REVIEW

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Cleaning Hospital Room Surfaces to Prevent Health Care–Associated Infections

A Technical Brief

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The cleaning of hard surfaces in hospital rooms is critical for reducing health care–associated infections. This review describes the evidence examining current methods of cleaning, disinfecting, and monitoring cleanliness of patient rooms, as well as contextual factors that may affect implementation and effectiveness. Key informants were interviewed, and a systematic search for publications since 1990 was done with the use of several bibliographic and gray literature resources. Studies examining surface contamination, colonization, or infection with *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus*, or vancomycin-resistant enterococci were included.

Eighty studies were identified—76 primary studies and 4 systematic reviews. Forty-nine studies examined cleaning methods, 14 evaluated monitoring strategies, and 17 addressed challenges or facilitators to implementation. Only 5 studies were randomized, controlled trials, and surface contamination was the most commonly assessed outcome. Comparative effectiveness studies of disinfecting methods and monitoring strategies were uncommon. Future research should evaluate and compare newly emerging strategies, such as self-disinfecting coatings for disinfecting and adenosine triphosphate and ultraviolet/fluorescent surface markers for monitoring. Studies should also assess patient-centered outcomes, such as infection, when possible. Other challenges include identifying high-touch surfaces that confer the greatest risk for pathogen transmission; developing standard thresholds for defining cleanliness; and using methods to adjust for confounders, such as hand hygiene, when examining the effect of disinfecting methods.

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Health care–associated infections (HAIs) are a leading cause of illness and death in the United States and worldwide. In 2011, an estimated 721 800 HAIs occurred in the United States, leading to 75 000 deaths (1). A multifaceted approach to preventing infection is critical to reducing the risk for HAIs, including hand hygiene practices, antimicrobial stewardship, and environmental cleaning and disinfecting.

Several studies demonstrate that health care–associated pathogens frequently contaminate the patient environment, including both porous surfaces (such as curtains) and hard, nonporous surfaces (such as bed rails and medical equipment) (2–4). Contaminated surfaces are a reservoir for transmission of pathogens directly through patient contact with the environment or indirectly through contamination of health care workers' hands and gloves.

Environmental cleaning is important for reducing microbial contamination of surfaces and subsequent risk for HAIs. Environmental cleaning is a complex, multifaceted process and involves the physical action of cleaning surfaces to remove organic and inorganic material, followed by application of a disinfectant, as well as monitoring strategies to ensure the appropriateness of these practices. In addition, contextual factors, such as management tools and organizational structure, and culture can affect the implementation and effectiveness of cleaning, disinfecting, and monitoring strategies.

See also:

Editorial comment 642

The goal of this review is to provide a systematic overview on environmental cleaning of hospital room surfaces to prevent HAIs. We focus on environmental cleaning of the hard surfaces most frequently touched by patients and health care workers, which are often called high-touch surfaces or objects. We also discuss key health care–associated pathogens for which there is the most evidence for environmental transmission, specifically methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), and *Clostridium difficile* (5–8). Finally, we enumerate the evidence gaps in the literature and propose future research directions.

Methods

This review is based on a protocol and technical brief produced by the ECRI Institute–Penn Medicine Evidence-based Practice Center for the Agency for Healthcare Research and Quality (AHRQ) (9). The protocol and final report are available at www.effectivehealthcare.ahrq.gov. Twelve key informants with expertise in infectious diseases, infection control, environmental disinfection, hospital epidemiology, microbiology, and management of environmental services staff in health care settings contributed to the protocol and report, including helping to refine the literature search, review limitations in the current evidence, and discuss potential directions for future research.

Data Sources and Search Strategy

We searched several databases and gray literature sources from 1 January 1990 through 4 February 2015.

The complete set of databases searched and the search strategy is available in Appendix Tables 1 and 2 (available at www.annals.org).

Study Selection

Titles, abstracts, and full-text articles were screened in duplicate using the database Distiller SR (Evidence Partners). We included studies of any design that addressed our clinical questions; examined any inpatient wards (such as medicine, surgery, and critical care); addressed high-touch surfaces; evaluated environmental contamination, colonization, or infection with *C. difficile*, MRSA, or VRE or included several unspecified pathogens that were likely to include those infections; and were published in English. Studies were excluded if they took place exclusively in pediatric, ambulatory, operating room, or long-term care settings; addressed only soft, porous surfaces (such as linens or curtains) or transmission routes not inherent to the environmental reservoir (such as caregiver hands, stethoscopes, or invasive medical devices); examined products or processes not available in the United States or not currently being investigated; or were in vitro studies that did not collect samples from actual patient rooms.

Data Extraction and Synthesis

A standardized data extraction form was used by 1 reviewer to collect information on patient populations; pathogens; high-touch surfaces; type of cleaning, disinfecting, monitoring, and implementation strategy; study design; and study outcomes. A random sample of 25% of abstracted data was verified by another reviewer. Descriptions of cleaning/disinfecting and monitoring methods currently used in hospital settings are shown in Appendix Tables 3 and 4 (available at www.annals.org), respectively. We developed an evidence map to synthesize information on the type and depth of research available on cleaning, disinfecting, and monitoring processes. We also highlighted important knowledge gaps in the evidence base.

Role of the Funding Source

This project was funded by AHRQ. A representative from AHRQ served as a contracting officer's technical representative and provided technical assistance and feedback during the conduct of the evidence report. AHRQ did not directly participate in the literature search; determination of study eligibility criteria; data analysis or interpretation; or preparation, review, or approval of the manuscript for publication. This work was also supported in part by the National Institutes of Health, which had no role in the design and conduct of the study; collection, management, analysis, or interpretation of the data; or preparation, review, or approval of the manuscript.

RESULTS

The literature searches yielded 80 clinical studies for inclusion in the review, 76 of which were primary studies and 4 of which were systematic reviews. The Appendix Figure (available at www.annals.org) shows the study selection process.

Key Summary Points

Environmental cleaning is an important component of a multifaceted infection control strategy to prevent health care–associated infections.

Emerging technologies have led to increased interest in evaluating environmental cleaning, disinfecting, and monitoring in the acute care hospital setting.

A major limitation of the evidence base is the lack of comparative studies addressing the relative effectiveness of various cleaning, disinfecting, and monitoring strategies.

Few studies assess clinical, patient-centered outcomes, including patient colonization and health care–associated infection rates.

Future studies are needed that directly compare newer disinfecting and monitoring methods, assess the effect of contextual factors on implementation, and evaluate patient-centered outcomes.

Of the 80 clinical studies, 49 (61%) (2 systematic reviews) focused on cleaning or disinfecting, 14 (18%) (2 systematic reviews) focused on monitoring, and 17 (21%) focused on implementation of cleaning or monitoring strategies. No conference abstracts presented within the past 2 years were identified for inclusion. Appendix Tables 5 and 6 (available at www.annals.org) describe identified clinical practice guidelines and clinical trials (ClinicalTrials.gov), respectively.

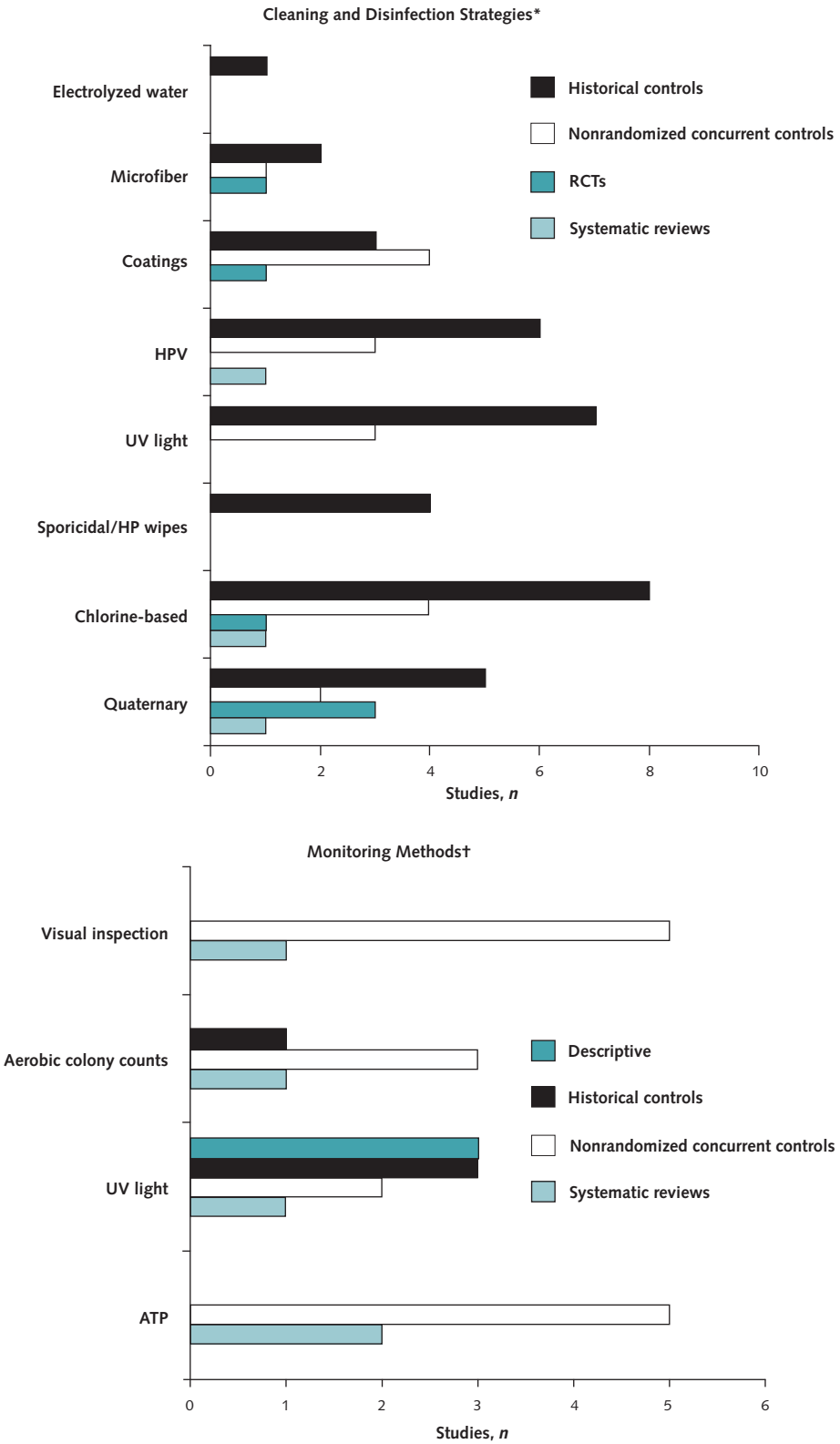
The primary setting for most studies was the intensive care unit. The most commonly examined high-touch objects included bed rails, call buttons, light switches, side or tray tables, and toilets, but the selection of high-touch objects across studies varied substantially.

Outcomes reported in the 76 primary studies were broadly categorized as surface contamination (such as bacterial burden, number of surfaces cleaned, and positive microbiological cultures), patient colonization (such as new VRE colonization), or infection rate (such as incidence rate expressed per 1000 patient days). Among the primary studies reporting pathogens of interest, the most commonly reported pathogen was *C. difficile* ($n = 40$), followed by MRSA ($n = 30$) and VRE ($n = 30$). Some studies evaluated several pathogens.

Evidence Map

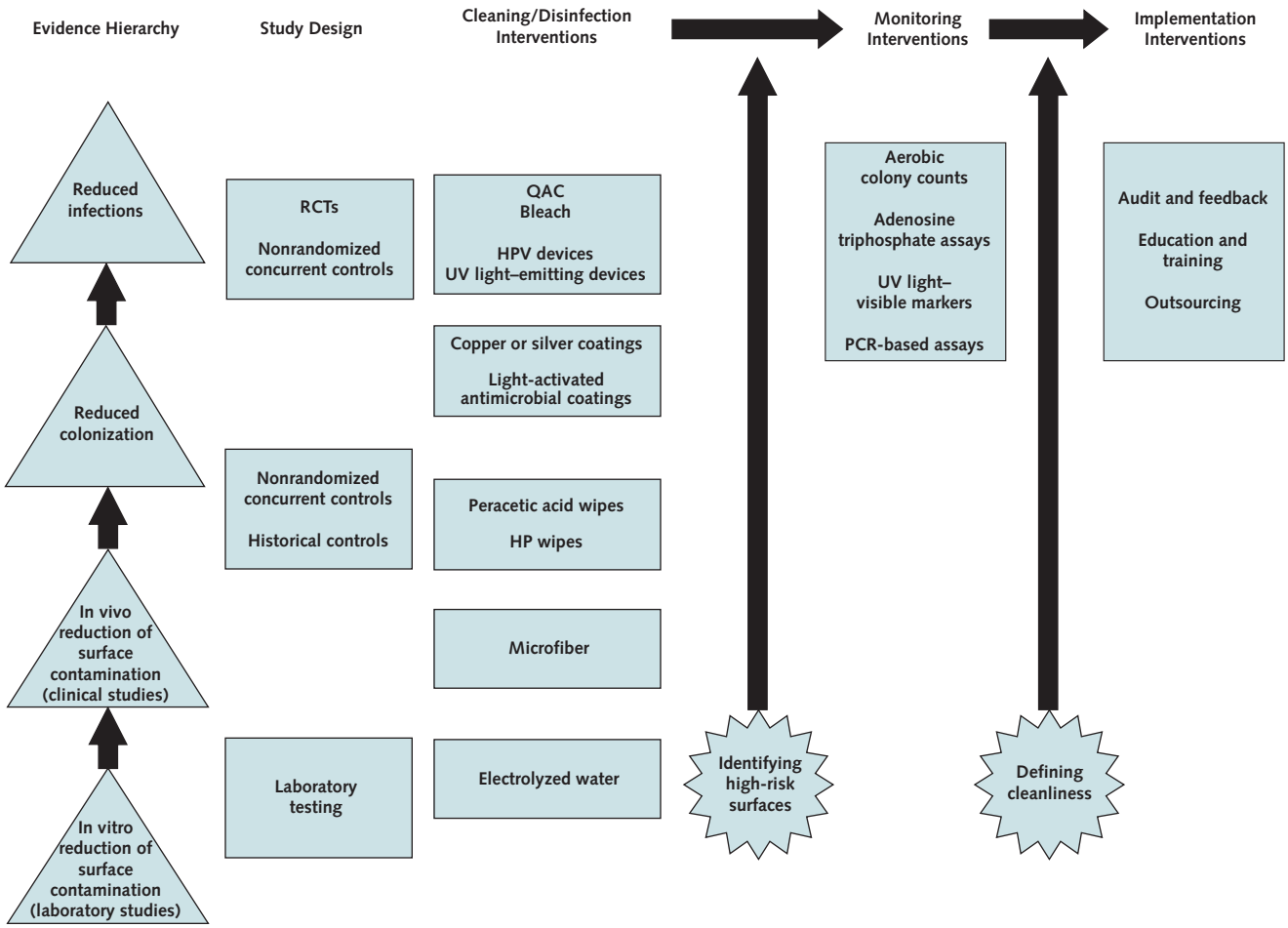
Figure 1 shows the number and research designs of published studies that address major categories of cleaning or disinfection strategies and monitoring methods, respectively. Figure 2 depicts evidence gaps that suggest high-impact areas for future research, as recommended by our key informants or indicated by our analysis of the current evidence base. The interventions are organized in a framework adapted from

Figure 1. Evidence map showing the number and study designs of published studies that address major categories of cleaning and disinfection strategies and monitoring methods.



ATP = adenosine triphosphate; HP = hydrogen peroxide; HPV = hydrogen peroxide vapor; RCT = randomized, controlled trial; UV = ultraviolet.
* 2 systematic reviews and 47 primary studies. Some studies evaluated >1 method.
† 2 systematic reviews and 12 primary studies. Some studies evaluated >1 method.

Figure 2. Evidence needs for future research in environmental cleaning.



Adapted from reference 10. HP = hydrogen peroxide; HPV = hydrogen peroxide vapor; PCR = polymerase chain reaction; QAC = quaternary ammonium compound; RCT = randomized, controlled trial; UV = ultraviolet.

McDonald and Arduino's recently proposed "evidence hierarchy" for environmental infection control (10). This framework represents the progression of evidence for the effectiveness of environmental interventions, from laboratory studies that measure surface contamination; to clinical studies that assess contamination in real-world settings; to studies that address patient-centered outcomes, such as pathogen colonization and infection.

Strategies for Environmental Cleaning

Forty-seven primary studies (11–57) and 2 systematic reviews (58, 59) focusing on cleaning and disinfecting were identified. Of the 47 primary studies, 27 (57%) were done in the United States and the remaining 19 were done in the United Kingdom, Australia, Sweden, Canada, Norway, and Italy. Studies were published between 1998 and September 2014; 28 (60%) were published since 2012, reflecting recently intensified interest in this topic.

Only 5 primary studies (11%) were randomized, controlled trials, and 1 (2%) was a randomized crossover study. Study durations ranged from 4 weeks to 43 months. Most studies (n = 31 [66%]) used a primary outcome of surface contamination. Only 16 studies (34%) reported pathogen colonization or infection rate as a primary outcome, and *C. difficile* was mostly commonly assessed.

Cleaning and disinfecting methods were generally categorized as surface cleaning or disinfecting, automated processes, or effectiveness of enhanced coatings or surfaces for disinfecting. Studies examining chemical disinfectants reported mixed findings, including reductions in VRE (51) and *C. difficile* rates (16, 20, 21, 54) with the use of bleach-based disinfectants; decreased *C. difficile* spore levels with the use of accelerated hydrogen peroxide (48); and ineffectiveness of a chlorine-based product in reducing *C. difficile* contamination and infection rates (14). Six studies integrating various wipes (such as hydrogen peroxide) into preventive strategies (15, 17, 25–28) reported positive outcomes, including sustained reductions in *C. difficile* infection rates (15, 27). Seventeen studies implementing no-touch methods (such as ultraviolet [UV] light and hydrogen peroxide vapor) reported positive findings (11,

13, 19, 29–31, 39, 40, 42, 44–46, 50, 52, 53, 56), and 3 of these studies specifically found reduced infection rates (29–31). Seven of 8 studies (88%) evaluating enhanced coatings, such as copper-coated surfaces, reported positive findings (12, 32–37). Appendix Tables 7 and 8 (available at www.annals.org) describe the characteristics of cleaning and disinfecting studies.

Strategies for Monitoring Cleanliness

Two systematic reviews (60, 61) and 12 primary studies (62–73) evaluated strategies for monitoring environmental cleaning and disinfecting. The locations for 11 of the 12 primary studies were reported and included the United States (*n* = 7 [64%]), United Kingdom (*n* = 3 [27%]), and Canada (*n* = 1 [9%]). Studies were published from 2003 to 2013; 3 (25%) were published since 2012.

The most common study design was nonrandomized using concurrent control groups (*n* = 5 [42%]). Study durations ranged from 4 weeks to 8 months; 4 studies did not report duration. Eight studies (67%) assessed percentage of targets cleaned (62, 65–67) or cleaning rate (63, 64, 68, 69) as the primary outcome. Less commonly reported outcomes included microbial burden counts (71, 73), sensitivity to detect pathogens (70), and number of positive cultures (72). Four studies focused on a single pathogen (63, 66, 68, 72).

Fluorescent/UV surface markers and adenosine triphosphate bioluminescence were the most commonly evaluated monitoring methods. Six of the 8 studies (75%) mainly focusing on fluorescent/UV surface markers (64–69) concluded that these monitoring methods were useful and highly objective and helped achieve substantial improvements in cleaning and disinfecting practices. Visual observation was found to be inferior to various other monitoring methods in 4 of 5 primary studies (80%) (62, 63, 70–73) and 1 review (100%) (61). Appendix Tables 7 and 9 (available at www.annals.org) describe the characteristics of monitoring studies.

Implementing Cleaning and Monitoring Strategies

Implementation Strategies

Seventeen primary studies focused specifically on implementing infection control interventions and contextual factors (74–90). These studies were published between 2006 and September 2014; 9 (53%) were published since 2012. Most studies (*n* = 14 [82%]) were done in the United States, with remaining studies done in Australia and Canada.

Thirteen studies (76%) used historical controls, including before-and-after study designs (*n* = 9), and interrupted time series (*n* = 4). Three studies (18%) were nonrandomized using concurrent control groups, and 1 (6%) was an uncontrolled, descriptive study. Study length ranged from 8 weeks to 4 years. Most studies reported a primary outcome of surface contamination. Only 2 studies (12%) reported pathogen acquisition as a primary outcome (83, 90). Clinical infection was reported as a primary and secondary outcome in 3 (80, 83, 90) and 2 (75, 76) studies, respectively. With regard to pathogen type, *C. difficile* and VRE were the primary focus of 3 (75, 80, 81) and 2 (85, 90) studies, respectively. The remaining studies focused on at least 2 pathogens of interest.

Three studies (18%) (75, 76, 80) used multicomponent strategies to prevent *C. difficile* infections and reported positive findings. Five studies (64, 76, 81, 84, 87) reporting on sustainability of preventive strategies described ongoing education, direct feedback, and commitment and flexibility of administrative leaders as key components to successful implementation.

Appendix Table 10 (available at www.annals.org) describes the characteristics of the implementation studies.

Contextual Factors

Contextual factors for implementation strategies examined in the 76 primary studies and identified by key informants included structural organizational characteristics, such as outsourcing of environmental services (80, 91) and organization of environmental services within the administrative hierarchy of a hospital. External factors that affect environmental cleaning efforts included adherence to "evidence-based policies and procedures" from various organizations (such as the Centers for Medicare & Medicaid Services and The Joint Commission). A positive patient safety culture that fosters collaboration and respect among clinical and support services staff, as well as between supervisors and front-line personnel, were examined in 5 studies (77, 80, 84, 87, 92). Implementation and management tools were identified as key contextual factors and include staff education and training, dedicated training time, use of internal audit and feedback, and presence of internal or external persons responsible for implementation. Of the 24 studies (32%) that integrated implementation tools, education was reported as a key component in most (*n* = 23 [96%]); 5 studies (21%) specifically reported on training staff (13–15, 77, 84) and 5 additional studies (21%), all published since 2012, described use of audits (14, 17, 81, 82, 84).

DISCUSSION

Contamination of high-touch environmental surfaces plays an important role in transmission of pathogens in the acute care hospital setting. Increasing attention has been directed toward the importance of environmental cleaning and disinfecting in the prevention of HAIs. We reviewed 4 systematic reviews and 76 primary studies of environmental cleaning. We found considerable diversity with regard to both study design and cleaning/disinfecting and monitoring methods examined across studies, as well as many limitations in the evidence base. There was a lack of direct, rigorous comparative studies of various methods, with only 5 studies designed as randomized, controlled trials. Our review of the literature also highlighted a limited focus on patient-centered outcomes, such as patient coloni-

zation or infection. Instead, surface contamination was the most commonly reported outcome.

The results of these studies, as well as synthesis of key informant input, suggest that evaluating the clinical effectiveness of cleaning and disinfecting methods is challenging. A major limitation is the gap between optimized use of surface cleaning or disinfecting agents in studies and practical implementation in real-world settings (such as appropriate dwell time and type of surface targeted). Manufacturers provide recommendations for proper use of their products, but most studies do not report thoroughness of cleaning or adherence to disinfectant dwell time; this information also remains largely unknown in daily practice. An important related concern is uncertainty by end users about the applicability of some manufacturer recommendations. Guidance that accompanies products may be based on laboratory testing under ideal conditions rather than clinical settings. Recommendations may also be developed based on certain types of pathogens, but users may choose to implement a product or technology for broader effects. Few studies directly compared the effectiveness of different methods; instead, many used before-and-after study designs to assess the effect of a single disinfecting method.

Another challenge to interpreting the results of the current evidence base is determining the specific effect of environmental cleaning and disinfecting interventions in the context of multicomponent infection prevention strategies (93). Infection prevention comprises many critical components in addition to hard surface cleaning, including sterilization of instruments, implementation of appropriate isolation precautions, and proper hand hygiene. These and other elements may sometimes be included as interventions within a larger infection prevention strategy, limiting the ability to discern the specific effect of any single approach. These factors also have the potential to modify the effectiveness of environmental cleaning interventions. Considerable uncertainty also remains about which surfaces, including high-touch objects, should be targeted for cleaning and disinfecting.

Limitations in the evidence base for monitoring methods were also identified, including the lack of direct, rigorous comparative studies of various technologies. Key informants noted that hospitals may be reluctant to adopt such methods as adenosine triphosphate and UV/fluorescent surface markers given the relative absence of data. Another important limitation in the literature is the lack of consensus for thresholds of cleanliness. Specifically, although various cleanliness thresholds with the use of adenosine triphosphate and certain microbiological methods were described across studies, there is no established benchmark for defining a surface as "clean." The real-world goal of environmental cleaning and disinfecting should be to reduce risk for pathogen transmission rather than establishing a continuously sterile surface. Benchmarks for surface cleanliness that correlate with decreases in pathogen acquisition should therefore be determined. As with studies evaluating cleaning and disinfecting methods, studies on monitoring methods demonstrated considerable variation in high-touch objects selected for evaluation, making it challenging to determine which surfaces are at greatest risk for microbial contamination and pathogen transmission.

Our review has important limitations. First, it provides only an inventory of available evidence and does not appraise the risk of bias of individual studies or provide overall ratings of the strength of evidence for each intervention and outcome examined. Second, the review was restricted to studies of *C. difficile*, MRSA, and VRE; thus, our findings may not be fully generalizable to interventions aimed at reducing infections due to other organisms (such as gram-negative pathogens). Future research should seek to review the evidence base for other pathogens. Further, many of the studies included in this review were undertaken during outbreaks and may not be representative of the effect of cleaning/disinfecting and monitoring in nonoutbreak settings.

Future research on environmental cleaning and disinfecting to reduce HAIs should address the following key questions: What surfaces, including high-touch objects, should be cleaned and disinfected? How should surfaces be cleaned and disinfected, and what is the comparative effectiveness of different methods? How should cleaning and disinfecting be monitored and measured, and what would be appropriate benchmarks for cleanliness and reduced risk for pathogen transmission? How should interventions be implemented, including in-depth study of facilitators and barriers to real-world implementation?

In summary, our review of the literature indicates an increased interest in environmental cleaning and disinfecting for the prevention of HAIs. However, there are many limitations in the current evidence base. Future research on environmental cleaning that addresses these limitations and evidence gaps will be critical for informing real-world interventions for reducing the risk for HAIs in the hospital setting.

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Appendix Table 1. Electronic Database Searches

Database	Date Limits	Platform or Provider
ClinicalTrials.gov	Through February 3, 2015	U.S. National Institutes of Health
CENTRAL	1990 through 2015, Issue 2	Wiley
The Cochrane Database of Methodology Reviews (Methodology Reviews)	1990 through 2015, Issue 2	Wiley
The Cochrane Database of Systematic Reviews (Cochrane Reviews)	1990 through 2015, Issue 2	Wiley
CINAHL	1990 through 2015, Issue 2	EBSCO*host*
DARE	1990 through 2015, Issue 2	Wiley
EMBASE	1990 through February 2, 2015	Elsevier
HTA Database	1990 through 2015, Issue 2	Wiley
Healthcare Standards Directory (ECRI Institute)	Through February 3, 2015	ECRI Institute
MEDLINE (via EMBASE)	1990 through February 2, 2015	Elsevier
PubMed (In-process, Publisher, and PubMedNotMedline records)	1990 through February 2, 2015	U.S. National Library of Medicine
Scopus*	Through February 4, 2015	Elsevier
U.K. NHS EED	1990 through 2015, Issue 2	Wiley
U.S. NGC	Through February 3, 2015	AHRQ

AHRQ = Agency for Healthcare Research and Quality; CENTRAL = Cochrane Central Register of Controlled Trials; DARE = Database of Abstracts of Reviews of Effects; EED = Economic Evaluation Database; HTA = Health Technology Assessment; NGC = National Guideline Clearinghouse; NHS = National Health Service.
* Used for citation tracking and searching trade publications.

Appendix Table 2. Search Strategies*

Concept	Set Number	Search Statement
Infections (broad terms, health care–associated)	1	("healthcare associated infection" OR "hospital infection")/de
	2	(("health care acquired" next/1 (infection* OR pathogen*)) OR ("healthcare acquired" next/1 (infection* OR pathogen*)) OR ("hospital acquired" next/1 (infection* OR pathogen*)) OR ("health care associated" next/1 (infection* OR pathogen*)) OR ("healthcare associated" next/1 (infection* OR pathogen*)) OR ("hospital associated" next/1 (infection* OR pathogen*))):ti,ab
	3	(HAI OR HAIs):ti
Infections (specific terms—bacterial)	4	("clostridium difficile" OR "clostridium difficile infection" OR "methicillin resistant staphylococcus aureus" OR "methicillin resistant staphylococcus aureus infection" OR enterococcus OR "vancomycin resistant enterococcus" OR "enterococcal infection")/de
	5	((antibiotic OR "multi-drug" OR multidrug OR methicillin OR vancomycin) next/1 resistan*):ti,ab OR difficile:ti,ab OR ("methicillin resistant" next/2 aureus):ti,ab OR ("vancomycin resistant" next/1 enterococc*):ti,ab
	6	(CDI OR MRSA OR VRE):ti
Limit to patients	7	(#4 OR #5 OR #6) AND (patient/exp OR (inpatient* OR patient*):ti,ab)
Combine infection sets	8	#1 OR #2 OR #3 OR #7
Setting (hospitals, inpatient facilities, patient rooms)	9	("health care facility" OR "hospital discharge")/de OR hospital/exp
	10	("acute care" OR "burn unit" OR "burn units" OR "common area" OR "common areas" OR "critical care" OR "healthcare facility" OR "healthcare facilities" OR "health care facility" OR "health care facilities" OR "healthcare setting" OR "healthcare settings" OR "health care setting" OR "health care settings" OR hospital OR hospitalis* OR hospitaliz* OR ICU OR institution OR institutions OR "intensive care" OR "patient care area" OR "medical facility" OR "medical facilities" OR "patient care areas" OR "patient room" OR "patient rooms" OR "patients rooms" OR ward OR wards):ti,ab
Setting (high-touch surfaces)	11	(fomite OR "hospital bed" OR "hospital equipment")/de
	12	(fomes OR fomite* OR "environmental reservoir" OR "environmental reservoirs" OR "surface contamination" OR "surface microbes"):ti,ab
	13	(bathroom* OR "bed rail" OR "bed rails" OR bedrail* OR cart OR carts OR chair OR chairs OR "clinical surfaces" OR commode* OR "environmental surfaces" OR "high contact" OR "high-touch" OR "hospital bed" OR "hospital beds" OR "hospital surfaces" OR "mobile equipment" OR "portable medical equipment" OR railing OR railings OR toilet* OR "shared medical equipment" OR wheelchair*):ti,ab
Combine setting sets	14	#9 OR #10 OR #11 OR #12 OR #13
Combine sets (any infection or setting)	15	#8 OR #14
General cleaning	16	(cleaning OR disinfection OR "environmental sanitation")/de OR "infection control"/mj
	17	("cleaning method" OR "cleaning methods" OR "cleaning practice" OR "cleaning practices" OR "cleaning protocol" OR "cleaning protocols" OR "cleaning regimen" OR "cleaning regimens" OR "cleaning routines" OR "cleaning technique" OR "cleaning techniques" OR "discharge cleaning" OR "discharge room cleaning" OR "enhanced cleaning" OR "environmental cleaning" OR "environmental decontamination" OR "environmental disinfection" OR "environmental sanitation" OR "hospital cleaning" OR "pre cleaning" OR precleaning OR "room cleaning" OR "room decontamination" OR "routine cleaning" OR "surface cleaning" OR "surface disinfection" OR "surface decontamination" OR "terminal cleaning" OR "terminal disinfection" OR "terminal room"):ti,ab
	18	(cleaning OR decontamination OR disinfect* OR "infection control"):ti
Disinfectants	19	"disinfectant agent"/exp OR ("bleaching agent" OR "quaternary ammonium derivative"/de)
	20	(biocidal OR biocide* OR "chemical agent" OR "chemical agents" OR "chemical disinfection" OR "cleaning agent" OR "cleaning agents" OR disinfectant* OR "disinfecting agent" OR "disinfecting agents" OR "disinfection agent" OR "disinfection agents" OR germicidal OR germicide* OR sporicidal OR sporicide*):ti,ab
	21	("accelerated hydrogen peroxide" OR aldehyde* OR alcohol OR alcohols OR bleach OR bleaching OR "benzalkonium chloride" OR "calcium hypochlorite" OR "chlorhexidine digluconate" OR glutaraldehyde OR "guanidine hydrochloride" OR hypochlorite* OR "ortho-phthalaldehyde" OR orthophthalaldehyde OR "peracetic acid" OR phenolic* OR phenol OR phenols OR "quaternary ammonium" OR QACs OR "sodium dichloroisocyanurate" OR "sodium hypochlorite" OR vinegar):ti,ab
Limit to disinfectant studies to cleaning	22	(#19 OR #20 OR #21) AND (clean* OR decontaminat* OR disinfect* OR housekeep*):ti,ab
Automated devices	23	("disinfection system" OR "ultraviolet irradiation" OR "ultraviolet radiation")/de OR ("hydrogen peroxide" AND (vapor OR "water vapor"))/de
	24	(automated next/2 (cleaning OR device* OR decontamination OR disinfection)):ti,ab OR (("no touch" OR "non touch") next/1 disinfect*):ti,ab OR ("room sterilisation" OR "room sterilization" OR "self disinfecting"):ti,ab
	25	((405nm OR "405 nm" OR "pulsed ultrasound" OR "pulsed xenon" OR ((ultraviolet OR UV) next/1 (disinfection OR light OR irradiation OR radiation))):ti,ab) AND (clean* OR decontaminat* OR disinfect* OR room OR rooms):ti,ab
	26	"superoxidised water":ti,ab OR "superoxidized water":ti,ab OR (("hydrogen peroxide" OR H2O2) AND (aerosol* OR fogging OR mist OR steam OR system OR systems OR vapor* OR vapour*)):ti,ab
Enhanced coatings and surfaces	27	(copper AND "material coating")/de
	28	"self disinfecting":ti,ab OR ((antimicrobial OR copper OR silver) NEAR/2 (coated OR coating* OR impregnated OR surface*)):ti,ab

Continued on following page

Appendix Table 2–Continued

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

* Strategy in EMBASE syntax; the search was simultaneously done across EMBASE and MEDLINE. A similar strategy was used to search the databases comprising CINAHL, the Cochrane Library, and PubMed.

Appendix Table 3. Cleaning and Disinfecting Methods Used in Acute Care Settings

Product Description	Application and Considerations for Use
Chemical disinfectants or touch modalities	
Quaternary ammonium compounds: Frequently used for routine cleaning and disinfection of noncritical environmental surfaces (e.g., floors, bed rails, tray tables). They are bactericidal, virucidal against enveloped viruses, and fungicidal but not sporicidal and generally not mycobactericidal or virucidal against nonenveloped viruses. High water hardness and materials such as cotton towels can diminish microbicidal activity (94–96). Case reports of occupational asthma have been documented due to use of benzalkonium chloride (97, 98).	Application Spray; moistened paper towel, textile, or microfiber cloth; premoistened wipe; paper towel or cloth soaked in disinfectant-filled bucket Considerations for use Microorganisms being targeted Type of surface Characteristics of a specific disinfectant (e.g., compatibility on various surfaces) Cost Ease of use Safety of environmental services personnel Use in spraying or fogging technologies not recommended
Hypochlorites: Most commonly used of the chlorine disinfectants, often for disinfecting bathroom and food preparation surfaces and blood spills. They are bactericidal, fungicidal, virucidal, mycobactericidal, and sporicidal and are generally included in recommendations for disinfecting surfaces or objects contaminated with hepatitis viruses, HIV, and *Clostridium difficile*. They may cause skin and eye irritation, as well as oropharyngeal, esophageal, and gastric burns (99–101). They are also corrosive to metals in high concentrations (>500 ppm) and can discolor fabrics. Given that their activity is reduced by organic matter (e.g., blood, feces), surfaces must be precleaned before disinfection (102, 103).	
Accelerated hydrogen peroxide: Recently introduced surface disinfectants with generally short required dwell times; they are bactericidal, virucidal, fungicidal, sporicidal, and mycobactericidal. Lower-level concentrations are used for disinfecting hard surfaces, while higher-level concentrations (2%) are used for high-level disinfection of medical instruments. They are considered safe for EVS staff (i.e., lowest EPA toxicity category IV), benign for the environment, surface-compatible, noncorrosive, and unaffected by organic material (104). However, they are more expensive than other disinfectants, such as quaternary ammonium.	
Phenolics: These are bactericidal, mycobactericidal, fungicidal, and virucidal but not sporicidal and are used for surface disinfection (e.g., bedrails, tables) and for disinfecting noncritical medical devices. These are less commonly used because of several disadvantages, including absorption by porous materials, ability for residual product to irritate tissue, and depigmentation of skin.	
Peracetic acid: Disinfectants that are bactericidal, fungicidal, virucidal, mycobactericidal, and sporicidal and generally remain active in the presence of organic material. Most commonly used in automated machines designed to sterilize medical instruments (e.g., endoscopes, dental instruments) and in a formulation with hydrogen peroxide to disinfect hemodialyzers, although they have potential to corrode metals, such as copper and brass.	
Automated or no-touch modalities	
UV-C devices: Uses UV-C wavelength light, which is germicidal and involves breaking of molecular bonds in DNA, resulting in microorganism death. UV-C has microbicidal activity against a wide range of health care–associated pathogens, including *C. difficile*. More rapid room decontamination compared with hydrogen peroxide–producing systems but requires the user to move equipment/furniture away from walls to prevent shadowing.	Application Automated dispersal system Considerations for use Requires the room to be vacated before decontamination Adjunctive disinfection measure and limited to terminal disinfection (versus daily routine disinfection) Significant cost Significant time to effectively disinfect a room
Hydrogen peroxide systems: Several systems that produce hydrogen peroxide using differing methods are available (e.g., dry mist, vapor). These systems demonstrate reliable microbicidal activity against various health care–associated pathogens, including *C. difficile*. Can uniformly distribute hydrogen peroxide without requiring user to move equipment/furniture.	
Self-disinfecting surfaces	
Heavy metals, such as copper and silver: Copper generally toxic to most microorganisms due to generation of reactive oxygen species, resulting in damage of nucleic acids, proteins, and lipids, and ultimately cell death. Has been examined as a mechanism to kill clinically important pathogens, including MRSA, *Escherichia coli*, *Enterococcus* spp., and *Mycobacterium tuberculosis*. Silver has greatest antimicrobial activity of heavy metals, but mechanism of action not completely elucidated and clinical impact has not been evaluated.	Application Coating of high-touch surfaces, such as bed rails, trays, and intravenous poles Considerations for use Used as an adjunct to routine room disinfection Not currently considered standard of care
Altered topography: Materials with altered surface topography to inhibit bacterial biofilm formation are currently under investigation. No data exist on use in the real-world hospital environment, and disadvantages include potential difficulty in retrofitting surfaces with these materials, as well as lack of microbicidal properties.	
Light-activated antimicrobial surface coatings: Irradiation of certain compounds (e.g., titanium dioxide, photosensitizers) with visible or UV light results in the production of reactive radicals that nonselectively target microorganisms, although it is unclear whether these surfaces are sporicidal. Although these surfaces may provide a less toxic approach than the use of chemical disinfectants, a constant source of photoactivation is required.	

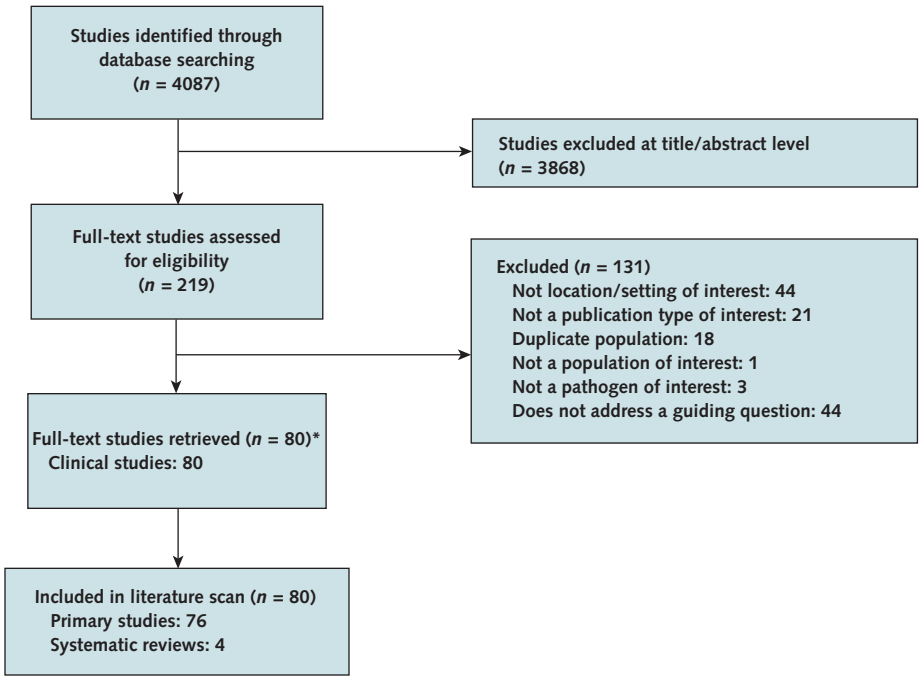
EPA = U.S. Environmental Protection Agency; EVS = environmental services; MRSA = methicillin-resistant *Staphylococcus aureus*; UV = ultraviolet; UV-C = ultraviolet C.

Appendix Table 4. Monitoring Methods Used in Acute Care Settings

Product Description	Considerations for Use
Visual inspection Covert visual monitoring of EVS staff during actual cleaning or visual inspection postcleaning is used to provide an objective assessment of an individual staff member's adherence to routine cleaning protocols, often in conjunction with direct feedback and educational interventions.	Advantages Straightforward Easy to implement Often performed by EVS managers May be related to patients' perceptions of cleanliness and satisfaction Disadvantages Direct visual inspection can assess only visible cleanliness (e.g., removal of organic debris, dust, moisture) from surfaces and not microbial contamination Interobserver variability Biases secondary to the Hawthorne effect (when the presence of observation affects observed behavior)
Aerobic colony counts A microbiologic method used to quantify microbial contamination of environmental surfaces. Swab cultures are typically used to sample irregular surfaces and inoculated onto agar, often with broth enrichment. Sampling of flat environmental surfaces can also be performed using Rodac contact plates, which are small petri plates filled with agar. 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.	Advantages Aerobic culture (with or without enumerating colony counts) is the only method that can provide information about the viability of pathogens of interest (e.g., MRSA, VRE) Disadvantages Lack of accepted criteria for defining a surface as "clean" Cost of processing (e.g., identifying isolates in the microbiology laboratory) Delay in results Small sample area per swab or slide Need to determine precleaning levels of microbial decontamination for each object/surface evaluated
UV light–visible surface markers Used to determine adequate removal of fluorescent markers (powder or gel formulations) on high-touch surfaces.	Advantages of fluorescent marker gel formulation Dries to a transparent finish on surfaces; is abrasion-resistant; and, unlike powder, is not easily disturbed Most well-studied method to assess surface cleaning and to quantify the impact of educational interventions Disadvantages of fluorescent markers 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 Cannot be used to detect the presence of a specific organism; therefore, its utility during a pathogen-specific outbreak may be limited
ATP bioluminescence assays Detect the presence of organic debris on surfaces. Cutoffs used to classify surfaces as "clean" by ATP bioluminescence assays depend on the assay system used.	Advantages Easy to use Can provide direct, rapid feedback to staff Disadvantages 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 Cutoff level to be used as a surrogate measure of an increased risk for health care–associated infections has not yet been defined
PCR PCR-based assays for assessing environmental contamination are currently investigational. These assays are done in the microbiology laboratory after sampling of surfaces, usually via swabs.	Advantages Rapid turnaround time for specific organisms Disadvantages Do not differentiate between viable versus nonviable organisms Cost

ATP = adenosine triphosphate; EVS = environmental services; MRSA = methicillin-resistant *Staphylococcus aureus*; PCR = polymerase chain reaction; UV = ultraviolet; VRE = vancomycin-resistant enterococcus.

Appendix Figure. Summary of evidence search and selection.



* Gray literature included 6 clinical practice guidelines and 2 background articles. These were used for background information and were not included in the systematic overview.

Appendix Table 5. Clinical Practice Guidelines

Organization	Reference	Country	Methods (Evidence-Based or Consensus-/ Narrative-Based)
American College of Gastroenterology	Surawicz CM et al. Guidelines for diagnosis, treatment, and prevention of *Clostridium difficile* infections. Am J Gastroenterol. 2013 Apr;108(4):478-98.	United States	Evidence-based
AHE, formerly known as ASHES (part of the American Hospital Association)	Association for the Healthcare Environment. Practice guidance for healthcare environmental cleaning, 2nd edition. Chicago (IL): American Hospital Association; 2010.	United States	Evidence-based
AHRQ	Collins AS. Chapter 41. Preventing health care–associated infections. In: Hughes RG, editor. Patient safety and quality: An evidence-based handbook for nurses. Rockville (MD): Agency for Healthcare Research and Quality; 2008. p. 547-75. Also available: www.ncbi.nlm.nih.gov/books/NBK2683/pdf/ch41.pdf.	United States	Evidence-based
APIC	Association for Professionals in Infection Control and Epidemiology. APIC position on mandatory public reporting of HAIs. Washington (DC): Association for Professionals in Infection Control and Epidemiology; 2005 Mar 14. 3 p. Also available: www.apic.org/Resource_/TinyMceFileManager/Position_Statements/MandRpt_posnPaoper_2005.pdf.	United States	Consensus/narrative
	Greene LR et al. APIC Position Paper: The importance of surveillance technologies in the prevention of healthcare-associated infections (HAIs). Washington (DC): 2009 May 29. 7 p.	United States	Evidence-based
	Cardo D et al. Moving toward elimination of healthcare-associated infections: a call to action. [White paper]. Am J Infect Control. 2010 Nov;38(9):671-5. "A joint white paper between APIC, SHEA, Infectious Diseases Society of America, Association of State and Territorial Health Officials, Council of State and Territorial Epidemiologists, Pediatric Infectious Diseases Society, and the Centers for Disease Control and Prevention."	United States	Consensus/narrative
	Friedman C et al. APIC/CHICA-Canada infection prevention, control, and epidemiology: Professionals and practice standards. Washington (DC): Association for Professionals in Infection Control and Epidemiology; 2008. 5 p.	Canada	Consensus/narrative
	Association for Professionals in Infection Control and Epidemiology, Inc. Guide to preventing *Clostridium difficile* infections. Washington (DC): Association for Professionals in Infection Control and Epidemiology, Inc.; 2013 Feb. 100 p. Also available: www.apic.org/Resource_/EliminationGuideForm/59397fc6-3f90-43d1-9325-e8be75d86888/File/2013CDiffFinal.pdf.	United States	Consensus/narrative
	Association for Professionals in Infection Control and Epidemiology. Guide to the elimination of methicillin-resistant *Staphylococcus aureus* (MRSA) transmission in hospital settings, 2nd edition. Washington (DC): Association for Professionals in Infection Control and Epidemiology; 2010. 65 p. Also available: www.apic.org/Resource_/EliminationGuideForm/631fcd91-8773-4067-9f85-ab2a5b157eab/File/MRSA-elimination-guide-2010.pdf.	United States	Evidence-based
	Association for Professionals in Infection Control and Epidemiology. Guide to the elimination of methicillin-resistant *Staphylococcus aureus* (MRSA) transmission in hospital settings. California supplement 2009. Washington (DC): Association for Professionals in Infection Control and Epidemiology, Inc.; 2009 Apr 3. 12 p. Also available: www.apic.org/Resource_/EliminationGuideForm/16c7a44f-55fe-4c7b-819a-b9c5907eca72/File/APIC-MRSA-California.pdf.	United States	Consensus/narrative
	Association for Professionals in Infection Control and Epidemiology. Guide to the elimination of methicillin-resistant *Staphylococcus aureus* (MRSA) in the long-term care facility. Washington (DC): Association for Professionals in Infection Control and Epidemiology; 2009. 74 p. Also available: www.apic.org/Resource_/EliminationGuideForm/08b12595-9f92-4a64-ad41-4afdd0088224/File/APIC-MRSA-in-Long-Term-Care.pdf.	United States	Evidence-based
AORN	Association of Perioperative Registered Nurses. Recommended practices for environmental cleaning. In: 2014 perioperative standards and recommended practices. Denver (CO): Association of perioperative Registered Nurses; 2013 Sep. p. 255-76. NGC summary.	United States	Evidence-based
	Allen G. Implementing AORN recommended practices for environmental cleaning. AORN J. 2014 May;99(5):570-82. See: http://dx.doi.org/10.1016/j.aorn.2014.01.023.	United States	Evidence-based
ASID	Stuart RL et al. ASID/AICA position statement: Infection control guidelines for patients with *Clostridium difficile* infection in healthcare settings. Healthc Infect. Mar 2011;16(1):33-9. Also available: http://dx.doi.org/10.1071/HI11011.	Australia	Consensus/narrative
	Cheng AC et al. Australasian Society for Infectious Diseases guidelines for the diagnosis and treatment of *Clostridium difficile* infection. Med J Aust. 2011 Apr 4;194(7):353-8.	Australia	Evidence-based
CIBMTR	Tomblyn M et al. Guidelines for preventing infectious complications among hematopoietic cell transplantation recipients: a global perspective. Biol Blood Marrow Transplant. 2009 Oct;15(10):1143-238.	Multinational	Evidence-based

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Appendix Table 5–Continued

Organization	Reference	Country	Methods (Evidence-Based or Consensus-/ Narrative-Based)
CDC, including HICPAC	Rutala WA, Weber DJ, Healthcare Infection Control Practices Advisory Committee. Guideline for disinfection and sterilization in healthcare facilities, 2008. Atlanta (GA): Centers for Disease Control and Prevention; 2008. 158 p. Also available: www.cdc.gov/hicpac/Disinfection_Sterilization/17_00Recommendations.html. See also: Recommendations for disinfection and sterilization in health-care facilities.	United States	Evidence-based
	Centers for Disease Control and Prevention. Antibiotic resistance threats in the United States, 2013. Atlanta (GA): Centers for Disease Control and Prevention; 2013. 114 p. Also available: www.cdc.gov/drugresistance/threat-report-2013/pdf/ar-threats-2013-508.pdf.	United States	Evidence-based
	Guh A. Carling P, Environmental Evaluation Workgroup. Division of Healthcare Quality Promotion; National Center for Emerging, Zoonotic and Infectious Diseases. Options for evaluating environmental cleaning. [Toolkit]. 2010. Atlanta (GA): Centers for Disease Control and Prevention; 2010 Dec.15 p. Also available: www.cdc.gov/HAI/pdfs/toolkits/Environ-Cleaning-Eval-Toolkit12-2-2010.pdf. Note: Additional resources.	United States	Consensus/narrative
	McKibben L et al. Guidance on public reporting of healthcare-associated infections: Recommendations of the Healthcare Infection Control Practices Advisory Committee. Am J Infect Control. 2005 May;33(4):217-26.	United States	Consensus/narrative
	Recommendations for Preventing the Spread of Vancomycin Resistance Recommendations of the Hospital Infection Control Practices Advisory Committee (HICPAC). MMWR Recomm Rep. 1995 Sep 22;44(RR-12):1-13.	United States	Consensus/narrative
	Sehulster L et al. Guidelines for environmental infection control in healthcare facilities. Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC) [Published errata appear in MMWR Recomm Rep 2003 Oct 24;52(42):1025-6]. MMWR Recomm Rep. 2003 Jun 6;52(RR-10):1-42.	United States	Evidence-based
	Siegel J et al. Guideline for isolation precautions: preventing transmission of infectious agents in healthcare settings. Atlanta (GA): Centers for Disease Control and Prevention; 2007 Jun. 219 p.	United States	Evidence-based
	Siegel JD et al. Management of multidrug-resistant organisms in healthcare settings. 2006. 74 p.	United States	Evidence-based
	Umscheid C et al. Updating the Guideline Methodology of the Healthcare Infection Control Practices Advisory Committee (HICPAC). Atlanta (GA): Centers for Disease Control and Prevention; 31 p. Also available: www.cdc.gov/hicpac/pdf/guidelines/2009-10-29HICPAC_GuidelineMethodsFINAL.pdf. Publication date not available.	United States	Evidence-based
ECDC	Vonberg RP et al. Infection control measures to limit the spread of *Clostridium difficile*. Clin Microbiol Infect. 2008 May;14:2-20. Also available: http://dx.doi.org/10.1111/j.1469-0691.2008.01992.x.	Europe	Evidence-based
ESCMID	European Society of Clinical Microbiology and Infectious Diseases. ESCMID consensus statements. Basel (Switzerland): European Society of Clinical Microbiology and Infectious Diseases; MRSA expert consensus documents, 2013 Feb 14. www.escmid.org/escmid_library/medical_guidelines/escmid_consensus_statements/. Accessed 2014 Oct 7. Note: See Humphreys H et al. Workshop 2 for cleaning.	Europe	Consensus/narrative
EPA	U.S. Environmental Protection Agency. Antimicrobial testing program – guideline methodology. Washington (DC): U.S. Environmental Protection Agency; 2014 Aug 21. www.epa.gov/oppad001/antimicrobial-testing-program.html. Accessed 2014 Oct 7. Note: includes test results from August 2014. See also: The antimicrobial testing program. Hospital disinfectant and tuberculocidal products tested or pending testing. [List of products]. 2014 Aug 21.	United States	Evidence-based
GAO	Bascetta CA. Health-care-associated infections in hospitals: Leadership needed from HHS to prioritize prevention practices and improve data on these infections: Report to the Chairman, Committee on Oversight and Government Reform, House of Representatives. Washington (DC): U.S. Government Accountability Office; 2008 Mar. 61 p. Also available: www.gao.gov/assets/280/274314.pdf.	United States	Evidence-based
Healthcare-Associated Infection Working Group of the Joint Public Policy Committee (APIC, CDC, CSTE, and SHEA)	Healthcare-Associated Infection Working Group of the Joint Public Policy Committee. Essentials of public reporting of HAIs, Healthcare-Associated Infection Working Group of the Joint Public Policy Committee toolkit. 4 p. Also available: www.apic.org/Resource_/TinyMceFileManager/Position_Statements/Essentials_Tool_Kit.pdf. Publication date not provided.	United States	Evidence-based

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Appendix Table 5–Continued

Organization	Reference	Country	Methods (Evidence-Based or Consensus-/ Narrative-Based)
Healthcare Infection Society (United Kingdom) (formerly, the Hospital Infection Society)	Coia JE et al. Guidelines for the control and prevention of methicillin-resistant *Staphylococcus aureus* (MRSA) in healthcare facilities. J Hosp Infect. 2006 May;63:1-44. Also available: http://dx.doi.org/10.1016/j.jhin.2005.10.014.	United Kingdom	Evidence-based
	Cookson BD et al. Guidelines for the control of glycopeptide-resistant enterococci in hospitals. J Hosp Infect. 2006 Jan;62(1):6-21. Also available: http://dx.doi .org/10.1016/j.jhin.2005.02.016.	United Kingdom	Evidence-based
	Loveday HP et al. epic3: national evidence-based guidelines for preventing healthcare-associated infections in NHS Hospitals in England. J Hosp Infect. 2014 Jan;86. Also available: http://dx.doi.org/10.1016/S0195-6701(13)60012-2.	United Kingdom	Evidence-based
	National *Clostridium difficile* Standards Group: Report to the Department of Health. J Hosp Infect. 2004 Feb;56 Suppl 1:1-38.	United Kingdom	Evidence-based
	Pratt RJ et al. epic2: National Evidence-Based Guidelines for Preventing Healthcare-Associated Infections in NHS Hospitals in England. J Hosp Infect. 2007 Feb;65. Also available: http://dx.doi.org/10.1016/S0195-6701(07)60002-4.	United Kingdom	Evidence-based
	Steer JA et al. Guidelines for prevention and control of group A streptococcal infection in acute healthcare and maternity settings in the UK. J Infect. 2012 Jan;64(1):1-18. Also available: http://dx.doi.org/10.1016/j.jinf.2011.11.001.	United Kingdom	Evidence-based
Infection Control Working Group	Neely AN et al. Computer equipment used in patient care within a multihospital system: recommendations for cleaning and disinfection. Am J Infect Control. 2005 May;33(4):233-7. Also available: http://dx.doi.org/10.1016/j.ajic .2005.03.002.	United States	Evidence-based
IPS, formerly ICNA	Infection Prevention Society. Care setting process improvement tool in & out patient areas/departments. Bathgate (Scotland): Infection Prevention Society; 44 p. Also available: www.ips.uk.net/files/8213/8044/9268/In_-_Out_Patient_Area _Departments_PIT.pdf. No publication date.	United States	Evidence-based
IOM	Institute of Medicine. Initial national priority for comparative effectiveness research. [book online]. Washington (DC): National Academies Press; 2009 Jan 1. [accessed 2010 Mar 3] [various].	United States	Evidence-based
IFIC	Damani N. Information resources in infection control, 6th edition. Armagh (Ireland): International Federation of Infection Control; 2009. 96 p. Also available: www.theific.org/pdf_files/resource_IFIC_Sept_2009.pdf.	United Kingdom	Evidence-based
Jhpiego Corporation, an affiliate of Johns Hopkins University	Tietjen L et al. Infection prevention guidelines for healthcare facilities with limited resources. Jhpiego Corporation; 2003. 419 p. Also available: http://pdf.usaid.gov/pdf_docs/Pnact433.pdf.	United States	Evidence-based
Joint Commission	It's all the on the surface: establishing protocols for cleaning and disinfecting environmental surface areas. Environ Care News. 2010 Mar;13(3):6-11. Also available: www.jointcommission.org/assets/1/18/Its_All_on_the_Surface.pdf.	United States	Evidence-based
	The Joint Commission. National patient safety goals effective January 1, 2014. Hospital accreditation program. Oakbrook Terrace (IL): The Joint Commission; 2013. 17 p. See: www.jointcommission.org/assets/1/6 /HAP_NPSG_Chapter_2014.pdf.	United States	Evidence-based
Massachusetts Nurses Association	Massachusetts Nurses Association. Exposure to environmental cleaning chemicals in healthcare settings. Canton (MA): Massachusetts Nurses Association; 2007 Oct 1. www.massnurses.org/nursing-resources/position-statements/env-cleaning-chem. Accessed 2014 Oct 7.	United States	Consensus/narrative
Mehta et al	Mehta Y et al. Guidelines for prevention of hospital acquired infections. Indian J Crit Care Med. 2014 Mar;18(3):149–63. Also available: http://dx.doi.org/10.4103 /0972-5229.128705.	India	Evidence-based
NICE	Prevention and control of healthcare-associated infections: quality improvement guide. PH36. London (UK): National Institute for Health and Care Excellence (NICE); 2011 Nov 1. http://publications.nice.org.uk/prevention-and-control-of -healthcare-associated-infections-ph36. Accessed 2013 Oct 1. See: Quality improvement statement 5: Environmental cleanliness.	United Kingdom	Evidence-based
NPSA United Kingdom	National Patient Safety Agency. National specifications for cleanliness: primary medical and dental premises. London (UK): National Patient Safety Agency; 2010 Aug. 44 p. Also available: www.nrls.npsa.nhs.uk/EasySiteWeb/getresource .axd?AssetID=75245%20.	United Kingdom	Consensus/narrative
NPSA	National Patient Safety Agency. The revised healthcare cleaning manual. London: National Patient Safety Agency; 2009 Jun. 174 p. Also available: www.nrls.npsa.nhs.uk/EasySiteWeb/getresource.axd?AssetID=61814.	United Kingdom	Evidence-based
PIDAC	Provincial Infectious Diseases Advisory Committee. Routine practices and additional precautions in all health care settings, 3rd edition. Ottawa (Ontario): Public Health Ontario; 2012 Nov.113 p. Also available: www.publichealthontario.ca/en/ eRepository/RPAP_All_HealthCare_Settings_Eng2012.pdf.	Canada	Evidence-based
	Provincial Infectious Diseases Advisory Committee. Best practices for environmental cleaning for prevention and control of Infections In all health care settings-2nd edition. Ottawa (Ontario): Public Health Ontario; 2012 May.183 p.	Canada	Evidence-based
	Provincial Infectious Diseases Advisory Committee. Review of literature for evidence-based best practices for VRE control. Ottawa (Ontario): Public Health Ontario; 2012. 24 p. Also available: www.publichealthontario.ca/en/eRepository /PIDAC-IPC_VRE_Evidence-based_Review_2012_Eng.pdf.	Canada	Evidence-based

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Appendix Table 5–Continued

Organization	Reference	Country	Methods (Evidence-Based or Consensus-/ Narrative-Based)
Public Health Agency of Canada	Public Health Agency of Canada. *Clostridium difficile* infection-infection prevention and control guidance for management in acute care settings. Ottawa (Ontario): Public Health Agency of Canada; 2013 Jan 1. www.phac-aspc.gc.ca/nois-sinp /guide/c-dif-acs-esa/index-eng.php. Accessed 2014 Oct 7. See the section: 14. Environmental cleaning.	Canada	Evidence-based
	Public Health Agency of Canada. Routine practices and additional precautions for preventing the transmission of infection in healthcare settings. Ottawa (ON): Public Health Agency of Canada; 2012. 195 p. Also available: http://publications .gc.ca/collections/collection_2013/aspc-phac/HP40-83-2013-eng.pdf.	Canada	Evidence-based
Royal College of Nursing	Royal College of Nursing. Creating a safe environment for care: Defining the relationship between cleaning and nursing staff. London: Royal College of Nursing; 2013. 11 p. Also available: www.rcn.org.uk/__data/assets/pdf_file/0007 /548719/004492.pdf.	United Kingdom	Consensus/narrative
	Royal College of Nursing. Essential practice for infection prevention and control: guidance for nursing staff. London: Royal College of Nursing; 2012. 36 p. Also available: www.rcn.org.uk/__data/assets/pdf_file/0008/427832/004166.pdf. Note: See sections: 3.2 Decontamination of equipment; and 3.3 Achieving and maintaining a clean clinical environment.	United Kingdom	Consensus/narrative
	Royal College of Nursing. Selection and use of disinfectant wipes. RCN guidance. London: Royal College of Nursing; 2011. 20 p. Also available: www.rcn.org .uk/__data/assets/pdf_file/0011/382538/003873.pdf.	United Kingdom	Evidence-based
Public Health England/ Department of Health	Department of Health, Health Protection Agency. *Clostridium difficile* infection: how to deal with the problem. [Guidance]. London (UK): Healthcare Associated Infection and Antimicrobial Resistance, Department of Health; 2008 Dec. 140 p. Note: See chapter 6: Prevention through environmental cleaning and disinfection.	United Kingdom	Evidence-based
	Wilcox M. Updated guidance on the management and treatment of *C. difficile* infection. London: Public Health England; 2013. 29 p. Also available: www.gov.uk/government/uploads/system/uploads/attachment_data/file/321891/ Clostridium_difficile_management_and_treatment.pdf.	United Kingdom	Evidence-based
Rudolf Schuelke Foundation (Germany)	Gebel J et al. The role of surface disinfection in infection prevention. [Consensus paper]. GMS Hyg Infect Control. 2013;8(1):Doc10. Also available: http://dx.doi.org/10.3205/dgkh000210.	Germany	Evidence-based
SHEA	Society for Healthcare Epidemiology of America. Compendium of strategies to prevent healthcare-associated infections in acute care hospitals—overview page. Arlington (VA): Society for Healthcare Epidemiology of America; 2014 Jan 1. www.shea-online.org/PriorityTopics/CompendiumofStrategiestoPreventHAIs.aspx. Accessed 2014 Oct 7. Note: This is an overview page. The recommendation sections related to this Technical Brief are listed in the next two documents.	United States	Evidence-based
	Calfee DP et al. Strategies to prevent methicillin-resistant *Staphylococcus aureus* transmission and infection in acute care hospitals: 2014 update. Infect Control Hosp Epidemiol. 2014 Jul;35(7):772-96. Also available: http://dx.doi.org/10 .1086/676534. Note: from the 2014 Compendium.	United States	Evidence-based
	Dubberke ER et al. Strategies to prevent *Clostridium difficile* infections in acute care hospitals: 2014 update. Infection control and hospital epidemiology: the official journal of the Society of Hospital Epidemiologists of America. 2014 Jun;35(6):628-45. Also available: http://dx.doi.org/10.1086/676023. Note: from the 2014 Compendium.	United States	Evidence-based
	Calfee DP et al. Strategies to Prevent Transmission of Methicillin-Resistant *Staphylococcus aureus* in Acute Care Hospitals. Infect Control Hosp Epidemiol. 2008 Oct;29 Suppl 1:S62-80. Note: from the 2008 Compendium.	United States	Evidence-based
	Dubberke ER et al. Strategies to Prevent *Clostridium difficile* Infections in Acute Care Hospitals. Infect Control Hosp Epidemiol. 2008 Oct;29 Suppl 1:S81-92. Note: from the 2008 Compendium.	United States	Evidence-based
	Cohen SH, et al. Clinical practice guidelines for *Clostridium difficile* infection in adults: 2010 Update by the Society for Healthcare Epidemiology of America (SHEA) and the Infectious Diseases Society of America (IDSA). Infect Control Hosp Epidemiol. 2010 May;31(5):431-55.	United States	Evidence-based
	Muto CA, et al. SHEA guideline for preventing nosocomial transmission of multidrug-resistant strains of *Staphylococcus aureus* and Enterococcus. Infect Control Hosp Epidemiol. 2003 May;24(5):362-86. Also available: www.journals.uchicago.edu/doi/pdf/10.1086/502213.	United States	Evidence-based

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Appendix Table 5–Continued

Organization	Reference	Country	Methods (Evidence-Based or Consensus-/ Narrative-Based)
CMS	U.S. Centers for Medicare and Medicaid Services. State operations manual: Appendix A–survey protocol, regulations and interpretive guidelines for hospitals. (Rev. 116, 06-06-14). Baltimore (MD): U.S. Centers for Medicare and Medicaid Services; 2014 Jun 6. 471 p. (CMS State Operations Manuals). Also available: www.cms.gov/Regulations-and-Guidance/Guidance/Manuals /downloads/som107ap_a_hospitals.pdf. Also may be of interest: Peasah SK et al. Medicare non-payment of hospital-acquired infections: infection rates three-years post-implementation. MMWR 2013;3(3).	United States	Consensus/narrative
HHS	U.S. Department of Health and Human Services. National action plan to prevent health care-associated infections: road map to elimination. Washington (DC): U.S. Department of Health and Human Services (HHS). www.health.gov/hai /prevent_hai.asp#hai_plan. Accessed 2014 Oct 7.	United States	Evidence-based
WHO	Ducel G et al. Prevention of hospital-acquired infections: a practical guide. 2nd edition. Geneva (Switzerland): World Health Organization; 2002. 72 p. Also available: www.who.int/csr/resources/publications/drugresist/en /whocdscsreph200212.pdf?ua=1.	International	Evidence-based

AHE = Association for the Healthcare Environment; AHRQ = Association for Healthcare Research and Quality; AORN = Association of Perioperative Registered Nurses; APIC = Association for Professionals in Infection Control and Epidemiology; ASHES = American Society for Healthcare Environmental Services; ASID = Australasian Society for Infectious Diseases; CDC = Centers for Disease Control and Prevention; CIBMTR = Center for International Blood and Marrow Transplant Research; CMS = Centers for Medicare & Medicaid Services; CSTE = Council of State and Territorial Epidemiologists; ECDC = European Centre for Disease Control and Prevention; EPA = U.S. Environmental Protection Agency; ESCMID = European Society of Clinical Microbiology and Infectious Diseases; GAO = Government Accounting Office; HHS = U.S. Department of Health and Human Services; HICPAC = Healthcare Infection Control Practices Advisory Committee; ICNA = Infection Control Nurses Association; IFIC = International Federation for Infection Control; IOM = Institute of Medicine; IPS = Infection Prevention Society; NGC = National Guideline Clearinghouse; NICE = National Institute for Health and Care Excellence; NPSA = National Patient Safety Agency; PIDAC = Public Health Ontario, Provincial Infectious Diseases Advisory Committee; SHEA = Society for Healthcare Epidemiology of America; WHO = World Health Organization.

Appendix Table 6. Ongoing Clinical Trials

ClinicalTrials.gov Identifier	Sponsor	Study Design	Purpose	Start Date	Expected Completion Date	Estimated Enrollment	Primary Outcomes
NCT01579370	Duke University	Randomized, controlled	To determine the efficacy and feasibility of enhanced terminal room disinfection strategies to prevent health care–associated infections and to determine the impact of environmental contamination on acquisition of MDR pathogens among hospitalized patients. The intervention group includes quaternary ammonium, bleach, quaternary ammonium and UV-C light, and bleach and UV-C light.	April 2012	October 2014	50 000	Incidence rate of 4 target organisms (MRSA, VRE, *Clostridium difficile*, and MDR-acinetobacter) among patients admitted to a study room Incidence rate of *C. difficile* among patients admitted to a study room
NCT01349192	University of North Carolina, Chapel Hill	Randomized, controlled	To determine whether an early eradication protocol is effective for eradicating MRSA and will provide an opportunity to obtain data about early clinical impact of new isolation of MRSA. The intervention group includes an environmental decontamination component, including wiping down high-touch surfaces and medical equipment with surface disinfecting wipes daily for 21 d.	April 2011	July 2015	80	Percentage of participants in each group with MRSA-negative respiratory cultures at day 28
NCT02348346	Dr. B. de Jong	Observational	To study the efficacy of MVX on the microbial colonization of surfaces in the ICU.	March 2015	December 2015	NR	–

ICU = intensive care unit; MDR = multidrug-resistant; MRSA = methicillin-resistant *Staphylococcus aureus*; MVX = titanium dioxide; NR = not reported; UV-C = ultraviolet-C; VRE = vancomycin-resistant enterococci.

Appendix Table 7. Characteristics of Systematic Reviews

Study, Year (Reference)	Objective	Search Strategy	Key Inclusion/Exclusion Criteria	Evidence Base	Interventions	Relevant Findings	Authors' Conclusions
Amodio and Dino, 2014 (60)	To systematically review the evidence on ATP bioluminescence	Searches were completed in PubMed and Scopus. Bibliographies of articles retrieved were also searched. 31 articles were considered for inclusion.	Articles were excluded for not pertaining to hospital surfaces, being an experimental design, or being published before 1990.	Studies: 12 studies published from 2000–2011 were included. Studies were done in the United Kingdom (8), United States (3), and Brazil (1). Methods: Surfaces were monitored after cleaning (4 studies), before and after cleaning (6 studies), or NR (2). Pathogens were not described.	ATP devices were provided by 3M (5), Biotrace (4), and Hygiena (3). ATP thresholds (RLUs): 100: 2 (16.7%) 250: 5 (41.7%) 500: 4 (33.3%) Both 250 and 500: 1 (8.3%)	ATP measurements before cleaning (RLUs): Ranged from 0 to >500 000. ATP measurements after cleaning (RLUs): Ranged from 3 to 500 000 Failure rates before cleaning: 21.2%–93.1%. Failure rates after cleaning: 5.3%–96.5%.	"Although the use of ATP bioluminescence can be considered a quick and objective method for assessing hospital cleanliness, it appears to be still poorly standardized at both the national and international level."
Mitchell et al, 2013 (61)	To describe monitoring methods used in environmental cleaning	Searches in MEDLINE, CINAHL, and PubMed for English-language publications. A search of the gray literature included infection-control professional organization Web sites, Australian state government sites, and international guidelines.	Article addressing the efficacy of cleaning. Environmental cleanliness was categorized as process evaluation (visual inspection, use of fluorescent gel marker) and outcome evaluation (use of ATP or microbial cultures).	124 articles were reviewed. Number of articles include: NR.	Visual inspection, fluorescent gel marker, ATP, microbial cultures	Visual inspection (6 studies): Poor performance at identifying microbial load with 17%–93% more surfaces identified as "clean" than other assessment methods. Fluorescent gel marker (7 studies): Frequently shows a "lack of attention to high-risk surfaces in the near-patient zone." ATP: ATP measurements have low specificity and sensitivity in detecting bacteria (1 study reported sensitivity/specificity of 57%). Factors that may affect ATP readings include residual detergents or disinfectants, including sodium hydrochloride, eroded surfaces, plasticizers found in microfiber cloths or ammonium compounds found in laundry products. Microbiological sampling: Sampling to detect specific bacteria is "generally only recommended as part of an ongoing outbreak investigation, as a research study, or as part of a policy or process evaluation" because the process may take at least 2 d, requires expertise and lab access.	"Methods that evaluate cleaning performance are useful in assessing adherence to cleaning protocols, whereas methods that sample bio-burden provide a more relevant indication of infection risk. Fast, reproducible, cost-effective and reliable methods are needed for routine environmental cleaning evaluation in order to predict timely clinical risk."
Falagas et al, 2011 (58)	To review the effectiveness of airborne hydrogen peroxide in a clinical setting	Searches were completed in PubMed through December 2009. Bibliographies of relevant articles were also searched.	Included studies focused on the effectiveness of airborne hydrogen peroxide for reducing bacterial burden in the hospital setting and discussed pathogens naturally dispersed in this setting.	Studies: 10 studies were included. Pathogens addressed were MRSA (5), *Clostridium difficile* (3), and multiple pathogens (2). Settings: Surgical wards, ward side rooms, single isolation rooms, multiple-bed ward bays, bathrooms, and other utility rooms. High-touch areas: Chairs, bed frames, control panels, bedside tables, remote controls, door handles, bed rails, telephones, sink taps, toilet seats, and sites handled by HCWs. Pathogens: MRSA, *C. difficile*, and others.	7 studies evaluated the BioQuell HPV system (BioQuell) 3 studies evaluated a hydrogen peroxide dry-mist system or "dry fog" (Gloster Sante Europe)	Disinfection: Contamination of sampled environmental sites Before cleaning (9 studies): 39.0% (range: 18.9%–81.0%) After terminal cleaning (6 studies): 28.3% (range: 11.9%–66.1%) After airborne hydrogen peroxide (10 studies): 2.2% (range: 0%–4.0%) Infection control: 1 study indicated eradication of MRSA in one 20-bed surgical ward. Another study indicated significant reductions in *C. difficile*–associated disease in a 500-bed university-affiliated hospital.	"Data from several relevant studies indicate that disinfection of the hospital environment using airborne hydrogen peroxide in vapour or dry mist formulations, appears to provide additional benefits to currently used cleaning regimens, including inactivation of bacterial spores. Few studies have evaluated the use of airborne hydrogen peroxide disinfection as an adjunctive infection control measure in actual hospital practice. These limited relevant data are favourable, but further studies are needed to assess the effectiveness, safety, costs, and applicability of this novel method against other available cleaning methods."

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Appendix Table 7–Continued

Study, Year (Reference)	Objective	Search Strategy	Key Inclusion/Exclusion Criteria	Evidence Base	Interventions	Relevant Findings	Authors' Conclusions
Dettenkofer et al, 2004 (59)	To review evidence for the effects of disinfection of environmental surfaces on hospital-acquired infection rates	Biological Abstracts/ BIOSIS Previews (1980–1988/1989–2001); Cochrane Library (2001, Issue 4) Cochrane Clinical Trials Register; HECLINET (1969–2000); MEDLINE (Ovid, 1966–2001); Science Citation Index (1991–1996); SwetScan (1997–2001); Web of Science (Science Citation Index Expanded, 1997–2001); EMBASE (1974–2001) and EMBASE alert; and Somed (1978–2000). General Internet search was also undertaken.	Randomized, controlled trials and cohort, case–control, and observational studies in English, German, French, Italian, and Spanish evaluating use of disinfectant or detergent for "inanimate surfaces" in health care settings were included.	4 trials discussed impact of disinfectant vs. detergent on environmental surfaces. Dharan study compared NI rates in 2 different wings of a medical unit over 4 mo. Danforth study used a crossover design to examine NI rates in 8 wards in a tertiary-care teaching hospital over 3 mo. Daschner study examined NI rates in ICU units over 12 mo. Mayfield study examined use of 2 disinfectants on incidence of *C. difficile* in bone marrow transplant patients and patients in neurosurgical ICU and general medicine units. High-touch areas: Floors, furniture, bathrooms, toilets, and isolation rooms (Dharan) Floor (Danforth) Floor, patient care equipment, bedside tables, and bed frame (Daschner) Not described (Mayfield) Pathogens: MRSA, *C. difficile*, and others	Dharan study: QAC, an active oxygen-based compound, and an alcohol solution Danforth study: Disinfectant ortho-benzyl parachlorophenol or detergent Daschner study: Disinfectant (0.5% aldehyde) and detergent Mayfield study: QAC or 1:10 hypochlorite solution	Dharan study Detergent only: Increase in bacterial surface counts QAC: No reduction in bacterial counts Active oxygen-based compound, the alcohol solution, and the dust-attracting floor mop: Significant reduction of bacterial counts Dharan, Danforth, and Dashner studies Occurrence of NI: No significant difference Mayfield study CDAD incidence: Significant decrease in rates in bone marrow transplant patients, no reduction in patients on neurosurgical ICU or general medicine unit	"Disinfectants may pose a danger to staff, patients, and the environment and require special safety precautions. However, targeted disinfection of certain environmental surfaces is in certain instances an established component of hospital infection control. Given the complex, multifactorial nature of nosocomial infections, well-designed studies that systematically investigate the role of surface disinfection are required."

ATP = adenosine triphosphate; CDAD = *Clostridium difficile*–associated diarrhea; HCW = health care worker; HECLINET = Health Care Literature Information Network; HPV = hydrogen peroxide vapor; ICU = intensive care unit; MRSA = methicillin-resistant *Staphylococcus aureus*; NI = nosocomial infection; NR = not reported; QAC = quaternary ammonium compound; RLU = relative light unit.

Appendix Table 8. Characteristics of Cleaning and Disinfecting Studies

Study, Year (Reference)	Country	Study Design	General Cleaning Method	Study Length	Study Size	Primary Setting	Pathogen	HTOs	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Best et al, 2014 (39)	United Kingdom	Before/after	SC and AC	20 wk	342 sites	Rehabilitation ward	*Clostridium difficile*	Bed, curtain track, wall trunking, patient line boxes, tops of hoist rail	Sites positive for *C. difficile**, CDI incidence† (*C. difficile* ribotypes)	"HPD, after deep cleaning with a detergent/chlorine agent, was highly effective for removing environmental *C. difficile* contamination. Long-term follow-up demonstrated that a CDI-symptomatic patient can rapidly recontaminate the immediate environment. Determining a role for HPD should include long-term cost-effectiveness evaluations."
Boyce et al, 2014 (55)	United States	Before/after	EC	4 wk	9 rooms 1155 samples	Ward not specified	NR	Bed rail, remote control, toilet, tray table, telephone, doorknob, sink	Mean ACC*	"Cultures of surfaces obtained before daily cleaning with a quaternary ammonium disinfectant showed no significant residual antimicrobial activity of the organosilane products, although a modest reduction could not be excluded."
Haas et al, 2014 (30)	United States	Before/after	AC	2 y	11 389 rooms	Ward not specified	*C. difficile*, MRSA, VRE	NR	Incidence rate of HAIs†	"During the time period UVD was in use, there was a significant decrease in overall hospital-acquired MDRO plus CD in spite of missing 24% of opportunities to disinfect contact precautions rooms. This technology was feasible to use in our acute care setting and appeared to have a beneficial effect."
Jinadatha et al, 2014 (11)	United States	Nonrandomized, controlled	SC and AC	2 mo	20 rooms (10 per group)	Ward not specified	MRSA	Bed rail, call buttons, toilet, tray table, bathroom handrail	ACC*, total MRSA† (individual surface counts, cleaning time in minutes)	"PPX-UV technology appears to be superior to manual cleaning alone for MRSA and HPC. Incorporating 15 minutes of PPX-UV exposure time to current hospital room cleaning practice can improve the overall cleanliness of patient rooms with respect to selected micro-organisms."
Mitchell et al, 2014 (13)	Australia	Interrupted time series	SC and AC	6 y	3600 discharge cleans	Ward not specified	MRSA	Bed, vent, sink, console, chair, table, locker, mattress, pillow	Incidence of MRSA†	"Use of HP disinfection led to a decrease in residual MRSA contamination in patient rooms compared with detergent. It may also have encouraged the reduction in patient MRSA acquisition despite several confounders including staff feedback on terminal cleaning, additional MRSA screening and quicker laboratory methods. Infection control is best served by concurrent interventions targeting both the patient and healthcare environment."
Sjöberg et al, 2014 (24)	Sweden	Before/after	SC	8 mo	10 rooms 150 samples	NR	*C. difficile*	Bed rail, call button, side table, toilet, doorknob	Sites positive for culture*	"We demonstrated a moderate spread of CD spores to the environment despite routine cleaning procedures involving Vikron."
Stewart et al, 2014 (57)	United Kingdom	Before/after	SC	4 mo	30 bed spaces	Elderly care	MRSA and MSSA	Bedside locker, left/right cotside, overbed table	CFU* (recontamination)	"Cleaning with electrolyzed water reduced ACC and staphylococci on surfaces beside patients. ACC remained below precleaning levels at 48 hours, but MSSA/MRSA counts exceeded original levels at 24 hours after cleaning. Although disinfectant cleaning quickly reduces bioburden, additional investigation is required to clarify the reasons for rebound contamination of pathogens at near patient sites."
Wiemken et al, 2014 (28)	United States	Randomized, controlled	SC	1 mo	9 rooms	Ward not specified	Hardy pathogens	Side table, toilet, sink	Adherence to room protocol* (time needed to clean)	"In conclusion, this study supports the use of RTU CD wipes over the traditional bucket method. Enhancing environmental processes may reduce the environmental bioburden, leading to reductions in HAIs because of environmentally hardy pathogens."

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Appendix Table 8–Continued

Study, Year (Reference)	Country	Study Design	General Cleaning Method	Study Length	Study Size	Primary Setting	Pathogen	HTOs	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Anderson et al, 2013 (40)	United States	Prospective cohort	AC	15 mo	27 rooms 142 samples	Ward not specified	Various pathogens, including *C. difficile*, VRE	Bed rail, floor, side table, toilet, chair arm, overbed table, sink counter	Total number of CFUs, median number of CFUs per sample*	"Our data confirm that automated UV-C-emitting devices can decrease the bioburden of important pathogens in real-world settings such as hospital rooms."
Boyce and Havill, 2013 (26)	United States	Before/after	SC	NR	72 rooms	Ward not specified	NR	Bed rail, remote control, toilet, tray table, phone, bedside panel, chair arm, blood pressure cuff, grab bar, and faucet handle	CFU* (RLU, adverse effects)	"The activated hydrogen peroxide wipe product evaluated in our study proved to be an effective surface disinfectant, as reflected by ACC and ATP bioluminescence assays. ATP bioluminescence assays can be used as a tool to monitor the effectiveness of cleaning practices while using an activated hydrogen peroxide disinfectant. Additional studies are warranted to determine whether ATP and ACC cutoff points used to classify surfaces as clean should vary depending on the surface sampled."
Friedman et al, 2013 (17)	Australia	Interrupted time series	SC	10 d	21 rooms 1026 samples	Cancer ward	VRE	Floor, remote control, toilet, tray table, phone, locker drawer handle, bathroom tap	VRE-positive samples* (VRE colonization rates, rates per 1000 patient-days)	"During use of a chlorine-based, 3-staged protocol, significantly higher residual levels of VRE contamination were identified, compared with levels detected during use of a benzalkonium chloride based product for disinfection. This reduction in VRE may be due to a new disinfection product, more attention to the thoroughness of cleaning, or other supplementary efforts in our institution."
Gillespie et al, 2013 (18)	Australia	Before/after	SC	3 mo	10 rooms 200 samples	General medical ward, residential aged care ward	*C. difficile*, VRE	Not specified	RLU‡	"Our pilot study supports using ultramicrofiber cloth and steam technology as an alternative to cleaning with chemicals."
Hess et al, 2013 (25)	United States	Randomized, controlled	SC	10 mo	132 rooms 4444 samples	ICU, surgical ward	Various pathogens, including MRSA	Bed rail, call button, light switch, tray table, bed control, desk, IV poles and infusion pumps, phone, room sink, supply cart, and others	Contamination rates for health care worker gowns and gloves‡	"Intense enhanced daily cleaning of ICU rooms occupied by patients colonized with MRSA or MDRAB was associated with a nonsignificant reduction in contamination of HCW gowns and gloves after routine patient care activities. Further research is needed to determine whether intense environmental cleaning will lead to significant reductions and fewer infections."
Levin et al, 2013 (29)	United States	Interrupted time series	AC	1 y	NR	ICU, contact precaution and other rooms	*C. difficile*	Patient room, including bathroom	Hospital-associated CDI rate per 10 000 patient days† (HA-CDI attributable deaths and colectomies)	"In 2010, the HA-CDI rate was 9.46 per 10,000 patient-days; in 2011, the HA-CDI rates was 4.45 per 10,000 patient-days (53% reduction, $P = 0.01$). The number of deaths and colectomies attributable to hospital-associated *C difficile* infection also declined dramatically."
Mahida et al, 2013 (50)	United Kingdom	Before/after	AC	NR	6 rooms 32 locations	Intensive therapy unit, OR, and ward isolation room	Various pathogens, including MRSA, VRE	Not specified	CFU* (disinfection times)	"UV-C is an emerging decontamination technology that is effective in reducing bacterial contamination in the clinical environment. There are significant advantages to using UV-C, and, based on the results of this study we would recommend using Tru-D at the higher reflected dose setting of 22,000 mWs/cm^2 for terminal room disinfection in most healthcare settings."
Manian et al, 2013 (31)	United States	Before/after	SC and AC	3 y	870 rooms 1123 rounds of cleaning	Ward not specified	*C. difficile*	Bed rail, call button, light switch, telephone, doorknob, sink	CDAD rate per 1000 patient-days†	"Implementation of an enhanced hospital-wide terminal cleaning program revolving around HPV decontamination of targeted hospital rooms was practical, safe, and associated with a significant reduction in the endemic rate of CDAD at our hospital. Further studies are needed to delineate better the role of HPV decontamination in reducing the endemic rate of transmission of other pathogens with significant environmental presence in hospitals."

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Appendix Table 8–Continued

Study, Year (Reference)	Country	Study Design	General Cleaning Method	Study Length	Study Size	Primary Setting	Pathogen	HTOs	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Passaretti et al, 2013 (42)	United States	Prospective cohort	SC and AC	30 mo	1039 rooms 6607 patients	ICU	Various pathogens, including *C. difficile*, MRSA, VRE	Bed rail, computer keyboard, electronic monitoring equipment	Adjusted incidence rate ratio† (proportion of contaminated rooms, MDRO concordance with current room occupant)	"HPV decontamination reduced environmental contamination and the risk of acquiring MDROs compared with standard cleaning protocols."
Salgado et al, 2013 (32)	United States	Randomized, controlled	SC and EC	11 mo	16 rooms (8 copper, 8 standard) 614 patients (294 cared for in rooms with copper)	ICU	*C. difficile*, MRSA, VRE	Bed rail, overbed table, bed footboard, IV poles, and arms of the visitor's chair	Rate of colonization§ (length of stay, mortality)	"Patients cared for in ICU rooms with copper alloy surfaces had a significantly lower rate of incident HAI and/or colonization with MRSA or VRE than did patients treated in standard rooms. Additional studies are needed to determine the clinical effect of copper alloy surfaces in additional patient populations and settings."
Schmidt et al, 2013 (33)	United States	Nonrandomized, controlled	AC and EC	3 mo	75 beds	ICU	Various pathogens	Bed rail	Bacterial burden*	"Copper, when used to surface hospital bed rails, was found to consistently limit surface bacterial burden before and after cleaning through its continuous antimicrobial activity."
Sigler and Hensley, 2013 (41)	United States	Before/after	SC	NR	10 rooms	Rooms occupied by patients with staphylococcal infections (usually MRSA)	Various pathogens, including MRSA	Bed rail, call button, floor, tray table, sink, TV button, telephone	PCR positive for staphylococci*	"Overall, genetic markers for several staphylococci known to colonize and infect humans remained ubiquitous in each room following daily disinfection practices."
Sitzlar et al, 2013 (19)	United States	Interrupted time series	SC and AC	21 mo	NR	General medical ward, surgical ward	*C. difficile*	Bed rail, call button, toilet, tray table, telephone	Percent of targets cleaned* (disinfection as measured by cultures)	"An intervention that included education as well as monitoring and feedback improved thoroughness of cleaning but did not significantly improve CDI room disinfection. The use of an automated UV device improved disinfection, but 35% of rooms remained culture positive after use. Disinfection was dramatically improved through formation of a dedicated daily disinfection team and implementation of a standardized process for clearing CDI rooms."
Goldenberg et al, 2012 (14)	United Kingdom	Before/after	SC	4 mo	13 wards	General medical ward, surgical ward, plastic surgery, orthopedics, elderly care, acute admissions	*C. difficile*	Bed rail, call button, floor, remote control, toilet, telephone, locker, chair, sluice room, side room, mop bucket, and others	Number of contaminated sites* (CDI rate)	"The prevalence of environmental contamination was unaffected with a rate of 8% (9/120) before and 8% (17/212) following the change. Rates of patient infection were also unchanged during these periods."
Grabsch et al, 2012 (51)	Australia	Interrupted time series	SC	24 mo	NR	ICU, cancer ward, liver transplant, renal	VRE	Call button, curtain, locker handle, chair, chart, supplies trolley, phone	VRE colonization§ (newly recognized VRE colonization, total burden of inpatient VRE colonization)	"The Bleach-Clean programme was associated with marked reductions in new VRE colonizations in high-risk patients, and VRE bacteraemia across the entire hospital. These findings have important implications for VRE control in endemic health care settings."
Havill et al, 2012 (52)	United States	Nonrandomized, controlled	AC	NR	15 rooms	Ward not specified	Various pathogens, including *C. difficile*	Bed rail, remote control, toilet, tray table	ACC*	"Both HPV and UVC reduce bacterial contamination, including spores, in patient rooms, but HPV is significantly more effective. UVC is significantly less effective for sites that are out of direct line of sight."

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Appendix Table 8–Continued

Study, Year (Reference)	Country	Study Design	General Cleaning Method	Study Length	Study Size	Primary Setting	Pathogen	HTOs	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Karpanen et al, 2012 (37)	United Kingdom	Crossover	EC	24 wk	19 rooms	General medical ward	*C. difficile*, MRSA, VRE	14 HTOs, including toilet seat, grab rail, and door handle	CFU*	"Copper alloys (greater than or equal to 58% copper), when incorporated into various hospital furnishings and fittings, reduce the surface microorganisms. The use of copper in combination with optimal infection-prevention strategies may therefore further reduce the risk that patients will acquire infection in healthcare environments."
Kundrapu et al, 2012 (43)	United States	Randomized, controlled	SC	NR	70 patients	Ward not specified	*C. difficile*, MRSA	Bed rail, call button, side table, toilet, telephone, chair, wall-mounted vital signs equipment, IV medication stand, door knobs and handles	CFU* (frequency of health care worker hand contamination)	"In a randomized nonblinded trial, we demonstrated that daily disinfection of high-touch surfaces in rooms of patients with *Clostridium difficile* infection and methicillin-resistant *Staphylococcus aureus* colonization reduced acquisition of the pathogens on hands after contacting high-touch surfaces and reduced contamination of hands of healthcare workers caring for the patients."
Schmidt et al, 2012 (23)	United States	Randomized, controlled	SC and AC	3 mo	NR	Ward not specified	Various pathogens, including MRSA, VRE	Bed rail	CFU* (overall microbial burden)	"There was no difference in effectiveness, with a mean relative reduction of microbial burden of 84% for the traditional method versus 88% for the PureMist method."
Schmidt et al, 2012 (12)	United States	Before/after	SC and EC	43 mo	1587 rooms 9522 objects	ICU	*C. difficile*, MRSA, VRE	Bed rail, call button, tray table, IV stand, visitor chair, computer mouse, data input device	CFU*	"The introduction of copper surfaces to objects formerly covered with plastic, wood, stainless steel, and other materials found in the patient care environment significantly reduced the overall MB on a continuous basis, thereby providing a potentially safer environment for hospital patients, health care workers (HCWs), and visitors."
Boyce et al, 2011 (105)	United States	Before/after	AC	NR	25 rooms	Ward not specified	*C. difficile*	Bed rail, toilet, tray table, television remote	Mean ACC (CFU per plate)* (proportion of surfaces yielding a positive culture result [>1 CFU]; number of surfaces yielding >2.5 CFUs/cm^2 for the ACC)	"The mobile UV-C light unit significantly reduced aerobic colony counts and *C. difficile* spores on contaminated surfaces in patient rooms."
Carter and Barry, 2011 (15)	United Kingdom	Before/after	SC	18 mo	NR	NR	*C. difficile*	Light switch, toilet, furniture, bed frame, IV pump	CDI rate per 1000 patients, overall rate of CDI†	"The introduction of sporicidal wipes resulted in a significant reduction in *C. difficile* rates. This supports the need to review and enhance traditional environmental cleaning regimens for preventing and controlling *C difficile* in acute settings."
Chan et al, 2011 (45)	Australia	Nonrandomized, controlled	SC and AC	NR	NR	Ward not specified	VRE	Call button, side, toilet, arm rest, cotside	CFU*	"These results showed that dry hydrogen peroxide vapour room decontamination is highly effective on a range of surfaces, although the cleanliness data obtained by these methods cannot be easily compared among the different surfaces as recovery of organisms is affected by the nature of the surface."
Orenstein et al, 2011 (27)	United States	Before/after	SC	2 y	NR	General medical ward	*C. difficile*	Not specified	*C. difficile* incidence rates†	"We found that daily room cleaning with 0.55% germicidal bleach wipes led to a sustained reduction in hospital-acquired CDI on units with high endemic incidence of CDI. Targeting the use of daily bleach wipe cleaning to units with an increased *C. difficile* colonization pressure is an effective method to wipe out healthcare-acquired CDI."

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Appendix Table 8–Continued

Study, Year (Reference)	Country	Study Design	General Cleaning Method	Study Length	Study Size	Primary Setting	Pathogen	HTOs	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Sexton et al, 2011 (44)	United States	Before/after	Steam vapor	2 d	8 rooms	Long-term care wing	Various pathogens, including *C. difficile*, MRSA	Bed rail, side table, guest chair arm, sink, door push panel	CFU* (log_{10} reduction)	"The steam vapor system reduced bacterial levels by >90% and reduced pathogen levels on most surfaces to below the detection limit. The steam vapor system provides a means to reduce levels of microorganisms on hospital surfaces without the drawbacks associated with chemicals, and may decrease the risk of cross-contamination."
Wilson et al, 2011 (47)	United Kingdom	Randomized crossover	SC and "enhanced cleaning"	1 y	20 736 samples 1152 bed-days	ICU	Various pathogens, including *C. difficile*, MRSA, VRE	Bed rail, drawer handle, chart, keyboard, syringe driver, nurse's hand, monitor	Number of bed areas from which target pathogens were isolated at least once during a sampling day‡ (unpooled results of screening for the target pathogens in bed/communal areas, total ACC)	"Enhanced cleaning reduced environmental contamination and hand carriage, but no significant effect was observed on patient acquisition of methicillin-resistant *Staphylococcus aureus*."
Alfa et al, 2010 (48)	Canada	Before/after	SC	19 mo	243 patients 714 samples	Ward not specified	*C. difficile*	Toilet	CFU*	"Our data indicate that the AHP formulation evaluated that has some sporicidal activity was significantly better than the currently used SHP formulation. This AHP formulation provides a one-step process that significantly lowers the *C. difficile* spore level in toilets during non-outbreak conditions without the workplace safety concerns associated with 5,000 ppm bleach."
Casey et al, 2010 (35)	United Kingdom	Nonrandomized, controlled	EC	10 wk	NR	General medical ward, common area	Various pathogens, including *C. difficile*, MRSA, VRE	Toilet, sink, door push plate	Median CFU/cm^2*	"The results of this trial clearly demonstrate that copper-containing items offer the potential to significantly reduce the numbers of micro-organisms in the clinical environment. However, the use of antimicrobial surfaces should not act as a replacement for cleaning in clinical areas, but as an adjunct in the fight against HCAI."
Hacek et al, 2010 (20)	United States	Before/after	SC	3 y	All rooms occupied by patients with *C. difficile* in 3 hospitals; number not specified	Ward not specified	*C. difficile*	Bed, bed rail, bed control, floor, side table, toilet, tray table, doorknob, sink, wall	*C. difficile* cases per 1000 patient-days†	"The implementation of a thorough, all-surface terminal bleach cleaning program in the rooms of patients with CDI has made a sustained, significant impact on reducing the rate of nosocomial CDI in our health care system."
Hamilton et al, 2010 (34)	United Kingdom	Nonrandomized, controlled	SC	7 wk	NR	Ward not specified	NR	Bed, floor, tray table	Total viable bacterial counts*	"Cleaning with UMF reduces TVC in the hospital environment and this effect is significantly enhanced (about two-fold) with additional CuWB50. The copper-based biocide has two beneficial effects: (i) a residual effect that requires 2-3 weeks of cleaning to establish, and (ii) an immediate effect on reducing TVC that is most evident shortly after cleaning."
Hedin et al, 2010 (36)	Sweden	Nonrandomized, controlled	EC	3 wk	12 rooms 36 samples	Infectious disease ward	Various pathogens, including MRSA	Side table	Total ACC*	"Significantly fewer bacteria were found on Appeartex-treated surfaces compared with untreated surfaces."
Nerandzic et al, 2010 (56)	United States	Before/after	AC	NR	66 rooms 261 sites	Ward not specified	*C. difficile*, MRSA, VRE	Call light, bedside table, telephone, and bed rail	Positive cultures* (ease of use)	"The Tru-D Rapid Room Disinfection device is a novel, automated, and efficient environmental disinfection technology that significantly reduces *C. difficile*, VRE and MRSA contamination on commonly touched hospital surfaces."
Rutala et al, 2010 (53)	United States	Before/after	AC	8 mo	8 rooms	Ward not specified	*C. difficile*, MRSA	Bed rail, floor	Total CFUs per site*	"This UV-C device was effective in eliminating vegetative bacteria on contaminated surfaces both in the line of sight and behind objects within approximately 15 minutes and in eliminating *C. difficile* spores within 50 minutes."
Andersen et al, 2009 (49)	Norway	Nonrandomized, controlled	SC	NR	4 rooms 192 samples	Geriatric ward	Various pathogens, including *C. difficile*, MRSA, VRE	Floor	CFU* (CFU in air, ease of use of ATP)	"Wet, moist and dry mopping seemed to be more effective in reducing bacteria on the floor, than the spray mopping ($P = 0.007$, $P = 0.002$ and $P = 0.011$, respectively). The burden of bacteria in air increased for all methods just after mopping. The overall best cleaning methods seemed to be moist and wet mopping."

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Appendix Table 8–Continued

Study, Year (Reference)	Country	Study Design	General Cleaning Method	Study Length	Study Size	Primary Setting	Pathogen	HTOs	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
McMullen et al, 2007 (21)	United States	Nonrandomized, controlled	SC	2.5 y	Entire medical and surgical ICUs included for 2.5 y	ICU, common area	*C. difficile*	Not specified	Cases of CDAD per 1000 patient-days†	"These findings are further evidence that use of sodium hypochlorite solution may be an effective means of reducing the occurrence of CDAD in acute care facilities where the disease is epidemic or hyperendemic."
Whitaker et al, 2007 (16)	United States	Before/after	SC	2 y	NR	Ward not specified	*C. difficile*	"Every lateral surface"	CDI rate per 1000 patient-days†	"A combination of automated daily isolation reports, use of a standardized methodology for isolation rounds, as well as development of a 10% hypochlorite disinfection protocol resulted in a dramatic decrease in health care-associated *C. difficile* cases." "Weekly nursing director reports and daily rounds by nursing leadership keep the direct line supervisors abreast of infection control issues on their respective nursing units. The addition of the dual-chamber bleach container ensured that the proper dilution was achieved when disinfecting reusable equipment."
De Lorenzi et al, 2006 (22)	Italy	Nonrandomized, controlled	Mopping methods	5 d	2 rooms	Surgical ward	NR	Floor	ACC*	"Dry wiping followed by damp washing did not produce any significant reduction in the average bacterial load. However, damp washing followed by dry wiping reduced the bacterial load for both types of flooring. The difference was statistically significant."
Wilcox et al, 2003 (54)	United Kingdom	Nonrandomized, controlled	SC	2 y	1128 samples	2 "elderly medicine wards"	*C. difficile*	Bed rail, floor, toilet	Incidence rate of CDI† (surface colonization)	"Our results provide some evidence that hypochlorite environmental cleaning may significantly reduce CDI incidence, but also emphasize the potential for confounding factors."
Byers et al, 1998 (38)	United States	Before/after	SC	NR	10 conventional rooms, 4 bucket method; 376 conventional samples, 135 bucket samples	Ward not specified	VRE	Bed rail, floor, side table, IV pole, phone, blood pressure cuff, wall panel control	Number of colonized sites§ (cost of labor and supplies, cost of keeping room empty)	"Sixteen percent of hospital room surfaces remained colonized by VRE after routine terminal disinfection. Disinfection with a new "bucket method" resulted in uniformly negative cultures. Conventional cleaning took an average of 2.8 disinfections to eradicate VRE from a hospital room, while only one cleaning was required with the bucket method."

AC = automated cleaning; ACC = aerobic colony counts; AHP = accelerated hydrogen peroxide; ATP = adenosine triphosphate; CD = cleaning and disinfection; CDAD = *Clostridium difficile*–associated diarrhea; CDI = *C. difficile* infection; CFU = colony-forming unit; EC = enhanced coating; HA-CDI = hospital-associated *C. difficile* infection; HAI = hospital-associated infection; HCAI = health care–associated infection; HCW = health care worker; HP = hydrogen peroxide; HPC = heterotrophic plate counts; HPD = hydrogen peroxide decontamination; HPV = hydrogen peroxide vapor; HTO = high-touch object; ICU = intensive care unit; IV = intravenous; MB = microbial burden; MDRAB = multidrug-resistant *Acinetobacter baumannii*; MDRO = multiple-drug–resistant organisms; MRSA = methicillin-resistant *Staphylococcus aureus*; MSSA = methicillin-susceptible *Staphylococcus aureus*; NR = not reported; OR = operating room; PCR = polymerase chain reaction; PPX-UV = pulsed xenon ultraviolet light; RLU = relative light unit; RTU = ready-to-use; SC = surface cleaning; SHP = stabilized hydrogen peroxide; TVC = total viable (bacterial) counts; UMF = ultramicrofiber; UV = ultraviolet; UV-C = ultraviolet C; UVD = ultraviolet environmental disinfection; VRE = vancomycin-resistant enterococci.

* Primary outcome focused on surface contamination.

† Primary outcome focused on infection rate.

‡ Primary outcome focused on outcomes other than surface contamination, colonization, and infection rate.

§ Primary outcome focused on colonization.

Appendix Table 9. Characteristics of Monitoring Studies

Study, Year (Reference)	Country	Study Design	Monitoring Method	Study Length	Sample Size	Primary Setting	Pathogens	HTO(s)	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Luick et al, 2013 (70)	United States	Nonrandomized, controlled	ATP bioluminescence, fluorescent/UV markers, visual observation	2 mo	50 rooms, 250 total surfaces	Ward not specified	NR	Bed rail, call button, toilet, tray table, telephone	Sensitivity to detect pathogens (specificity of tests, PPV, NPV)	"In a simultaneous assessment of 250 environmental surfaces after terminal cleaning using aerobic cultures as a gold standard, both fluorescent marker and an adenosine triphosphate bioluminescence assay system demonstrated better diagnosticity compared with subjective visual inspection."
Smith et al, 2013 (71)	United States	Nonrandomized, controlled	ATP bioluminescence, visual observation, swab cultures	NR	10 rooms	Ward not specified	Various pathogens, including *Clostridium difficile*, MRSA, VRE	Bed rail, call button, light switch, side table, toilet, sink, telephone, door handle	RLU/cm^2; CFU/cm^2	"Although quantitative microbiology and ATP detection measure somewhat different aspects of environmental contamination, they both generally agree in distinguishing clean from dirty surfaces."
Snyder et al, 2013 (62)	United States	Nonrandomized, controlled	ATP bioluminescence, fluorescent/UV markers, visual observation	3 mo	20 rooms, 290 surfaces	Ward not specified	NR	Bed rail, call button, light switch, side table, toilet, tray table, door knob, telephone, sink	Percentage of targets cleaned (test characteristics of UV, ATP, and visual inspection)	"In assessing the effectiveness of PDC, there was poor correlation between the two most frequently studied commercial methods and a microbiologic comparator. Visual inspection performed at least as well as commercial methods, directly addresses patient perception of cleanliness, and is economical to implement."
Mulvey et al, 2011 (63)	United Kingdom	Nonrandomized, controlled	ATP bioluminescence, visual observation, agar slide cultures	4 wk	90 samples	General medical and surgical wards	MRSA	Bed, bed rail, floor, tray table	Cleaning rate (surface contamination [measured by ATP and dipslides])	"Microbiological and ATP monitoring confirmed environmental contamination, persistence of hospital pathogens and measured the effect on the environment from current cleaning practices. This study has provided provisional benchmarks to assist with future assessment of hospital cleanliness. Further work is required to refine practical sampling strategy and choice of benchmarks."
Munoz-Price et al, 2011 (64)	United States	ITS	Fluorescent/UV markers	20 wk	284 rooms, 2292 surfaces	ICU	Various pathogens	Bed rail, bed control, call button, light switch, monitor control panel, remote control, side table, toilet, tray table	Cleaning rate	"We found that regular surveillance using an inexpensive technology coupled with regular feedback of results produced sustained improvements in environmental cleaning, which may explain the coincident reduction in hospital-acquired infections. The ability of this brief (12 weeks) intervention to produce rapid benefits (within 4 weeks) and prolonged benefits (more than 20 weeks) speaks to its efficacy. Further studies aimed at optimizing reintroduction of the intervention to optimize cleaning rates should be considered."

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Appendix Table 9–Continued

Study, Year (Reference)	Country	Study Design	Monitoring Method	Study Length	Sample Size	Primary Setting	Pathogens	HTO(s)	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Carling et al, 2010 (65)	United States	Before/after	Fluorescent/UV markers	NR	260 rooms, 3532 samples, 27 hospitals	ICU	NR	NR	Percentage of targets cleaned	"Significant improvements in intensive care unit room cleaning can be achieved in most hospitals by using a structured approach that incorporates a simple, highly objective surface targeting method and repeated performance feedback to environmental services personnel."
Alfa et al, 2008 (68)	Not specified	Descriptive	Fluorescent/UV markers	8 mo	20 patients, 201 samples	Ward not specified	*C. difficile*	Toilet	Cleaning rate	"Our data demonstrated the value of UVM for monitoring the compliance of housekeeping staff with the facility's toilet cleaning protocol. In addition to providing good physical cleaning action, agents with some sporicidal activity against *C. difficile* may be needed to effectively reduce the environmental reservoir."
Alhamad and Maxwell, 2008 (72)	United Kingdom	Before/after and correlation of 2 monitoring methods	Agar slide cultures, "wipe-rinse method," used an assay	4 wk	130 samples	ICU and "high dependency unit"	MRSA	Bed rail, monitor control panel, cabinet, door handle, telephone, keyboard	Number of samples with positive culture (overall CFU/cm^2)	"There was no direct correlation between the findings of total aerobic count and MRSA isolation. We suggest, however, that combining both standards will give a more effective method of assessing the efficacy of cleaning/disinfection strategy. Further work is required to evaluate and refine these standards in order to assess the frequency of cleaning required for a particular area, or for changing the protocol or materials used."
Blue et al, 2008 (66)	Canada	Before/after	Fluorescent/UV markers	4 mo	364 samples	Ward not specified	VRE	Bed rail, call buttons light switch, toilet, tray table, doorknob	Percentage of targets cleaned (VRE infection rate)	"The GlitterBug product is an effective tool to evaluate environmental cleaning and adherence to policies and procedures and this method was superior to previous visual inspection methods. The use of GlitterBug potion improved physical cleaning and enhanced staff contribution. The Brevis GlitterBug product was incorporated into the CSS environmental cleaning program at Hamilton Health Sciences as a quality indicator to monitor environmental cleaning practices."

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Appendix Table 9–Continued

Study, Year (Reference)	Country	Study Design	Monitoring Method	Study Length	Sample Size	Primary Setting	Pathogens	HTO(s)	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Carling et al, 2008 (69)	United States	Descriptive study of UV fluorescent monitoring	Fluorescent/UV markers	12 wk	1119 rooms, 13 369 "high risk-objects"	ICU and other units	NR	Bed rail, call button, light switch, side table, toilet, tray table, sink, telephone, doorknob	Cleaning rate	"We identified significant opportunities in all participating hospitals to improve the cleaning of frequently touched objects in the patient's immediate environment. The information obtained from such assessments can be used to develop focused administrative and educational interventions that incorporate ongoing feedback to the environmental services staff, to improve cleaning and disinfection practices in healthcare institutions."
Carling et al, 2006 (67)	United States	Descriptive study of fluorescent marker monitoring	Fluorescent/UV markers	NR	157 rooms, 1404 samples	Ward not specified	NR	Bed rail, call button, side table, toilet, tray table, sink, doorknob, telephone	Percentage of targets cleaned	"The use of a novel target compound to evaluate housekeeping practices confirmed high rates of cleaning of traditional sites but poor cleaning of many sites that have significant potential for harboring and transmitting microbial pathogens. This methodology has the potential for being used to evaluate objectively the cleaning/disinfecting activities in various health care settings."
Malik et al, 2003 (73)	United Kingdom	Nonrandomized, controlled	ATP bioluminescence, visual observation, agar slide cultures	NR	8 hospital wards	Ward not specified	NR	Not specified	RLU, CFU/cm^2	"The data suggest that visual assessment is a poor indicator of cleaning efficacy and that the ACE audit gives a better assessment of cleaning programs compared with the other 2 audit methods in relation to microbial surface counts. It is recommended that hospital cleaning regimes be designed to ensure that surfaces are cleaned adequately and that efficacy is assessed with use of internal auditing and rapid hygiene testing."

ACE = audit for cleaning efficacy; ATP = adenosine triphosphate; CFU = colony-forming unit; CSS = infection control and customer support services; HTO = high-touch object; ICU = intensive care unit; ITS = interrupted time series; MRSA = methicillin-resistant *Staphylococcus aureus*; NPV = negative predictive value; NR = not reported; PDC = postdischarge cleaning; PPV = positive predictive value; RLU = relative light unit; UV = ultraviolet; UVM = ultraviolet visible marker; VRE = vancomycin-resistant enterococci.

Appendix Table 10. Characteristics of Implementation Studies

Study, Year, Country (Reference)	Study Design; Length	Single or Multicomponent Strategy	Sample Size	Primary Setting	Pathogen(s) Described	HTO(s)	Implementation Tools	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Branch-Elliman et al, 2014, United States (74)	Before/after; 2 mo	Single	820 surfaces, 210 rooms	Ward not specified	MRSA, VRE	Side rail, overbed rail, toilet seat	Education, monitoring, feedback	Proportion of surfaces cleaned (NR)	"We successfully implemented a quality improvement and education project to improve environmental cleaning in our hospital. Our study demonstrates that quality-assessment tools, such as the ATP luminometer, can be used at the point of cleaning to improve cleaning performance. Use of the tool in a positive feedback loop directly with front-line EVS staff resulted in enhanced collaboration, communication, and education among services."
Koll et al, 2014, United States (75)	ITS; 22 mo	Multicomponent infection prevention bundle, including contact precautions for patients with diarrhea and sign placement for patients with confirmed/ suspected CDI	35 hospitals	Burn, telemetry, and medical surgical unit	*Clostridium difficile*	>20 HTOs, including bed, bed rail, call button, floor, toilet, tray table, over 20 HTOs	Cleaning checklists	Adherence to room cleaning protocol (CDI rates)	"The use of a collaborative model to implement a multifaceted infection prevention strategy was temporally associated with a significant reduction in hospital-onset CDI rates in participating New York metropolitan regional hospitals."
Ramphal et al, 2014, United States (76)	ITS; 14 mo	Multicomponent/hand hygiene, improved kits for line-changing procedures	3185 HTOs	Ward not specified	Various pathogens, including *C. difficile*	20 HTOs, including bed rail, call button, remote control, and tray table	Education, training, "blinded monitoring with transparent reporting of the results in a positive, engaging manner"	Percentage of targets cleaned (*C. difficile* rates)	"The percentage of cleaned surfaces improved incrementally between the three trials–with values of 20%, 49%, and 82%–showing that repeat training favorably changed behavior in the staff ($P = 0.007$). During the study period, during which other infection control interventions were also introduced, there was a decline from 0.27 to 0.21 per 1000 patient days for *Clostridium difficile* infection, 0.43 to 0.21 per 1000 patient days for ventilator-associated infections, 1.8% to 1.2% for surgical site infections, and 1.2 to 0.7 per 1000 central venous line days for central line–associated bloodstream infections."
Rupp et al, 2014, United States (77)	Before/after; 4 y	Single	90 rooms, 1117 surface measurements	Medical/surgical critical care units	NR	Bed rail, tray table, room door handle, thermometer, monitor, bed rail, release button, nurse call monitor, and other items	43-point room-cleaning checklist, housekeeper educational program, training DVD, face-to-face meetings with housekeeping	Adherence to room cleaning protocol (NR)	"Over a 4-year period, we observed that monthly feedback of performance data in face-to-face meetings with frontline personnel was crucial in maintaining environmental-cleaning effectiveness in adult critical care units."
Rupp et al, 2014, United States (78)	Observational; 4 mo	Single	292 rooms, 17 housekeepers	Surgical/medical ICU	NR	18 HTOs, including bed rail, call button, light switch, and toilet	NR	Housekeeper efficiency and effectiveness based on RLUs (NR)	"A subgroup of housekeepers was identified who were significantly more effective and efficient than their coworkers. These optimum outliers may be used in performance improvement to optimize environmental cleaning."
Smith et al, 2014, United States (79)	Non-RCT; 20 mo	Single	13 345 sites	5 units, including telemetry, ICU, medical/ surgical, and cardiac	*C. difficile*, MRSA, VRE	16 HTOs, including toilet seat, light switch, call light, mattress, and bedrail	Educational interventional activities such as hands-on training and education with ATP devices, education via "Clean Sweep" electronic game, laminated pocket-size cleaning order, and high-touch surface lists in both English and Spanish	Cleaning score measures over time (trends in HAIs)	"The ATP detection device combined with educational feedback for EVS workers resulted in significant improvement in cleaning efficacy of the hospital room environment."

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Appendix Table 10–Continued

Study, Year, Country (Reference)	Study Design; Length	Single or Multicomponent Strategy	Sample Size	Primary Setting	Pathogen(s) Described	HTO(s)	Implementation Tools	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Brakovich et al, 2013, United States (80)	ITS; 7 mo	Multicomponent/a tiered approach that included environmental cleaning and disinfection, diagnostics and surveillance, and infection control measures, including antibiotic stewardship	50 beds	Long-term acute care hospital	*C. difficile*	Not specified	Lipstick challenge, checklists, training on use of chemicals, color-coded microfiber cloths, database output of quarterly reports	Incidence rate of CDI (cost)	"This program was successful in decreasing the incidence of CDI in the LTACH creating a safe and cost-effective environment for patients, families, and the community."
Trajtman et al, 2013, United States (81)	Non-RCT; 24 wk	Single	7680 sites	General medical ward	*C. difficile*	Bathroom	Feedback and UVM audit tool	Adherence to room cleaning protocol (NR)	"The use of UVM as an audit tool combined with weekly feedback of results to housekeeping staff resulted in significant, sustained improvement in the overall level of cleaning compliance of housekeeping staff."
Ragan et al, 2012, Canada (82)	Before/after; 8 wk	Single	823 HTOs	ICU	*C. difficile*, MRSA, VRE	Light switch, toilet, tray table, IV pole, drawer handle, door knob and other items	Audit and feedback, check list for HTOs	Percentage of targets cleaned (NR)	"We demonstrate that auditing with fluorescent targeting can be implemented in both the ward and intensive care unit settings using only modest resources, resulting in rapid improvements in cleaning thoroughness."
Datta et al, 2011, United States (83)	Retrospective cohort; 19 mo	Single	17 652 patients	ICU	MRSA, VRE	Not specified	Education	Infection rate: MRSA and VRE (acquisition by prior occupant status)	"Enhanced intensive care unit cleaning using the intervention methods may reduce MRSA and VRE transmission. It may also eliminate the risk for MRSA acquisition due to an MRSA-positive prior room occupant."
Murphy et al, 2011, Australia (84)	Before/after; 17 wk	Single	37 rooms, 986 HTOs	Ward not specified	MRSA, VRE	Light switch, toilet, bedroom door handle, bedroom soap dispenser, bedroom tap handle, paper towel dispenser	Audit and feedback, education to EVS staff, survey of EVS staff	Adherence to room cleaning protocol (percentage of targets cleaned)	"The [fluorescent marker] was useful to assess HTO cleaning thoroughness. It facilitated relevant feedback and education and motivated staff to strive for continual improvements in environmental cleaning. Without on-going education, preliminary improvements were unsustained. However, investigators better understood flaws in cleaning and policy/procedure conflicts."
Hota et al, 2009, United States (85)	Before/after; 25 wk	Single	2901 sites for thoroughness of cleaning, 1472 sites for contamination	ICU	VRE	Bed rail, tray table, infusion pump; countertop; soap dispenser, and other items	Education, intensified monitoring	Percentage of targets cleaned (contamination of sites postcleaning, VRE prevalence)	"These findings suggest that surface contamination with VRE is due to a failure to clean rather than to a faulty cleaning procedure or product."
Po et al, 2009, United States (86)	ITS; 9 mo	Single	16 beds	ICU	*C. difficile*, VRE	Computer keyboard on wheels	Education and feedback, process improvement interventions (e.g., assigned 1 specific individual to clean COWS), modification to cleaning protocols	Cleaning rate (NR)	"Following a series of educational and programmatic interventions, we were able to improve the thoroughness of cleaning to 100%."

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Appendix Table 10–Continued

Study, Year, Country, (Reference)	Study Design; Length	Single or Multicomponent Strategy	Sample Size	Primary Setting	Pathogen(s) Described	HTO(s)	Implementation Tools	Primary Outcome (Secondary Outcomes)	Authors' Conclusions
Carling et al, 2008, United States (87)	Before/after; NR	Single	20 646 HTOs	General medical ward, special care areas	*C. difficile*, MRSA, VRE	14 HTOs, including bed rail, toilet, and tray table	Audit and feedback	Percentage of targets cleaned (NR)	"Significant improvements in disinfection cleaning can be achieved in most hospitals, without a substantial added fiscal commitment, by the use of a structured approach that incorporates a simple, highly objective surface targeting method, repeated performance feedback to environmental services personnel, and administrative interventions. However, administrative leadership and institutional flexibility are necessary to achieve success, and sustainability requires an ongoing programmatic commitment from each institution."
Goodman et al, 2008, United States (88)	Before/after; 8 mo	Single	85 rooms, 1121 surfaces	Respiratory step-down unit	MRSA, VRE	15 HTOs, including bed rail, curtain, light switch, and toilet	Education, monitoring, and feedback	Positive cultures (number of rooms with positive culture)	"Increasing the volume of disinfectant applied to environmental surfaces, providing education for Environmental Services staff, and instituting feedback with a black-light marker improved cleaning and reduced the frequency of MRSA and VRE contamination."
Eckstein et al, 2007, United States (89)	Before/after; 16 wk	Single	17 rooms	Surgical ward	*C. difficile*, VRE	Bed rail, call button, side table, toilet, and door knob	Audit and feedback, education, housekeeping staff asked for input on additional resources needed to perform job well	Percentage of positive cultures (NR)	"Our findings provide additional evidence that simple educational interventions directed at housekeeping staff can result in improved decontamination of environmental surfaces. Such interventions should include efforts to monitor cleaning and disinfection practices and provide feedback to the housekeeping staff."
Hayden et al, 2006, United States (90)	Before/after; 255 d	NR	485 cleaning episodes	ICU	VRE	Bed rail, infusion pump, countertop, door handle, telephone, and other items	Educational in services, increased monitoring, audit, and feedback	Colonization with VRE (time to clean, antibiotic use)	"Decreasing environmental contamination may help to control the spread of some antibiotic resistant bacteria in hospitals."

ATP = adenosine triphosphate; CDI = *Clostridium difficile* infection; COWS = computer-on-wheels; EVS = environmental services; HAIs = health care–associated infections; HTO = high-touch object; ICU = intensive care unit; ITS = interrupted time series; IV = intravenous; LTACH = long-term acute care hospital; MRSA = methicillin-resistant *Staphylococcus. aureus*; NR = not reported; RCT = randomized, controlled trial; RLU = relative light unit; UVM = ultraviolet marker; VRE = vancomycin-resistant enterococci.

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