ORIGINAL ARTICLE

No-Touch Disinfection Methods to Decrease Multidrug-Resistant Organism Infections: A Systematic Review and Meta-analysis

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BACKGROUND. Recent studies have shown that using no-touch disinfection technologies (ie, ultraviolet light [UVL] or hydrogen peroxide vapor [HPV] systems) can limit the transmission of nosocomial pathogens and prevent healthcare-associated infections (HAIs). To investigate these findings further, we performed a systematic literature review and meta-analysis on the impact of no-touch disinfection methods to decrease HAIs.

METHODS. We searched PubMed, CINAHL, CDSR, DARE and EMBASE through April 2017 for studies evaluating no-touch disinfection technology and the nosocomial infection rates for *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), and other multidrug-resistant organisms (MDROs). We employed random-effect models to obtain pooled risk ratio (pRR) estimates. Heterogeneity was evaluated with I^2 estimation and the Cochran Q statistic. Pooled risk ratios for *C. difficile*, MRSA, VRE, and MDRO were assessed separately.

RESULTS. In total, 20 studies were included in the final review: 13 studies using UVL systems and 7 studies using HPV systems. When the results of the UVL studies were pooled, statistically significant reduction ins *C. difficile* infection (CDI) (pRR, 0.64; 95% confidence interval [CI], 0.49–0.84) and VRE infection rates (pRR, 0.42; 95% CI, 0.28–0.65) were observed. No differences were found in rates of MRSA or gram-negative multidrug-resistant pathogens.

CONCLUSIONS. Ultraviolet light no-touch disinfection technology may be effective in preventing CDI and VRE infection.

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Overall, 4% of hospitalized patients develop at least 1 healthcare-associated infection (HAI).[1] This represents almost 650,000 patients yearly[1] with an annual cost of $10 billion.[2] The risk of patient-to-patient transmission associated with prior room occupancy exists[3–6] because multidrug-resistant organisms (MDROs) are able to survive in the environment for days or even weeks.[7,8] Thus, environmental hygiene is an important component of an effective infection prevention program.[9] No-touch technologies, as adjuncts to traditional environmental cleaning, have become increasingly common in US hospitals.[10,11] Two types of devices have been developed and used for disinfection of hospital rooms: devices that utilize ultraviolet light (UVL) and devices that utilize hydrogen peroxide mist or vapor (HPV).

Over the last few years, research applying these no-touch modalities has led to a large amount of conflicting data on the prevention of MDRO infections in hospital settings.[13–16] In addition, questions have been raised regarding the cost-benefit of applying these systems.[12–16]

This study aims to review the literature on the impact of no-touch disinfection methods (UVL and HPV) on HAIs due to MDROs, such as methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant Enterococci (VRE), *Clostridium difficile*, and other MDROs.

METHODS

Systematic Review and Inclusion and Exclusion Criteria

This review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement[17] and the Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines.[18] Institutional review board approval was not required. Inclusion criteria for studies in this systematic review were as follows: original research manuscripts; published in peer-reviewed, scientific journals; involved human inpatients; conducted in acute-care settings that implemented no-touch disinfection methods

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(ie, ultraviolet light (UVL) and hydrogen peroxide producing systems) against MDRO HAIs; and controlled trial or quasi-experimental study design. The literature search was from database inception to April 30, 2017. Editorials, commentaries, and outbreak studies were excluded. Studies in which no-touch disinfection methods were used to evaluate the efficacy of reducing contamination of hospital surfaces were also excluded.

Search Strategy

We performed literature searches in PubMed, the Cumulative Index to Nursing and Allied Health (CINAHL), the Cochrane Database of Systematic Reviews (CDSR), the Cochrane Central Register of Controlled Trials (CENTRAL), the Database of Abstracts of Reviews of Effects (DARE), and Scopus (which includes EMBASE abstracts). The entire search strategy is described in Supplementary Appendix 1. We reviewed the reference lists of retrieved articles to identify studies that were not identified from the preliminary literature searches.

When searched alone, the term "hydrogen peroxide vapor" yielded 199 articles; "hydrogen peroxide producing systems" yielded 147 articles; "ultraviolet light" yielded 9,287 articles; "environmental decontamination" yielded 3,606 articles; "environmental disinfection" yielded 8,396 articles; "room disinfection" yielded 960 articles; "terminal cleaning" yielded 152 articles; "MRSA" yielded 18,480 articles; "VRE" yielded 2,463 articles; "*Clostridium difficile*" yielded 12,030 articles; "multi-drug resistant organisms" yielded 468 articles; and "healthcare associated infections" yielded 1,730 articles. After applying exclusion criteria, we reviewed the full articles for 88 papers; finally, 20 studies met the inclusion criteria and were included in the systematic review (Figure 1).

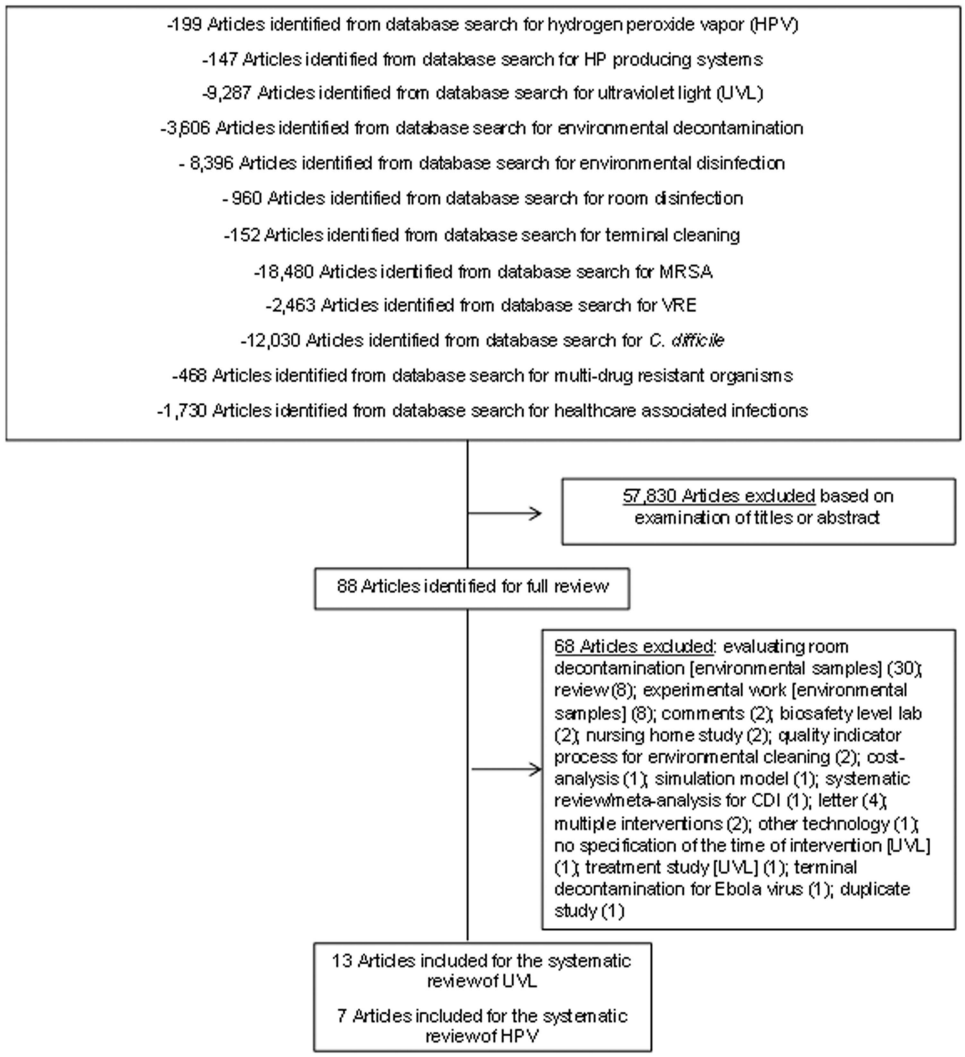

FIGURE 1. Literature search for articles on no-touch disinfection methods. Abbreviations: UVL, ultraviolet light; HPV, hydrogen peroxide vapor.

Data Abstraction and Quality Assessment

The titles and abstracts of all articles were screened to assess whether they met inclusion criteria. The reviewers (A.R.M. and M.B.E.) abstracted data on study design, population, setting, interventions tested, and measurement of no-touch technologies for UVL or HPV systems, respectively. We also collected information about the year of intervention, compliance with alternative interventions (eg, hand hygiene and antimicrobial stewardship), outcome and cost-effectiveness evaluation. We used the scales employed by Aboelela et al[19] and Cohen et al[20] to evaluate study quality. These tools have items regarding sample representativeness, bias and confounding, description of the intervention, outcomes and follow-up, and statistical analysis, which are each scored 1–4, where 4 indicates the highest quality. Each reviewed paper was assessed as to whether it addressed the aforementioned categories in a manner that was "completely adequate," "partially adequate," "inadequate, not stated or impossible to tell" or "not applicable."[19,20] The authors (A.R.M. and M.B.E.) performed component quality analysis independently, reviewed all inconsistent assessments, and achieved consensus by discussion.[21] For quasi-experimental studies, we evaluated whether time series analysis was performed, the rationale for why randomization was not used, and other caveats of a quasi-experimental design.[22]

Statistical Analysis

To meta-analyze the extracted data, we calculated the natural log of the risk ratios (RR) and standard errors (SE) for UVL and HPV systems independently using 2 outcomes: CDI and VRE infection. We also performed stratified analysis with forest plots of the association between UVL and CDI, comparing high baseline CDI rates ($\geq$1.5 CDI/1,000 patient days) to low baseline CDI rates (<1.5 CDI/1,000 patient days); controlled versus noncontrolled trials; academic versus community hospitals; and the quality of studies (those reporting compliance rates as completely adequate vs not completely adequate).[19,20] All of the studies in the meta-analysis evaluated infections as the outcome, not colonization, except that of Passaretti et al,[40] which evaluated infection and colonization combined for MRSA and VRE.[40] We employed random-effect models to obtain pooled risk ratio estimates (pRR), using Microsoft Excel software (2007, Redmond, WA) and the Cochrane Review Manager (RevMan) version 5.3 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, 2014). Heterogeneity between studies was evaluated using I^2 estimation and the Cochran Q statistic test.

RESULTS

Characteristics of Included Studies

Twenty studies met the inclusion criteria and were included in the final review (Table 1). Of these 20 studies, 18 (90%) were nonrandomized, quasi-experimental studies[23–40]; 17 (94.4%) compared infection rates before and after implementation of no-touch technology (UVL or HPV)[23–39]; and 1 was a prospective observational cohort study.[40] Another 2 studies (10%) were clinical trials: 1 was a randomized trial[41] and 1 was a controlled trial.[42] Of the 20 studies, 13 (65%) used a UVL disinfection system,[24,26,28,31,32,34–39,41,42] and 7 studies (35%) used an HPV disinfection system.[23,25,27,29,30,33,40] Of the UVL disinfection system studies,[24,26,28,31,32,34–39,41,42] 8 studies used pulsed Xenon UVL (PX-UV),[24,26,28,32,35,36,38,42] 4 studies used UV-C radiation (UV-C),[34,37,39,41] and 1 study did not specify the type of UVL.[31]

Most of the studies included in our review were conducted in the United States (17 studies)[23,24,26,28–32,34–42]; 2 studies were performed in the United Kingdom[25,27]; and 1 study took place in Australia.[33] All of the UV system studies were conducted in the United States (13 studies).[24,26,28,31,32,34–39,41,42] Studies varied on the type of rooms that used the no-touch technology. The majority of the studies used no-touch technology after terminal cleaning of rooms of patients on contact precautions (11 studies),[23,25,27,29,30,33,34,36,38–42] but other studies evaluated the no-touch technology after terminal cleaning of all patient rooms hospital-wide (4 studies),[28,31,32,37] after terminal cleaning in oncology units (2 studies),[34,42] and ICU patient rooms[26,35] (2 studies, 1 of which also used no-touch technology after terminal cleaning in the operating room of a burn unit).[26] Another study investigated no-touch technology after terminal cleaning in all operating rooms hospital-wide.[24] All of the HPV system studies were conducted after terminal cleaning of rooms of patients on contact precautions.[23,25,27,29,30,33,40]

The year that HPV no-touch technology was used ranged from 2005 to 2012.[23,25] For UVL systems, the studies ranged from 2011 to 2014.[24,26–42] The longest study time was 6 years (an HPV system study)[33] and the shortest study duration <1 year (a UVL system study).[42]

Many of the UVL and HPV studies included in our review were conducted at community medical centers (12 studies)[24,27–33,35,37–39]; 6 studies were performed at academic medical centers[23,25,34,36,40,42]; and 1 study was performed at a military medical center.[26] One study[41] was conducted in 9 hospitals: 6 community medical centers, 2 academic medical centers, and 1 Veterans Affairs medical center. For HPV systems, 4 studies were performed at community medical centers[27,29,30,33] and 3 studies were performed at academic medical centers.[23,25,40]

The outcome for the majority of the studies (17 studies) was CDI rates[23,25,27–32,34–42]; among these, 11 were studies of UVL disinfection systems[28,31,32,34–39,41,42] and 6 were studies of HPV disinfection systems.[23,25,27,29,30,40] For the UVL disinfection system baseline CDI rates, 6 studies were considered to have a high baseline rate (≥1.5 per 1,000 patient days)[28,31,32,34,41,42] and 5 studies had a low baseline CDI rate (<1.5 per 1,000 patient days).[35–39] For HPV disinfection, 2 studies had high baseline CDI rates,[23,40] 3 studies had low

TABLE 1. Summary of Characteristics of Studies Included in the Systematic Review for UVL Studies (A) and HPV Studies (B)

A. UVL Studies

First Author, Year, Location	Method	Study Design	Study Period/ Intervention Period, Months	Hospital Type (No. of Beds)	Intervention Site	Year of Intervention	Outcome	Baseline CDI Rate	Alternative Interventions Compliance Reported[a]	Cost-Effectiveness Evaluation
Levin, 2013, Worcester, MA	UV-PX	Before–after	48/12	Community (140)	All patient rooms HW	2011	Decreased infection, death, colectomy due to HA-CDI	High	Yes	No
Haas, 2014, Valhalla, NY	UV-PX	Before–after	30/22	Academic (643)	MRSA, VRE, CD, MDR-GN rooms HW	2011	Decreased HA-CDI, HA-MRSA, HA-VRE, HA-MDR-GN infections	Low	No	No
Miller, 2015, Southeastern	UV-PX	Before–after	48/24	LTACH (NA)	All patient rooms	2012	Decreased HA-CDI	High	Yes	No
Nagajara, 2015, Valhalla, NY	UV-PX	Before–after	24/12	Community (652)	All contact precautions rooms	2011	Decreased ICU HA-CDI	Low	No	No
Vianna, 2016, Orlando, FL	UV-PX	Before–after	44/22	Community (126)	All ICU rooms; CD non-ICU rooms	2012	Decreased HA-CDI, HA-MRSA, HA-VRE infections	Low	No	Yes
Napolitano, 2015, Culver City, CA	UV-C	Before–after	11/6	Community (420)	All patient rooms HW	2012	Decreased HA-CDI, HA-AB, HA-KP infections; No decrease in HA-MRSA, HA-VRE infections	Low	No	No
Bernard, 2015, Mohawk, NY	NA	Before–after	24/12	Community (NA)	All patient rooms HW	2013	Decreased HA-CDI	High	Yes	No
Catalanotti, 2016, Lowell, MA	UV-PX	Before–after	36/20	Community (200)	All ORs	2013	Decreased class I SSI but not class II	Not studied	No	No
McMullen, 2016, St Louis, MO	UV-C	Before–after	31/7	Community (1,250)	CD, CRE or diarrhea patient room HW	2014	No decrease in HAI-CDI	Low	No	No
Sampathkumar, 2016, Rochester, MN	UV-PX	CT	> 6/6	Academic (2,207)	All patient rooms in 2 oncology units, 1 medical-surgical unit	NA	Decreased HA-CDI	High	Yes	No
Pegues, 2017, Philadelphia, PA	UV-C	Before–after	24/12	Academic (789)	All patient rooms in 3 oncology units	2014	Decreased HA-CDI	High	Yes	Yes
Green, 2017, San Antonio, TX	UV-PX	Before–after	18/3	Military (425)	9 ICU rooms and 2 ORs in burn unit	2014	No decrease in HAI, HA-MDR	Not studied	No	No
Anderson, 2017, Burlington, Chapel Hill, Durham, High Point, Raleigh, NC; Chesapeake, VA	UV-C	RCT	28/28	6 community, 2 academic, 1 VA (3,947)	CD, MRSA, VRE, MDR-AB rooms	2012	Decreased VRE and composite HA-target organisms (CD + MRSA + VRE + MDR-AB); no decrease in HA-CDI, HA-MRSA, MDR-AB	High	Yes	No

B. HPV Studies

First Author, Year, Location	Study Design	Study Period/ Intervention Period. Months	Hospital Type (No. of Beds)	Intervention Site	Year of Intervention	Outcome	Baseline CDI Rate	Alternative Interventions Compliance Reported*	Cost-Effectiveness Evaluation
Boyce, 2008, New Haven, CT	Before–after	20/10	Academic (500)	CD rooms in 5 wards with highest CD rates	2005	Decreased HA-CDI	High	Yes	No
Cooper, 2011, UK	Before–after	29/8	Academic (NA)	CD rooms HW	2008	Decreased HA-CDI but no statistical testing performed	No data	No	No
Passaretti, 2013, Baltimore, MD	Prospective cohort	30/18	Academic (994)	CD, MRSA, VRE rooms in 6 high-risk units	2008	Decreased composite MDRO (CD + MRSA + VRE + MDR-GN) acquisition rates; decreased VRE acquisition rates; no decrease in CD, MRSA and MDR-GN acquisition rates	High	No	No
Manian, 2013, St Louis, MO	Before–after	36/12	Community (900)	CD, MDRO rooms HW	2009	Decreased HA-CDI	Low	Yes	No
Mitchell, 2014, Tasmania, Australia	Before–after	72/48	Community (300)	MRSA rooms HW	2009	Decreased MRSA bacteremia	Not studied	Yes	No
Horn, 2015, UK	Before–after	36/12	Community (270)	CD, MRSA, VRE, ESBL rooms HW	2011	Decreased HA-CDI, VRE, ESBL-GN rates/ no decrease in MRSA rates	Low	Yes	No
McCord, 2016, Tupelo, MS	Before–after	48/24	Community (650)	CD rooms HW	2012	Decreased HA-CDI	Low	No	No

NOTE. UVL, ultraviolet light; HPV, hydrogen peroxide vapor; CP, contact precaution; HAI, healthcare-associated infection; MRSA, methicillin-resistant *S. aureus*; MSSA, methicillin-susceptible *S. aureus*; VRE vancomycin-resistant enterococci; CD, *Clostridium difficile*; CDI, *Clostridium difficile* infection; MDR-GN, multidrug-resistant gram negative; MDRO, multidrug-resistant organism; ESBL, extended-spectrum β-lactamase; CRE, carbapenem-resistant Enterobacteriaceae; UV-PX, ultraviolet-pulsed xenon; UV-C, ultraviolet-C light; RCT, randomized control trial; CT, clinical trial; HW, hospital-wide; LTACH long-term acute-care hospital; OR, operating room; EC, environmental cleaning; VA, Veterans Affairs; NA, not available.

[a]Alternative interventions include hand hygiene, antimicrobial stewardship.

baseline CDI rates,[27,29,30] and 1 study did not report rate data.[25] In 7 studies, the outcome evaluated was MRSA rates[27,33,35–37,40,41]: 4 were studies of UVL systems[35–37,41] and 3 were studies of HPV.[27,30,40] In addition, 6 studies evaluated VRE rates as the outcome[27,35–37,40,41]: 4 studies of UVL[35–37,41] and 2 studies of HPV.[27,40] In addition, 2 UVL disinfection studies evaluated gram-negative MDRO infections as an outcome measure.[26,36] One UVL system study evaluated HAI rates (generically)[26] and another study evaluated the impact of surgical site infection as an outcome.[24]

Outcomes Measures and Follow-Up

When we considered the assessment quality of the reviewed papers (Supplementary Appendix 2) more than one-third of the studies (9 studies) were considered "completely adequate" for reporting compliance rates of no-touch technology for hospital room disinfection.[28,29,34,36,37,39–42] More than a half of these studies (n = 12) had a clearly defined outcome[28–30,32–38,40,41] but only 2 of these studies tested differences between groups and variability.[34,41]

When the results of the studies were pooled, after terminal cleaning using UVL no-touch technology, we detected a statistically significant reduction in *Clostridium difficile* infection (CDI) rates (pRR, 0.64; 95% CI, 0.49–0.84; $P = .001$)[28,31,32,34,36–39,41,42] and VRE infection rates (pRR, 0.42; 95% CI, 0.28–0.65; $P < .001$).[35–37,41] The results of both meta-analyses for CDI and for VRE were homogeneous (for CDI: heterogeneity $P = .63$; $I^2 = 0\%$; for VRE: heterogeneity $P = .93$; $I^2 = 0\%$; Figure 2A and 2B). There was a nonsignificant reduction in MRSA infections using UV (pRR, 0.78; 95% CI, 0.51–1.20; $P = .26$)[35,36,37,41] as well as nonsignificant reductions in other infection rates for gram-negative MDRO pathogens (pRR, 1.83; 95% CI, 0.49–6.82; $P = .37$)[26,36] (Supplementary Appendix 3A and 3B).

After performing a stratified analysis with forest plots, we observed a statistically significant reduction in *Clostridium difficile* infection (CDI) rates in UVL system studies with high baseline CDI rates (pRR, 0.60; 95% CI, 0.43–0.86; $P = .005$)[28,31,32,34,41,42] but not for studies with low baseline CDI rates (pRR, 0.70; 95% CI, 0.17–2.90; $P = .63$) (Figure 3A). Also, there was a statistically significant reduction in CDI rates for UVL in studies that were not controlled trials (pRR, 0.58; 95% CI, 0.41–0.83; $P = .003$)[28,31,32,34–39] but not for controlled trials (pRR, 0.65; 95% CI, 0.26–1.62; $P = .35$)[41,42] (Figure 3B). We used a statistically significant reduction in CDI rates for UVL for both academic[34,36,42] and community hospital studies[28,31,32,35,37–39] (for academic hospitals: pRR, 0.58; 95% CI, 0.37–0.91; $P = .02$; and for community hosptials: pRR, 0.48; 95% CI, 0.30–0.77; $P = .002$) (Figure 3C). Considering the quality of studies reporting compliance rates as completely adequate[28,34,36,37,39,41,42] versus not completely adequate studies,[31,32,35,38] we found statistically significant reductions

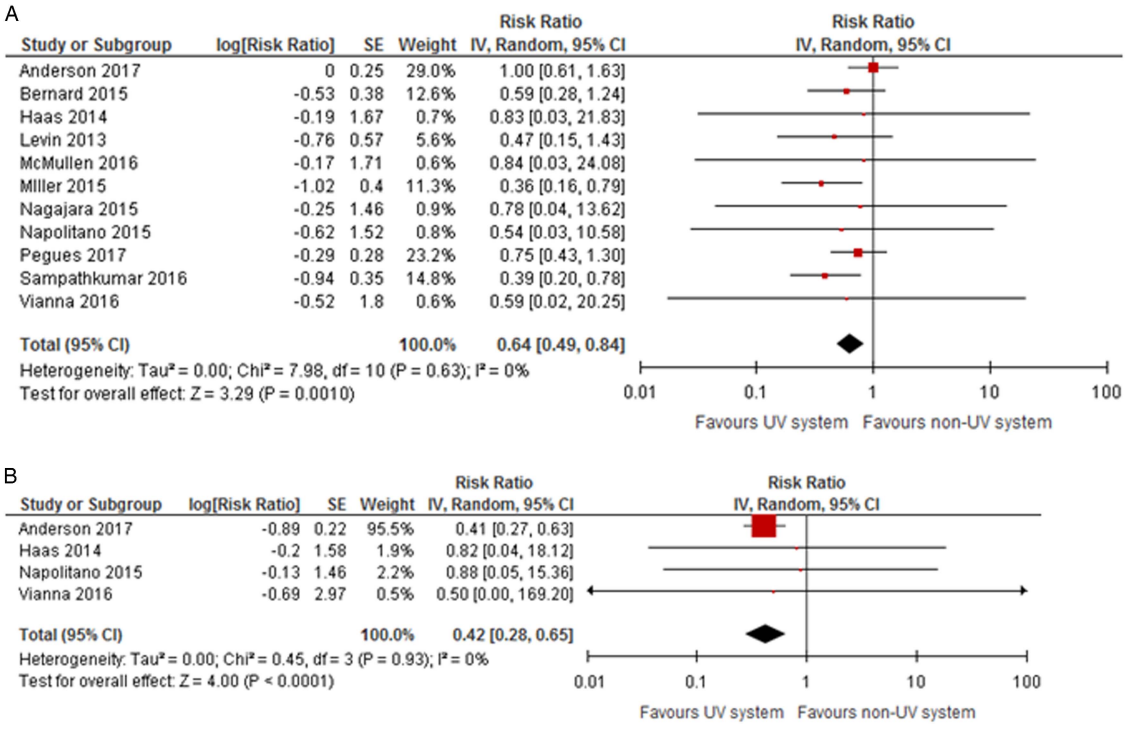

FIGURE 2. Forest plots of the associations between UVL no-touch technology and *Clostridium difficile* infection (CDI) or vancomycin-resistant *Enterococcus* (VRE): (A) CDI and (B) VRE. Abbreviations: CI, confidence interval; IV, inverse variance weighting; SE, standard error.

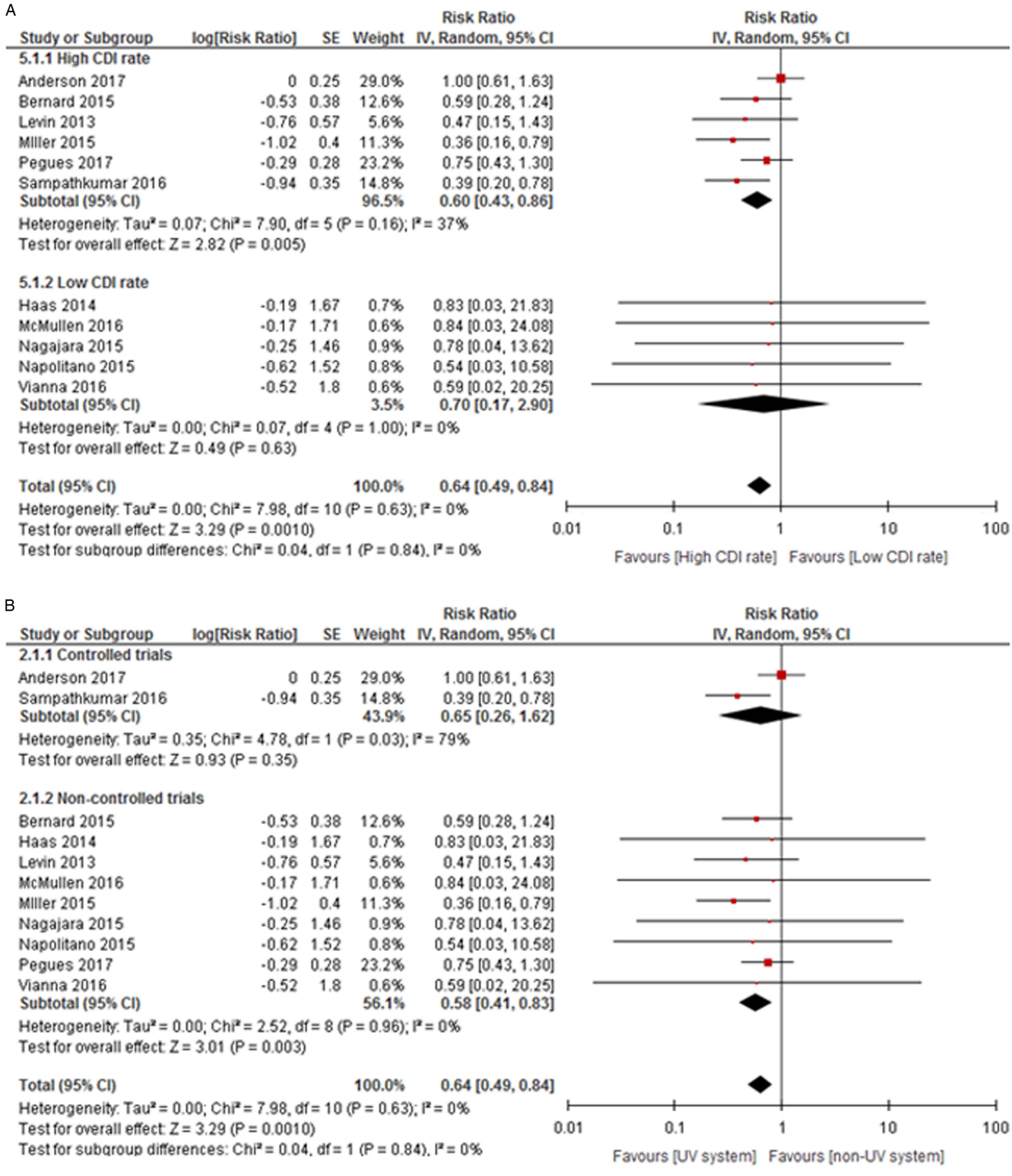

FIGURE 3. Forest plots of the associations between UVL no-touch technology and *Clostridium difficile* infection (CDI) comparing (A) high baseline CDI rates versus low baseline, (B) controlled trials versus noncontrolled trials, (C) academic versus community hospitals, (D) quality of studies reporting compliance rates (completely adequate vs not completely adequate). Abbreviations: CI, confidence interval; IV, inverse variance weighting; SE, standard error.

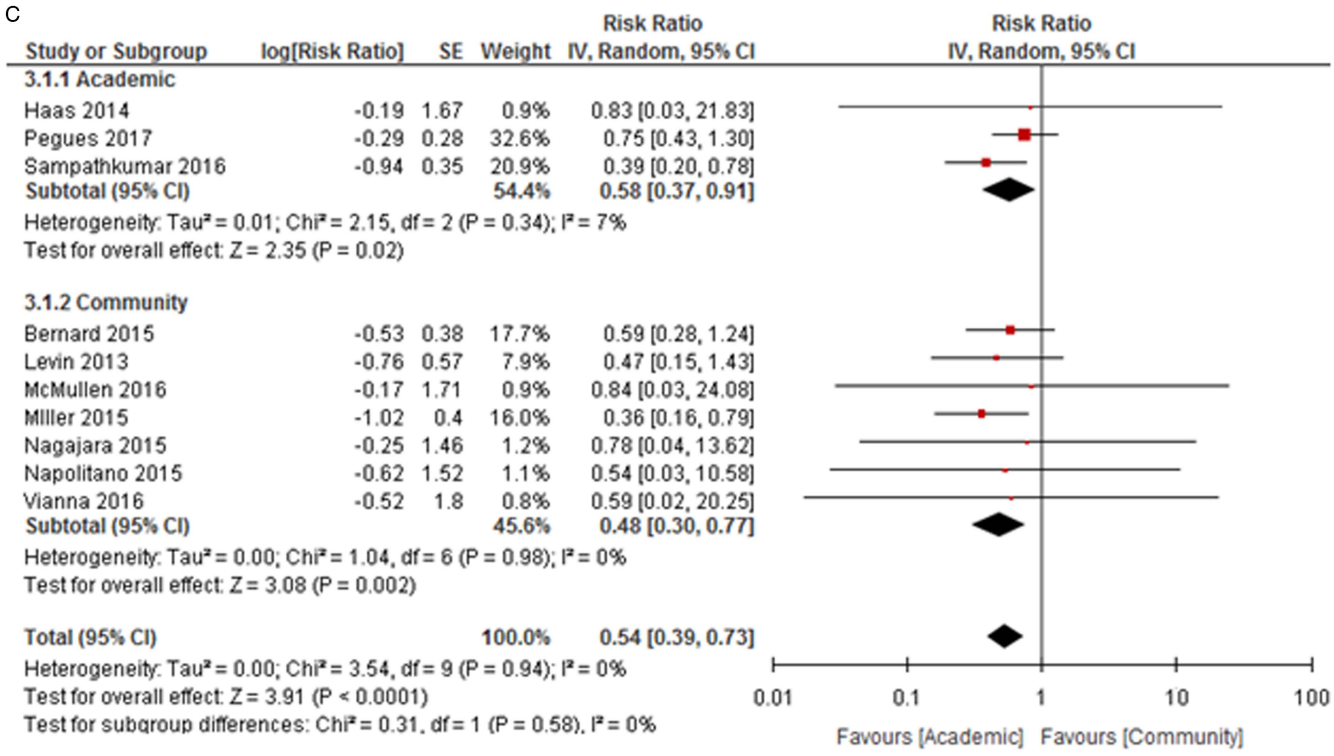

FIGURE 3. Continued.

in CDI rates for both (pRR, 0.71; 95% CI, 0.52–0.96; $P = .03$ and pRR, 0.48; 95% CI, 0.28–0.81; $P = .006$, respectively) (Figure 3D).

Among the results of the studies that used HPV no-touch technology (Figure 4), we found a nonsignificant reduction in CDI rates (pRR, 0.52; 95% CI, 0.15–1.81; $P = .30$).[23,27,29,30,40]

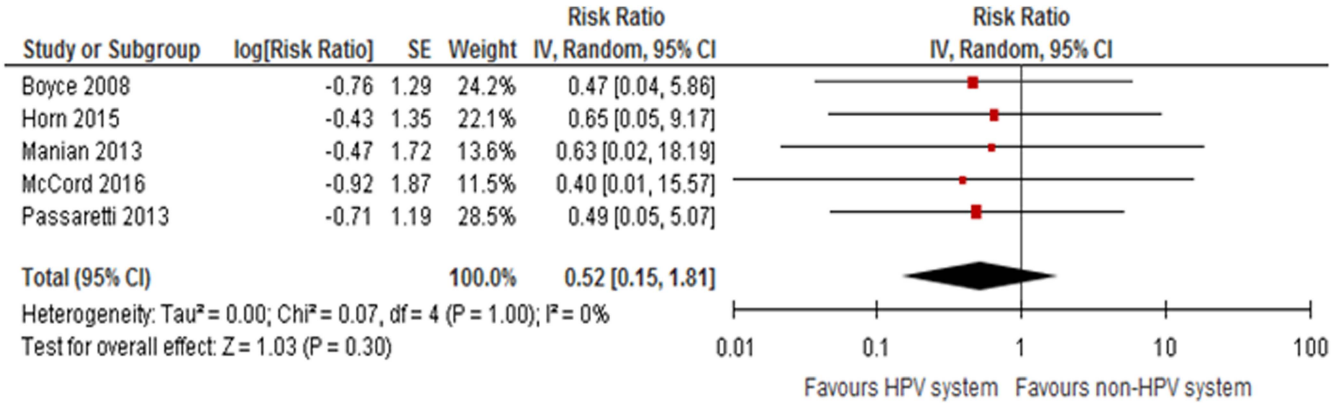

FIGURE 4. Forest plots of the associations between HPV no-touch technology and *Clostridium difficile* infection (CDI). Abbreviations: CI, confidence interval; IV, inverse variance weighting; SE, standard error.

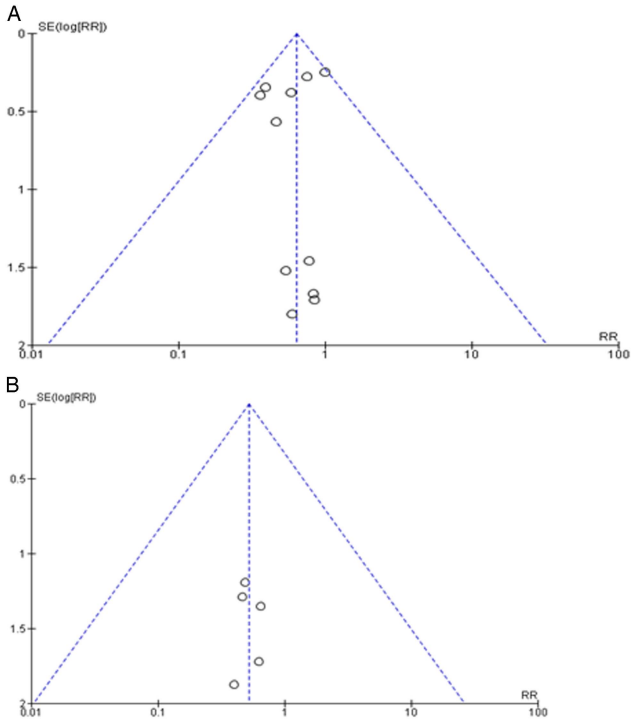

FIGURE 5. Funnel plots demonstrating the association between (A) UVL no-touch technology and *Clostridium difficile* infection (CDI) and (B) HPV no-touch technology and CDI. Abbreviations: SE, standard error; RR, risk ratio.

The HPV study by Cooper et al[25] was not included in the meta-analysis because it was not possible to calculate the risk ratio with the available data. There was also no statistically significant difference for MRSA infection rates (pRR, 0.54; 95% CI, 0.07–4.13; $P = .55$; Supplementary Appendix 4). The results of meta-analyses for CDI and for MRSA were homogeneous (for CDI: heterogeneity $P = 1.00$; $I^2 = 0\%$; for MRSA: heterogeneity $P = 1.00$; $I^2 = 0\%$ (see Figure 4 for CDI and Supplementary Appendix 4 for MRSA). Only 2 studies used HPV for VRE.[27,40] Both showed a reduction for VRE infection/colonization rates (from 0.21 to 0.01 cases per 1,000 patient days in one study[27] and from 11.6 to 2.4 per 1,000 patient days in another study[40]). We did not pool the results because a single study[40] would have contributed 99.5% of the weight in this analysis (data not shown).

Our analysis of the potential for publication bias with funnel plots (Figures 5A and 5B) suggested that there was little evidence of publication bias among UVL and HPV studies when CDI was evaluated as the outcome. Too few studies evaluated other outcomes to determine whether publication bias was present (Supplementary Appendix 5). Also, analyzing the potential for publication bias with funnel plots (Supplementary Appendix 6A–6D) showed little evidence of publication bias among the majority of UVL studies when CDI subgroups were evaluated as the outcome.

DISCUSSION

This systematic review and meta-analysis showed that using UVL no-touch technology to enhance environmental hygiene can decrease HAIs for specific pathogens, specifically CDI and VRE infections. For CDI prevention it seems that there is a benefit for hospitals with high baseline CDI rates. There was some evidence of a decrease in and VRE infection with HPV disinfection, but more studies are needed to confirm these results. A growing number of hospitals are using no-touch technologies (UVL or HPV system) for environmental decontamination,[14–16] as there is now a greater understanding that environmental contamination contributes to HAIs.[43] The great majority of disinfection studies consider surface contamination as an outcome measure and they advocate that eradicating microorganisms from patient room surfaces contributes to infection control[8,13–16]; however, fewer disinfection studies have evaluated, and MDROs can survive on inanimate surfaces for prolonged periods.[7,10] Contact with hospital room surfaces or medical equipment by HCWs also contributes to the environmental transmission of microorganisms and

frequently leads to the contamination of hands and gloves.[8,10,12,14] Clonal outbreaks of pathogens contaminating the room surfaces of colonized or infected patients have also been demonstrated.[10,14]

There is a risk of pathogen acquisition for patients associated with prior room occupancy[5,6] not only for gram-positive organisms,[6] such as MRSA and VRE[3,6] and *C.* difficile,[4,5] but also for gram-negative organisms such[6] as *Acinetobacter*.[4] Manual terminal cleaning of rooms decreases the burden of microbial contamination but cannot eliminate it completely.[13,44] In fact, one study found that only 50% of room surfaces are properly cleaned after terminal disinfection of patient rooms.[11] Cleaning is a complex, multifaceted process, plagued with random variation and the potential for introducing new pathogens if cleaning cloths and solutions become contaminated. Other problems include the high turnover of housekeepers in hospitals, incorrect disinfectant contact times, and overdilution of disinfectant solutions. All of these problems underscore the need for enhancement with automated decontamination processes such as UVL and HPV no-touch technologies.[8,13,15,16]

In our systematic review, we identified 2 clinical trials comparing UVL system disinfection after terminal cleaning with standard terminal cleaning.[41,42] One of the studies is a multicenter, cluster-randomized crossover trial with 4 comparisons after terminal cleaning: UVL alone, UVL plus bleach, bleach alone, and a quarternary ammonium disinfectant (except for *C. difficile*, for which bleach was used).[41] The other UVL controlled clinical trial compared 3 UVL hospital units (intervention arm) with 3 control units (control arm) where UVL disinfection was not used.[42] There are no clinical trials evaluating HPV systems. Most of the UVL or HPV studies evaluating the impact on HAIs (18 studies) were nonrandomized, quasi-experimental studies.[23–40] Quasi-experimental studies attempt to demonstrate causality between an intervention and an outcome and encompass a broad range of nonrandomized intervention studies. These designs are frequently used when it is not logistically feasible or ethical to conduct a randomized controlled trial.[22] In our review, the outcome measures demonstrated a benefit to the use of UVL disinfection to decrease *Clostridium difficile* and VRE infections, and HVP was shown to decrease VRE infection. Importantly, however, only 2 HPV studies evaluated VRE infection rates.[27,40] Also, few studies (6 studies)[23,25,26,30,34,41] applied these no-touch technologies after terminal cleaning in all patient rooms hospital-wide, independent of whether the patients were in contact precautions. Most of these studies applied no-touch technology in restricted situations such as the rooms of patients with *C. difficile,* MRSA, VRE, or other MDROs.[23,25,27,29,30,33,34,36,38–42]

A limitation of our study was that we included many studies that were before-and-after quasi-experimental studies, which are subject to multiple biases.[22] However, this is the most common study design in the infection prevention literature.[22] The disadvantages of no-touch technologies are that the patient room must be vacated and cleaned before the technology can be used. This can cause logistical problems and can impede patient flow and nursing care. In addition, the room equipment and furniture must be moved away from walls to prevent shadowing for UVL, and air vents, doors, and windows must be isolated and sealed for the use of HPV. Other disadvantages are the contact time, device distance and the inability of UV to reach around corners or reach partially opened items such as drawers. In our study, one-third of these studies (7 studies) reported the turnaround time and details about how to run the no-touch robots.[23,29,34,37,38,40,41] Only 2 studies (UVL) performed a cost-effectiveness evaluation of using no-touch technology after terminal cleaning,[34,35] with annual costs for the first year estimated to be nearly $300,000 (including personnel and equipment acquisition), and approximately $200,000 for the next year.[34] This finding must be balanced against the cost of HAIs; *C. difficile* and VRE cases are nonreimbursable and cost $14,000 per case on average.[35,46,47]

We believe that no-touch methods (UVL and HPV systems) augment traditional cleaning but cannot replace it. Given the goal to eliminate all preventable HAIs, hospitals will need to continue to improve in both hand hygiene and environmental disinfection. More randomized trials should be performed to evaluate these no-touch systems, as well as cost-effectiveness analyses to determine the role that no-touch systems can have in hospital infection control.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2017.226

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REFERENCES

1. Magill SS, Edwards JR, Bamberg W, Beldavs ZG, Dumyati G, Kainer MA, Lynfield R, Maloney M, McAllister-Hollod L, Nadle J, Ray SM, Thompson DL, Wilson LE, Fridkin SK. Emerging Infections Program Healthcare-Associated Infections and Antimicrobial Use Prevalence Survey Team. Multistate point-prevalence survey of health care-associated infections. *N Engl J Med* 2014;370:1198–1208.
2. Zimlichman E, Henderson D, Tamir O, Franz C, Song P, Yamin CK, Keohane C, Denham CR, Bates DW. Health care-associated infections: a meta-analysis of costs and financial impact on the US health care system. *JAMA Intern Med* 2013;173:2039–2046.

3. Huang SS, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. *Arch Intern Med* 2006;166:1945–1951.
4. Weber DJ, Rutala WA, Miller MB, Huslage K, Sickbert-Bennett E. Role of hospital surfaces in the transmission of emerging healthcare-associated pathogens: norovirus, *Clostridium difficile*, and *Acinetobacter* species. *Am J Infect Control* 2010;38: S25–S33.
5. Shaughnessy MK, Micielli RL, DePestel DD, Arndt J, Strachan CL, Welch KB, Chenoweth CE. Evaluation of hospital room assignment and acquisition of *Clostridium difficile* infection. *Infect Control Hosp Epidemiol* 2011;32:201–206.
6. Mitchell BG, Dancer SJ, Anderson M, Dehn E. Risk of organism acquisition from prior room occupants: a systematic review and meta-analysis. *J Hosp Infect* 2015;91:211–217.
7. Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC Infect Dis* 2006;6:130.
8. Dancer SJ. Controlling hospital-acquired infection: focus on the role of the environment and new technologies for decontamination. *Clin Microbiol Rev* 2014;27:665–690.
9. Wenzel RP, Edmond MB. Infection control: the case for horizontal rather than vertical interventional programs. *Int J Infect Dis* 2010;14(S1):S3–S5.
10. Weber DJ, Anderson D, Rutala WA. The role of the surface environment in healthcare-associated infections. *Curr Opin Infect Dis* 2013;26:338–344.
11. Carling PC, Parry MF, Bruno-Murtha LA, Dick B. Improving environmental hygiene in 27 intensive care units to decrease multi-drug-resistant bacterial transmission. *Crit Care Med* 2010;38:1054–1059.
12. Leas BF, Sullivan N, Han JH, Pegues DA, Kaczmarek JL, Umscheid CA. Environmental cleaning for the prevention of healthcare-associated infections. Rockville, MD: Agency for Healthcare Research and Quality (US); 2015 Aug. Report no.: 15-EHC020-EF.
13. Boyce JM. Modern technologies for improving cleaning and disinfection of environmental surfaces in hospitals. *Antimicrob Resist Infect Control* 2016;5:10.
14. Doll M, Morgan DJ, Anderson D, Bearman G. Touchless technologies for decontamination in the hospital: a review of hydrogen peroxide and UV devices. *Curr Infect Dis Rep* 2015;17:44.
15. Weber DJ, Rutala WA, Anderson DJ, Chen LF, Sickbert-Bennett EE, Boyce JM. Effectiveness of ultraviolet devices and hydrogen peroxide systems for terminal room decontamination: focus on clinical trials. *Am J Infect Control* 2016;44(5 Suppl):e77–e84.
16. Weber DJ, Kanamori H, Rutala WA. "No touch" technologies for environmental decontamination: focus on ultraviolet devices and hydrogen peroxide systems. *Curr Opin Infect Dis* 2016;29: 424–431.
17. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Plos Med* 2009;6:e1000097.
18. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, Moher D, Becker BJ, Sipe TA, Thacker SB. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis of observational studies in epidemiology (MOOSE) group. *JAMA* 2000;283:2008–2012.
19. Aboelela SW, Saiman L, Stone P, Lowy FD, Quiros D, Larson E. Effectiveness of barrier precautions and surveillance cultures to control transmission of multidrug-resistant organisms: a systematic review of the literature. *Am J Infect Control* 2006;34:484–494.
20. Cohen CC, Cohen B, Shang J. Effectiveness of contact precautions against multi-drug-resistant organism transmission in acute care: a systematic review of the literature. *J Hosp Infect* 2015;90:275–284.
21. Alderson PGS, Higgins JPT. editors Assessment of study quality. Cochrane reviewer's handbook 4.2.3 [Updated November 2004]. Chichester, UK: John Wiley & Sons; 2004.
22. Harris AD, Lautenbach E, Perencevich E. A systematic review of quasi-experimental study designs in the fields of infection control and antibiotic resistance. *Clin Infect Dis* 2005;41:77–82.
23. Boyce JM, Havill NL, Otter JA, McDonald LC, Adams NM, Cooper T, Thompson A, Wiggs L, Killgore G, Tauman A, Noble-Wang J. Impact of hydrogen peroxide vapor room decontamination on *Clostridium difficile* environmental contamination and transmission in a healthcare setting. *Infect Control Hosp Epidemiol* 2008;29:723–729.
24. Catalanotti A, Abbe D, Simmons S, Stibich M. Influence of pulsed-xenon ultraviolet light-based environmental disinfection on surgical site infections. *Am J Infect Control* 2016;44:e99–e101.
25. Cooper T, O' Leary, Yezli S, Otter JA. Impact of environmental decontamination using hydrogen peroxide vapour on the incidence of *Clostridium difficile* infection in one hospital Trust. *J Hosp Infect* 2011;78:238–240.
26. Green C, Pamplin JC, Chafin KN, Murray CK, Yun HC. Pulsed-xenon ultraviolet light disinfection in a burn unit: Impact on environmental bioburden, multi-drug resistant organism acquisition and healthcare associated infections. *Burns* 2017;43: 388–396.
27. Horn K, Otter JA. Hydrogen peroxide vapor room disinfection and hand hygiene improvements reduce *Clostridium difficile* infection, methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant enterococci, and extended-spectrum β-lactamase. *Am J Infect Control* 2015;43:1354–1356.
28. Levin J, Riley LS, Parrish C, English D, Ahn S. The effect of portable pulsed xenon ultraviolet light after terminal cleaning on hospital-associated *Clostridium difficile* infection in a community hospital. *Am J Infect Control* 2013;41:746–748.
29. Manian FA, Griesnauer S, Bryant A. Implementation of hospital-wide enhanced terminal cleaning of targeted patient rooms and its impact on endemic *Clostridium difficile* infection rates. *Am J Infect Control* 2013;41:537–541.
30. McCord J, Prewitt M, Dyakova E, Mookerjee S, Otter JA. Reduction in *Clostridium difficile* infection associated with the introduction of hydrogen peroxide vapour automated room disinfection. *J Hosp Infect* 2016;94:185–187.
31. Bernard H, Little J. The impact of ultraviolet (UV) disinfection system coupled with evidence-based interventions on the incidence of hospital onset *Clostridium difficile* (HO-C-Diff). *Am J Infect Control* 2015;43:S27.
32. Miller R, Simmons S, Dale C, Stachowiak J, Stibich M. Utilization and impact of a pulsed-xenon ultraviolet room disinfection system and multidisciplinary care team on *Clostridium difficile* in a long-term acute care facility. *Am J Infect Control* 2015; 43:1350–1353.

33. Mitchell BG, Digney W, Locket P, Dancer SJ. Controlling methicillin-resistant *Staphylococcus aureus* (MRSA) in a hospital and the role of hydrogen peroxide decontamination: an interrupted time series analysis. *BMJ Open* 2014;4:e004522.
34. Pegues DA, Han J, Gilmar C, McDonnell B, Gaynes S. Impact of ultraviolet germicidal irradiation for no-touch terminal room disinfection on *Clostridium difficile* infection incidence among hematology-oncology patients. *Infect Control Hosp Epidemiol* 2017;38:39–44.
35. Vianna PG, Dale CR Jr, Simmons S, Stibich M, Licitra CM. Impact of pulsed xenon ultraviolet light on hospital-acquired infection rates in a community hospital. *Am J Infect Control* 2016;44:299–303.
36. Haas JP, Menz J, Dusza S, Montecalvo MA. Implementation and impact of ultraviolet environmental disinfection in acute care setting. *Am J Infect Control* 2014;42:586–590.
37. Napolitano NA, Mahapatra T, Tang W. The effectiveness of UV-C radiation for facility-wide environmental disinfection to reduce healthcare-acquired infections. *Am J Infect Control* 2015;43:1342–1346.
38. Nagaraja A, Visintainer P, Haas JP, Menz J, Wormser GP, Montecalvo MA. *Clostridium difficile* infections before and during use of ultraviolet disinfection. *Am J Infect Control* 2015;43:940–945.
39. McMullen K, Wood H, Buol W, Johnson D, Bradley A, Dubberke E, Woeltje K, Warren D. Impact of a pulsed xenon ultraviolet light (PX-UV) light room disinfection system on *Clostridium difficile* infection rates. Infectious Diseases Society of America website. https://idsa.confex.com/idsa/2015/webprogram/Handout/POSTER240_1714.pdf. Published 2015. Accessed October 16, 2017.
40. Passaretti CL, Otter JA, Reich NG, Myers J, Shepard J, Ross T, Carroll KC, Lipsett P, Perl TM. An evaluation of environmental decontamination with hydrogen peroxide vapor for reducing the risk of patient acquisition of multi-drug-resistant organisms. *Clin Infect Dis* 2013;56:27–35.
41. Anderson DJ, Chen LF, Weber DJ, Moehring RW, Lewis SS, Triplett PF, Blocker M, Becherer P, Schwab JC, Knelson LP, Lokhnygina Y, Rutala WA, Kanamori H, Gergen MF, Sexton DJ, CDC Prevention Epicenters Program. Enhanced terminal room disinfection and acquisition and infection caused by multidrug resistant organisms and *Clostridium difficile* (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. *Lancet* 2017;389:805–814.
42. Sampathkumar P, Nation L, Folkert C, Wentink JE, Zavaleta KW. A trial of pulsed xenon ultraviolet disinfection to reduce *C. difficile* infection. *Am J Infect Control* 2016;44:S30–S31.
43. Weber DJ, Rutala WA. The role of environment in transmission of *Clostridium difficile* infection in healthcare facilities. *Infect Control Hosp Epidemiol* 2011;32:207–209.
44. Shams AM, Rose LJ, Edwards JR, Cali S, Harris AD, Jacob JT, LaFae A, Pineles LL, Thom KA, McDonald LC, Arduino MJ, Noble-Wang JA. Assessment of the overall and multidrug-resistant organism bioburden on environmental surfaces in healthcare facilities. *Infect Control Hosp Epidemiol* 2016;37:1426–1432.
45. Carling PC, Parry MF, Von Boheren SM, Healthcare Environmental Hygiene Study Group. Identifying opportunities to enhance environmental cleaning in 23 acute care hospitals. *Infect Control Hosp Epidemiol* 2008;29:1–7.
46. Dubberke ER, Olsen MA. Burden of *Clostridium difficile* on the healthcare system. *Clin Infect Dis* 2012;55(Suppl):S88–S92.
47. Cosgrove SE. The relationship between antimicrobial resistance and patient outcomes: mortality, length of hospital stay, and health care costs. *Clin Infect Dis* 2006;42(Suppl):S82–S89.