evidence-based
CDC, including HICPAC	Siegel JD et al. Management of multidrug-resistant organisms in healthcare settings. 2006. 74 p.[104]	USA	Evidence-based
CDC, including HICPAC	Umscheid C et al. Updating the Guideline Methodology of the Healthcare Infection Control Practices Advisory Committee (HICPAC). Atlanta (GA): Centers for Disease Control and Prevention (CDC); 31 p. http://www.cdc.gov/hicpac/pdf/guidelines/2009-10-29HICPAC_GuidelineMethodsFINAL.pdf.[105] Publication date not available.	USA	Evidence-based
European Centre for Disease Control and Prevention (ECDC)	Vonberg RP et al. Infection control measures to limit the spread of Clostridium difficile. Clin Microbiol Infect. 2008 May;14:2-20. http://dx.doi.org/10.1111/j.1469-0691.2008.01992.x.[106]	Europe	Evidence-based

Organization	Reference	Country	Methods (Evidence-based or Consensus/narrative-based)
European Society of Clinical Microbiology and Infectious Diseases (ESCMID)	European Society of Clinical Microbiology and Infectious Diseases. ESCMID consensus statements. Basel (Switzerland): European Society of Clinical Microbiology and Infectious Diseases; MRSA expert consensus documents, 2013 Feb 14. https://www.escmid.org/escmid_library/medical_guidelines/escmid_consensus_statements/. Accessed 2014 Oct 7.[107] Note: See Humphreys H et al. Workshop 2 for cleaning.	Europe	Consensus/narrative
Environmental Protection Agency (EPA)	U.S. Environmental Protection Agency. Antimicrobial testing program – guideline methodology. Washington (DC): U.S. Environmental Protection Agency; 2014 Aug 21. http://www.epa.gov/oppad001/antimicrobial-testing-program.html. Accessed 2014 Oct 7.[108] Note: includes test results from August 2014. See also: The antimicrobial testing program. Hospital disinfectant and tuberculocidal products tested or pending testing. [List of products]. 2014 Aug 21.	USA	Evidence-based
Government Accounting Office (GAO)	Bascetta CA. Health-care-associated infections in hospitals: Leadership needed from HHS to prioritize prevention practices and improve data on these infections: Report to the Chairman, Committee on Oversight and Government Reform, House of Representatives. Washington (DC): U.S. Government Accountability Office; 2008 Mar. 61 p. http://www.gao.gov/assets/280/274314.pdf.[109]	USA	Evidence-based
Healthcare-Associated Infection Working Group of the Joint Public Policy Committee. APIC, CDC, Council of State and Territorial Epidemiologists (CSTE), and Society for Healthcare Epidemiology of America (SHEA)]	Healthcare-Associated Infection Working Group of the Joint Public Policy Committee. Essentials of public reporting of HAIs, Healthcare-Associated Infection Working Group of the Joint Public Policy Committee toolkit. 4 p. http://www.apic.org/Resource_/TinyMceFileManager/Position_Statements/Essentials_Tool_Kit.pdf.[110] Publication date not provided.	USA	Evidence-based
Healthcare Infection Society (UK) (formerly, the Hospital Infection Society)	Coia JE et al. Guidelines for the control and prevention of methicillin-resistant Staphylococcus aureus (MRSA) in healthcare facilities. J Hosp Infect. 2006 May;63:1-44. http://dx.doi.org/10.1016/j.jhin.2005.10.014.[111]	UK	Evidence-based
Healthcare Infection Society (UK)	Cookson BD et al. Guidelines for the control of glycopeptide-resistant enterococci in hospitals. J Hosp Infect. 2006 Jan;62(1):6-21. http://dx.doi.org/10.1016/j.jhin.2005.02.016[112]	UK	Evidence-based
Healthcare Infection Society (UK)	Loveday HP et al. epic3: national evidence-based guidelines for preventing healthcare-associated infections in NHS Hospitals in England. J Hosp Infect. 2014 Jan;86. http://dx.doi.org/10.1016/S0195-6701(13)60012-2.[113]	UK	Evidence-based
Healthcare Infection Society (UK)	National Clostridium difficile Standards Group: Report to the Department of Health. J Hosp Infect. 2004 Feb;56 Suppl 1:1-38.[114]	UK	Evidence-based
Healthcare Infection Society (UK)	Pratt RJ et al. epic2: National Evidence-Based Guidelines for Preventing Healthcare-Associated Infections in NHS Hospitals in England. J Hosp Infect. 2007 Feb;65. http://dx.doi.org/10.1016/S0195-6701(07)60002-4.[115]	UK	Evidence-based

Organization	Reference	Country	Methods (Evidence-based or Consensus/narrative-based)
Healthcare Infection Society (UK)	Steer JA et al. Guidelines for prevention and control of group A streptococcal infection in acute healthcare and maternity settings in the UK. J Infect. 2012 Jan;64(1):1-18. http://dx.doi.org/10.1016/j.jinf.2011.11.001[116]	UK	Evidence-based
Infection Control Working Group	Neely AN et al. Computer equipment used in patient care within a multihospital system: recommendations for cleaning and disinfection. Am J Infect Control. 2005 May;33(4):233-7. http://dx.doi.org/10.1016/j.ajic.2005.03.002.[117]	USA	Evidence-based
Infection Prevention Society (IPS), formerly the Infection Control Nurses Association (ICNA)	Infection Prevention Society. Care setting process improvement tool in & out patient areas / departments. Bathgate (Scotland): Infection Prevention Society; 44 p. http://www.ips.uk.net/files/8213/8044/9268/In_-_Out_Patient_Area_Departments_PIT.pdf.[118] No publication date.	USA	Evidence-based
Institute of Medicine (IOM)	Institute of Medicine (IOM). Initial national priority for comparative effectiveness research. [book online]. Washington (DC): National Academies Press; 2009 Jan 1. [accessed 2010 Mar 3] [various].[119]	USA	Evidence-based
International Federation for Infection Control (IFIC)	Damani N. Information resources in infection control, 6th edition. Armagh (Ireland): International Federation of Infection Control; 2009. 96 p. http://www.theific.org/pdf_files/resource_IFIC_Sept_2009.pdf.[120]	UK	Evidence-based
JHPIEGO Corporation, an affiliate of Johns Hopkins University	Tietjen L et al. Infection prevention guidelines for healthcare facilities with limited resources**.** JHPIEGO Corporation; 2003. 419 p. http://pdf.usaid.gov/pdf_docs/PNACT433.[121]	USA	Evidence-based
Joint Commission	It's all the on the surface: establishing protocols for cleaning and disinfecting environmental surface areas. Environ Care News. 2010 Mar;13(3):6-11. http://www.jointcommission.org/assets/1/18/Its_All_on_the_Surface.pdf.[122]	USA	Evidence-based
Joint Commission	The Joint Commission. National patient safety goals effective January 1, 2014. Hospital accreditation program. Oakbrook Terrace (IL): The Joint Commission; 2013. 17 p. See: http://www.jointcommission.org/assets/1/6/HAP_NPSG_Chapter_2014.pdf.[123]	USA	Evidence-based
Massachusetts Nurses Association	Massachusetts Nurses Association. Exposure to environmental cleaning chemicals in healthcare settings. Canton (MA): Massachusetts Nurses Association; 2007 Oct 1. http://www.massnurses.org/nursing-resources/position-statements/env-cleaning-chem. Accessed 2014 Oct 7.[124]	USA	Consensus/narrative
Mehta et al.	Mehta Y et al. Guidelines for prevention of hospital acquired infections. Indian J Crit Care Med. 2014 Mar;18(3):149–63. http://dx.doi.org/10.4103/0972-5229.128705.[**125**]	India	Evidence-based
National Institute for Health and Care Excellence	Prevention and control of healthcare-associated infections: quality improvement guide. PH36. London (UK: National Institute for Health and Care Excellence (NICE); 2011 Nov 1. http://publications.nice.org.uk/prevention-and-control-of-healthcare-associated-infections-ph36. Accessed 2013 Oct 1.[126] See: Quality improvement statement 5: Environmental cleanliness.	UK	Evidence-based

Organization	Reference	Country	Methods (Evidence-based or Consensus/narrative-based)
National Patient Safety Agency (NPSA) UK	National Patient Safety Agency (NPSA). National specifications for cleanliness: primary medical and dental premises. London (UK): National Patient Safety Agency (NPSA); 2010 Aug. 44 p. http://www.nrls.npsa.nhs.uk/EasySiteWeb/getresource.axd?AssetID=75245%20.[127]	UK	Consensus/narrative
NPSA	National Patient Safety Agency. The revised healthcare cleaning manual. London: National Patient Safety Agency; 2009 Jun. 174 p. http://www.nrls.npsa.nhs.uk/EasySiteWeb/getresource.axd?AssetID=61814.[128]	UK	Evidence-based
Public Health Ontario, Provincial Infectious Diseases Advisory Committee (PIDAC)	Provincial Infectious Diseases Advisory Committee (PIDAC). Routine practices and additional precautions in all health care settings, 3rd edition. Ottawa (Ontario): Public Health Ontario; 2012 Nov.113 p. http://www.publichealthontario.ca/en/eRepository/RPAP_All_HealthCare_Settings_Eng2012.pdf.[129]	Canada	Evidence-based
PIDAC	Provincial Infectious Diseases Advisory Committee (PIDAC). Best practices for environmental cleaning for prevention and control of Infections In all health care settings - 2nd edition. Ottawa (Ontario): Public Health Ontario; 2012 May.183 p.[130]	Canada	Evidence-based
PIDAC	Provincial Infectious Diseases Advisory Committee (PIDAC). Review of literature for evidence-based best practices for VRE control. Ottawa (Ontario): Public Health Ontario; 2012. 24 p. http://www.publichealthontario.ca/en/eRepository/PIDAC-IPC_VRE_Evidence-based_Review_2012_Eng.pdf.[131]	Canada	Evidence-based
Public Health Agency of Canada	Public Health Agency of Canada. Clostridium difficile infection - infection prevention and control guidance for management in acute care settings. Ottawa (Ontario): Public Health Agency of Canada; 2013 Jan 1. http://www.phac-aspc.gc.ca/nois-sinp/guide/c-dif-acs-esa/index-eng.php. Accessed 2014 Oct 7.[132] See the section: 14. Environmental cleaning.	Canada	Evidence-based
Public Health Agency of Canada	Public Health Agency of Canada. Routine practices and additional precautions for preventing the transmission of infection in healthcare settings. Ottawa (ON): Public Health Agency of Canada; 2012. 195 p. http://publications.gc.ca/collections/collection_2013/aspc-phac/HP40-83-2013-eng.pdf.[133]	Canada	Evidence-based
Royal College of Nursing	Royal College of Nursing. Creating a safe environment for care: Defining the relationship between cleaning and nursing staff. London: Royal College of Nursing; 2013. 11 p. http://www.rcn.org.uk/__data/assets/pdf_file/0007/548719/004492.pdf.[134]	UK	Consensus/narrative

Organization	Reference	Country	Methods (Evidence-based or Consensus/narrative-based)
Royal College of Nursing	Royal College of Nursing. Essential practice for infection prevention and control: Guidance for nursing staff. London: Royal College of Nursing; 2012. 36 p. http://www.rcn.org.uk/__data/assets/pdf_file/0008/427832/004166.pdf.[135] Note: See sections: 3.2 Decontamination of equipment; and 3.3 Achieving and maintaining a clean clinical environment.	UK	Consensus/narrative
Royal College of Nursing	Royal College of Nursing. Selection and use of disinfectant wipes. RCN guidance. London: Royal College of Nursing; 2011. 20 p. http://www.rcn.org.uk/__data/assets/pdf_file/0011/382538/003873.pdf.[136]	UK	Evidence-based
Public Health England/Department of Health	Department of Health, Health Protection Agency. Clostridium difficile infection: how to deal with the problem. [Guidance]. London (UK): Healthcare Associated Infection and Antimicrobial Resistance, Department of Health; 2008 Dec.140 p.[137] Note: See chapter 6: Prevention through environmental cleaning and disinfection.	UK	Evidence-based
Public Health England/Department of Health	Wilcox M. Updated guidance on the management and treatment of C. difficile infection. London: Public Health England; 2013. 29 p. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/321891/Clostridium_difficile_management_and_treatment.pdf.[138]	UK	Evidence-based
Rudolf Schuelke Foundation (Germany)	Gebel J et al. The role of surface disinfection in infection prevention. [Consensus paper]. GMS Hyg Infect Control. 2013;8(1):Doc10. http://dx.doi.org/10.3205/dgkh000210.[139]	Germany	Evidence-based
SHEA	Society for Healthcare Epidemiology of America (SHEA). Compendium of strategies to prevent healthcare-associated infections in acute care hospitals – overview page. Arlington (VA): Society for Healthcare Epidemiology of America (SHEA); 2014 Jan 1. http://www.shea-online.org/PriorityTopics/CompendiumofStrategiestoPreventHAIs.aspx. Accessed 2014 Oct 7.[140] Note: This is an overview page. The recommendation sections related to this Technical Brief are listed in the next two documents.	USA	Evidence-based
SHEA	Calfee DP et al. Strategies to prevent methicillin-resistant staphylococcus aureus transmission and infection in acute care hospitals: 2014 update. Infect Control Hosp Epidemiol. 2014 Jul;35(7):772-96. http://dx.doi.org/10.1086/676534.[141] Note: from the 2014 Compendium.	USA	Evidence-based
SHEA	Dubberke ER et al. Strategies to prevent Clostridium difficile infections in acute care hospitals: 2014 update. Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America. 2014 Jun;35(6):628-45. http://dx.doi.org/10.1086/676023.[142] Note: from the 2014 Compendium.	USA	Evidence-based

Organization	Reference	Country	Methods (Evidence-based or Consensus/narrative-based)
SHEA	Calfee DP et al. Strategies to Prevent Transmission of Methicillin-Resistant Staphylococcus aureus in Acute Care Hospitals. Infect Control Hosp Epidemiol. 2008 Oct;29 Suppl 1:S62-80.[143] Note: from the 2008 Compendium.	USA	Evidence-based
SHEA	Dubberke ER et al. Strategies to Prevent Clostridium difficile Infections in Acute Care Hospitals. Infect Control Hosp Epidemiol. 2008 Oct;29 Suppl 1:S81-92.[144] Note: from the 2008 Compendium.	USA	Evidence-based
SHEA	Cohen SH, et al. Clinical practice guidelines for Clostridium difficile infection in adults: 2010 Update by the Society for Healthcare Epidemiology of America (SHEA) and the Infectious Diseases Society of America (IDSA). Infect Control Hosp Epidemiol. 2010 May;31(5):431-55.[145]	USA	Evidence-based
SHEA	Muto CA, et al. SHEA guideline for preventing nosocomial transmission of multidrug-resistant strains of Staphylococcus aureus and Enterococcus. Infect Control Hosp Epidemiol. 2003 May;24(5):362-86. http://www.journals.uchicago.edu/doi/pdf/10.1086/502213.[146]	USA	Evidence-based
U.S. Centers for Medicare and Medicaid Services (CMS)	U.S. Centers for Medicare and Medicaid Services (CMS). State operations manual: Appendix A—survey protocol, regulations and interpretive guidelines for hospitals. (Rev. 116, 06-06-14). Baltimore (MD): U.S. Centers for Medicare and Medicaid Services (CMS); 2014 Jun 6. 471 p. (CMS State Operations Manuals; http://www.cms.gov/Regulations-and-Guidance/Guidance/Manuals/downloads/som107ap_a_hospitals.pdf.[147] Also may be of interest: Peasah SK et al. Medicare non-payment of hospital-acquired infections: infection rates three-years post-implementation. MMWR 2013;3(3).	USA	Consensus/narrative
U.S. Department of Health and Human Services (HHS)	U.S. Department of Health and Human Services (HHS). National action plan to prevent health care-associated infections: road map to elimination. Washington (DC): U.S. Department of Health and Human Services (HHS). http://www.health.gov/hai/prevent_hai.asp#hai_plan. Accessed 2014 Oct 7.[148]	USA	Evidence-based
World Health Organization (WHO)	Ducel G et al. Prevention of hospital-acquired infections: A practical guide. 2nd edition. Geneva (Switzerland): World Health Organization (WHO); 2002. 72 p. http://www.who.int/csr/resources/publications/drugresist/en/whocdscsreph200212.pdf?ua=1.[149]	International	Evidence-based

Table D-2. Ongoing clinical trials

Clinicaltrials.gov Identifier	Sponsor	Study Design	Purpose	Start Date	Expected Completion Date	Estimated Enrollment	Primary Outcomes
NCT01579370	Duke University	Randomized controlled	To determine the efficacy and feasibility of enhanced terminal room disinfection strategies to prevent HAIs and to determine the impact of environmental contamination on acquisition of multidrug-resistant pathogens among hospitalized patients. The intervention arm includes quaternary ammonium, bleach, quaternary ammonium and UV-C light, and bleach and UV-C light.	April 2012	October 2014	50,000	• Incidence rate of four target organisms (MRSA, VRE, *C. difficile* and MDR-Acinetobacter) among patients admitted to a study room • Incidence rate of *C. difficile* among patients admitted to a study room
NCT01349192	University of North Carolina, Chapel Hill	Randomized controlled	To determine whether an early eradication protocol is effective for eradicating MRSA and will provide an opportunity to obtain data regarding early clinical impact of new isolation of MRSA. The intervention arm includes an environmental decontamination component, including wiping down high-touch surfaces and medical equipment with surface disinfecting wipes daily for 21 days.	April 2011	July 2015	80	Percent of subjects in each arm with MRSA negative respiratory cultures at day 28
NCT02348346	Dr. B. de Jong	Observational	To study the efficacy of MVX (titanium dioxide) on the microbial colonization of surfaces in the ICU.	March 2015	December 2015	Not Reported	

ICU=intensive care unit; MRSA=methicillin-resistant *Staphylococcus aureus*; UV-C=ultraviolet-C; VRE=vancomycin-resistant enterococci.

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