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 I² 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 in 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.
(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. and Cohen et al. 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." The authors (A.R.M. and M.B.E.) performed component quality analysis independently, reviewed all inconsistent assessments, and achieved consensus by discussion. 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.

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 (≥1.5 CDI/1,000 patient days) to low baseline CDI rates (<1.5 CDI/1,000 patient days); controlled versus uncontrolled interventions; academic versus community hospitals; and the quality of studies (those reporting compliance rates as completely adequate vs not completely adequate). All of the studies in the meta-analysis evaluated CDI rates. Some of the HPV studies included in our review were performed in the United States (13 studies), the United Kingdom (11 studies), and one study took place in Australia. All of the UV system studies were conducted in the United States (13 studies). 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), but other studies evaluated the no-touch technology after terminal cleaning of all patient rooms hospital-wide (4 studies), after terminal cleaning in oncology units (2 studies), and ICU patient rooms (2 studies) of which one study used UVL and one study used UV-C disinfection methods to decrease MDROs.

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; 17 (94.4%) compared infection rates before and after implementation of no-touch technology (UVL or HPV); and 1 was a prospective observational cohort study. Another 2 studies (10%) were clinical trials: 1 was a randomized trial and 1 was a controlled trial. Of the 20 studies, 13 (65%) used a UVL disinfection system, and 7 studies (35%) used an HPV disinfection system. Of the UVL disinfection system studies, 8 studies used pulsed Xenon UVL (PX-UV), 4 studies used UV-C radiation (UV-C), and 1 study did not specify the type of UVL.

Most of the studies included in our review were conducted in the United States (17 studies); 2 studies were performed in the United Kingdom; and 1 study took place in Australia. All of the UV system studies were conducted in the United States (13 studies). 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), but other studies evaluated the no-touch technology after terminal cleaning of all patient rooms hospital-wide (4 studies), after terminal cleaning in oncology units (2 studies), and ICU patient rooms (2 studies) of which one study used UVL and one study used UV-C disinfection methods to decrease MDROs.
<table>
<thead>
<tr>
<th>First Author, Year, Location</th>
<th>Method</th>
<th>Study Design</th>
<th>Study Period/Intervention Period, Months</th>
<th>Hospital Type (No. of Beds)</th>
<th>Intervention Site</th>
<th>Year of Intervention</th>
<th>Outcome</th>
<th>Baseline CDI Rate</th>
<th>Alternative Interventions Compliance Reporteda</th>
<th>Cost-Effectiveness Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levin, 2013, Worcester, MA</td>
<td>UV-PX</td>
<td>Before–after</td>
<td>48/12</td>
<td>Community (140)</td>
<td>All patient rooms HW</td>
<td>2011</td>
<td>Decreased infection, death, colectomy due to HA-CDI</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Miller, 2015, Southeastern</td>
<td>UV-PX</td>
<td>Before–after</td>
<td>48/24</td>
<td>LTACH (NA)</td>
<td>All patient rooms</td>
<td>2012</td>
<td>Decreased HA-CDI</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Nagajara, 2015, Valhalla, NY</td>
<td>UV-PX</td>
<td>Before–after</td>
<td>24/12</td>
<td>Community (652)</td>
<td>All contact precautions rooms</td>
<td>2011</td>
<td>Decreased ICU HA-CDI</td>
<td>Low</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Vianna, 2016, Orlando, FL</td>
<td>UV-PX</td>
<td>Before–after</td>
<td>44/22</td>
<td>Community (126)</td>
<td>All ICU rooms; CD non-ICU rooms</td>
<td>2012</td>
<td>Decreased HA-CDI, HA-MRSA, HA-VRE infections</td>
<td>Low</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Napolitano, 2015, Culver City, CA</td>
<td>UV-C</td>
<td>Before–after</td>
<td>11/6</td>
<td>Community (420)</td>
<td>All patient rooms HW</td>
<td>2012</td>
<td>Decreased HA-CDI, HA-AB, HA-KP infections; No decrease in HA-MRSA, HA-VRE infections</td>
<td>Low</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Napolitano, 2015, Culver City, CA</td>
<td>UV-C</td>
<td>Before–after</td>
<td>10/6</td>
<td>Community (420)</td>
<td>All patient rooms HW</td>
<td>2012</td>
<td>Decreased HA-CDI</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Bernard, 2015, Mohawk, NY</td>
<td>NA</td>
<td>Before–after</td>
<td>24/12</td>
<td>Community (NA)</td>
<td>All patient rooms HW</td>
<td>2013</td>
<td>Decreased HA-CDI</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Catalanotti, 2016, Lowell, MA</td>
<td>UV-PX</td>
<td>Before–after</td>
<td>36/20</td>
<td>Community (200)</td>
<td>All ORs</td>
<td>2013</td>
<td>Decreased class I SSI but not class II</td>
<td>Not studied</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>McMullen, 2016, St Louis, MO</td>
<td>UV-C</td>
<td>Before–after</td>
<td>31/7</td>
<td>Community (1,250)</td>
<td>CD, CRE or diarrhea patient room HW</td>
<td>2014</td>
<td>No decrease in HAI-CDI</td>
<td>Low</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Sampathkumar, 2016, Rochester, MN</td>
<td>UV-PX</td>
<td>Before–after</td>
<td>&gt; 6/6</td>
<td>Academic (2,207)</td>
<td>All patient rooms in 2 oncology units, 1 medical-surgical unit</td>
<td>NA</td>
<td>Decreased HA-CDI</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Puges, 2017, Philadelphia, PA</td>
<td>UV-C</td>
<td>Before–after</td>
<td>24/12</td>
<td>Academic (789)</td>
<td>All patient rooms in 3 oncology units</td>
<td>2014</td>
<td>Decreased HA-CDI</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Green, 2017, San Antonio, TX</td>
<td>UV-PX</td>
<td>Before–after</td>
<td>18/3</td>
<td>Military (425)</td>
<td>9 ICU rooms and 2 ORs in burn unit</td>
<td>2014</td>
<td>No decrease in HA-MDR</td>
<td>Not studied</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Anderson, 2017, Burlington, Chapel Hill, Durham, High Point, Raleigh, NC, Chesapeake, VA</td>
<td>UV-C</td>
<td>Before–after</td>
<td>28/28</td>
<td>6 community, 2 academic, 1 VA (3,947)</td>
<td>CD, MRSA, VRE, MDR-AB rooms</td>
<td>2012</td>
<td>Decreased VRE and composite HA-target organisms (CD + MRSA + VRE + MDR-AB); no decrease in HA-CDI, HA-MRSA, MDR-AB</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
### B. HPV Studies

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

**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.

*Alternative interventions include hand hygiene, antimicrobial stewardship.
baseline CDI rates, 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 and 3 were studies of HPV. 27,30,40 In addition, 6 studies evaluated VRE rates as the outcome, 27,36-37,41 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; I² = 0%; for VRE: heterogeneity P = .93; I² = 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 hospitals: pRR, 0.48; 95% CI, 0.30–0.77; P = .002) (Figure 3C). Considering the quality of studies reporting compliance rates as completely adequate 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.
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).\textsuperscript{23,27,29,30,40}
The HPV study by Cooper et al.\(^\text{25}\) 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.\(^\text{27,40}\) Both showed a reduction for VRE infection/colonization rates (from 0.21 to 0.01 cases per 1,000 patient days in one study\(^\text{27}\) and from 11.6 to 2.4 per 1,000 patient days in another study\(^\text{40}\)). We did not pool the results because a single study\(^\text{40}\) 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 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,\(^\text{14–16}\) as there is now a greater understanding that environmental contamination contributes to HAIs.\(^\text{42}\) 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\(^\text{8,13–16}\); however, fewer disinfection studies have evaluated, and MDROs can survive on inanimate surfaces for prolonged periods.\(^\text{7,10}\) 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.\textsuperscript{8,10,12,14} Clonal outbreaks of pathogens contaminating the room surfaces of colonized or infected patients have also been demonstrated.\textsuperscript{10,14}

There is a risk of pathogen acquisition for patients associated with prior room occupancy\textsuperscript{5,6} not only for gram-positive organisms,\textsuperscript{8} such as MRSA and VRE\textsuperscript{5,6} and C. difficile.\textsuperscript{8,15,16} but also for gram-negative organisms such\textsuperscript{9} as Acinetobacter.\textsuperscript{4} Manual terminal cleaning of rooms decreases the burden of microbial contamination but cannot eliminate it completely.\textsuperscript{1,13,44} In fact, one study found that only 50\% of room surfaces are properly cleaned after terminal disinfection of patient rooms.\textsuperscript{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.\textsuperscript{8,13,15,16}

In our systematic review, we identified 2 clinical trials comparing UVL system disinfection after terminal cleaning with standard terminal cleaning.\textsuperscript{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 quaternary ammonium disinfectant (except for C. difficile, for which bleach was used).\textsuperscript{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.\textsuperscript{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.\textsuperscript{23–34,37,38,40} 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.\textsuperscript{22} In our review, the outcome measures demonstrated a benefit to the use of UVL disinfection to decrease Clostridium difficile and VRE infections, and HPV was shown to decrease VRE infection. Importantly, however, only 2 HPV studies evaluated VRE infection rates.\textsuperscript{27,46} Also, few studies (6 studies)\textsuperscript{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.\textsuperscript{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.\textsuperscript{22} However, this is the most common study design in the infection prevention literature.\textsuperscript{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.\textsuperscript{23,29,34,37,38,40,41} Only 2 studies (UVL) performed a cost-effectiveness evaluation of using no-touch technology after terminal cleaning.\textsuperscript{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.\textsuperscript{24} 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.\textsuperscript{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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