

# *Draft Technical Brief*

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Number XX

## **Environmental Cleaning for the Prevention of Healthcare-Associated Infections (HAI)**

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**Contract No.:** [REDACTED]

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**AHRQ Publication No. xx-EHCxxx**  
<Month Year>

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**Suggested Citation:** <Authors>. Environmental Cleaning for the Prevention of Healthcare-Associated Infections (HAI). <Report Series Name in Title Caps No.> <#>. (Prepared by the <EPC Name> Evidence-based Practice Center under Contract No. <##>.) AHRQ Publication No. XX-EHCXXX-EF. Rockville, MD: Agency for Healthcare Research and Quality. <Month Year>. [www.effectivehealthcare.ahrq.gov/reports/final.cfm](http://www.effectivehealthcare.ahrq.gov/reports/final.cfm).

## 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. The EPCs systematically review the relevant scientific literature on topics assigned to them by AHRQ and conduct additional analyses when appropriate prior to 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 for which there are 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](mailto:epc@ahrq.hhs.gov).

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## **Acknowledgments**

The authors gratefully acknowledge the following individuals for their contributions to this project:

## **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, methodological 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 TOO and the EPC work to balance, manage, or mitigate any conflicts of interest.

The list of Key Informants who participated in developing this report will be added to the final report.

## **Peer Reviewers**

Prior to 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 non-financial conflicts may be retained. The TOO and the EPC work to balance, manage, or mitigate any potential non-financial conflicts of interest identified.

The list of Peer Reviewers will be added to the final report.

# Environmental Cleaning for the Prevention of Healthcare-Associated Infections (HAI)

## Structured Abstract

**Background:** Environmental 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 evidence of their comparative effectiveness is limited.

**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 grey literature since 1990 was performed using PubMed, EMBASE, CINAHL, the Cochrane Library, and other resources. Clinical studies examining cleaning high-touch surfaces in adult inpatient hospital rooms were included. Conference abstracts and non-English publications were excluded. Primary outcomes of interest were infection, colonization, or contamination with *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus*, or vancomycin-resistant enterococci. Additionally, 12 Key Informants were interviewed about cleaning and monitoring practices, practice implementation, knowledge gaps, and research challenges.

**Findings:** Seventy-seven studies were included. Forty-six 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. Six studies were randomized controlled trials; most studies used nonrandomized concurrent or historical controls. Surface contamination was reported in 54 studies; infection rates were reported in 25.

**Conclusions:** Most cleaning and monitoring modalities are not well studied in clinical settings. The evidence base is limited by weak study designs, lack of consensus around important concepts (such as cleanliness thresholds and delineation of high-touch surfaces), and reliance on nonclinical outcomes.

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# Background

## Introduction

Environmental cleaning (EC) is a fundamental principle of preventing infection in the hospital setting. Many hard, nonporous surfaces 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 Carbapenem-resistant *Enterobacteriaceae*. These 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 plays an important role in the transmission of pathogens. Appropriate cleaning of these surfaces is necessary to reduce the risk of healthcare-associated infections (HAIs). However, little consensus exists for optimal approaches to EC. A wide variety of cleaning agents and disinfection technologies are commercially available, each with its own benefits and disadvantages. Additionally, hospitals often seek to monitor the quality of room cleaning 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 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 and monitoring to prevent HAIs and highlight future research directions.

## 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 cleaning include peracetic acid and accelerated liquid hydrogen peroxide. The effectiveness of chemical disinfectants can depend both upon the antimicrobial activity of the disinfectant and appropriate application, including adequacy of cleaning, contact time, and concentration of the disinfectant. An alternative to these manually applied chemicals is the use of “no-touch” modalities for hospital room disinfection, including application of ultraviolet light (UV-C)<sup>1-3</sup> or fogging with hydrogen peroxide vapor or mist.<sup>4-6</sup> These processes can be used only for terminal cleaning, 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.<sup>7,8</sup> These surfaces are designed to resist contamination and augment routine cleaning processes.

## Assessing Disinfection Following Environmental Cleaning

In addition to selecting optimal cleaning methods, hospitals also attempt to assess how effectively cleaning processes are being implemented. Visual inspection is the simplest method for evaluating cleanliness, but concerns about the adequacy of visual inspection alone<sup>9-11</sup> 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, with UV light inspection following cleaning. This approach provides immediate, direct feedback but also increases costs. 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.

A related and important consideration is the need for identifying standardized criteria for determining that surfaces are “clean” on the basis of each monitoring modality. While routine and enhanced cleaning 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.

## **Managing and Monitoring 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.

## **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. For the purposes of this Technical Brief, however, the scope of interest 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 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 hard surfaces that form a fixed part of the patient room environment and that the patient and providers frequently touch, 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 these organisms.

## **Guiding Questions**

### **Guiding Question 1. Overview of Modalities Currently Used To Clean 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?
- Are there current benchmarks 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 and Monitoring Modalities Are Implemented**

- What elements interact with and impact the implementation of cleaning and monitoring?
- What equipment is necessary to support environmental services operations?
- What other resources are required?
- What are important considerations when training environmental services staff?
- What are current U.S. Food and Drug Administration (FDA) and Occupational Safety and Health Administration (OSHA) regulations that 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 and Monitoring Modality**

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

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

- What outcomes are relevant?
  - HAI rate
  - Colonization rate
  - Surface pathogen bioburden
  - Pathogen/infection-specific data vs. composite of common pathogens
  - Patient satisfaction
  - Cost analysis
- How can studies control for important confounders?
  - Multi-component 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 followup
- 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 literature sources and gray literature 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 agents and monitoring strategies, the types of outcomes that are 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, how front-line personnel are trained and evaluated, and other elements that are critical to implementation and sustainability. One KI represented the Centers for Medicare & Medicaid Services (CMS) and was asked about federal regulations and hospital oversight, coverage decisions and payment policy, and measures of hospital quality and effectiveness. We sought feedback about the study protocol (<http://effectivehealthcare.ahrq.gov/protocol>), research design, guiding questions, inclusion and exclusion criteria, and overall project goals from the topic nominator.

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. Their input was also sought to inform our findings for Guiding Questions 2 and 4.

#### Gray Literature Search

Gray literature sources were searched 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: Agency for Healthcare Research and Quality (AHRQ), Centers for Disease Control and Prevention (CDC), U.S. Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA), ClinicalTrials.gov, ECRI Institute, Healthcare Standards, Medscape, and the National Guideline Clearinghouse™.

We also searched the websites of relevant professional organizations, including the American Organization for Nurse Executives, Association for Professionals in Infection Control and Epidemiology (APIC), Association for the Healthcare Environment, Healthcare Infection Society, Infectious Diseases Society of America, 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.

## Published Literature Search

Medical librarians within 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 September 5, 2014. 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. Table 1 presents the inclusion and exclusion criteria.

**Table 1. Inclusion and exclusion criteria**

| Topic                      | Inclusion  | Exclusion   |
|----------------------------|--|---|
| Setting                    | Patient rooms and isolation rooms in acute care hospital wards in the United States  | <ul style="list-style-type: none"> <li>• Ambulatory care settings</li> <li>• Long-term care facilities or physical rehabilitation centers</li> <li>• Surgical suites</li> <li>• Pediatric hospital wards</li> </ul> |
| Language                   | English  | Non-English   |
| Literature                 | Systematic reviews, clinical practice guidelines, randomized or nonrandomized controlled trials, 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   | <ul style="list-style-type: none"> <li>• Soft surface, porous objects</li> <li>• Linens or curtains</li> <li>• Invasive medical devices</li> </ul>  |
| Pathogens                  | Infection or contamination with <i>C. difficile</i> , MRSA, VRE; or unspecified pathogens where <i>C. difficile</i> , MRSA and VRE were not explicitly excluded in study | Studies not evaluating <i>C. difficile</i> , 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 | Multi-component interventions if change in cleaning or monitoring was a primary or prominent component   | Multi-component interventions if cleaning 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 tabled. 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 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 tabled separately from primary studies.

A member of the project team 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.

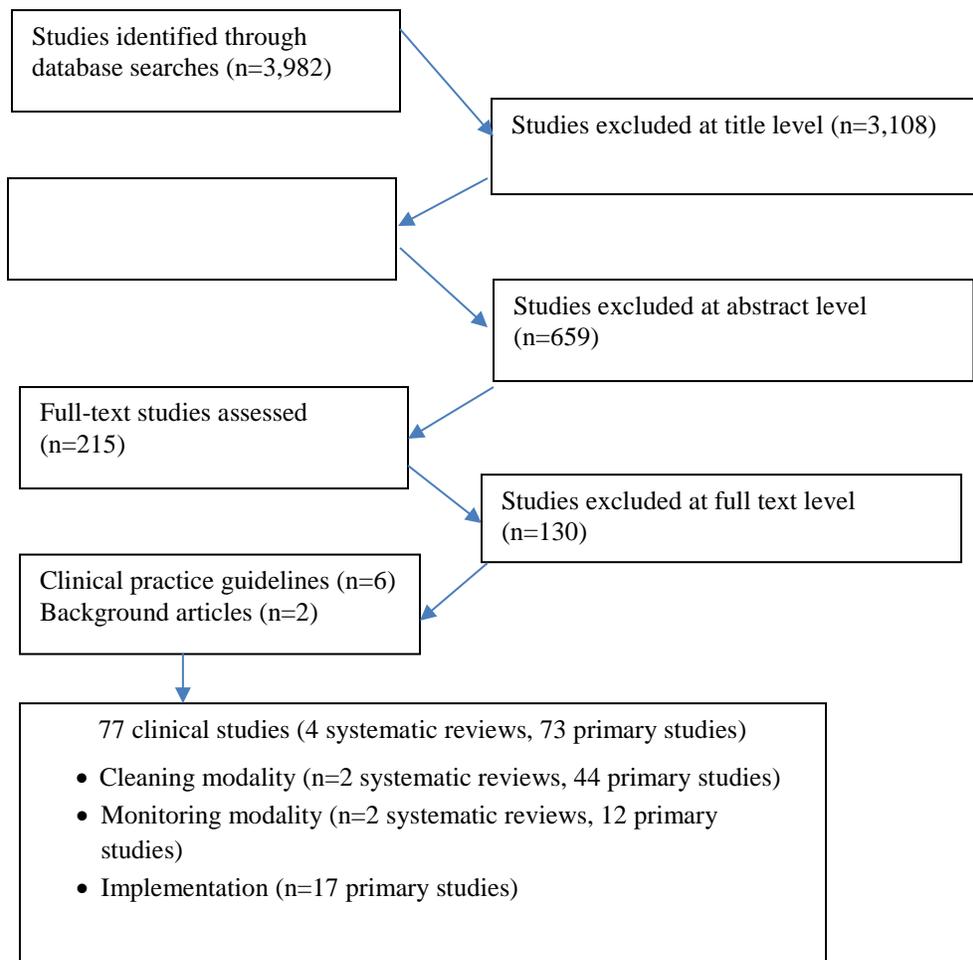
Findings were organized into an evidence map that chronicles the scope and depth of existing research on cleaning, disinfecting, and monitoring processes, while highlighting important gaps in the evidence base. Published studies, gray literature, and significant perspectives and insights gathered from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

# Findings

Our searches identified 3,982 potentially relevant studies. We excluded 3,767 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 215 articles. We excluded 130 studies at the full-text level. See Appendix B for a list of studies organized by reason for exclusion.

Of the 85 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 Topic Triage documentation) or guidance documents (e.g., tool kits) 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 73 published studies that fit our inclusion criteria and addressed modalities for cleaning, assessing cleanliness, or implementing EC processes. We did not identify for inclusion any conference abstracts presented within the past 2 years. To locate ongoing clinical trials of EC to prevent HAIs, we searched Clinicaltrials.gov. We identified two clinical trials categorized as “currently recruiting” and “ongoing, but not recruiting,” respectively. We also identified one trial (NCT00566306) completed in

August 2008. No outcome data were reported, and no publications are available from this trial. We are unsure whether this is due to publication bias, the tendency to publish only positive results, and to not publish results that suggest no difference in measured outcomes. For more information on the ongoing trials, see Table D-2 in Appendix D.

## Overview of Cleaning 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

Four categories of chemical agents are currently used in hospitals. These disinfectants are usually applied with a spray, moistened paper towel, or premoistened wipe, and some formulations can also be used as a liquid for mopping floors. Selecting a chemical agent for use in the 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, cost and ease of use, and safety of environmental services 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).<sup>12</sup>

### 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 of noncritical environmental surfaces (e.g., walls, floors), as well as for medical equipment that contacts intact skin (e.g., 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 and gauze pads can diminish microbicidal activity.<sup>13-15</sup> Finally, a few case reports of occupational asthma have been documented due to use of benzalkonium chloride.<sup>16,17</sup>

### Hypochlorite

Hypochlorites are EPA-registered surface disinfectants, and the most commonly used of the chlorine disinfectants (e.g., 4%–6% sodium hypochlorite solutions are formulated as household bleach). 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 are unaffected by water hardness, relatively stable and fast-acting, and generally safe with a low incidence of serious toxicity.<sup>18,19</sup> However, sodium hypochlorite (i.e., household bleach) may cause skin and eye irritation, as well as oropharyngeal, esophageal,

and gastric burns.<sup>20-22</sup> 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.<sup>18,19</sup>

## 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.<sup>23</sup> 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.<sup>23</sup> 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.<sup>24</sup> 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.<sup>25,26</sup>

## 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. 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 what type of alloy and selection of specific surfaces. Copper-containing surfaces are not commonly used in the hospital setting and are not considered standard of care.

### 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.<sup>27,28</sup>

## **Other**

Other modalities for self-disinfecting surfaces are under investigation, including materials with altered surface typography to inhibit bacterial biofilm formation. 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*.<sup>29</sup>

## **No-Touch Modalities**

Two kinds of technologic devices have been developed and commercially produced to disinfect hospital rooms. One type of device emits ultraviolet (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.

### **Ultraviolet Light**

The use of an UV wavelength light as a no-touch, automated modality for hospital room disinfection has received significant recent attention. The UV-C wavelength of 200-270 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 cleaning in hospital rooms of patients with *C. difficile* infection. Disadvantages of this technology include the requirement for the room to be vacated before decontamination, its use only for terminal disinfection (versus 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.

### **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 the 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 significant amount of time is required for effective disinfection. 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 cleaning following 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 decontamination. Covert visual monitoring of EVS staff during actual cleaning is used to provide an objective assessment of an individual staff member's adherence to cleaning protocols, often in conjunction with direct feedback and educational interventions. This method is straightforward, easy to implement in hospitals, and often performed by EVS managers. However, limitations of this monitoring method include interobserver variability and biases secondary to the Hawthorne effect (when the presence of observation affects observed behavior).

## Aerobic Colony Counts

Aerobic colony counts (ACCs) are a microbiologic method used to quantify 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 hands of health care workers. Swab cultures are most often used to identify specific pathogens during epidemiologic investigation of an outbreak.

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. Advantages of contact plates include ease of use and standardized approaches for quantitative measurement (e.g., results are often expressed as colony-forming units per cm<sup>2</sup>). 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.

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 decontamination for each object or surface being evaluated.

## UV Light Inspection

Fluorescent markers can be used in powder or gel form to mark high-touch surfaces before room cleaning. Following cleaning, 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 cleaning and to quantify the impact of educational interventions. 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 a failure 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 limited.

## **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. In addition, 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. 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. As these technologies become less expensive, they may have a larger role in assessing effectiveness of cleaning and disinfection, particularly in the outbreak setting.

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

### **Key Informant Feedback**

KIs 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.” KIs identified several aspects of implementation that can influence the effectiveness of environmental cleaning. 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, as cleaning 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, 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 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.

KIs cited training as vital to ensure that EVS staff recognizes the clinical significance of adhering to proper work procedures and guiding them on how to manage routine workflow. Staff in some hospitals undergoes extensive initial and ongoing education, including training on how to foster a “customer service” atmosphere when interacting with patients. 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, however, in work environments where staff turnover is high. Additionally, one KI noted that while many staffers 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 front-line personnel. Conversely, failure to build a positive culture can contribute to suboptimal work performance. Institutional leadership and the value that executives place on support services are important contributing factors in organizational culture. KIs described examples of hospitals whose leadership embraced and emphasized the importance of EC, resulting in better compliance with best practices. Alternatively, a few KIs cautioned that when faced with financial challenges, some hospital executives may view cleaning as low priority and resort to cutting staff and supplies.

An important aspect of the work culture is how clinical and administrative professionals within the hospital perceive the role of EVS staff. Almost every KI indicated that staff is often underappreciated despite playing a critical role within the infection control community. Some KIs suggested that hospitals should view cleaning 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.

## **Analytic 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*.<sup>30</sup> 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).

Using this framework, we present (below) contextual data relevant for implementation from all 73 studies, followed by detailed information on the 17 studies primarily focused on implementation.<sup>31-47</sup> None of the studies addressed structural organizational characteristics. However, one KI suggested that how EVS is organized within a hospital (e.g., location of EVS in the administrative hierarchy, inclusion of infection preventionists in EVS leadership) are important structural factors that affect the success of EC processes.

## External Factors

Compliance with “evidence-based policies and procedures” from organizations such as CDC, CMS, Joint Commission, FDA, EPA, 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, FDA, EPA, and others in regulating these agents. For a list of EPA and OSHA regulations related to sterilants and disinfectants, see Table 2.<sup>48</sup>

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.<sup>49</sup>

Of the 73 primary studies, only 1 (1%) recently published study reported on the influence of external factors. Mitchell et al. 2014<sup>50</sup> described an external quality control process undertaken by a hydrogen peroxide vapor decontamination device manufacturer.

**Table 2. EPA and OSHA regulations for sterilants and disinfectants**

| Organization | Topic                                     | Regulation  |
|--------------|---|---|
| OSHA         | Ethylene oxide                            | Established a permissible exposure limit (PEL) standard for ethylene oxide of 1 ppm in air as an 8-hour time-weighted average, and 5 ppm over any 15-minute sampling period.  |
|              | Hazard Communication Standard (HazCom)    | Requires that information concerning any associated health or physical hazards be transmitted to employees via comprehensive hazard communication programs ( <a href="#">Go to HERC HazCom page</a> ). The programs must include: <ul style="list-style-type: none"> <li>○ <b>Written Program.</b> A written program that meets the requirements of the Hazard Communication Standard (HazCom).</li> <li>○ <b>Labels.</b> In-plant containers of hazardous chemicals must be labeled, tagged, or marked with the identity of the material and appropriate hazard warnings.</li> <li>○ <b>Safety Data Sheets</b> (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.</li> <li>○ <b>Employee Information and Training.</b> 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.</li> </ul> |
|              | 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, <b>employers must provide</b> suitable mechanisms for quick drenching or flushing of the eyes and body within the work area for immediate emergency use [ <a href="#">1910.151(c)</a> ].  |

**Table 2. EPA and OSHA regulations for sterilants and disinfectants (continued)**

| Organization | Topic  | Regulation  |
|--------------|--|---|
| EPA          | Ethylene oxide   | Issued nationwide standards ( <a href="#">NESHAP Subpart WWWW</a> ) to reduce emissions of ethylene oxide (EtO) from hospital sterilizers. This regulation requires hospitals to implement a management practice to reduce EtO emissions by sterilizing full loads to the extent practicable. Hospitals that route EtO to a control device are in compliance with the rule requirements. Existing sources must be in compliance by December 29, 2008. New sources (construction after Nov. 6, 2006) must be in compliance at the time of startup. Affected hospitals must submit a Notification of Compliance Status within 180 days after their compliance date (for guidance on how to comply see: EPA guidance document <a href="#">Summary of Regulations Controlling Air Emissions from the Hospital Sterilizers Using Ethylene Oxide</a> ). |
|              | Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) | Provides EPA with the authority to oversee the registration, distribution, sale, and use of <a href="#">pesticides</a> . FIFRA applies to all types of pesticides, including <a href="#">antimicrobials</a> , which includes sterilants, disinfectants, and other cleaning compounds that are intended to control microorganisms on surfaces. FIFRA requires users of products to follow the <a href="#">labeling directions</a> on each product explicitly ( <a href="#">go to FIFRA page</a> ).   |

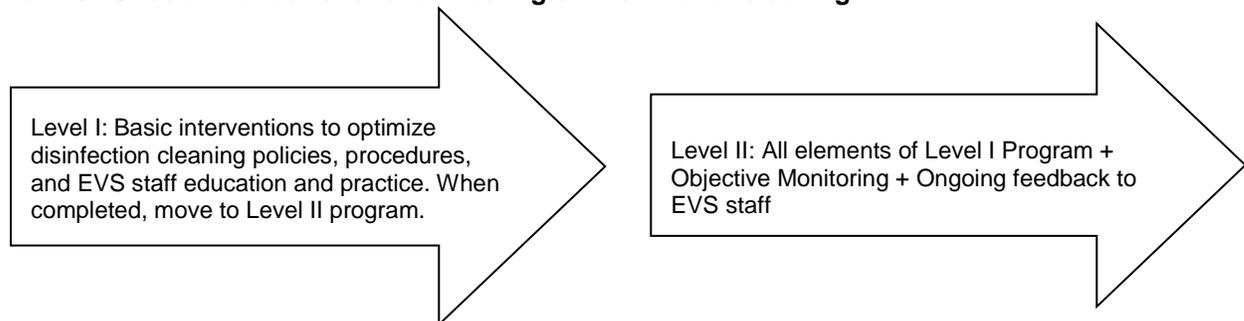
EPA = Environmental Protection Agency (EPA); HERC = Healthcare Environmental Resource Center; NESHAP = National Emission Standards for Hazardous Air Pollutants; OSHA = Occupational Safety and Health Administration; ppm = parts per million

## Patient Safety Culture

Institutional culture has been described as “the accumulation of invisible, often unspoken ideas, values, and approaches that permeate organizational life.”<sup>51</sup> Clarke et al. 2006<sup>52</sup> 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 EC processes by leaders from the Department of Infection Control,<sup>34</sup> an IP Registered Nurse, a Quality and Safety Committee, a Clinical Quality Outcomes Coordinator,<sup>37</sup> and EVS management.<sup>38</sup> Two earlier studies reported the influence of project directors<sup>44</sup> and the Department of Infection Control.<sup>46</sup>

Collaboration between infection prevention and control and EVS management during implementation phases (both planning and ongoing) is one of several key components presented in a two-level program to evaluate environmental cleaning by CDC. The 2010 toolkit *Options for Evaluating Environmental Cleaning*<sup>53</sup> presents context (specific to terminal room cleaning) to assist hospitals in developing programs “to optimize the thoroughness of high- touch surface cleaning.” While the toolkit recommends that most institutions start at Level I (basic) and proceed to Level II (advanced), hospitals with increased HAI rates are encouraged to implement Level II programs at the onset. See Figure 2 for an overview.

**Figure 2. CDC recommendations for evaluating environmental cleaning**



Adapted from Carling et al. Methods for assessing the adequacy of practice and improving room disinfection. 2013<sup>54</sup>

Administrative leadership is also “critical in managing outbreak situations,” according to APIC’s *Guide to Preventing Clostridium difficile Infections*.<sup>55</sup> The administrator’s responsibilities include ensuring staff has 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<sup>12,56</sup>) and use of a checklist for cleaning “objects in the patient zone.” Cleaning checklists for HTOs were used in 5 studies;<sup>32,34,36,37,40</sup> 1 study used a 43-point room cleaning checklist.<sup>34</sup> 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 front-line 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 5 studies specifically reported on training staff.<sup>34,37,50,57,58</sup> Smith et al. 2014<sup>36</sup> 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 (first, second, and third from cleanest to least clean) from a drop-down menu, then submits the data for feedback on their selection. In 2007, Whitaker et al. provided education for staff, patients, and visitors,<sup>59</sup> while other studies used a training DVD, competency-based training,<sup>50</sup> training on preparation, use and storage of products,<sup>57</sup> and training on the use of chemicals.<sup>37</sup>

Next, CDC recommends developing measures for monitoring staff that may include competency evaluations and utilizing patient satisfaction surveys. One approach to evaluate skill acquisition is the Dreyfus model.<sup>60</sup> This model describes five levels of expertise from the novice level to the 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 described audits (all published since 2012).<sup>38-40,57,61</sup> One study included a UV monitoring audit tool,<sup>39</sup> while another integrated monthly EC audits.<sup>57</sup> Ramphal et al. 2014<sup>33</sup> implemented “blinded monitoring with transparent reporting of the results in a positive, engaging manner,” while Hota et al. 2009<sup>42</sup> utilized “intensified monitoring.” 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. An ECRI Institute infection preventionist also 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 and rankings) to EVS, hospital leadership, and unit administrators;<sup>62</sup> feedback of UV-powder surveillance results to EVS staff, hospital leadership, and unit administrators,<sup>62</sup> feedback from staff focus groups;<sup>63</sup> and feedback to EVS staff (monthly meetings, small group meetings, and individual meetings).<sup>64</sup> 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.<sup>65</sup> Scores were measured on the Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) 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.

Finally, an important approach adopted by some hospitals is outsourcing of EVS. Environmental support services provided by companies such as Crothall Healthcare Environmental Services (Wayne, PA) and Sodexo (Gaithersburg, MD) can include training and development programs, designing of comprehensive protocols, competency testing, and participation on infection prevention teams.<sup>66,67</sup> While supporting a large EVS department (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., 3M Clean-Trace and Tru-D [UV irradiation device]).<sup>67</sup> One study, Brakovich et al. 2013,<sup>37</sup> 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 the 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.

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

### **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; 9 (53%) studies were published since 2012. Most studies were conducted in the United States, and others were conducted in Australia,<sup>38</sup> Canada,<sup>39,40</sup> and the Netherlands.<sup>47</sup> Complete information on these studies is available in Appendix C.

## Study Characteristics

Thirteen studies used historical controls, including before/after study designs (9), and interrupted time series (4).<sup>32,33,37,43</sup> Three studies used nonrandomized concurrent controls<sup>36,39,41</sup> and one was an uncontrolled, descriptive study.<sup>35</sup> Study length ranged from 8 weeks to 4 years. Three studies implemented multicomponent strategies.<sup>32,33,37</sup> 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.<sup>32</sup> Other studies incorporated hand hygiene<sup>33</sup> and antibiotic stewardship<sup>37</sup> with their environmental control strategies.

The “populations” studied in order of most to least common, included patient rooms, HTOs, hospital units, hospitals, beds, and patients. The primary setting for six studies was the intensive care unit (ICU).<sup>35,40-43,68</sup> Other settings included burn units,<sup>32</sup> telemetry units,<sup>32</sup> long-term acute care hospitals,<sup>37</sup> general medical wards,<sup>39</sup> respiratory step down units<sup>45</sup> and a surgical ward.<sup>46</sup> Wards were not specified in three studies.<sup>31,33,38</sup>

*C. difficile* was the primary focus of three studies.<sup>32,37,39</sup> VRE was the primary focus of two studies.<sup>42,47</sup> The remaining studies focused on at least two of the three pathogens of interest. Five studies reported cleaning of more than 15 HTOs.<sup>32,33,35,36,45</sup> One study’s sole focus was the bathroom.<sup>39</sup> 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 methods reported by some studies included hypochlorite-based disinfectant,<sup>32</sup> QAC,<sup>36,41,42</sup> hydrogen peroxide vapor, and microfiber mops.<sup>37</sup>

Several studies reported on the sustainability of their preventive strategies. Ramphal et al. 2014<sup>33</sup> reported sustaining gains for 6 months. Trajtman et al. 2013<sup>39</sup> described use of graphs posted on the wards and in the housekeeping office to assist in “sustained improvement in cleaning compliance.” In 2011, Murphy et al.<sup>38</sup> reported unsustainable gains without ongoing education. In 2008, Carling et al.<sup>44</sup> reported results of collaborative efforts by 36 hospitals to sustain improved cleaning. The authors reported an absolute decrease of 10% to 20% in the rates of high-risk object cleaning for eight hospitals and predicted unsustainable cleaning levels without ongoing “programmatic commitment by each institution.” Of the remaining 56 studies, only 1 study reported sustainability of its EVS strategy and reported “prolonged benefits” from a 12-week use of fluorescent markers combined with regular feedback of results.<sup>62</sup>

## Study Outcomes

Primary outcomes for most studies were variants of surface contamination (e.g., surfaces cleaned, positive cultures, compliance with room cleaning). Infection rate was reported as a primary outcome in three studies<sup>37,41,47</sup> and as a secondary outcome in two studies.<sup>32,33</sup>

All three studies implementing multicomponent preventive strategies reported positive results. Koll et al. 2014<sup>32</sup> reported significant reductions in hospital-onset CDI rates at 35 participating New York metropolitan regional hospitals. Ramphal et al. 2014<sup>33</sup> reported statistically significant improvements in cleaning rates due to repeated training, while Brakovich et al. 2013<sup>37</sup> reported success in decreasing CDI incidence.

Of the remaining 14 implementation studies, the study length of 6 studies was 6 months or fewer. Two studies (2 months in duration)<sup>31,40</sup> reporting use of ATP and fluorescent markers as monitoring tools resulted in “rapid improvements in cleaning thoroughness”<sup>40</sup> and “enhanced

collaboration, communication and education.”<sup>31</sup> One 4-month trial (Rupp et al. 2014)<sup>35</sup> 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,<sup>46</sup> fluorescent/ markers,<sup>38</sup> UV markers<sup>39</sup>) as useful tools to audit and educate staff. One of the studies reported significant, sustained improvements in overall cleaning.<sup>39</sup>

One recently conducted 4-year study (Rupp et al. 2014)<sup>34</sup> concluded that monthly feedback and face-to-face meetings with frontline staff were crucial to EC success. Datta et al. 2011<sup>41</sup> 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,<sup>43,45</sup> with an expectation that the decrease in environmental contamination would help control spread of multiple-drug-resistant organisms (MDROs).<sup>47</sup>

Lastly, Hota et al. 2009<sup>42</sup> purported that VRE contamination is caused by poor adherence to and use of cleaning procedures and products, respectively, “rather than to a faulty cleaning procedure or product.” Carling et al. 2008<sup>44</sup> 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.

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

We identified 4 systematic reviews and 56 primary studies that met the inclusion criteria for this question. The focus of 2 systematic reviews<sup>69,70</sup> and 44 primary studies<sup>1,50,57-59,61,63,64,71-106</sup> was cleaning and disinfection. The focus of 2 systematic reviews<sup>107,108</sup> and 12 primary studies was monitoring.<sup>9,10,62,109-117</sup>

### Systematic Reviews

Two systematic reviews addressed this topic. First, Falagas et al. 2011<sup>69</sup> reviewed the effectiveness of airborne hydrogen peroxide in hospital settings in 10 studies published before December 2009. Seven studies evaluated the BioQuell hydrogen peroxide vapor system (BioQuell Ltd., Andover, Hampshire, UK), while three studies evaluated a hydrogen peroxide dry-mist system or “dry fog” (Gloster Sante Europe, Labège cedex, France). 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 (airborne or dry-mist formulations) compared with standard terminal cleaning (39.0% [range 18.9-81.0%] baseline, 28.3% [range 11.9-66.1%] after standard terminal cleaning, 2.2% [range 0-4.0%] after airborne hydrogen peroxide). Two studies addressed use of airborne hydrogen peroxide as an adjunctive infection control strategy. 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.”<sup>69</sup>

Second, Dettenkofer et al. 2004<sup>70</sup> evaluated the effects of disinfection 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 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.”<sup>70</sup> The two systematic reviews are summarized in Appendix C.

### Primary Studies

Of the 44 primary studies addressing this topic, 26 (59%) were conducted in the United States. The remaining 18 (41%) studies were conducted in the United Kingdom,<sup>57,58,74,83,88,98,99,102</sup> Australia,<sup>50,61,63,81,91</sup> Sweden,<sup>97,104</sup> Canada,<sup>84</sup> Norway,<sup>85</sup> and Italy.<sup>101</sup> Studies were published between 1998 and September 2014, but 26 (59%) were published since 2012, reflecting recently growing interest in the role of EC. Cleaning and disinfection methods were generally categorized as surface cleaning, automated cleaning, or enhanced coatings or surfaces. Two studies examined steam vapor<sup>80</sup> and mopping methods.<sup>101</sup> Of the remaining

studies, 30 focused solely on either surface cleaning (20 studies), automated cleaning (7 studies), or enhanced coatings (3 studies), while 12 studies reported on a combination of cleaning/disinfection 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), and other detergents (e.g., potassium monopersulfate.) Sixteen studies evaluated the effectiveness of no-touch modalities, including automated UV light, hydrogen peroxide vapor, or steam vapor to reduce microbial burden. Nine studies (published since 2010) examined UV-C devices such as Tru-D<sup>64,75,82,88,93,95</sup> or PPX-UV.<sup>1,86,87</sup> Seven studies evaluated use of hydrogen peroxide vapor systems such as BioQuell<sup>50,74,77,81,93,103</sup> or steam vapor using the VaporJet PC 2400.<sup>80</sup> Enhanced coatings or surfaces included copper,<sup>72,73,92,98,99</sup> organosilane antimicrobial,<sup>105</sup> and “Appaertex,” an antimicrobial coating.<sup>97</sup> Lastly, two distinct studies compared cleaning methods (i.e., mopping methods,<sup>85</sup> quaternary ammonium delivery by spray or bucket<sup>71</sup>). Table 3 summarizes key characteristics of the studies included in the systematic reviews and identified by our search. Further information about the primary studies is presented in Appendix C.

**Table 3. Summary of cleaning and disinfection studies**

| Modality                   | N, Studies | Pathogen: <i>C. Difficile</i> | Pathogen: VRE | Pathogen: MRSA | Study design: RCT | Study design: Non-Randomized Concurrent Controls | Study design: Before-After | Study design: Interrupted Time Series | Study Design Not Reported | Outcome: Infection | Outcome: Colonization | Outcome: Surface Contamination |
|----------------------------|------------|-------------------------------|---------------|----------------|-------------------|--|----------------------------|---------------------------------------|---------------------------|--------------------|-----------------------|--------------------------------|
| QAC                        | 10         | 4                             | 5             | 6              | 3                 | 2  | 3                          | --                                    | 2                         | 3                  | 1                     | 6                              |
| Chlorine-based             | 13         | 8                             | 2             | 1              | 1                 | 4  | 6                          | 1                                     | 1                         | 10                 | 1                     | 5                              |
| Peracetic acid or HP wipes | 4          | 2                             | 1             | --             | --                | --   | 2                          | 2                                     | --                        | 1                  | 1                     | 3                              |
| Ultraviolet light emitting | 9          | 7                             | 3             | 4              | --                | 3  | 4                          | 2                                     | --                        | 3                  | --                    | 7                              |
| Hydrogen peroxide vapor    | 17         | 8                             | 2             | 8              | --                | 3  | 3                          | 1                                     | 10                        | 6                  | --                    | 14                             |
| Coatings                   | 7          | 3                             | 3             | 4              | 1                 | 4  | 2                          | --                                    | --                        | 1                  | 1                     | 6                              |
| Microfiber                 | 4          | 2                             | 2             | 2              | 1                 | 1  | 2                          | --                                    | --                        | 1                  | --                    | 4                              |
| <b>All studies</b>         | <b>58</b>  | <b>30</b>                     | <b>14</b>     | <b>17</b>      | <b>6</b>          | <b>12</b>  | <b>20</b>                  | <b>5</b>                              | <b>13</b>                 | <b>20</b>          | <b>4</b>              | <b>43</b>                      |

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 randomized controlled trials and one was a randomized crossover study. Twelve studies used nonrandomized concurrent controls, while 25 used historical controls, including 20 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).<sup>50,83,91</sup> The multicomponent strategies in one study included

monitoring of hand- hygiene compliance and antimicrobial usage, additional MRSA active surveillance screening of patients with more rapid turnaround of laboratory results, and implementation of isolation precautions.<sup>50</sup> Preventive strategies in another study included hand-hygiene education and enforcement of an antibiotic policy.<sup>83</sup> The third study integrated modified protocols to rely on alcohol-based hand hygiene and sleeveless aprons in place of long-sleeved gowns and gloves.<sup>91</sup> One study (Byers et al. 1998)<sup>71</sup> was a description of disinfection practices in the context of an outbreak.

The “study populations” were most commonly patient rooms or microbiologic samples. Numbers of rooms ranged from 4<sup>85</sup> to as many as 11,389 rooms.<sup>86</sup> Numbers of samples ranged from 142<sup>75</sup> to as many as 20,736 samples<sup>83</sup> The primary setting for most studies was the ICU or general medical or surgical wards. Other settings included cancer wards,<sup>61,91</sup> “intensive therapy unit”,<sup>88</sup> a transplant ward,<sup>91</sup> and a long-term care ward.<sup>80</sup>

Monitoring methods used in these studies were categorized as swab cultures (11 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.<sup>57,58,64,74,82,84,87,94,96,100,102-104</sup> VRE was the primary focus of four studies,<sup>61,71,81,91</sup> while MRSA was the focus of only two studies.<sup>1,50</sup> The remaining studies focused on at least two of the three pathogens of interest (*C. difficile*, MRSA, VRE). Most commonly reported HTOs were bed rails, side/tray tables, toilets, and floors. Table 4 summarizes the cleaning modalities by type of pathogen.

**Table 4. Summary of studies of cleaning agents by type of pathogen**

| Pathogen            | QAC | Chlorine-based | Peracetic acid or HP wipes | Ultraviolet light emitting | Hydrogen peroxide vapor | Coatings | Microfiber |
|---------------------|-----|----------------|----------------------------|----------------------------|-------------------------|----------|------------|
| <i>C. difficile</i> | 3   | 8              | 2                          | 7                          | 5                       | 3        | 2          |
| VRE                 | 5   | 2              | 1                          | 3                          | 2                       | 3        | 2          |
| MRSA                | 6   | 1              | --                         | 4                          | 3                       | 4        | 2          |

HP = hydrogen peroxide; MRSA = Methicillin-resistant *Staphylococcus aureus*; QAC = quaternary ammonium compounds; VRE = Vancomycin-resistant *enterococci*

## Study Outcomes

The primary outcome for 27 (61%) studies was surface contamination (e.g., bacterial burden, number of surfaces cleaned, positive cultures). Sixteen (36%) studies reported infection rate (e.g., incidence rate expressed per 1,000 patient days) as a primary or secondary 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 air contamination rates (e.g., RLUs),<sup>63</sup> compliance with room cleaning protocol,<sup>106</sup> contamination rates for health care worker gowns/gloves,<sup>90</sup> and number of bed areas from which target pathogens were isolated during a sampling day.<sup>83</sup>

Secondary outcomes of interest included *C. difficile* ribotypes,<sup>74</sup> cleaning time,<sup>1,106</sup> adverse effects,<sup>89</sup> hospital-acquired *C. difficile* infection–attributable deaths/colectomies,<sup>87</sup> ease of use of ATP,<sup>85</sup> and cost of labor, supplies, and keeping rooms empty.<sup>71</sup>

Studies examining chemical disinfectants reported mixed findings. Grabsch et al. 2012<sup>91</sup> found marked reductions in new VRE colonization after implementation of the Bleach-Clean

program (a multicomponent strategy). Four studies examining bleach<sup>59,96,100,101</sup> reported reduced *C. difficile* rates. One study examining the effectiveness of AHP versus stabilized hydrogen peroxide suggested that the AHP formulation was significantly better.<sup>84</sup>

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 CDI rates.<sup>57</sup> Sjoberg et al. 2014<sup>104</sup> reported a “moderate spread of *C. difficile* spores despite use of a potassium monopersulfate-based disinfectant (Virkon™).”<sup>104</sup> One randomized trial by Schmidt et al. 2012<sup>79</sup> 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.

Studies integrating wipes into their cleaning regimens reported positive findings. Friedman et al. 2013<sup>61</sup> 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 cleaning 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,<sup>90</sup> a significant reduction in *C. difficile* rates,<sup>58</sup> effectiveness as a surface disinfectant,<sup>89</sup> and sustained reductions in hospital-acquired *C. difficile* infection.<sup>94</sup> They supported the use of ready-to-use wipes over a traditional bucket method.<sup>106</sup>

Authors of the nine studies examining UV light devices<sup>64,75,82,88,93,95</sup> or PPX-UV devices<sup>1,86,87</sup> concluded that the devices effectively reduced bacterial bioburden,<sup>64,75,82,88,95</sup> significantly reduced hospital-acquired *C. difficile* infection rates,<sup>87</sup> significantly decreased overall hospital-acquired MDRO rates,<sup>86</sup> or was superior to manual cleaning.<sup>1</sup> One study stated that the integration of education, monitoring, feedback, a dedicated daily disinfection team, and implementation of a standardized process played a role in the improved thoroughness of cleaning.<sup>64</sup> One study comparing UV-C to hydrogen peroxide vapor<sup>93</sup> 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<sup>50,74,77,81,103</sup> or steam vapor,<sup>80</sup> investigators reported reductions in MRSA contamination from a multicomponent strategy,<sup>50</sup> significant reductions in *C. difficile*-associated diarrhea rates,<sup>103</sup> reduced environmental contamination and risk of acquiring MDROs compared with standard cleaning,<sup>77</sup> and >90% or highly effective reduction in bacterial levels.<sup>74,80,81</sup>

Of the seven studies examining enhanced coatings or surfaces, authors indicated significantly lower rates of incident HAI and/or colonization compared with patients in standard rooms;<sup>73</sup> that the integration of copper reduced<sup>72,98</sup> or significantly reduced<sup>92,97,99</sup> surface bacterial bioburden, and no sustained impact on antimicrobial activity for organosilane products tested.<sup>105</sup>

Anderson et al. 2009<sup>85</sup> compared various modes of mopping and indicated that wet, moist, and dry mopping were more effectively reduced bacterial burden on the floor than spray mopping. Lastly, Byers et al. 1998<sup>71</sup> 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)

## Systematic Reviews

The primary focus of two systematic reviews was monitoring tools. The sole focus of one systematic review (Amodio and Dino 2014)<sup>107</sup> was ATP bioluminescence. The other review (Mitchel et al. 2013)<sup>108</sup> took a broader approach and addressed visual inspection, fluorescent gel markers, ATP bioluminescence, and microbiological sampling.

Amodio and Dino 2014<sup>107</sup> 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 (4 studies), before and after cleaning (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 relative light units ranged from 100 to 500 RLUs. One study evaluated two thresholds (250 and 500 RLUs). Reported 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<sup>108</sup> reviewed 124 articles for inclusion in the review (the final number of studies included was not reported). Drawbacks were described for all monitoring methods. 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 only recommended 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, 7 (58%) studies were conducted in the United States. Other settings included the United Kingdom (3 studies) and Canada (1 study); 1 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 11 (85%) and 6 (46%) studies, respectively. Other monitoring methods evaluated were visual observation (5 [38%] studies), agar slide cultures (3 [23%] studies), and swab cultures (1 [(0.07%)] study). Alhamad and Maxwell evaluated agar slide cultures and the wipe-rinse method and assays. Fluorescent/UV markers were the focus of six studies,<sup>62,109,110,113,114,117</sup> while six other studies<sup>9,10,111,112,115,116</sup> evaluated several monitoring methods. Information on cleaning methods and implementation factors associated with these studies were mostly unreported. Table 5 summarizes the studies on monitoring modalities identified in the systematic reviews and our primary literature searches. Additional information on the studies is available in Appendix C.

**Table 5. Summary of modalities examined and study designs used in monitoring studies**

| Modality           | N, Studies | RCT       | Non-Randomized Concurrent Controls | Before-After | Interrupted Time Series | Descriptive | Study Design Not Reported |
|--------------------|------------|-----------|------------------------------------|--------------|-------------------------|-------------|---------------------------|
| ATP                | 17         | --        | 5                                  | 6            | 0                       | 4           | 2                         |
| UV                 | 15         | --        | 2                                  | 2            | 1                       | 3           | 7                         |
| ACC                | 4          | --        | 3                                  | 1            | --                      | --          | --                        |
| Visual inspection  | 12         | --        | 5                                  | --           | --                      | --          | 7                         |
| <b>All studies</b> | <b>39</b>  | <b>--</b> | <b>5</b>                           | <b>9</b>     | <b>1</b>                | <b>7</b>    | <b>13</b>                 |

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

## Study Characteristics

Five studies used nonrandomized concurrent controls, 5 used historical controls, and three studies did not have comparison arms. One study (Alhamad and Maxwell 2008)<sup>112</sup> 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. Most “study populations” were reported as rooms (7 studies) or microbiologic samples (6 studies). Numbers of rooms ranged from 10 to 1,119 rooms. Numbers of microbiologic samples ranged from 90 to 3,532. Other “populations” examined included surfaces (3 studies), hospitals (1 study reported, including 27 hospitals),<sup>117</sup> patients (1 study), and hospital wards (1 study). The study population in 1 study (Carling et al. 2008)<sup>113</sup> 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.<sup>10,109,110,112</sup> 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<sup>9,109,114,117</sup> or cleaning rate.<sup>10,62,110,113</sup> Two studies<sup>115,116</sup> reported air or surface microbial burden counts (RLUs or colony-forming units [CFUs]), while other studies reported sensitivity to detect pathogens<sup>111</sup> or number of positive cultures<sup>112</sup> as the primary outcome of interest.

Six studies mainly focused on fluorescent/UV markers<sup>62,109,110,113,114,117</sup> reported positive results. The technologies were reported as useful, inexpensive, simple, highly objective surface targeting methods<sup>62,114,117</sup> that helped to achieve significant improvements or opportunities<sup>113,117</sup> to improve cleaning and disinfection practices at their respective institutions. Blue et al. 2008<sup>109</sup> reported that the fluorescent chemical GlitterBug was “superior to previous visual inspection methods.”

Results from the six studies<sup>9,10,111,112,115,116</sup> evaluating various monitoring methods mostly described the inferiority of visual observation compared to other monitoring methods. Of the six studies, five were nonrandomized controlled.<sup>9,10,111,115,116</sup> Luick et al. 2013<sup>111</sup> reported that fluorescent marker and ATP assay “demonstrated better diagnosticity” compared with visual inspection. Smith et al. 2013<sup>115</sup> 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<sup>9</sup> reported poor correlation between ATP/fluorescent markers and a microbiologic comparator. One study<sup>10</sup> proposed an ATP benchmark value of 100 RLUs since it would offer the closest correlation with microbial growth

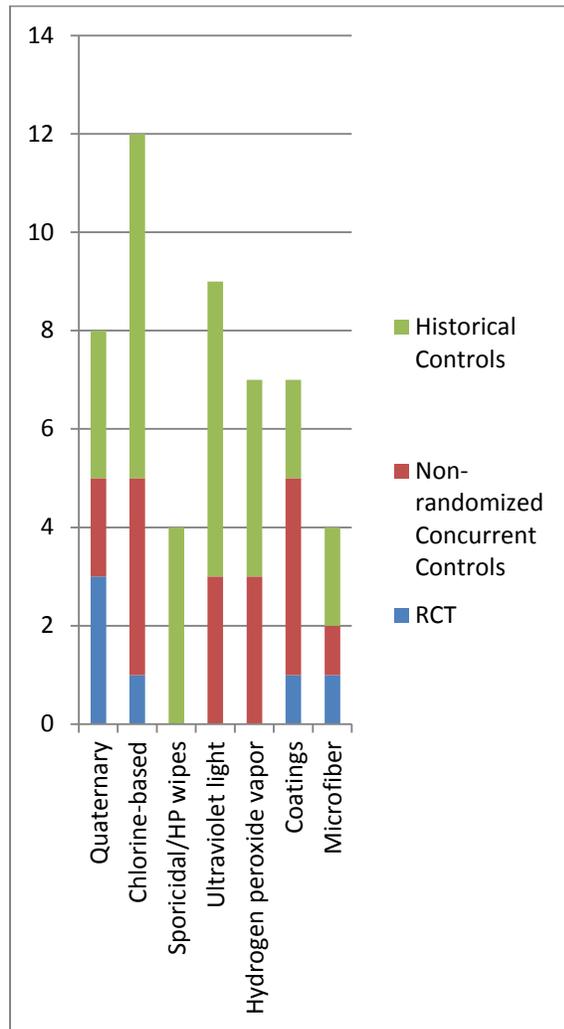
levels  $<2.5$  CFU/cm<sup>2</sup> while a 2003 study<sup>116</sup> recommended assessing effectiveness of hospital cleaning with internal audit and rapid hygiene testing. Lastly, results from a before/after study (Alhamad and Maxwell 2008)<sup>112</sup> indicated a “poor correlation between the findings 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)

### Summary of Published Evidence

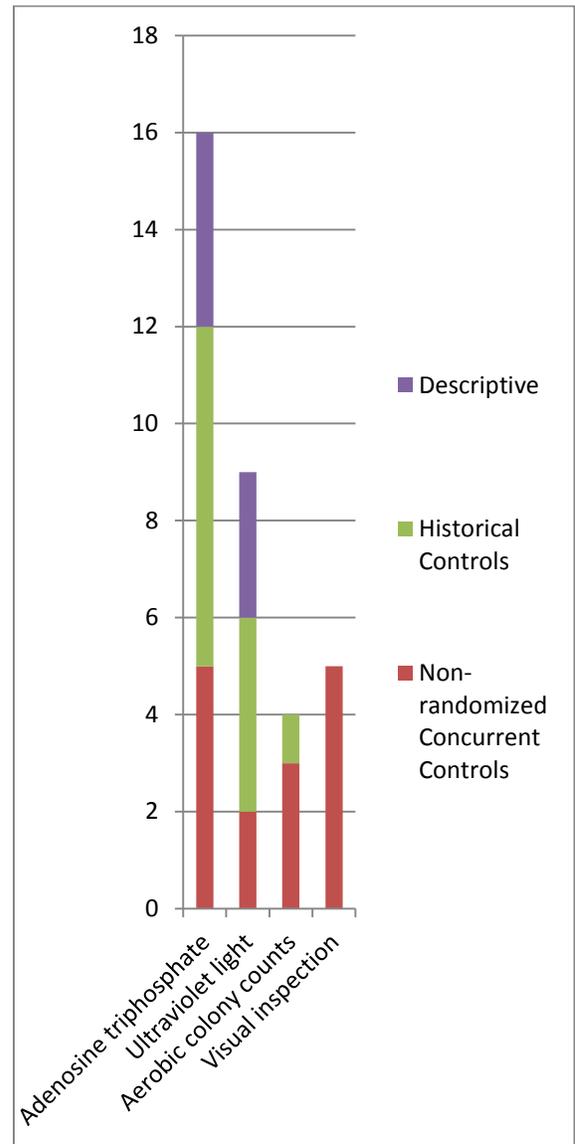
**Figure 3. Cleaning modalities**

2 systematic reviews, 44 primary studies

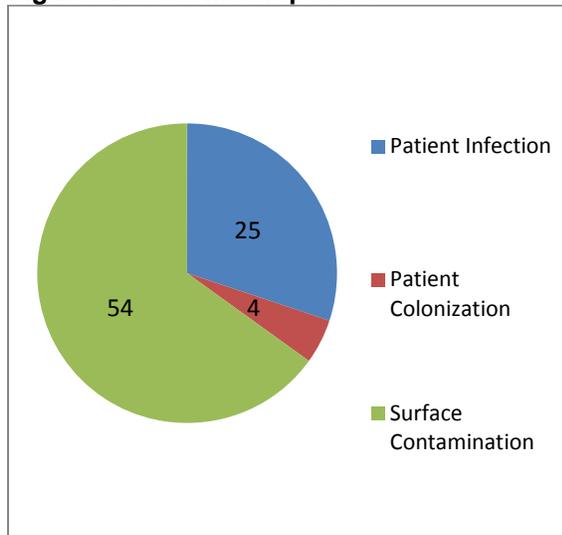


**Figure 4. Monitoring modalities**

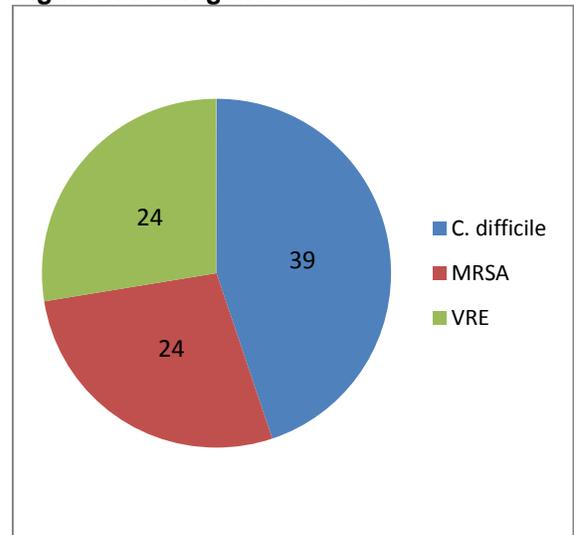
2 systematic reviews, 12 primary studies



**Figure 5. Outcomes reported**



**Figure 6. Pathogens studied**



## Evidence Gaps

### Emerging Technologies

- Peracetic acid or hydrogen peroxide wipes
- Coatings
- Microfiber
- PCR

### Patient-Centered Outcomes

- Patient infection rates
- Patient colonization

### Study Design

- Randomized controlled trials
- Head-to-head studies
- Methods of controlling for other interventions

### Definition of Core Concepts

- Thresholds of cleanliness
- High-touch/high-risk objects

## Summary and Implications

A wide variety of studies have been published examining strategies for environmental cleaning, including 44 studies of surface cleaning modalities, 12 studies of strategies for monitoring cleanliness, and 17 studies addressing implementation of best practices for cleaning. Many surface cleaning techniques were evaluated, including well-established products such as quaternary ammonium and bleach, recently emerging technologies such as UV-C light, hydrogen peroxide vapor, 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, and use of process standardization and feedback to staff, can serve as facilitators or barriers to improving cleaning practices. Important challenges were also highlighted, including regulatory requirements, use of outsourcing to provide cleaning services, and sustaining improvement over time.

### Cleaning Modalities

Surface cleaning 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 cleaning of hospital rooms, with hypochlorites often recommended for surface disinfection of rooms of patients infected with *C. difficile*. The use of wipes soaked in peracetic acid or hydrogen peroxide may be an alternative to QAC and bleach for manual surface cleaning, but studies supporting their effectiveness have only recently emerged.

Augmentation of manual surface cleaning 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 high purchase, staffing, and maintenance costs may deter many 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.

Evidence for all the currently used cleaning methods is limited by three important factors. First, most studies do not directly compare the effectiveness of different techniques. Most studies instead used historical controls, such as before/after or interrupted time series study designs, to assess the impact of a single cleaning 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 agents and technologies.

A second limitation of the evidence base, which KIs highlighted frequently, is the gap between appropriate use of surface cleaning agents in studies and practical implementation in real-world settings. Surface disinfectants work best when they are applied properly to all relevant surfaces for a sufficient contact time. Manufacturers typically provide recommendations for proper use of their products, but most studies do not report adherence to disinfectant contact time; it 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 modality. Conversely, if study results reflect the optimal use of a product, failure

to adhere to appropriate product application and contact time in practice may lead to suboptimal outcomes.

A third 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 handwashing/hygiene. These and other elements may sometimes be included as interventions within a larger multi-component infection prevention strategy, limiting the ability to discern the specific impact of the cleaning approach. These factors also play a critical role in the routine EC performed on a daily basis. 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 negate the value of any surface cleaning technique.

## **Monitoring Modalities**

Visual inspection was the traditional method employed by EVS personnel and supervisors to ensure that rooms were cleaned adequately. ATP and UV bioluminescence strategies have emerged in recent years to provide more precise evaluations of cleanliness. Sixteen studies were identified that examined ATP, and nine studies assessed UV detection of fluorescent markers. ACCs are also used to evaluate surface microbial contamination.

As with cleaning 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 a randomized controlled trial, 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 are not well established. Similarly, thresholds for ACCs are not clearly delineated. Without commonly agreed-upon measures of key outcomes, selection of optimal approaches is difficult.

## **Additional Considerations**

The challenge of identifying optimal outcome measures extends beyond the metrics associated with monitoring techniques. In general, patient-centered outcomes have not been emphasized in research on environmental cleaning. Surface contamination is the most common outcome reported in studies of both cleaning and monitoring strategies. Patient infection rates are less frequently measured, although they were reported in 20 studies. Patient colonization measures were rarely recorded, but a few KIs suggested that colonization is a useful surrogate outcome that should be measured and reported in studies of EC. Among the potential advantages of measuring colonization 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. Patients also have preferences in addition to clinical outcomes. KIs reported that patients often expect their room to “look clean 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.

One final limitation of the overall evidence base on EC is uncertainty regarding which surfaces should be focused on during disinfection. The scope of this Technical Brief was limited to high-touch objects. Focusing on surfaces that most frequently come into contact with both patients and health care workers makes sense, but consensus is weak on which specific objects are most important for preventing HAIs. Studies of cleaning 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. Moreover, some KIs expressed concern that almost no evidence exists to clarify whether any specific surfaces present greater risk of pathogen transmission to patients. One KI suggested that future research identify “high-risk” objects, rather than “high-touch” surfaces.

## **Next Steps (Guiding Question 4)**

Several important gaps in the current evidence base limit efforts to improve infection prevention programs and reduce HAI rates. Six key areas for future research emerged from the literature review and discussions with KIs.

## **Newly Emerging Technologies for Cleaning and Monitoring**

Relatively few studies have been published examining the effectiveness of no-touch cleaning modalities, enhanced surface coatings, peracetic acid or HP wipes, or microfiber mops and cloths. Similarly, more studies are needed that examine how cleanliness is monitored. Future research should concentrate on the comparative effectiveness of different cleaning and monitoring approaches. RCTs are not always feasible or necessary, but nonrandomized comparative studies can provide valuable data. Additional research on these strategies will help guide future infection control programs.

## **Implementation and Process Research**

Factors that affect real-world implementation are crucial but are rarely studied systematically or in depth. While studies have previously addressed organizational culture and staff feedback, there remains little understanding of these and other elements. Important considerations of implementation, including how programs are sustained and the frequency and impact of EVS outsourcing, have not been studied.

## **Thresholds for Cleanliness**

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 and monitoring tools will be difficult. Further research is necessary to correlate measures of cleanliness with clinical outcomes such as patient colonization or infection with health-care-associated pathogens.

## **Patient-Centered Outcomes**

Future studies should aim to measure and report outcomes that are clinically important to patients and health care providers. This includes infection rates when possible. Patient

colonization rates are a useful surrogate measure that can substitute for, or supplement, infection rates.

### **High-Touch/High-Risk Surfaces**

Future research should identify which objects and surfaces pose the greatest risk of transmission of pathogens and determine whether 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 cleaning personnel.

### **Controlling for Confounders and Multi-Component Interventions**

Innovative approaches for designing or analyzing studies are necessary to discern the specific impact of environmental cleaning strategies within the larger context of infection prevention programs and hand-hygiene compliance for preventing HAIs.

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