5. Infections Due to Other Multidrug-Resistant Organisms

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Introduction

Background

Multidrug-resistant organisms (MDROs) are microorganisms, mainly bacteria, that are resistant to one or more classes of antimicrobial agents.[1] These include methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant Enterococci species (VRE), carbapenemase-producing Enterobacteriaceae, and Gram-negative bacteria that produce extended spectrum beta-lactamases (ESBLs). These last two types of pathogens produce chemicals that allow them to resist the effect of certain antimicrobials, and this adaptation is easily passed between different species.

Other species of note include MDR *Escherichia coli* and *Klebsiella pneumoniae*, *Acinetobacter baumannii* (abbreviated AB; some strains are resistant to all antimicrobial agents), and organisms such as *Stenotrophomonas maltophilia* that are intrinsically resistant to the broadest-spectrum antimicrobial agents.[1] MDROs' resistances limit treatment options for patients, making infection critical to preventing further harms.

Importance of Harm Area

The World Health Organization (WHO) now recognizes that MDROs are a growing threat in every geographic region of the world.[2] Drug-resistant bacteria pose a significant public health risk both domestically and abroad due to their ability to colonize individuals without causing symptoms, their endurance in the environment, and the clinical threat they pose.[3] The growing presence of resistant microbes is of particular concern for vulnerable patients, such as those who have received organ transplantation, those with cancer, preterm infants, and immune-suppressed and other medically vulnerable individuals.[2]

With treatment complicated by the limited availability of antimicrobials to treat these infections, MDROs are responsible for approximately 23,000 deaths annually from antibiotic-resistant pathogens in the United States alone.[4] The Centers for Disease Control and Prevention (CDC) (2018) states that 11 percent of individuals screened in healthcare facilities are asymptomatic carriers for a transmissible, "hard-to-treat" microorganism.[5]

Drug-resistant organisms are becoming increasingly present in all settings and geographic areas. As cited in Tacconelli et al. (2014), carbapenem resistance increased in five European countries from 2008 to 2011.[6] In the United States, infections caused by multidrug-resistant, Gram-negative bacteria have increased over the past decade, and one out of five hospitals reporting invasive infections implicated a carbapenem-resistant *K. pneumoniae*, one of the most common MDROs.[6] While rates of hospital-onset, MRSA-related bacteremia in the United States have declined, community-onset MRSA-related bacteremia has increased in recent years.[7]

The patient safety practices (PSPs) in this report have universal application for reducing the burden of colonization and infection. When differences are significant (e.g., Enterococci in the digestive tract vs. *S. aureus* on patient skin), we make a note in the findings. The large benefit of these practices, however, comes from this universality: whether the organism is an extremely drug resistant *A. baumannii* or methicillin-susceptible *S. aureus,* infection prevention reduces risks and prevents patient harms.

Methods for Selecting PSPs

To determine the optimal methods for controlling MDROs and preventing MDRO-related infection, we reviewed CDC guidelines[8] and the compendium of strategies from the Society for Healthcare Epidemiology of America.[9,10] Using these systematic reviews and reports, we developed an initial list of 23 PSPs that target diagnostic errors, and the Technical Expert Panel, Advisory Group, and AHRQ reviewed it.

Based on the reviewers' recommendations, we identified six priority PSPs:

- Chlorhexidine bathing to control MDROs
- Hand hygiene to reduce MDRO transmission
- Active surveillance strategies for MDROs
- Environmental cleaning and disinfection strategies
- Minimizing exposure to invasive devices and reducing device-associated MDRO risks
- Communication of patients' MDRO status

What's New/Different Since the Last Report

The previous Making Health Care Safer reports included recommendations for infection control practices, including multicomponent interventions for device-associated infections as well as general infection prevention. In this report, we focus on the evidence for those practices (and some new practices) to reduce the transmission of and infections caused by MDROs.

As noted in previous Making Health Care Safer reports, the epidemiology of MRSA, VRE, and other MDROs has continued to evolve; this report updates the literature with responses to that emerging, evolving resistance in the following ways:

- Chlorhexidine bathing is a practice that can be combined with others (such as active surveillance and contact precautions) in response to MDRO outbreaks or added to routine patient bathing to control MDROs and prevent infection. Current guidelines focus mainly on acute care populations, especially critical care. In this report, we include studies of non-critical care populations and some studies on chlorhexidine in community settings. This review also includes information on chlorhexidine resistance and important considerations when adding chlorhexidine bathing to routine patient care.
- Hand hygiene is a universal strategy for preventing transmission of MDROs and MDRO-related infection, regardless of patient care risk factors. This review also includes new findings on the role of patient hand hygiene and mathematical models to measure the impact of hand hygiene (in combination with other PSPs or alone).

- For active surveillance, this review looks at specific strategies for identify MDRO-infected and MDRO-colonized patients, particularly active surveillance cultures/testing of patients and their environment, to prevent MDRO transmission.
- Environmental cleaning is a new practice in this report, and our review focuses both on the efficacy of different cleaning products and strategies to ensure thorough cleaning.
- Many practices and resources for minimizing the risk of harm due to device use were covered in the previous version of Making Health Care Safer; this review includes updated literature and any additional resources since that publication was written.
- Finally, communicating patients' MDRO status (also new in this report) allows facilities to take appropriate infection prevention precautions from the start of the patient encounter. This report provides evidence on the negative effects of missed communication and some examples of communication strategies.

References for Introduction

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5.1 PSP: Chlorhexidine Bathing To Control MDROs

Reviewer: Sam Watson, M.H.A.

Chlorhexidine solutions have broad antimicrobial activity and are already commonly in use as topical disinfectants and antiseptics as part of recommended strategies for MDRO control and infection prevention.[1-3] Either universal or targeted chlorhexidine bathing can complement other infection control methods of screening, isolation, and eradication.[4]

This chapter examines specific efficacy of chlorhexidine to prevent different infections (by organism, by type of infection), the mode and frequency of successful chlorhexidine bathing for disease prevention, and considerations for or unintended consequences of general chlorhexidine use. The review' key findings are located in the box to the right.

Key Findings

- The strongest evidence supports using chlorhexidine bathing to reduce colonization and infection, particularly by multidrug--resistant Gram-positive bacteria (MDR-GPB) such as MRSA and VRE, and for healthcare-associated infections (HAIs) related to medical devices that create a break in the skin (e.g., central lines).
- Less evidence is available to support chlorhexidine bathing for preventing infection from MDR Gram-negative bacteria (MDR-GNB), such as carbapenem-resistant Enterobacteriaceae (CRE), and for other types of HAIs.
- As an intervention, chlorhexidine is low cost to implement (especially if routine bathing is already in place) and generally well received by staff, but compliance with bathing can wane over time.
- While the literature has not described any clinical effects of chlorhexidine resistance, this practice should continue to be monitored.

5.1.1 Practice Description

For the purpose of this review, we define "chlorhexidine bathing" as application of chlorhexidine to the skin or oropharyngeal surfaces to promote decolonization and to prevent infection. As described below, oropharyngeal surfaces represent a reservoir for MDROs in mechanically ventilated patients who cannot perform their own oral care. Since chlorhexidine bathing is recommended for patients at high risk for MDRO-related infections—generally intensive-care patients, many of whom may be mechanically-ventilated as part of their care—we include oral care as part of a chlorhexidine bathing routine.[3]

5.1.2 Methods

To investigate the current literature for chlorhexidine bathing—for which patients, in what form, how often, and with what effectiveness—we searched three databases (CINAHL, MEDLINE, and Cochrane) for a combination of the keywords "chlorhexidine bathing" and MeSH terms related to "cross infection prevention," "drug resistance, multiple, bacterial," and "drug resistance, microbial." Articles from 2008 through December 31, 2018, were included. (Any relevant articles published after the original search are included in the PRISMA diagram as additional sources.)

The initial search yielded 323 results (including 6 articles from other sources); after duplicates were removed, 300 were screened for inclusion, and 124 full-text articles were retrieved. Of those, 42 were selected for inclusion in this review. Articles were excluded if they did not mention chlorhexidine's role in preventing MDROs, mentioned a PSP other than bathing, or discussed use of chlorhexidine outside the healthcare environment. Chlorhexidine oral care was included in this review, as were in vitro studies that assessed the impact of chlorhexidine use on the selection or development of resistant organisms.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report appendixes A through C.

5.1.3 Review of Evidence

One of the aims of this review is to better understand the nuances of chlorhexidine's efficacy for controlling and preventing infection caused by MDROs.

The questions of interest for this review are: Which chlorhexidine applications are most effective for decolonization and for infection control, against which organisms is chlorhexidine the most effective, and what are the potential outcomes related to chlorhexidine resistance? Further, which patients benefit the most from chlorhexidine bathing?

Many of the studies included in this report and in systematic reviews focus on intensive care unit (ICU) patients, who have the most risk factors for MDRO colonization and infection. While these patient populations show benefits in terms of reduced colonization, carriage, and infection, the studies that include relatively healthy populations (both in community and hospital settings) show more nuanced results without a clear benefit.

The studies summarized in this section include several well-designed, rigorous studies, some of which have very large populations (tens or hundreds of thousands). When findings are nuanced, we note where limitations may have contributed a null finding or if mediating factors showed benefit for one subgroup but not the whole population.

This summary indicates the best-supported uses of chlorhexidine and the level of evidence for other uses. Section 5.3.4 provides a list of resources for implementing chlorhexidine bathing protocols. Where the evidence is not definitive, such as using chlorhexidine bathing to prevent infection for relatively healthy patient populations or reduce MDROs in community settings, we hope this review will help clinical staff make their own determination on implementing chlorhexidine bathing.

5.1.3.1 Efficacy for Controlling MDROs and Preventing Infection

In the sections below, we summarize the clinical results of chlorhexidine bathing for major MDROs (MRSA, VRE, CRE), HAIs, and other results. This summary is accompanied by a table that briefly describes the supporting evidence for each section. Additional information can be found in the Chlorhexidine Bathing Evidence Table (see Appendix B).

5.1.3.1.1 MRSA

Evidence suggests that chlorhexidine bathing in the hospital setting reduces MRSA acquisition and carriage but may not always result in fewer MRSA infections. Three systematic reviews found evidence that chlorhexidine bathing alone reduces MRSA acquisition and carriage.[5-7] This finding is supported by five strong studies (four experimental, one quasi-experimental) that also found chlorhexidine bathing reduced MRSA carriage and acquisition.[8-12] While most of these studies found that bathing also reduced MRSA infections, Derde and colleagues' review (2012) included some studies that found no significant reduction in infections.[6]

One prospective cohort study found no reduction in MRSA colonization rates, specifically, but did find a significant reduction in the rates of infections caused by all MDROs (measured in aggregate, not by specific MDRO).[13] Interpreting these results is made more difficult by the fact that chlorhexidine bathing

is recommended as part of a multicomponent strategy that includes nasal mupirocin and, in a few studies, oral antibiotics, as described in general MDRO and MRSA control guidelines.[3,14]

In long-term care facilities, Peterson and colleagues' cluster-randomized study (2016) demonstrated that a thorough decolonization protocol that includes chlorhexidine bathing can reduce MRSA colonization without the need for patient isolation.[12] This is an important finding for implementation, because extended patient isolation and gown and glove use may not be feasible or desirable in long-term or residential care settings.

Table 1 below presents the results from each study.

Table 1: Summary of MRSA Results

Study	Type of Study	Setting	MRSA Results
Climo et al., 2013[8]	Multicenter, cluster-randomized, non-blinded crossover trial	Hospital (ICU)	Reduced MRSA acquisition: total MDRO acquisition (MRSA or VRE) decreased from 6.6/1,000 patient-days to 5.1/1,000 patient-days (p=0.03).
Denny & Munroe, 2017[5]	Systematic review	Hospital	Reduced MRSA acquisition, colonization, transmission, and infection rates (statistical findings not reported for all studies).
Derde et al., 2012[6]	Systematic review	Hospital	Reduced MRSA acquisition and carriage but not consistently reduced MRSA infections (statistical findings not reported for all studies).
Huang et al., 2019[9]	Cluster-randomized trial	Hospital, non-critical care units	No statistically significant reduction in MRSA-positive cultures, except for a subgroup of patients with invasive medical devices. The hazard ratio (HR)[a] for the decolonization group of those patients was 0.8 (95% CI 0.69 to 0.96) compared with the routine care group's HR of 1.17 (95% CI 1.00 to 1.37) for MRSA- or VRE-positive culture (p=0.0004).
Huang et al., 2013[10]	Cluster-randomized trial	Hospital (ICU)	Significantly reduced MRSA-positive clinical cultures in chlorhexidine decolonization groups (p<0.001 for test of all groups being equal) compared with a screening and isolation approach: 0.75 HR for targeted decolonization (3.2 vs. 4.3 isolates/1,000 days), 0.63 for universal decolonization (2.1 vs. 3.4 isolates/1,000 days), and 0.92 for screening and isolation (crude rate, 3.2 vs. 3.4 isolates/1,000 days).
Musuuza et al., 2017a[11]	Quasi-experimental, pre-test/post-test study	Hospital (ICU)	Reduced MRSA colonization, but not statistically significant (9.2% to 5.6%, p=0.119).
Peterson et al., 2016[12]	Prospective, cluster-randomized trial	Long-term care facility	Reduced MRSA colonization.
Ruiz et al., 2017[13]	Prospective cohort study	Hospital (ICU)	No reduction in MRSA colonization.
Sidler et al., 2014[7]	Systematic review	Hospital (ICU)	Reduced MRSA acquisition and carriage but not consistently reduced MRSA infections.

5.1.3.1.2 VRE

Several studies found evidence that chlorhexidine can reduce VRE acquisition and colonization. One rigorous, multicenter study found that chlorhexidine bathing can reduce VRE acquisition.[8] Three systematic reviews found that chlorhexidine can reduce VRE carriage in hospital patients.[5-7] Finally, two quasi-experimental studies found reduced VRE colonization among patients who were bathed daily with

[a]A hazard ratio represents the risk of a negative outcome (in this case, MRSA-positive clinical culture) at any point in the study, versus relative risk or odds ratio, both of which represent cumulative risk over the length of the study.

chlorhexidine, and the Mendes and colleagues study (2016) additionally observed reduced VRE infections.[11,15] Table 2 below presents the results from each study.

Table 2: Summary of VRE Results

Study	Type of Study	Setting	VRE Results
Climo et al., 2013[8]	Multicenter, cluster-randomized, non-blinded crossover trial	Hospital (ICU)	Reduced VRE acquisition: total MDRO acquisition (MRSA or VRE) decreased from 6.6/1,000 patient-days to 5.1/1,000 patient-days (p=0.03).
Denny & Munro, 2017[5]	Systematic review	Hospital	Reduced VRE carriage (statistical findings not reported for all studies).
Derde et al., 2012[6]	Systematic review	Hospital	Reduced VRE carriage (statistical findings not reported for all studies).
Huang et al., 2019[9]	Cluster-randomized trial	Hospital, non-critical care units	No statistically significant reduction in VRE-positive cultures, except for a subgroup of patients with invasive medical devices. The HR for the decolonization group of those patients was 0.8 (95% CI 0.69 to 0.96) compared with the routine care group's HR of 1.17 (95% CI 1.00 to 1.37) for MRSA- or VRE-positive culture (p=0.0004).
Mendes et al., 2016[15]	Quasi-experimental observational and in vitro resistance study	Hospital (transplant ward)	Reduced VRE colonization and infection rates (colonization change in trend: Beta-3=–0.040, p=0.001; infection change in trend: Beta-3=–0.086, p=0.001).
Musuuza et al., 2017a[11]	Quasi-experimental, pre-test/post-test study	Hospital (ICU)	Reduced VRE colonization (14.5% to 8.4%, p=0.030).
Sidler et al., 2014[7]	Systematic review	Hospital (ICU)	Reduced VRE carriage in one meta-analysis reviewed (VRE colonization: incidence rate ratio 0.51; 95% CI 0.36 to 0.73; VRE infection: incidence rate ratio 0.57; 95% CI 0.33 to 0.97).

5.1.3.1.3 CRE

Few studies directly addressed chlorhexidine effects on CRE specifically (a number focused on the larger category of MDR-GNB). Of those that did, two observational cohort studies found that chlorhexidine bathing could reduce CRE colonization.[13,16] Table 3 below presents the results from each study.

Table 3: Summary of CRE Results

Study	Type of Study	Setting	CRE Results
Abboud et al., 2016[16]	Observational pre-post cohort study	Hospital (surgery ICU)	Significant reduction in CRE colonization (26.8% pre-intervention, 9.3% post-intervention; p<0.001).
Ruiz et al., 2017[13]	Prospective cohort study	Hospital (ICU)	Reduction in MDRO colonization, including Enterobacteriaceae (22.0% vs. 18.4%; p=0.01).

5.1.3.1.4 HAIs

Many studies examined the effect of chlorhexidine bathing on rates of various HAIs, such as catheter-associated urinary tract infection (CAUTI), ventilator-associated pneumonia (VAP)[b], and central line-associated blood stream infection (CLABSI). Where possible, we specify whether all infections or MDRO-only infections are noted in the results, but not all studies provided that level of detail. Based on the studies included, chlorhexidine bathing is most effective at reducing colonization by and HAIs from

[b]A note on terminology: In this review, we used the authors' words describing the HAIs they studied, which may be different from the terms currently in use (for example, ventilator-associated events or VAE is preferred over VAP due to difficulties with the definition of "VAP").

Gram-positive MDROs in patients who have a break in the skin due to a needed medical device (e.g., central line). Table 3 and the paragraphs below summarize these findings.

One review and several studies, including two large studies (Huang et al., 2013, and Huang et al., 2019) with more than 10,000 patients and 400,000 patients, respectively, have found evidence that chlorhexidine bathing can reduce the risk of HAIs, especially in intensive care units.[9,10] Huang and colleagues' 2013 REDUCE MRSA trial found universal decolonization involving daily chlorhexidine bathing throughout the patient's entire ICU stay and twice-daily intranasal mupirocin for 5 days was more effective than targeted decolonization or screening and isolation in reducing MRSA-positive clinical cultures and all-cause bloodstream infections.[10]

In a subsequent study (the ABATE Infection trial, 2019), Huang et al. evaluated the impact of universal chlorhexidine bathing and targeted mupirocin use for MRSA carriers in non-ICU settings.[9] The authors found that the intervention did not significantly reduce MRSA- or VRE-positive clinical cultures for the overall study population. In a post-hoc analysis, patients with medical devices (including central lines, midline catheters, and lumbar drains) were found to experience a significantly greater benefit from the intervention.

Similarly, Denny and Munroe's systematic review (2017) found the strongest evidence for reducing surgical site infection (SSI) and CLABSI rates, as well as acquisition, colonization, and infection for MRSA and VRE.[5] Among ICU patients, Climo and colleagues' 2013 study found a significant reduction in CLABSIs (the only HAI outcome included in that study).[8] As mentioned above, only a few studies included in this review examined chlorhexidine bathing for CRE, and only one, Abboud and colleagues' observational cohort study (2016), looked at CRE-related HAIs. Abboud and colleagues found reductions in those HAIs in CRE-colonized patients after chlorhexidine bathing was implemented.[16]

While some studies did not show an effect of chlorhexidine bathing on HAIs, most of these studies were considerably smaller than the two studies by Huang and colleagues. A rigorous cluster-randomized trial by Noto and colleagues (2015) found no impact on CLABSI, CAUTI, VAP, or *Clostridioides difficile* infection rates among the 9,340 patients in the study.[17] Ruiz et al. (2017) reduced MDRO colonization with chlorhexidine wipes, but this did not lead to a reduction in HAIs in their single-site study. Ruiz and colleagues also noted that longer ICU stays (in one Spanish hospital) were associated with overall incidence of HAIs, suggesting that chlorhexidine bathing alone was not sufficient to reduce the infection risk posed by extended stays in intensive care.[13]

Two studies directly compared the use of chlorhexidine bathing against bathing with soap and water, finding no improvement in HAI rates when chlorhexidine was used. Kengen et al.'s study of 6,634 ICU patients (2016, Australia) found no statistically significant difference in HAIs when patients received daily bathing with chlorhexidine instead of soap and water.[18]

Similarly, Boonyasiri and colleagues' smaller study of 418 Thai ICU patients (2016) found no benefit to chlorhexidine bathing over soap and water bathing on HAI rates in environments where most HAIs were caused by MDR-GNB.[19] However, Camus and colleagues (2014) reduced HAIs from MDR-GNB by adding mupirocin application to chlorhexidine bathing.[20]

Most studies of chlorhexidine for HAI prevention focused on BSIs, but a few looked at VAP and SSIs. Duszynska and colleagues' observation study (2017) also found no reduction in intubation-related

pneumonia, nor in UTIs, although overall infections and catheter-related infections were significantly lower.[21] A randomized trial of oropharyngeal decontamination using chlorhexidine found no effect on reduced BSIs from MDR-GNB in mechanically ventilated patients.[22]

Although chlorhexidine is routinely used for preoperative antisepsis in surgical settings, Abboud and colleagues (2016) found no supporting literature that chlorhexidine bathing reduced SSIs (although they did observe a reduction in SSIs among CRE-colonized patients in their study).[16] In their systematic review, Denny and Munroe (2017) did not find clear evidence of the efficacy of chlorhexidine bathing for preventing SSIs.[5]

Finally, Urbanic and colleagues (2018) raise an important limitation that applies to all these studies: because of other HAI prevention initiatives, the absolute number of HAIs is, in some cases, very low.[23] The number needed to treat with chlorhexidine bathing in order to significantly reduce HAIs may be, in some cases, larger than the number of patients enrolled in studies. This finding suggests that chlorhexidine bathing has limited benefit for HAI reduction in settings where HAIs are already well controlled by other means.

Table 4 below presents the results from each study.

Table 4: Summary of HAI Results

Authors	Type of Study	Setting	HAI Results
Abboud et al., 2016[16]	Observational pre-post cohort study	Hospital (surgery ICU)	Significant reduction in CLABSI (2.07/1,000 line-days to 0.23/1,000 line-days, p<0.002), VAP, and UTI rates in CRE-colonized patients. Reduced SSIs only in noncolonized, bathed patients (2.4% to 0.8%, p<0.003).
Boonyasiri et al., 2016[19]	Randomized, open-label controlled trial	Hospital (ICU)	No impact on HAI rates in settings where >60% of HAIs were caused by MDR-GNB.
Camus et al., 2014[20]	Multicenter, placebo-controlled, randomized, double-blind trial	Hospital (ICU)	When combined with mupirocin and administration of oral antibiotics, reduction in HAIs caused by MDR-GNB (5.45% to 1.59%, p<0.0001).
Climo et al., 2013[8]	Multicenter, cluster-randomized, nonblinded crossover trial	Hospital (ICU)	Reduction in CLABSIs (6.60/1,000 patient-days to 4.78/1,000 patient-days, p=0.007).
Denny & Munro, 2017[5]	Systematic review	Hospital	Reduced CAUTI, VAP, and CLABSI rates, across all studies reviewed (statistical findings not reported for all studies).
Duszynska et al., 2017[21]	Observational study	Hospital (ICU)	Reduction in catheter-related infections (p=0.005); non-significant reductions in UTIs and intubation-associated pneumonia.
Huang et al., 2019[9]	Cluster-randomized trial	Hospital, non-critical care units	No statistically significant reduction in all-cause BSIs among total population (189,081 patients in the baseline period and 339,902 patients in the intervention period). However, a sub-group of high-risk patients (those with medical devices) did have a significantly reduced HR of all-cause BSIs in the decontamination group compared with the routine care group (0.81 [95% CI 0.70 to 0.94] vs. 1.13 [95% CI 0.96 to 1.33]; p=0.0032).
Huang et al., 2013[10]	Cluster-randomized trial	Hospital (ICU)	Significantly greater reduction of all-cause BSIs in universal decolonization group, compared with both targeted decolonization and screening with isolation. All-cause BSI HRs were 0.99 (crude rate, 4.1 vs. 4.2 infections/1,000 days) for screening and isolation, 0.78 (3.7 vs. 4.8 infections/1,000 days) for targeted decolonization, and 0.56 (3.6 vs. 6.1 infections/1,000 days) for universal decolonization (p<0.001 for test of all groups being equal). MRSA-related BSIs reduced in decolonization groups, but not significantly.

Authors	Type of Study	Setting	HAI Results
Kengen et al., 2018[18]	Single-site retrospective, open-label, sequential period, interrupted time series analysis	Hospital (ICU)	No reduction in rates of ICU-associated, clinically significant positive blood cultures, blood culture contamination, newly acquired MDRO isolates, and *C. difficile* infections (CDIs).
Noto et al., 2015[17]	Pragmatic cluster-randomized, crossover study	Hospital (ICU)	No difference detected between the rates of CLABSI, CAUTI, VAP, and *C. difficile* infections.
Ruiz et al., 2017[13]	Prospective cohort study	Hospital (ICU)	No reduction in CLABSI, VAP, or UTI rates.
Wittekamp et al., 2018[22]	Randomized trial of oropharyngeal decontamination	Hospital (ICU)	No reduction in BSIs caused by MDR-GNB.

5.1.3.1.5 Other Results

This section summarizes other relevant results that do not fall under the categories above. Most of these studies focused on MDRO generally or MDR-GNB specifically. The studies we reviewed do not support chlorhexidine use but also do not warrant a recommendation *against* using it for MDR-GNB, although it may not be the most effective precaution for those organisms. Table 5 below presents the studies and their results.

None of the systematic reviews recommended chlorhexidine bathing for preventing/reducing MDR-GNB colonization.[6,7,24] One review (Tacconelli et al., 2014) found only temporary decolonization of MDR-GNB using chlorhexidine, and one randomized, open-label controlled trial (Boonyasiri et al., 2016) found that chlorhexidine bathing offered no reduction or delay in MDR-GNB acquisition.[19,24] Kengen and colleagues' retrospective time study (2018) found no difference in MDRO acquisition with chlorhexidine bathing compared with soap and water, whereas Ruiz and colleagues (2017) saw a reduction in MDRO acquisition, including MDR-GNB.[13,18]

Musuuza and colleagues' pre-post study (2017) found lower colonization with MDR-GNB (specifically, fluoroquinolone-resistant GNB) after chlorhexidine bathing, but Mendes and colleagues' quasi-experimental observational study (2016) did not.[15,25] Maxwell and colleagues (2017) found no difference between chlorhexidine and soap bathing for lowering MDRO infection rates (from GNB or GPB).[26] Pedreira and colleagues (2009) observed no reduction in MDRO colonization rates when chlorhexidine was added to standard oral care (toothbrushing) in pediatric ICU patients.[27]

Table 5: Summary of Other Results

Study	Type of Study	Setting	Other Results
Boonyasiri et al., 2016	Randomized, open-label controlled trial	Hospital (ICU)	No reduction/delay in MDR-GNB acquisition.
Derde et al., 2012[6]	Systematic review	Hospital	Little evidence supporting chlorhexidine bathing for MDR-GNB.
Kengen et al., 2018[18]	Single-site retrospective, open-label, sequential period, interrupted time series study	Hospital (ICU)	No reduction in ICU-associated, clinically significant blood cultures or in MDRO acquisition.
Maxwell et al., 2017[26]	Prospective, randomized control trial	Hospital (ICU)	No difference between soap and chlorhexidine at reducing infectio26ns from GNB or GPB.
Mendes et al., 2016[15]	Quasi-experimental observational study	Hospital (transplant ward)	Not effective in r19educing colonization from MDR-GNB.
Musuuza et al., 2017[11]	Quasi-experimental, pre-test/post-test study	Hospital (ICU)	Reduced prevalence of colonization with fluoroquinolone-resistant GNB.

Study	Type of Study	Setting	Other Results
Pedreira et al., 2009[27]	Randomized control study	Hospital (PICU)	No reduction in MDRO colonization rates (compared with standard care) when chlorhexidine was added to oral care (tooth-brushing) in pediatric ICU patients.
Ruiz et al., 2017[13]	Prospective cohort study	Hospital (ICU)	Reduction in overall MDRO colonization, including MDR-GNB.
Sidler et al., 2014[7]	Systematic review	Hospital (ICU)	Little evidence supporting chlorhexidine bathing for MDR-GNB.
Tacconelli et al., 2014[24]	Systematic review	Hospital	Only temporary decolonization of MDR-GNB.

5.1.3.2 Process Outcomes

5.1.3.2.1 Application

Chlorhexidine bathing, as described in the literature, covers a range in terms of concentration used, mode of application, and frequency. Of those studies that described the frequency of application (24 of 42), almost all described daily chlorhexidine bathing, with a smaller number using multiple applications per day (4 out of 24, of which one was an oropharyngeal-only application of chlorhexidine).

In terms of concentration, the vast majority of reviews and studies used a 2% chlorhexidine gluconate solution (either in prepackaged wipes or applied using a soaked washcloth). The exception was one oropharyngeal application (Camus et al., 2016) that used a 4% aqueous solution.[28] For otherwise healthy patients outside a hospital setting, Whitman and colleagues (2010) found daily bathing with 2% chlorhexidine cloths to be ineffective in reducing soft skin and tissue infection.[29] Chlorhexidine's effectiveness includes prolonged residual disinfection, so it is important not to rinse after use.[5]

5.1.3.2.2 Adverse Effects

The most common adverse effect in the literature was skin irritation, as seen in one systematic review and several studies.[5,10,19] When use of chlorhexidine wipes was discontinued, pruritus stopped. Oral mucosa lesions were observed in 9.8 percent of the 8,665 mechanically ventilated patients in Wittekamp and colleagues' chlorhexidine mouthwash study (2018).[22]

More serious adverse effects can occur with exposure to sensitive areas (eyes, esophagus, intestinal lining, inner ear), as noted in one systematic review.[5] Severe anaphylaxis is possible but rare (only found in case reports), as reported in reviews by Denny and Munroe (2017).[5]

5.1.3.3 Economic Outcomes

Only one study (Peterson et al., 2016) addressed the cost of chlorhexidine bathing, which was negligible when chlorhexidine was incorporated into an established daily bathing routine.[12] Since staff are already accustomed to daily bathing, no additional time is required, and the only potential cost is the difference between chlorhexidine supplies and previous bathing solutions.

5.1.3.4 Evaluations of Chlorhexidine Resistance

The most important unintended consequence of the wide use of chlorhexidine is the development of resistance to chlorhexidine and other biocides.[30] None of the MDROs in the studies in this review showed biocide resistance at the concentrations typically used for chlorhexidine bathing; the in vitro studies compared survivability of resistant MDROs in low concentrations of chlorhexidine. An equal number of studies supported or refuted the hypothesis that chlorhexidine bathing increases the prevalence of resistance genes in hospitals; however, many of these studies looked at isolates from a

single hospital and may have limited generalizability. Regardless of changes in prevalence, these authors hypothesize that overdiluted concentrations or residual chlorhexidine may be selecting for resistant organisms (either resistant clones/strains or organisms less susceptible to chlorhexidine) and should be monitored for clinical impact.[31-33]

5.1.3.4.1 In Vitro Studies

Resistance to chlorhexidine is detected by observing higher minimum inhibitory concentrations (MICs) to inhibit bacterial growth and higher minimum bactericidal concentrations (MBCs) to eliminate the organisms. One Scottish and one U.S. study found chlorhexidine resistance to be more common in settings where chlorhexidine bathing was routine.[34,35] In one in vitro study of MDRO isolate cultures from U.S. ICUs with and without daily bathing, Suwantarat and colleagues (2014) found that hospital ICU units that bathed patients were more likely to have CLABSI-causing organisms that could withstand higher levels of chlorhexidine (compared with units that did not conduct bathing).[35]

Hijazi and colleagues' (2016) in vitro study of samples collected over 7 years from Scottish ICUs found that implementing chlorhexidine bathing increased the prevalence of resistance genes in those organisms.[34] One retrospective cohort study in the United States found no conclusive trends in the prevalence of chlorhexidine-resistant MDROs after implementing chlorhexidine bathing, but the authors hypothesize that some increases may be due to readmitted patients who were unsuccessfully decolonized in previous hospitalizations.[36]

McNeil and colleagues' study of *S. aureus* in a U.S. pediatric hospital environment (2014) showed that organisms with resistance genes had MICs twice as high and MBCs 8 to 16 times as high as the more susceptible organisms ($p<0.005$).[37] However, several studies found that prevalence of resistance genes did not always result in measurable resistance. One in vitro study of cultures from an ICU after implementing chlorhexidine bathing found that resistance genes were linked to higher MICs in one MRSA strain but not another.[38]

Similarly, Musuuza and colleagues' pre-post study (2017) did not show increased MICs in MRSA and fluoroquinolone-resistant GNB after a daily bathing intervention in their U.S. hospital.[11] While not genetically resistant, oral MRSA biofilms studied in vitro by Smith and colleagues (2013) show considerable resistance to chlorhexidine mouthwashes, which may account for failure of mouth washing to prevent VAP and for frequent MRSA recolonization.[39]

5.1.3.4.2 Clinical Implications

The clinical impact of chlorhexidine resistance genes is unclear. One in vitro study of MRSA isolates in a U.S. hospital found that MRSA strains showed more resistance to chlorhexidine than methicillin-susceptible strains.[40] Similarly, Alotaibi and colleagues (2017) found more chlorhexidine resistance in VRE than in vancomycin-susceptible Enteroccoci strains in isolates from Danish hospitals.[41] Hayashi and colleagues (2017) found that *A. baumanii* epidemic strains from Japanese isolates showed increased resistance to chlorhexidine in vitro but not at concentrations typically used for disinfection.[42]

Two studies found evidence that might suggest that chlorhexidine bathing can favor chlorhexidine-resistant MDROs (particularly MDR-GNB) by eliminating the "competition" from chlorhexidine-susceptible MDROs. Abboud and colleagues (2016) found an increase in colonization with *Pseudomonas aeruginosa* and *A. baumanii* after chlorhexidine bathing was implemented in a Brazilian hospital ICU.[16] However, Camus and colleagues (2016, France) found no increase in MDR-GNB after implementation of

a multicomponent chlorhexidine bathing intervention for ventilated patients that also included oral care, mupirocin ointment, and oral antibiotics.[28] In that study, however, it is unclear what effect the additional components, particularly mupirocin ointment use, had on MDR-GNB rates. Cho and colleagues (2018) and McNeil and colleagues (2014) also found that chlorhexidine resistance genes were associated with mupirocin resistance in both South Korean and U.S. isolates; this finding may be due to the frequent combination of chlorhexidine and mupirocin in hospitals' decolonization strategies.[37,43]

Importantly, no studies suggested that chlorhexidine bathing was ineffective due to resistance; at the concentrations typically used (1-4%), chlorhexidine still kills even the most resistant organisms. However, overdiluted solutions may fail to kill organisms as intended and create unwanted transmission and infection, especially in cases where biofilms have formed.

5.1.3.4.3 Alternatives to Chlorhexidine

Several of the studies mentioned above examined multiple biocides and alternatives to chlorhexidine. Some alternatives, such as triclosan and hydrogen peroxide, have their own risk of resistance selection, as detailed in Wesgate and colleagues' in vitro study (2016).[44] Grare and colleagues' (2010) in vitro study shows the effectiveness of alternative cationic compounds[c] that show promising effectiveness against MDROs, but it will be some time before these products are commercially available.[45]

5.1.4 Implementation

As described above, the most common frequency of chlorhexidine bathing was daily, and the most common application was a 2% chlorhexidine gluconate solution, either in prepackaged wipes or in soaked washcloths. One important aspect of chlorhexidine use is to allow long-term contact with the skin. Ekizoğlu and colleagues (2016) recommended a contact time of at least 5 minutes, and no-rinse applications can further take advantage of chlorhexidine's persistent antimicrobial effects on the skin.[31] DeBaun and colleagues' in vitro study of MRD isolates (2008) suggests that extreme dilutions (between 1:2,048 and 1:8,192) of chlorhexidine may still be effective against MRSA and *A. baumanii*, but such extreme dilutions may not always be sufficiently bactericidal or inhibitory for resistant organisms (as discussed above under chlorhexidine resistance).[46]

Chlorhexidine can be successfully used for MRSA decontamination, when combined with mupirocin and active surveillance.[6] However, the effectiveness of decolonization for otherwise healthy populations is unclear. While Whitman and colleagues (2010) successfully reduced skin and soft tissue infections in healthy populations by instituting daily bathing with 2% chlorhexidine-impregnated clothes, Huang and colleagues (2019) did not find benefits to introducing chlorhexidine in a non-critical care hospital setting.[9,29]

Interestingly, a study by Fritz and colleagues (2012) found that a household intervention of *S. aureus* decolonization and personal care hygiene (i.e., relegating personal care items to a single individual and frequent, hot-water washing of linens and towels) reduced skin and soft tissue infections in household members but not the index case patients. Fritz et al. hypothesized that the acquisition of new *S. aureus* strains may put someone at higher risk for infection, rather than simply being colonized; 20 percent of the index patients (pediatric patients with a skin or soft tissue infection) were not colonized with *S. aureus* at screening, despite having an *S. aureus* culture from the infection site.[47]

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[c]Negatively charged chemical compounds that bind to proteins and can disrupt microorganisms' membranes.

5.1.4.1 Barriers and Facilitators to Implementation

In general, daily chlorhexidine bathing is a low-cost strategy that is well received by staff. Chlorhexidine bathing also has the advantage of being easy and quick to implement, as noted by Huang and colleagues (2013).[10] Two studies found that the staff responsible for implementing a chlorhexidine bathing intervention rated chlorhexidine bathing positively (Boonyasiri et al., 2016; Duszynska et al., 2017), and Huang and colleagues noted high rates of compliance (over 80%) in their MRSA decolonization study (2013).[10,19,21] However, Musuuza and colleagues (2017) noted that compliance can wane over time.[11]

In a survey of Thai hospitals, Apisarnthanarak and colleagues (2017) found that good leadership support for an infection control program was statistically significantly associated with regular use of chlorhexidine bathing (that is, hospitals without that support were less likely to use chlorhexidine bathing).[48] When facilities implement chlorhexidine bathing, leadership support for infection prevention programs can help sustain compliance with bathing over time.

5.1.4.2 Resources To Assist With Implementation

- A universal ICU decolonization protocol from the Agency for Healthcare Research and Quality. This protocol was followed in Huang et al., 2013, in which the authors demonstrated a statistically significant reduction in BSIs.
  https://www.ahrq.gov/hai/universal-icu-decolonization/index.html
- A chlorhexidine bathing implementation toolkit from the University of Wisconsin.
  https://www.hipxchange.org/CHGBathing

5.1.5 Gaps and Future Directions

As covered in Denny and colleagues' systematic review (2017), additional research could include[5]:

- Studies on the frequency and duration of bathing (how many times a day, for what period);
- Evaluations of chlorhexidine bathing's role in multicomponent programs (also suggested in commentary by Horner et al., 2012)[49]; and
- Continued research on chlorhexidine resistance and related clinical outcomes, especially the role of biofilms (as noted in commentary by Grascha, 2014) and Gram-negative bacteria (also suggested in commentary from Strich & Palmore, 2017).[50,51]

Although none of the studies included in this report indicated negative clinical outcomes due to chlorhexidine resistance, commentary by Kampf (2016) cautions against use of chlorhexidine for general, nonspecific applications such as hand hygiene or instrument soaking, where insufficient concentrations are more likely to occur.[52] Further studies to prevent these vulnerabilities in chlorhexidine bathing would be valuable to establishing bathing protocols.

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5.2 PSP: Hand Hygiene To Reduce MDRO Transmission

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Hand hygiene is one of the most fundamental and cost-effective infection control practices.[1] Yet despite over 150 years of efficacy evidence, hand hygiene opportunities continue to be missed in healthcare settings, with hand hygiene rates of only 40 to 60 percent in intensive care settings.[2] Johnston and Bryce (2009) identified several factors that support or impede hand hygiene compliance: environmental factors (making handwashing supplies accessible and convenient), individual factors (whether the person believes in the need for handwashing at the indicated opportunities), and organizational factors (whether a person's workflow allows proper handwashing to take place).[3]

The reasons for these missed opportunities are complex: patient care workload and limited time; inadequate staff education or knowledge about transmission risk; lack of convenient, accessible cleaning products and sinks; and even awareness that an opportunity for hand hygiene is occurring. In a nonsystematic review, Otter et al. (2013) found that although several MDROs (notably, *A. baumannii*) are known to contaminate the patient environment and survive on dry surfaces, healthcare personnel are less likely to conduct hand hygiene after environmental contact than after patient contact.[4] In addition, long artificial or natural nails can harbor harmful organisms, as can rings worn during care.[5-7]

Key Findings

- Hand hygiene is indispensable for preventing the transmission of MDROs. Hand hygiene compliance and compliance with other PSPs are complementary: high compliance with one practice is associated with high compliance with others.
- The World Health Organization's "My Five Moments for Hand Hygiene" was recommended or used by many studies in this review as the most effective tool for improving hand hygiene compliance, but many effective campaign materials are available.
- Staff can make existing campaigns even more effective by personalizing the implementation with educational and promotional materials and supporting each other in observing hand hygiene.
- The biggest barriers to hand hygiene compliance are: (1) realizing an opportunity for hand hygiene is occurring and (2) remembering to complete hand hygiene protocol, consistently, at every opportunity. Education can help with the first, and direct observation with immediate feedback helps improve the second.

New technology in the healthcare setting can aid hand hygiene (such as "smart badges" that remind staff to clean hands), but technological changes to workflow also introduce new hand hygiene opportunities (such as the use of personal cell phones in the clinical setting, as studied in Graveto and colleagues' 2018 review).[8] Hand hygiene interventions are generally well received and inexpensive to implement, and they align with medicine's principle of "first do no harm."[9] Several studies in this review demonstrate that it is possible to achieve very high rates of hand hygiene compliance. We include lessons learned from those studies for consideration when seeking to not just achieve but maintain those very high rates. The review's key findings are located in the box above.

5.2.1 Practice Description

Hand hygiene, as defined by the Centers for Disease Control and Prevention (CDC), is "cleaning your hands by using either handwashing (washing hands with soap and water), antiseptic hand wash, antiseptic hand rub (i.e., alcohol-based hand sanitizer including foam or gel), or surgical hand

antisepsis."[d] In this review, we include evidence-supported methods for disinfecting the skin of hands by using a cleaning solution (with or without water), with or without concurrent use of medical gloves. (This chapter does not focus on glove use.)

5.2.2 Methods

To investigate the role of hand hygiene in preventing transmission of MDROs and containing MDRO outbreaks, we searched three databases (CINAHL, MEDLINE, and Cochrane) for a combination of the keywords "hand hygiene," "hand disinfection," "hand sanitization," and "hand washing," as well as MeSH terms "cross infection prevention," "drug resistance, multiple, bacterial," and "drug resistance, microbial." Articles from January 1, 2008, through December 31, 2018, were included. (Any relevant articles published after the original search are included in the PRISMA diagram as additional sources.)

The initial search yielded 225 results (including 11 articles from other sources); after duplicates were removed, 207 were screened for inclusion, and 168 full-text articles were retrieved. Of those, 17 were selected for inclusion in this review. Articles were excluded if they did not mention hand hygiene's role in preventing MDRO transmission, described gown and glove use without also mentioning handwashing or hand disinfection, or did not include implementation in a healthcare setting. Outbreak response case studies are included in this review if they describe the role of hand hygiene in ending the outbreak.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report appendixes A through C.

5.2.3 Review of Evidence

Consistent hand hygiene at all opportunities in patient care is essential, since MDROs can be acquired from contact with a colonized patient or contaminated surface and transferred to new patients or surfaces.[6,9] In their systematic review of prevention for MDR Gram-negative bacteria (MDR-GNB), Tacconelli and colleagues (2014) strongly recommend correct hand hygiene before and after patient contact, as well as before and after contact with the patient environment, regardless of gown and glove use.[6] Even in facilities where hand hygiene compliance rates are high (above 80%), outbreaks can be opportunities to achieve near-perfect compliance. Palmore and Henderson (2013) note, however, that compliance will eventually return to baseline levels after an outbreak ends, highlighting the challenge of sustaining universal hand hygiene.[10]

Of the 17 studies and reviews included in this report, 5 studies and 1 review explicitly examined the causal relationship between better hand hygiene compliance and reduced MDRO transmission. An additional four studies used mathematical models to estimate the role of hand hygiene in multicomponent MDRO prevention strategies. Two studies looked at the role of patient hand hygiene in preventing MDROs, one study reviewed hand hygiene costs and cost savings (due to infection prevention), and one review looked at hand hygiene opportunities related to cell phone use. Finally, two

[d]Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, National Center for Emerging and Zoonotic Infectious Diseases, Division of Healthcare Quality Promotion. Accessed February 12, 2020 from https://www.cdc.gov/handhygiene/providers/index.html.

reviews and one study looked at factors influencing hand hygiene and best practices for increasing compliance.

5.2.3.1 Reducing MDRO Rates Through Hand Hygiene

Four studies found that improved hand hygiene reduced MDRO transmission and one found that the association between hand hygiene and reduced MDRO transmission varied by MDRO, as summarized in the table below. One review by Taconnelli et al. (2014) did not provide statistical findings but recommended hand hygiene for MDR-GNB based on the evidence of frequent hand contamination during patient care, MDRO survivability on hands, and risk of contamination due to fomites (objects or surfaces that are likely to carry infectious pathogens) in the patient environment.[6]

Table 6 summarizes the findings from studies evaluating the efficacy of hand hygiene for reducing MDRO transmission and infection.

Table 6: Summary of Clinical Outcomes of Hand Hygiene Interventions

Study	Sample Size, Population	Hand Hygiene Measures, MDROs	Outcomes
De la Rosa-Zamboni et al., 2018[11] Pre-post study of a hand hygiene communication campaign	All patients in a pediatric hospital in Mexico between January 2013 and October 2016	Direct hand hygiene observation MRSA, VRE, MDR-ESKAPE pathogens[e]	The authors observed a correlation between hand hygiene adherence and reduced attack rates for: • MRSA (coef, -17.10, 95% CI -30.67 to -3.53, p=0.019). • VRE (coef. -54.87, 95% CI -73.28 to -36.46, p=0.001). • *Enterobacter* spp. (coef. -33.04, 95% CI -51.14 to -14.94, p=0.002). • MDR-ESKAPE group (coef. -7.76, 95% CI -15.08 to 0.37, p=0.059.
Pires dos Santos et al., 2011[13] Pre-post study of a multi-component intervention, including hand hygiene and antibiotic stewardship	749-bed hospital in Brazil	Liters of alcohol-based hand rub consumed Carbapenem-resistant *P. aeruginosa* (CR-PA)	Antibiotic stewardship had little impact, but improved hand hygiene was significantly associated with reduced infection rates.
Sopirala et al., 2014[12] Pre-post quality improvement study including hand hygiene promotion and feedback, routine surveillance, and glove and gown use	All patients in a 1,191-bed hospital between January 1, 2006, and September 30, 2009	Direct observation of hand hygiene, volume of and soap/ sanitizer used MRSA	The program achieved high compliance with hand hygiene (93%) with reduced total MRSA cases from 0.49 to 0.34 per 1,000 patient-days (incidence rate ratio [IRR]=0.59, 95% CI 0.42 to 0.84, p=0.003) and MRSA-related bacteremia from 0.18 to 0.10 per 1,000 patient days (IRR=0.68, 95% CI 0.56 to 0.84, p<0.001).

[e] *Enterococcus faecium*, *S. aureus*, *K. pneumoniae*, *A. baumanii*, and *P. aeruginosa*.

Study	Sample Size, Population	Hand Hygiene Measures, MDROs	Outcomes
McLaws et al., 2009[15] Pre-post study of a hand hygiene promotion campaign	All public hospitals in the Australian State of New South Wales	MDR-AB, MRSA, and VRE	Hand hygiene rates increased in six of the nine hospital systems in the study (no change in two and a decrease in one). Between pre- and post-intervention periods, MRSA infections from nonsterile sites inside the ICU dropped by 16 percent, and those nonsterile sites outside the ICU dropped by 25 percent. MRSA infections in sterile sites (both within and outside the ICU) remained stable. VRE rates remained stable (except for an outbreak in some hospitals), and MDR-AB infections in ICU sterile sites fell (although not in other sites).
Vernaz et al., 2008[14] Interrupted time series analysis of increased alcohol-based hand rub use (as part of an intervention that included antibiotic use, patient isolation, screening on admission, automated computerized alerts, topical decolonization of MRSA carriers)	All hospital patients between February 2000 and September 2006, Switzerland	Hand rub use MRSA, *C. difficile* (not an MDRO but included in the study)	Consumption of hand rubs increased over the study period, from an average of 1.303 L per 100 patient-days in 2001 to 2.016 L per 100 patient-days. Only MRSA showed a temporal association between the increase in hand rub use and a decrease in MRSA rates.

De la Rosa-Zamboni and colleagues (2018) studied the efficacy of a hand hygiene intervention in a pediatric teaching hospital in Mexico. Alcohol-based hand rubs were placed in every patient unit and periodic education programs were individualized for each group of healthcare workers (attending physicians, nurses, residents, students, and ancillary staff) to highlight the mortality and costs associated with healthcare-associated infections and the evidence about efficacy of hand hygiene. Monthly monitoring and feedback were provided to each group about infection rates and hand hygiene compliance.

Hand hygiene adherence increased from 34.9 percent during the baseline period to 80.6 percent in the last 3 months of the pre-post study. The overall infection rate decreased from 7.54 to 6.46 per 1,000 patient-days (p=0.004), with central line-associated bloodstream infections declining from 4.84 to 3.66 per 1,000 central line-days (p=0.05).[11]

Sopirala and colleagues (2014) used a hand hygiene program that trained staff nurses in infection control and linked them to infection prevention staff for ongoing monthly education, achieving very high rates of hand hygiene compliance (93%) and reducing MRSA rates by almost half in the pre-post study.[12]

Pires dos Santos and colleagues (2011) studied multiple strategies to reduce CR-PA infections in a hospital in Brazil. They found that antibiotic stewardship had little impact, but improved hand hygiene (as measured by hospitalwide use of alcohol-based hand rub) was significantly associated with reduced infection rates.[13]

Vernaz and colleagues (2008) conducted an interrupted time series study of the temporal relationship between increased alcohol-based hand rub use (as part of multicomponent intervention) and reduced MRDOs. The authors established a temporal association between increased alcohol-based hand rub use and reductions in MRSA rates but not *C. difficile* rates. (This finding is consistent with evidence in this

report and in the guidelines reviewed, that alcohol-based hand rubs are not effective for spore-forming bacteria such as *C. difficile*.)[14]

Finally, one study of nine hospitals in Australia found that results varied across facility and different MDROs. McLaws and colleagues (2009) found mixed results across the sites included in their pre-post study of hospital regions in Australia. Hand hygiene rates increased in six of the nine hospital systems in the study. For the remaining three hospitals, one had a decrease and the other two had no observed change. Although hand hygiene increased overall, two of four clinical indicators of MRSA infection remained unchanged. The authors concluded that concurrent clinical and infection control practices at different facilities possibly influenced MRSA infection rates and modified the effects of hand hygiene compliance across the different locations.[15]

5.2.3.1.1 Mathematical Models of Hand Hygiene's Impact

We reviewed four studies that used mathematical models to estimate the impact of changes in hand hygiene compliance on MDRO acquisition and infection, controlling for the influence of other concurrent infection control or antibiotic stewardship interventions. To create these models, these studies used measurement from an existing facility or ICU; because these were based on single sites, the generalizability of these models may be limited. Still, these models offer examples of how to retroactively assess the effectiveness of individual components of multicomponent interventions, a common challenge given that few hand hygiene compliance programs are implemented without other concurrent practices or programs.[16]

Barnes and colleagues (2014) simulated scenarios of patient-to-patient transmission via the hands of transiently contaminated healthcare workers to quantify the effects of hand hygiene versus environmental cleaning on rates of MDRO acquisition. For all organisms studied (*A. baumannii*, MRSA, and VRE), increases in hand-hygiene compliance outperformed equal increases in thoroughness of terminal environmental cleaning. The authors estimated that a 20 percent improvement in terminal cleaning would be required to match the reduction in organism-acquisition achieved by a 10 percent improvement in hand hygiene compliance.[17]

D'Agata and colleagues (2012) modeled the impact of several distinct strategies for infection control. They found that improved hand hygiene compliance reduced MDRO colonization slightly more than improved compliance with contact precautions. They estimated that a 20 percent increase in hand hygiene compliance reduced colonization between 8 and 12 percent, while a similar 20 percent increase in contact precaution compliance reduced colonization between 6 and 10 percent.[9]

Harris and colleagues (2017) randomly assigned 20 ICUs to infection control interventions and used the resulting data to understand the relative contribution of the interventions. They found that approximately 44 percent of the subsequent decrease in the MRSA acquisition rate was due to universal glove and gown use, 38.1 percent of the decrease was due to improvement in hand hygiene compliance after exiting patient rooms, and 14.5 percent of the decrease was due to the reduction in physical contacts between healthcare workers and patients.[18]

Wares and colleagues (2016) modeled transmission in an outpatient dialysis unit and found that even with perfect compliance with hand hygiene, 13.4 percent of patients remained colonized with MDRO. They concluded that although the hands of healthcare workers are among the main vectors of MDRO

spread, transmission of MDRO occurs through numerous paths, including a contaminated environment and hospital-acquired colonization.[19]

5.2.3.1.2 Patient Hand Hygiene

Two studies examined the role of patient hand hygiene in reducing MDROs. Cheng and colleagues conducted two studies in Hong Kong of patient hand hygiene: one pre-post study (2015) in a hospital setting and one cluster-randomized trial (2018) in nursing homes.[20,21] In the hospital study, an intervention of single room isolation, strict contact precautions, and directly observed hand hygiene in conscious patients immediately before receiving meals and medications resulted in reduced bacteremia caused by MDR-AB. The rate decreased from 14 cases in 2013 to 1 case in the first 6 months of 2014 ($p<0.001$).[20]

In the second study, directly observed hand hygiene was performed in intervention nursing homes at 2-hour intervals during the daytime and before meals and medication rounds. The volume of alcohol-based hand rub used per resident per week was three times higher in the intervention nursing homes than in the controls ($p=0.006$), suggesting that hand hygiene education was effective in increasing use. Serial monitoring of environmental specimens revealed a significant reduction in MRSA in the intervention versus control nursing homes (13.2 percent vs. 32.8 percent; $p<0.001$) and a reduction in CR-AB species (9.3 percent vs. 15.7 percent; $p=0.001$).[21]

5.2.3.2 Process Outcomes

One study and one guideline review measured factors that can affect the efficacy of hand hygiene interventions. These factors include awareness of the need for hand hygiene in a given opportunity, knowledge of proper hand hygiene technique, and knowledge of what can make hand hygiene less effective even when performed correctly.

Rupp and colleagues' 2008 crossover trial in two ICUs demonstrated that hand hygiene compliance improved when alcohol-based hand rub was available on the unit. However, no improvement was seen in the rates of device-associated infection, infection due to multidrug-resistant pathogens, or infection due to *C. difficile* (for which alcohol-based hand rubs are not recommended). In addition, cultures of samples from the hands of nursing staff revealed that an increased number of both microbes and microbe species was associated with longer fingernails, wearing of rings, and lack of access to hand gel.[22]

Even after hand hygiene is improved, sustainability remains a challenge. In Palmore and Henderson's outbreak case study (2013), the authors achieved nearly perfect hand hygiene compliance from the hospital's already-high rate of 85 percent that was sustained for 6 months after the outbreak. However, after that point, the authors observed a return to baseline in the followup period.[10]

Ongoing observation and feedback are recommended for both increasing and sustaining compliance, but Ellingson and colleagues' (2014) guideline review notes a few challenges in carrying out this type of measurement and evaluation.[16] First, direct observation requires a trained observer, and no current guidelines note how frequently observation should take place to increase or sustain hand hygiene compliance. Indirect measurement can also be done by measuring the volume of hand hygiene solution used, with or without technological solutions such as "smart counters" that track and report dispenser use. These and other technological solutions, such as smart badges that alert remind healthcare personnel about an opportunity for hand hygiene, have programmatic limitations. They may be able to

alert on entry/exit but not for contact with surfaces or patients. In addition, there are costs in buying, installing, and maintaining this technology.

5.2.3.3 Economic Outcomes

Hand hygiene promotion programs can be very cost-effective in that they help reduce all infections (not just MDROs). One observational study provided economic findings: Sickbert-Bennett and colleagues studied a large U.S. teaching hospital (2016) before and after implementation of a hospitalwide initiative that included education about hand hygiene and instruction that all staff should provide immediate feedback and reminders to each other.

During the 17-month study period, there was a significant increase in the overall hand hygiene compliance rate ($p<0.001$) and a significant decrease in the overall HAI rate ($p=0.0066$). There were 197 fewer healthcare-associated infections and an estimated 22 fewer deaths, for an estimated saving of U.S. $5 million. The authors noted that while infections declined, there was no similar reduction in MDRO infections. They posit that many MDRO infections occur in patients who are colonized before admission to the hospital and cannot be prevented through better hand hygiene.[23]

5.2.4 Implementation

5.2.4.1 Summary of Evidence on Implementation

When practiced consistently, hand hygiene is an effective tool in reducing MDRO colonization and infections. The challenge is finding cost-effective strategies to increase hand hygiene compliance and sustain it over time. Lee and colleagues' systematic review (2019) found that, overall, implementing any infection control program reduces HAI rates; however, the greatest reductions come from interventions with multiple, reinforcing components that address:

- Knowledge (education),
- Consistency (monitoring and feedback), and
- Accessibility (providing supplies in places that make sense given the patient care workflow and hand hygiene opportunities).[24]

Maintaining hand hygiene requires education and culture change, creating workflows that support hand hygiene and technological solutions to automate monitoring and feedback. In some hospital settings, however, the time required for meticulous hand hygiene is a barrier. In their 2017 nonsystematic review, Strich and Palmore point out that if hand hygiene were performed in compliance with WHO guidelines (including 20–30 seconds per hand hygiene episode), each nurse would spend an estimated 58 to 70 minutes on hand hygiene for each patient during a 12-hour ICU shift, which conflicts with patient care duties. They also note that early-generation electronic monitoring systems have had mixed results in improving and sustaining hand hygiene compliance.[2]

In their guidelines for preventing HAIs through hand hygiene (including MDRO infections), Ellingson and colleagues (2014) recommend direct observation as the primary method for measuring hand hygiene compliance, combined with at least one other measurement method (self-report, technologically-automated tracking) to strengthen measurement against limitations from any single method.[16]

5.2.4.2 Barriers and Facilitators

Trautner and colleagues (2017) surveyed nursing home staff across 13 States and found large gaps in knowledge about proper hand hygiene procedures. Although all respondents reported receiving training in hand hygiene, less than 30 percent knew the correct length of time to rub hands (28.5 percent of licensed personnel and 25.2 percent of unlicensed personnel understood this fact) or the most effective hand cleaning agent to use (11.7 percent of licensed personnel and 10.6 percent of unlicensed personnel understood).[25]

One way to address the issue of organizational culture is to personalize a well-supported intervention to promote hand hygiene compliance. Luangasanatip and colleagues' systematic review (2015) recommends the WHO's "My Five Moments" intervention for its efficacy in increasing hand hygiene compliance. They also suggest that this intervention is even more effective and sustainable when goal setting, incentive rewards for achievement, and mechanisms to ensure accountability are added.[26]

A study of general infection prevention practices by Clock and colleagues (2010) found that individuals who adhered to one set of infection control behaviors were likely to adhere to all. They recommend focusing on changing the behaviors of those likely to be systematically noncompliant, such as visitors and staff not directly involved in patient care.[27]

Several studies in this review addressed compliance by improving access to hand hygiene equipment and supplies. However, if hand hygiene equipment becomes contaminated, the equipment itself can become a source of transmission. As observed by Hota and colleagues (2009) in their CR-PA outbreak response, handwashing sinks increased environmental contamination due to splashing from contaminated drains. In their study of ICU and transplant units, contaminated sink drains were implicated in 36 infections over a 15-month period, by organisms that were phenotypically similar; 17 of these patients died.[28]

Kotsanas and colleagues' (2013) investigation of a CR-*K. pneumoniae* outbreak found that once an MDRO is established in sink drains, it is difficult to eradicate without complete removal and redesign of sinks.[29] (Johnson et al., 2018, investigated a 2016 hospital outbreak of *Sphingomonas koreensis* and identified facility plumbing as a reservoir.[30]) The authors recommend that preventive efforts focus on appropriate sink design to minimize "spray" and enforcement of clear policies to use designated sinks for hand hygiene only, not for waste disposal. They also recommend frequent surveillance/testing of sink drains and surrounding environment for contamination.

5.2.4.3 Resources To Assist With Implementation

Since hand hygiene has a long, established history of efficacy and implementation, many promotional tools and campaigns have been developed. Below, we present the tools and campaigns described or evaluated in the above studies and reviews.

- The most frequent tool mentioned by the studies in this review was the WHO's "My Five Moments for Hand Hygiene" program, which can be found at https://www.who.int/infection-prevention/campaigns/clean-hands/5moments/en/.
- The Association for Professionals in Infection Control and Epidemiology also offers a number of implementation guides, educational tools, and articles to promote and support hand hygiene, available at https://apic.org/resources/topic-specific-infection-prevention/hand-hygiene/.

- The U.S. Department of Veterans Affairs' "Infection: Don't Pass It On" campaign materials are available at https://www.publichealth.va.gov/infectiondontpassiton/index.asp.
- Materials from the "Clean Hands Save Lives" campaign studied by McLaws et al. (2009) can be found at http://www.cec.health.nsw.gov.au/topics/concluded-projects/clean-hands.[15]
- Materials and guides from the "Clean In, Clean Out" program implemented by Sickbert-Bennett et al. (2016) is available at http://news.unchealthcare.org/empnews/handhygiene.[23]
- The CDC offers resources to support hand hygiene in healthcare settings under the "Clean Hands Count" campaign, available at https://www.cdc.gov/handhygiene/index.html.
- Additional health promotion materials from the CDC's "Life is Better with Clean Hands" campaign can be found at https://www.cdc.gov/handwashing/campaign.html.
- Commentary from Landers and colleagues on suggested moments for patient hand hygiene can be found in their 2012 article.[31]

5.2.5 Gaps and Future Directions

As described in the process outcomes section above, it is important to understand the systemic reasons that hand hygiene is not successfully completed at all opportunities. One of these is awareness that a hand hygiene opportunity is occurring, such as touching contaminated surfaces (as mentioned in Otter and colleagues' 2013 nonsystematic review).[4]

Graveto and colleagues' systematic review (2018) found that in addition to known fomites such as patient linens and healthcare personnel's clothing, cell phones are frequently used in clinical settings, are often colonized with infectious organisms, and are rarely sanitized.[8] While this finding represents a threat to successful hand hygiene, cell phones have important clinical utility, and it would be impractical to ban cell phones in all healthcare settings. The authors note that data are limited about the connection between cell phone contamination and HAIs. The authors recommend that cell phone use be incorporated into hand hygiene promotion, including handwashing before and especially after cell phone use, and routine disinfection of cell phones.

Even when hand hygiene compliance is nearly perfect, resistance to antimicrobial solutions is an increasing concern, given the widespread and rapid rise of antibiotic resistance. In Kampf's nonsystematic review (2016), the frequency of handwashing events greatly increased the exposure of MDROs to low levels of chlorhexidine and the selective pressure for resistance.[32] Although Ho and Brantley's commentary (2012) on a pre-post study of chlorhexidine resistance genes in MRSA did not demonstrate a correlation between increased antiseptic use for hand hygiene and increased resistance gene prevalence, the authors note that other studies have shown some association and recommend further study.[33]

Outside the clinical setting, alcohol-based hand rubs are also used as a hand hygiene alternative when soap and water washing is not available. At the time of this report, the Food and Drug Administration was investigating benzalkonium chloride, ethyl alcohol, and isopropyl alcohol for safety and efficacy in over-the-counter hand rubs when used in place of soap and water washing among the general population. These ingredients are deferred from further rulemaking as data are gathered on their

general safety and efficacy, and future research should include considerations about which solutions to use or avoid in community settings.[f]

[f]More information on this final rule can be found on the *Federal Register* website at: https://www.federalregister.gov/documents/2017/12/20/2017-27317/safety-and-effectiveness-of-health-care-antiseptics-topical-antimicrobial-drug-products-for.

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5.3 PSP: Active Surveillance for MDROs

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"Active surveillance" is a broad practice that encompasses many activities, including sample collection, laboratory testing, data collection, data analysis, and reporting and feedback. Active surveillance helps prevent the spread of infection by identifying when an MDRO enters a healthcare facility and quickly triggering infection control measures. Active surveillance can also help with diagnosis and appropriate treatment of infections and antibiotic stewardship by generating data that can be used to create a local profile of antibiotic susceptibility or antibiogram.[1]

Key Findings

- Targeted active surveillance performs as well as universal active surveillance for many MDROs and uses fewer resources. However, in places where universal active surveillance is already in place, screening for other MRDOs using the same sample may be cost-effective, as patients colonized with an MDRO share risk factors for others.
- Some consensus exists for screening high-risk patients (those with a history of MDROs or risk factors associated with MDRO colonization/infection) on admission, but any screening approach will require compliance with infection prevention protocols when a patient's culture result is positive.
- Surveillance may improve compliance with other PSPs when it is part of a multicomponent intervention, but more research is needed on the mechanisms and circumstances of this association, as it can be confounded by the coimplementation of other, bundled practices.

5.3.1 Practice Description

With the infection prevention and healthcare practitioner in mind, this report provides evidence to support strategies for "active surveillance"—the collection and culturing of samples specifically for identifying MDRO colonization and infection among patients. However, "active surveillance" is a broad practice that encompasses many activities (sample collection, lab testing, data collection, data analysis, and reporting and feedback) and occurs at many levels.[1]

Considering the broad scope, we also include best practices for active surveillance that continue beyond obtaining laboratory results. Where described in the literature, we include best practices in using active surveillance results to:

- Direct infection prevention responses;
- Evaluate the effectiveness of IP practices;
- Track and communicate MDRO status, prevalence, and risk to prevent intra- and inter-facility transmission; and
- Develop local, regional, and global datasets of MDRO prevalence that inform risk-based approaches to active surveillance and infection prevention.

Epidemiologically, genotyping of active surveillance samples can help identify potential modes of transmission or assess need for patient bathing/deeper environmental cleaning by identifying related organisms from multiple sample sites.[1,2] These genotyping data can also be used to identify whether the MDROs identified in screening are endemic to the environment or are imported by asymptomatic carriers. However, this practice requires access to labs with the capacity to do quick-turnaround, real-time genotyping.[1]

Integration of active surveillance programs into electronic medical records can help automate identification and analysis but requires facilities with those capacities or access to them. However, generating larger, regional and even global surveillance systems allows individual facilities to identify

risk factors for incoming patients (for example, knowing what areas of the world have high prevalence of certain MDROs).[1]

Many resource challenges arise in creating sophisticated laboratory and data integration systems that can identify, genotype, and share information on MDROs. At the same time, investing in these systems benefits other infection control practices by generating the data that allow facilities to take a risk-based approach to screening, isolation, and contact precautions, which represent an opportunity for cost saving.[1] Finally, facilities must make decisions about when to stop active surveillance, balancing the costs of an active surveillance program against the possibilities of failed eradication and recolonization.[3] Key findings are located in the box above.

5.3.2 Methods

To investigate how active surveillance has been implemented to prevent transmission of MDROs and contain MDRO outbreaks, we searched three databases (CINAHL, MEDLINE, and Cochrane) for a combination of the keywords "monitoring," "surveillance," and "monitoring and surveillance," as well as MeSH terms "cross infection prevention," "drug resistance, multiple, bacterial," and "drug resistance, microbial." Articles from January 1, 2008, through December 31, 2018, were included. (Any relevant articles published after the original search are included in the PRISMA diagram as additional sources.)

The initial search yielded 392 results (including 24 articles from other sources); after duplicates were removed, 352 were screened for inclusion, and 175 full-text articles were retrieved. Of those, 23 were selected for inclusion in this review. Articles were excluded if they did not mention active surveillance's role in preventing MDRO transmission, only described surveillance for determining treatment, or did not include implementation in a healthcare setting.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report appendixes A through C.

5.3.3 Review of Evidence

The Key Findings box presents a high-level summary of the findings in this review. Although the ideal method for active surveillance varies by MDRO (based on how the organism is acquired and shed by patients), one common theme is using targeted, active surveillance based on MDRO risk factors, such as recent hospitalization or history of MDRO colonization. Screening results should then be used to guide other infection control practices, such as contact precautions or decolonization protocols. Without adherence to these practices, the value of active surveillance is limited.

Screening decisions for facilities should be based on the available epidemiological surveillance data on which organisms are likely to be prevalent in a facility's patient population. Rare MDROs will result in far higher screening costs to prevent one infection/colonization event, compared with MDROs with higher prevalence. For MDROs or other pathogens frequently present on admission (such as MRSA or *C. difficile*), screening results may be useful in identifying a patient at risk for other MDROs. Conducting tests for multiple MDROs on one sample may reduce the materials and time needed for sample collection but may increase costs related to lab processing.

Where active surveillance may provide the most value is in improving compliance with other PSPs in multicomponent interventions. However, it is not clear how strong that association may be or why an association appears in some studies but not others. As mentioned above, identifying patients colonized or infected with an MDRO is only valuable if the correct procedures to reduce transmission (such as hand hygiene or decolonization) are followed consistently based on that knowledge. More research is needed to understand the synergistic effect of active surveillance to maximize its benefits.

5.3.3.1 Active Surveillance To Control MDRO Transmission

Active surveillance for MDROs is necessary because routine surveillance of clinical samples will undercount colonized or infected patients.[3,4] The proportion of clinically evident cases also varies by organism and susceptibility of the patient population, which means many asymptomatic carriers will go unnoticed without active surveillance.[4] In addition, an accurate screening process will reduce the number of patients on isolation or contact precautions unnecessarily.[5] In an outbreak of an MDRO in an otherwise low-prevalence setting, active surveillance is needed to verify that the outbreak has been successfully contained.[6]

It should be noted that in each of the studies included, active surveillance was combined with other infection control preventions. Tacconelli et al. (2014) strongly recommend always pairing surveillance with other infection prevention practices.[4] Cipolla et al., in their 2011 commentary, suggest that active surveillance results can be used to build a local antibiogram to complement antibiotic stewardship initiatives.[7] Gasink and Brennan's nonsystematic review (2009) further found that active surveillance without preemptive isolation has not been shown to be effective.[8]

This variation in practice makes it difficult to evaluate the effect of infection prevention with and without active surveillance, as noted in Strich and Palmore's commentary (2017).[9] While Strich and Palmore suggest that universal contact precautions may ultimately be more effective for MDRO prevention than active surveillance, these universal measures come with extra costs and potential for additional negative outcomes (discussed below).

In this summary, we present ways healthcare facilities used these strategies, including both successful and unsuccessful approaches. Several organizations have produced evidence-based recommendations on the best ways to use active surveillance to identify and contain MDROs, links to which can be found in section 5.3.4.4. However, the field of MDRO research continues to evolve, and we provide recent findings to supplement existing recommendations. We also present lessons learned from outbreak responses, especially lessons learned about challenges that threaten the validity and effectiveness of active surveillance.

5.3.3.1.1 Screening Methods for Detecting MDROs

Although screening is widely used, findings are mixed as to the correct screening method (patient sites, type of swabs used), frequency, target population, and culturing of samples. The sensitivity and specificity of a sample collection site or type varies by type of MDRO.

Given the costs associated with active surveillance and subsequent patient isolation, Freire and colleagues (2017; prospective cohort study) recommend universal surveillance in facilities where the incidence of MDROs is moderate to high and for patients for whom the rate of conversion from colonization to infection is high (e.g., transplant patients).[10] In universal surveillance, Barbadoro and colleagues' 2017 time series analysis found that skin, blood, and respiratory samples performed better

at initially identifying the presence of an MDRO than did urine samples.[11] The CDC (2019) offers guidelines for surveillance based on different categories of organisms and resistance mechanisms, with a recommended approach for each.[12]

Based on the findings in our review, we summarize the evidence for active surveillance around five topic areas, comparing both universal and targeted approaches (when findings are available):

- Surveillance for general MDR Gram negative bacteria (MDR-GNB)
- Surveillance for methicillin-resistant *Staphylococcus aureus* (MRSA)
- Surveillance for vancomycin-resistant Enterococci (VRE)
- Surveillance for carbapenem-resistant or carbapenemase-producing Enterobacteriaceae (CRE/CPE)
- Surveillance for MDROs using environmental sampling

General MDR-GNB: No consensus exists on frequency of screening or timing of screening for MDR-GNB. A nonsystematic review by Gasink and Brennan (2009) showed that screening during admission with weekly followup prevented the spread of MDR-*A. baumanii*.[8] However, a similar program for MDR-*K. pneumoniae* was not successful.[4] In epidemic settings, targeted screening on admission for high-risk patients is recommended. Screening can also be used to reinforce other prevention practices in the outbreak response, such as hand hygiene.

In the endemic setting, active surveillance should be used as an additional measure to control the spread of MDR-GNB between facilities or units. Otter and colleagues, in their 2015 commentary review, suggest using surveillance data from endemic settings to build risk assessment protocols and implement targeted screening policies that will catch MDR-GNB carried by transferred patients without adding unnecessary costs or burden.

As far as sampling sites, Tacconelli and colleagues (2014) found that rectal swabs, urine, or respiratory secretions were sufficient for almost all MDR-GNB, with rectal swabs being the most sensitive and groin being most specific. However, one study in that systematic review showed that sensitivity of screening is low (29%) even when six body sites are included. Finally, Tacconelli and colleagues note that (as of writing in 2014) rapid polymerase chain reaction-based methods to identify MDR-GNB were still in development, so culture-based tests remain the standard.[4]

Once an MDR-GNB pathogen is identified, Tacconelli and colleagues recommend weekly screening until no cases of colonization/infection or cross-transmission are observed.[4] Several outbreak responses have noted that MDR-GNB pathogens, particularly MDR-AB, produce significant environmental contamination due to their method of shedding (shed skin cells, stool, and/or urine).[13,14] However, the mean colonization time for MDR-GNB in their reviewed studies was 144 days, representing a significant length of time. Tacconelli and colleagues also noted that the efficacy of screening was linked to the level of compliance, so screening must be maintained over time.[4]

Methicillin-resistant *Staphylococcus aureus* (MRSA): Given the increasingly endemic nature of MRSA in both healthcare and community settings, questions have emerged about the clinical value of screening for MRSA, especially among asymptomatic carriers.[15,16] If conducting screening for MRSA, Lin and colleagues (2018) found nasal screening to be most sensitive: nasal culturing alone identified 84 percent

(327/388) of MRSA positive patients; only 61 patients (16%) were both nasal-culture negative and groin-culture positive. Nasal screening also had a strong negative predictive value of 98 percent (95% CI, 97.6% to 98.5%).[16]

MRSA screening may be a useful tool for identifying colonization of other, nonendemic MDROs. Evidence supports some association between MRSA status at admission and later discovery of MDRO colonization. Jones and colleagues' retrospective cohort study (2015) found that 2.4 percent of patients with positive MRSA screening later had a positive MDR-GNB culture, compared with 0.9 percent of patients with a negative MRSA screening ($p<0.001$). This association was strongest for *Acinetobacter* species of MDR-GNB. Jones et al. also found that 85.5 percent of those with a subsequent MDR-GNB negative culture also had an MRSA-negative screen.[17]

In facilities where universal MRSA screening is already in place, a positive result may be considered a risk factor for other MDROs. By knowing risk factors associated with colonization by MDROs other than MRSA, hospitals and other facilities can develop risk-based testing approaches for screening on admission, reducing costs in time and materials.[18]

Vancomycin-resistant Enterococci (VRE): Active surveillance for VRE can help detect asymptomatic carriers, but the clinical benefit of this strategy is unclear and methods for VRE surveillance can vary widely in practice.[19] Active surveillance helps detect asymptomatic VRE colonization in patients with *C. difficile* infection (CDI) in facilities with a high VRE prevalence, given high correlation between colonization with the two organisms. More than 50 percent of patients with CDI were also colonized with VRE.[20]

Despite this finding, it is not clear whether surveillance for asymptomatic VRE carriers reduces VRE-related infections. Almyroudis and colleagues' interrupted time series study (2016) found that active surveillance with precautions for sporadic (not horizontally-transmitted) VRE did not protect patients against VRE bacteremia.[21] Huskins et al. (2011) also observed no difference in mean colonization and infection rates between the active surveillance and control groups in a cluster-randomized trial of active VRE and MRSA surveillance upon admission.[22]

Carbapenem-resistant/carbapenemase-producing Enterobacteriaceae (CRE/CPE): Although the global prevalence of CRE/CPE is increasing, not all regions or all facilities in a region share the same risk for CRE outbreaks. Active surveillance following identification of CRE can reveal additional asymptomatic cases, as Banach and colleagues learned in their 2014 observational study using *C. difficile* samples to test for concurrent CRE carriage. Rescreening of clinical samples collected for other testing (such as Banach et al.'s approach to perform testing for CRE on *C. difficile* stool samples) is one way to efficiently screen patients who have risk factors for multiple MDROs and identify asymptomatic carriers.[23]

Karampatakis and colleagues' quasi-experimental study (2018) showed that a multicomponent intervention, including active surveillance, reduced rates of *K. pneumoniae* and *P. aeruginosa* infection but not of other MDR-GNB (*A. baumannii*), further highlighting the importance of tailoring infection prevention response to the organisms.[24] As described below in environmental surveillance, *A. baumannii* may require enhanced environmental cleaning protocols compared with CRE, due to the increased environmental contamination from colonized patients.

In light of no clear evidence for or against universal screening for CRE, one commentary by Asensio and colleagues (2014) recommends active surveillance on admission for patients in any of the following elevated risk groups:

- Patients transferred from a healthcare facility in any foreign country (in light of a lack of data on global CRE prevalence
- Patients transferred from acute or long-term care facilities with known high CRE prevalence
- Patients previously colonized or infected with CRE
- Patients who have had close contact with a person with CRE.

Finally, any surveillance must have clear definitions to avoid under- or over-reporting of CRE cases.[25] In Mayer and colleagues' retrospective laboratory audit (2016), underreporting due to misunderstanding definitions was far more frequent than overreporting.[26]

Environmental Sampling for MDRO Surveillance: Active surveillance of the environment, in addition to patients, combined with monitoring staff's adherence to infection control practices, can identify the transmission patterns and expose areas for improvement. For example, Sui and colleagues' 2013 outbreak response found that, compared with MRSA, MDR-AB patients were more likely to contaminate their environment.[27]

Environmental sampling as part of active surveillance can be used to identify areas in need of intensive cleaning or where cleaning has been missed, as identified by Lesho and colleagues (2018) and Liu and colleagues (2014) in their respective outbreak responses.[28,29] Nusair and colleagues' observational study (2008) found that evaluating the outcomes of different types of sampling (such as the most frequently positive patient body sites) can also help streamline the sample collection process for future surveillance.[30]

Cheng and colleagues (2018; outbreak response case study) found that environmental surveillance may serve as an indicator of MDRO carriers, at least in the case of MDR-AB, where the organism is consistently shed by patients.[31] In another outbreak (of MDR-*E. coli*), however, environmental surveillance failed to identify an environmental source.[32] The outbreak was successfully contained only after it was moved to a temporary neonatal ICU, showing that negative environmental samples do not reliably indicate that the environment is free of MDROs. In addition, the Healthcare Infection Control Practices Advisory Committee recommends culturing environmental samples when epidemiological evidence shows an environmental source of ongoing transmission.[33]

5.3.3.1.2 Genotyping MDRO Cultures

Genotypic testing can help determine whether MRDOs identified in active surveillance are horizontally transmitted between patients, coming from a common environmental reservoir, or are imported from other facilities. One interrupted time series study of active screening of high-risk patients by Borer and colleagues (2011) found that 45 percent of CR-*K. pneumoniae* infections and 57 percent of all positive cultures were community acquired.[34] Benenson and colleagues' 2013 screening of neonates in an Israeli ICU found both imported and horizontally-transmitted strains of ESBL-producing *K. pneumoniae*. The authors significantly decreased the number of positive cultures using surveillance in combination with cohorting of neonates with positive cultures.[35]

In Kohlenberg and colleagues' outbreak report (2010), active surveillance detected environmental reservoirs of CR-PA unrelated to the outbreak strain, based on genotyping results of the cultured organisms.[36] Finally, Wendel and colleagues' MDR-*P. aeruginosa* outbreak response case study (2015) used genotyping to confirm transmission through shared hair washbasins, which allowed the authors to halt the epidemic and prevent further transmission by discontinuing their use.[37]

5.3.3.2 Surveillance for Process Outcomes

Surveillance, by its nature, is a practice that gathers process and outcome data, allowing evaluation of other patient safety practices. This section describes how different modes of active surveillance have been evaluated for effectiveness and how active surveillance can be used to evaluate the effectiveness of other practices or bundles.

Tracking MDRO isolates over time and between different units allows hospitals to evaluate the effectiveness of their infection control protocols. In Ahern and Kemper's 2009 case study, the authors showed reduction in MDROs despite increased rate of antibiotic prescription.[g] Bryce and colleagues' pre-post study (2015) found that risk-based active surveillance could be as effective as universal surveillance in reducing the target MDRO, VRE, as well as MRSA and *C. difficile* infection.[38] In D'Agata and colleagues' mathematical model simulation (2012), targeted screening for MRSA and VRE for patients receiving antimicrobials (a known risk factor for MDRO acquisition) reduced MDRO acquisition while universal screening did not.[39]

Active surveillance programs have been observed indirectly enhancing compliance with other patient safety practices, but more research is needed to understand when and why adding active surveillance helps compliance with other practices, as our review also uncovered examples of no association.[40] For example, Evans et al. (2017) observed decreases in transmission and HAIs related to MRSA in U.S. Veterans Affairs hospitals after implementing an infection prevention bundle. The authors speculate that universal screening for MRSA as part of the bundle served as a reminder to comply with other practices such as hand hygiene and contact precautions. Other hand hygiene and device-placement bundles were already in place, but MRSA transmission and infection rates did not drop until the active surveillance bundle was implemented.[41]

Mawdsley et al. (2010) found that weekly surveillance rounding successfully improved compliance with contact isolation initiation and required minimal resources (two person-hours of work per week, split among six infection preventionists).[42] Compliance surveillance in Palmore and colleagues' outbreak response effort (2011) helped identify a staff subpopulation that were more likely to fail to comply with infection control policies (in this case, physicians).[43]

Conversely, Huskins et al. (2011) observed that reporting culture results did not yield high compliance with contact precaution requirements. Despite being aware of patient's colonization status, healthcare providers used clean gloves only 82 percent of the time, gowns 77 percent of the time, and hand hygiene 69 percent of the time during observed periods.[22] Similarly, Lin and colleagues' observational study of 25 Illinois hospitals (2018) found that only 54 percent of patients whose point prevalence

[g]Ahern JW and Alston, WK (2009). Use of Longitudinal Surveillance Data to Assess the Effectiveness of Infection Control in Critical Care. Infection Control and Hospital Epidemiology, 30, 11, 1109-12.

culture was positive for MRSA were on contact precautions, despite new State legislation mandating active MRSA surveillance on admission and contact precautions for any patients with a positive result.[16]

5.3.3.3 Economic Outcomes

Cost-effectiveness of active surveillance interventions depends on how many infections are reduced (or are likely to be reduced) by the intervention, which varies by facility and even within facilities. Early detection and containment of MDROs reduces the costs associated with decontamination and eradication.[44] In cases where an MDRO is already endemic, such as in Zarpellon and colleagues' (2018) prospective study of active surveillance, the authors took a modified, risk-based approach. MRSA was considered endemic in the study hospital, except in pediatric and neonatal wards. Accordingly, the authors screened for MRSA only in pediatric and neonatal wards, where the MDRO was not yet established.[45]

Cost avoidance in targeted active surveillance can also take the form of reduction in products needed for contact isolation (gloves, gowns, hospital linens), laboratory reagents, and lost revenue (due to needing private rooms for patient isolation), as described by Bryce and colleagues in their 2015 pre-post study of targeted monitoring for VRE.[38] Johnston and Bryce's nonsystematic review (2009) found that screening patients at high risk for colonization with MRSA or VRE may be cost-effective if coupled with barrier precautions.[3]

The more accurate the active surveillance methodology, the fewer patients will be put on contact precautions unnecessarily.[46] Morgan and colleagues' 2009 systematic review also notes that faster screening tests can reduce the time patients are kept on preemptive precautions or in single-patient rooms.[47]

Finally, Banach and colleagues' observational study (2014) demonstrated the efficacy of a low-cost strategy to screen for CRE using sampling already being done for CDI, as both organisms share risk factors. The total cost of detecting one CRE-colonized patient ranged from $580 to $649 and required between 68 and 76 samples to be tested (based on the prevalence at the facilities in the study).[23]

5.3.3.4 Unintended Consequences

5.3.3.4.1 Negative

Active surveillance is used to identify patients to be placed on contact precautions, which reduce transmission but may have unintended adverse effects on the patient. Morgan and colleagues' systematic review (2009) found that contact precautions were associated with less contact from healthcare workers, delays in care, adverse events (non-infection- associated), increased symptoms of depression and anxiety, and decreased patient satisfaction with care.[47] This finding was also noted in commentary from Lemmen & Lewalter (2018).[5]

A study by Day and colleagues (2013) found that patients on contact precautions were not at any greater risk of developing depression or anxiety, although they may have more symptoms of anxiety and depression at the start of contact precautions.[48] Rapid-result genetic testing can also reduce any potential adverse effects of contact isolation by limiting the time spent in preemptive isolation pending screening results.[8]

Palmore and Henderson found an unintended negative consequence of public education in their 2013 outbreak response report: coverage of the outbreak in the wider media emphasized mortality rates,

which increased community anxiety when information was shared about the outbreak.[49] When sharing information on outbreaks and infection prevention responses with patients and families, one must convey the importance of preventing transmission and managing patients' understanding of their individual morbidity and mortality risk. Publications on techniques used to control the outbreak in a facility as well as media coverage of the outbreak, for example, could be shared.

5.3.3.4.2 Positive

Active surveillance has shown positive unintended effects. Bryce and colleagues' pre-post study (2015) found that risk-management surveillance reduced other infections (MRSA, CDI) in addition to the target organism (VRE).[38] In one observational study, environmental surveillance for MDROs led to discovery of a leaking water pipe that led to significant mold growth that could have resulted in additional harm among the immunocompromised patients.[30] Finally, Sánchez García and colleagues' active surveillance for MRSA during an outbreak (2010) identified a novel strain that was resistant to linezolid and allowed implementation of protocols to contain and ultimately eliminate it.[50]

5.3.4 Implementation

5.3.4.1 Summary of Evidence on Implementation

Reduction in MDRO infection rates does not come from active surveillance alone; rather, it should guide healthcare staff in informed decision making, such as implementing patient isolation and contact precautions. Regular monitoring through clinical sampling is a simple way to detect emergent pathogens, but it has limitations. Orsi et al. (2011) and Sandora et al. (2010) describe tradeoffs between routine surveillance of clinical samples and active surveillance.[51,52]

Routine clinical surveillance of already-collected samples is less costly in terms of collection time, but active surveillance testing can determine presence on admission or temporality of colonization, as well as identifying asymptomatic carriers (as mentioned above). Therefore, Orsi et al. (2011) recommend active surveillance to close the gaps in clinical sampling during outbreaks or for MDROs not endemic in a facility.[51]

5.3.4.2 Barriers and Facilitators

Adding weekly dissemination of the results of active surveillance (MDRO rates, location of acquisition) was key to successfully controlling MDROs. Although other components (active surveillance, patient isolation) had been in place already, Quan and colleagues (2015) demonstrated that automated systems could support enforcement of contact precautions and save considerable infection preventionist time.[53]

Horizontal transmission of MDRO strains may not need universal active surveillance, but MDRO acquisition or infection between facilities warrants communication to identify patients at elevated risk. In a retrospective analysis using a regional surveillance system for MDROs based on an existing MRSA and VRE alert system, Rosenman and colleagues (2014) observed several crossovers between institutions.[54]

Coordination with regional and national public health agencies can help with interfacility transmission by coordinating notification and infection prevention efforts across all facilities. Grundmann's 2014 commentary recommends a stepwise approach (local to regional to national to global) for creating a global surveillance network.[55]

Investing in active surveillance can require expenditures for laboratory and computer resources, as noted in O'Brien and Stelling's systematic review (2011), but these investments can help reduce the cost of other infection prevention efforts.[1] If a facility cannot absorb the costs of running a laboratory, partnering with public health agencies for surveillance may be an option.

In addition to the costs associated with conducting active surveillance, a few other challenges are described in the literature. Faster results can be available using molecular testing methods such as polymerase-chain reaction, but these tests can be costly, have limited specificity in some cases, and are not available in all facilities.[51]

5.3.4.3 Additional Important Contextual Factors

Santos et al., in their 2008 commentary review, note that although active surveillance for MDROs has significant benefits for infection prevention and treatment for the patient, it can also be considered quality improvement (research). Therefore, surveillance and isolation precautions do not require specific patient consent.[56] However, education and clear communication about the need for and impact of active surveillance on patients are critical. In addition, the financial burden of active surveillance should be assumed by the facility, not the patient.

5.3.4.4 Resources To Assist With Implementation

- The CDC offers MDRO surveillance and reporting instruction modules for its National Healthcare Safety Network system, available for a range of healthcare facilities at https://www.cdc.gov/nhsn/enrolled-facilities/index.html.
- The CDC also offers a series of recommendations for containing MDROs, based on the categories of MDRO sorted according to type of organism, prevalence, and resistance mechanisms. These recommendations (*Interim Guidance for a Public Health Response To Contain Novel or Targeted Multidrug-Resistant Organisms*) can be found at https://www.cdc.gov/hai/pdfs/containment/Health-Response-Contain-MDRO-H.pdf.
- Evidence-based recommendations from the Healthcare Infection Control Practices Advisory Committee (HICPAC; last updated in 2006) on surveillance and other practices for managing MDROs can be found at https://www.cdc.gov/infectioncontrol/guidelines/MDRO/index.html.
- The Health Research & Educational Trust Hospital Improvement Innovation Network offers many resources for addressing MDROs, including surveillance guidelines, in the MDRO Change Package available from its website: http://www.hret-hiin.org/topics/multi-drug-resistant-organisms.shtml.

5.3.5 Gaps and Future Directions

The greatest challenge to active surveillance cultures/testing for MDROs is understanding which surveillance protocols are the most sensitive and specific for correctly identifying carriers while minimizing the burden for collecting samples and processing data. Although evidence-based recommendations exist for MRSA, VRE, and CRE, numerous pathogens (particularly other MDR-GNB such as *K. pneumoniae* and emerging MDR pathogens such as *Candida auris*) lack a consistent recommendation for whom and when to screen.

Duffy and colleagues (2011), in their synopsis of a working group of infection prevention professionals, recommend strengthening partnerships between healthcare facilities and public health departments to

build capacity for identifying and tracking emerging MDROs.[57] Further studies that evaluate targeted surveillance protocols based on risk factor analysis would give healthcare facilities another tool for effective, lower cost surveillance.

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5.4 PSP: Environmental Cleaning and Disinfection

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This section reviews research from 2008 to 2018 on environmental cleaning and disinfection as a strategy to prevent the transmission of multidrug-resistant organisms (MDROs) and reduce healthcare-associated infections (HAIs). Following a practice description and methods, the evidence summary reviews the research on different disinfectant agents, no-touch decontamination methods, and antimicrobial surfaces. Next, we explore several implementation facilitators, including environmental screening, audit and feedback, education, and facility policies. Finally, we look at gaps and future directions. Key findings are located in the box on the right.

Key Findings

- Cleaning with chlorine-based solutions (e.g., bleach) was studied as part of enhanced cleaning methods for MDROs. Research is lacking on cleaning with bleach as a single intervention.
- Moderate evidence supports the use of quaternary ammonium compounds for certain MDROs, although evidence is mixed in support of their usefulness in the targeted disinfection of high-touch surfaces.
- More studies are needed in clinical settings that examine the different cleaning and disinfecting agents.
- No-touch disinfection technologies are promising additions to disinfection practices but must be further studied to determine the most efficacious and cost-effective options.
- Environmental screening is a useful tool for auditing and monitoring ongoing cleaning practices and for identifying highly contaminated surfaces for targeted cleaning during outbreak scenarios.
- Efficacy of approaches varied against different species of bacteria and for sensitivity versus drug-resistant strains.

5.4.1 Practice Description

Environmental surfaces serve as an intermediate vector for transmitting MDROs in healthcare settings.[1] Environmental contamination can occur from contact with MDRO-infected individuals or their body fluids and can result in transmission to another individual. The "environment" includes furniture and other surfaces in patient rooms; medical equipment; personal items belonging to patients, visitors, or staff; and structural components of the facility (e.g., sinks, air vents).

To remove MDROs or disinfect the environment, healthcare facilities use specific cleaning and disinfection practices. Enhanced or standard cleaning may be implemented on a daily basis or when a patient vacates a room (called terminal cleaning). In the event of an outbreak or increased rate of transmission, facilities may perform a more thorough, one-time environmental cleaning. The latter is frequently done when other infection control practices or standard environmental cleaning does not reduce infection rates or when a specific source of contamination is suspected or identified by environmental screening. Enhanced environmental measures also include reinforcing training of environmental services staff and monitoring adherence to environmental cleaning protocols.[2]

Before a disinfectant is applied, cleaning is required to manually scrub and wash any visibly soiled surfaces because disinfectants cannot typically penetrate organic matter or thick substances to eradicate microbes beneath.[3] After cleaning, a disinfectant is applied and left in contact with a surface for the amount of time designated by the manufacturer as necessary to kill/deactivate microorganisms. The variations and efficacy of these environmental cleaning and disinfection practices—highlighting MDROs in healthcare settings—are the focus of the following systematic literature review.

5.4.2 Methods

To determine the most effective environmental cleaning and disinfection practices for reducing the spread of MDROs, three databases (CINAHL, MEDLINE, and Cochrane) were searched for "bacterial drug

resistance," "microbial drug resistance," and synonyms, in combination with "disinfection methods," "environmental monitoring," "environmental cleaning," and associated phrases. Articles from 2008 through 2018 were included.

The initial search yielded 375 results (including 9 from other sources); after duplicates were removed, 347 were screened for inclusion, and 130 full-text articles were retrieved. Of those, 58 were selected for inclusion in this review. Articles were excluded if they were outside the scope of this review, included insufficient detail on a patient safety practice, did not describe an intervention (e.g., surveillance only), demonstrated insufficient rigor, or were included in another PSP section of this report.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report appendixes A through C.

5.4.3 Review of Evidence

This review includes evidence from 4 systematic reviews and 54 studies. Of the studies:

- Twenty-one were before-and-after intervention studies (one of which was a mathematically modelled and simulated intervention),
- Thirteen were outbreak studies,
- Nine were laboratory studies,
- Five were cross-sectional surveys,
- Two were cluster-randomized controlled trials,
- Two were cluster-randomized crossover studies,
- One was a prospective cohort study, and
- One was a prospective controlled quasi-experimental study.

Of all included articles, 25 took place or reviewed studies that took place in the United States, 31 occurred outside the United States, and 2 included studies from both the United States and abroad. The included studies focused on cleaning and decontamination agents to reduce MDROs and infection from MDROs, as well as facilitators and barriers to cleaning and sterilization in the healthcare environment.

5.4.3.1 Disinfection Products

5.4.3.1.1 Chlorine-Based Disinfectants

The most commonly referenced disinfectants were chlorine-based products (e.g., bleach), which were used in various studies for deep, terminal, or daily routine cleaning and often as part of multicomponent interventions.

Standard or enhanced environmental cleaning with chlorine-based disinfectants has been associated with controlling outbreaks and reducing MDROs.[4-6] In one study, a sink trap was determined as the likely source of an increased number of patient infections with multidrug-resistant *A. baumannii*.[4] As a response to the outbreak and the results of environmental sampling, bleach was used to disinfect sinks and plumbing. During the 6 months after the intervention, the number of new cases greatly declined. In

an in vitro study, sodium hypochlorite at 0.5% concentration, standing for 30 seconds, was found to successfully eradicate imipenem-resistant *A. baumannii*, but the article noted that an overdiluted bleach solution (0.08%) was insufficient to reduce environmental contamination.[7]

Cleaning with chlorine-based agents was a component of several multicomponent interventions to decrease MDRO transmission.[8-16] For example, cleaning with chlorine-based disinfectants was part of a multicomponent intervention to reduce pandrug-resistant *A. baumannii*.[16] The intervention included hand hygiene, surveillance, and patient isolation. In another multicomponent intervention, enhanced cleaning with a chlorine-based detergent, combined with patient isolation, chlorhexidine bathing, and staff education was associated with ending an outbreak of linezolid-resistant *Enterococcus faecium*.[17]

A multifacility cluster-randomized crossover study in nine U.S. hospitals compared bleach with the detergent used at baseline (quaternary ammonium),[h] ultraviolet-C light (UV-C), and a combination of bleach and UV-C in preventing transmission of several MDROs. The incidence of target organisms among exposed patients was not significantly changed with the use of bleach alone, or the combination of bleach and UV-C, compared with quaternary ammonium.[18]

A before-and-after study in a burn ICU found that adding a chlorohexidine-alcohol disinfectant to standard cleaning with sodium hypochlorite was more effective than standard cleaning with sodium hypochlorite alone, although other implementation variables (e.g., frequency of cleaning, targeted cleaning) were also altered and may have contributed to the results.[19]

5.4.3.1.2 Quaternary Ammonium Compounds

Quaternary ammonium compounds (QACs) have demonstrated mixed success in environmental cleaning and disinfection. In one study, terminal cleaning with QAC reduced environmental contamination with MDR-AB in patient rooms within ICUs at an American teaching hospital.[20] QACs were also incorporated into environmental cleaning practices as a part of successful multicomponent outbreak interventions for MDR-AB.[11,15] Lastly, in one before-and-after study, the use of Bio-Kil (which contained QAC) compared with manual surface cleaning with 500 ppm sodium hypochlorite was found to disinfect and provide ongoing microbial activity, resulting in reduced environmental bacterial contamination and sepsis incidence in the ICU.[21]

QACs have also been included in interventions that use enhanced environmental cleaning practices. One cluster-randomized controlled trial supplemented routine cleaning of ICU rooms with a one-time disinfection of high-touch surfaces in each room. Both routine and enhanced cleaning used a QAC disinfectant. Adding the supplementary cleaning did not result in a significant difference in the subsequent colonization of healthcare workers' gowns and gloves with MRSA or MDR-AB and thus was not determined to add value to environmental cleaning and disinfection practices.[22] While no clinical outcomes were reported, the contamination of healthcare workers' gowns and gloves is a suspected source of transmission to patients. This study did not provide sufficient evidence to support the use of QACs to target high-touch surfaces.

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[h]Quaternary ammonium is commonly used in ordinary sanitation of patient care equipment and healthcare facility surfaces. Manufacturers indicate that it is generally fungicidal, bactericidal, and active against some viruses, but not sporicidal or tuberculocidal. For more information, refer to Rutala WA, Weber DJ. Disinfection, sterilization, and control of hospital waste. In: Bennett JE, Dolin R, Blaser MJ, eds. Mandell, Douglas, and Bennett's Principles and Practice of Infectious Diseases. 8th ed. Philadelphia, PA; 2015.

QACs are not sporicidal and thus should not be relied on to eradicate spore-producing organisms such as *C. difficile* from the environment.[18] They are also considered to have very low, if any, toxicity to humans.[21] Lastly, a cross-sectional in vitro study of 12 vancomycin-susceptible *E. faecium* and 37 vancomycin-resistant *E. faecium* isolates found that the resistant isolates had decreased susceptibility to benzalkonium chloride. Further research is needed to investigate the potential for MDRO cross-resistance with antibiotic resistance and QAC-based disinfectants.[23]

5.4.3.1.3 Hydrogen Peroxide

Several studies examined hydrogen peroxide in various forms for reducing/eliminating MDROs. Hydrogen peroxide was tested in four variations in a laboratory study. In this study, a novel hydrogen peroxide disinfectant including anionic and nonionic surfactants in an acidic product was compared in vitro with traditional hydrogen peroxide disinfectants. The "improved" hydrogen peroxide product was more effective in reducing bacteria than QAC or any of three tested concentrations of hydrogen peroxide.[24]

In a cross-sectional study of clinical isolates, vancomycin-resistant and vancomycin-sensitive bacteria were not found to differ in their minimum inhibitory concentrations for hydrogen peroxide (in contrast to chlorohexidine and benzalkonium chloride).[23] No further studies directly addressed the use of hydrogen peroxide in its liquid state for environmental disinfection of clinical settings. We discuss the use of hydrogen peroxide vapor and no-touch methods below.

Silver ions are used on antimicrobial surfaces and in cleaning products for their antibacterial properties. One in vitro study by De Giglio et al. (2014) investigated the use of a combination of 0.1% silver ion and 5% hydrogen peroxide disinfectant on sensitive and resistant strains of *Staphylococcus aureus* and *P. aeruginosa*. The disinfectant was effective for both sensitive and multidrug-resistant strains, although it took twice as long for the latter (10 minutes versus 5 minutes). The efficacy decreased in the presence of organic matter, doubling the required contact time for both sensitive and resistant strains.

This study indicates that use of silver ion solutions for disinfecting surfaces should be preceded by cleaning of any soiling or organic matter. In addition, close attention should be paid to contact time of the disinfectant, especially if multidrug-resistant strains are known to be contaminating the environment.[25]

5.4.3.1.4 Chlorhexidine

We found several before-and-after and outbreak studies of chlorhexidine and alcohol-based disinfectants, used separately or in conjunction. For example, one before-and-after study in an Italian burn ICU compared standard environmental cleaning using sodium hypochlorite with a chlorohexidine-60% isopropyl alcohol disinfectant. Additional changes were made to the daily cleaning regimen, including increased focus on high-touch surfaces and more frequent disinfection.

After the intervention, there was a decline in the percentage of positive carbapenem-resistant *A. baumannii* environmental cultures from 13 percent to 4 percent and a reduction in samples exceeding the acceptable adenosine triphosphate (ATP) limits from 21.7 percent to 14 percent.[19] A cross-sectional study of chlorohexidine for vancomycin-sensitive and vancomycin-resistant Enterobacteriaceae clinical isolates found a lower susceptibility to chlorohexidine in vancomycin-resistant isolates than in the drug-sensitive isolates.[23]

5.4.3.1.5 Multiple Disinfectants

Chlorine-based disinfectants have been used in combination with other disinfectant chemicals in outbreak settings. Enhanced cleaning was initiated at the start of an outbreak of *A. baumannii* during which the organism was isolated from 22 neonates in a neonatal ICU.[26] Infection control measures included disinfection with bleach for surfaces, hydrogen peroxide gas plasma for reusable equipment, and disinfection of nursery incubators with 4% chlorhexidine. The intervention also included closure of the ward and hand hygiene promotion. The last case occurred 8 months after the first identified *A. baumannii* isolate. The source of the outbreak was likely a mother admitted to the adult ICU.[26] The researchers credit control of the outbreak to enhanced infection control measures.

5.4.3.1.6 Other Disinfectant Agents

Sodium dichloroisocyanurate was used as part of a multicomponent intervention in a Korean ICU to stop an outbreak of carbapenem-resistant *A. baumannii.* The disinfectant was used for terminal and indepth cleaning, and effectiveness was audited with environmental cultures. Additional measures included contact precautions, patient isolation, and change to a closed suctioning mechanical ventilation system. Within 5 months of implementing these more intensive disinfection and isolation practices, there were no new colonizations or infections,[27] but it is not possible to separate whether this finding was due mainly to the disinfectants used or to other components of the intervention.

Glucoprotamin was investigated in one in vitro laboratory study included in our review. This disinfectant had varying levels of efficacy against several MDROs. For example, glucoprotamin was more effective against Gram-negative than Gram-positive bacteria. In addition, tetracycline-resistant *P. aeruginosa* was found to be more resistant to glucoprotamin disinfectant than was tetracycline-sensitive *P. aeruginosa,* but not at levels typically used in environmental cleaning.[28]

Phenolic agents were used in one pre-post intervention study in a large Thai tertiary care hospital. In the baseline period, no interventions were performed other than standard infection control practices. In the second intervention stage, sodium hypochlorite (bleach) was used for environmental cleaning. In the third intervention stage, phenolic agents with detergent were used for environmental cleaning instead of bleach, without any other changes to the intervention.

Compared with the pre-intervention period, the second stage that used sodium hypochlorite had a 67 percent reduction in colonization and infections by pandrug-resistant *A. baumannii* (from 3.6 to 1.2 cases per 1,000 patient-days; $p<0.001$) and the third stage using phenolic agents with detergent had a 76 percent reduction in infections and colonizations (from 3.6 to 0.85 cases per 1,000 patient-days; $p<0.001$).[16]

A separate before-and-after study tested similar stages for control of extensively drug-resistant *A. baumannii* (XDR-AB). The same researchers found that the use of sodium hypochlorite decreased clinical and surveillance isolates of XDR-AB compared with the use of detergent-disinfectant in the baseline period. The rate decreased from 11.1 to 1.74 cases per 1,000 patient-days for clinical isolates ($p<0.001$); and from 2.11 to 0.98 per 1,000 patient-days for surveillance isolates ($p<0.001$).[8]

5.4.3.1.7 No-Touch Disinfection Methods

While traditional methods of disinfection require the manual application of chemicals to a contaminated surface, new no-touch disinfection methods are being developed. These techniques often supplement

existing cleaning and disinfection policies or are implemented in outbreak situations in which routine cleaning practices have not been sufficient to reduce transmission. The two most common no-touch disinfection methods are hydrogen peroxide vaporization (HPV) and ultraviolet light-C decontamination (UV-C). We also briefly discuss studies about no-touch methods that use gas plasma, argon, helium, hydrogen peroxide/peracetic acid, and steam.

Ultraviolet disinfection was investigated by one before-and-after study, one cluster-randomized crossover study, three in vitro studies, two systematic reviews, and three nonsystematic reviews. One systematic review recommended that no-touch technologies such as UV (wavelength range not specified) should be used to augment traditional cleaning methods, especially for *C. difficile* and VRE.[29] A second systematic review stated that there is very low-quality evidence to support the efficacy of UV-C or xenon UV disinfection.[30]

Only two studies on no-touch methods included in this review took place in clinical settings. One before-and-after study found that UV-C radiation at close range was effective in reducing Gram-negative bacilli, *C. difficile*, *S. aureus,* and *Enterococcus* on computer keyboards.[31] The other study, a cluster-randomized crossover study found that adding UV-C room decontamination after standard cleaning reduced incidence of several target organisms, including three MDROs and *C. difficile.* The incidence of colonization or infection among exposed patients was lower after the addition of UV-C disinfection (relative risk [RR] 0.70, 95% CI 0.50–0.98; p=0.036).[18]

Two in vitro studies found UV-C disinfection effectively reduced bacterial load on environmental surfaces, although both concluded that the technology was more effective against MRSA than for *Candida* or *C. difficile*.[32,33] Presence of organic matter was also found to reduce UV-C efficacy,[33] indicating the importance of thoroughly cleaning soiled surfaces before UV-C disinfection.

Another study in a laboratory setting found 405 nanometer violet light (a slightly longer wavelength than UV light) was effective in reducing presence of ampicillin-resistant *E. coli*.[34] In summary, some evidence suggests that UV disinfection of patient rooms can reduce hospital-acquired infections caused by common MDROs and *C. difficile*, but much of the evidence comes from laboratory research and not clinical settings. In addition, standard cleaning and disinfection practices should be augmented and not replaced by this technology, especially if there is soiling of the surface being disinfected.

HPV was the focus of five before-and-after studies, one prospective cohort study, one cluster-randomized crossover study, and one systematic review. The five before-and-after studies [35-39] found HPV effectively reduced contamination from MRSA (two studies), VRE (one study), multidrug-resistant *A. baumannii* (four studies), multidrug-resistant Gram negative bacteria (MDR-GNB) (one study), and OXA-48 carbapenemase-producing Enterobacteriaceae (one study). HPV was also found to inactivate spores and to be effective for both porous and nonporous surfaces.[35]

A cluster-randomized crossover study by Blazejewski et al. (2015) found that HPV reduced MDRO contamination in patient rooms.[40] A prospective cohort study found patients admitted to rooms decontaminated using HPV were 64 percent less likely to acquire any MDRO (p<0.001) and 80 percent less likely to acquire VRE (p<0.001); acquisition of *C. difficile*, MRSA, and MDR-GNB were also reduced,

although not statistically significantly.[i] In addition, one systematic review found evidence to support HPV effectiveness in decreasing VRE colonization and infection.[29] The studies suggest that HPV room decontamination both reduced environmental contamination by MDROs and MDRO transmission/acquisition in healthcare facilities.

Other no-touch technologies were each mentioned by one study, and additional research and evidence are needed before their safety and efficacy can be validated for use in reducing MDROs in healthcare settings. First, in a laboratory setting, Park et al. (2015) demonstrated that two types of plasma (an ionized gas), argon gas-feeding dielectric barrier discharge and nano-second pulsed plasma, effectively inactivated sensitive and resistant bacteria. The article did not discuss implementation or clinical applications.[41]

Helium and helium-air plasma are two other plasma decontamination technologies that were found by one in vitro study to reduce *S. aureus* and methicillin-resistant bacteria on glass surfaces,[42] but this technology was not effective for *C. difficile* spores. One last plasma technology, hydrogen peroxide gas plasma, was used as part of a multicomponent infection control intervention to stop an outbreak of XDR-AB in an Italian neonatal ICU.[26] This plasma technology successfully decontaminated the assisted-ventilation equipment that was partially implicated in the outbreak.

Another technology, aerosolized hydrogen peroxide and peracetic acid, had similar efficacy as HPV, in one cluster-randomized crossover study in a French ICU.[40] Lastly, steam vapor has been tested in laboratory studies on MDROs and has been found to be successful at decontaminating glass surfaces, even in the presence of organic matter.[43]

At present, HPV and UV decontamination are the most well-studied no-touch technologies and are discussed in the implementation section below because they differ in the time and effort each requires in a clinical setting. While other no-touch technologies have been developed and successfully tested in vitro to disinfect surfaces contaminated with MDROs, more studies will be needed before these can be applied in clinical settings.

5.4.3.2 Tools: Microfiber Cloths and Mops

Three before-and-after studies investigated the use of microfiber cloths in combination with one or more strategies to enhance cleaning. The use of microfiber cloths in daily cleaning and disinfection, in addition to patient cohorting, was implemented in a before-and-after study in a Spanish ICU. Care was taken not to reuse dirty cloths, and clean microfiber cloths were soaked in a bleach solution prior to use. This intervention was associated with a significant reduction in XDR-AB carriage.[44]

Another before-and-after study found that using microfiber cloths to clean along with fluorescent markers to identify the presence of organic matter to aid with cleaning reduced MDRO environmental contamination of high-touch surfaces significantly, compared with a baseline period.[45] As part of another multicomponent intervention, microfiber cloths were used for daily cleaning in an ICU in the United States, resulting in decreased incidence of MDRO infections.[9]

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[i]Passaretti CL, Otter JA, Reich NG, et al. An evaluation of environmental decontamination with hydrogen peroxide vapor for reducing the risk of patient acquisition of multidrug-resistant organisms. Clin Infect Dis. 2013;56(1):27-35. doi: 10.1093/cid/cis839.

5.4.3.3 Antimicrobial and Easy-To-Disinfect Objects and Surfaces

While certain contaminated areas are easy to clean and disinfect because of their accessibility and composition (e.g., flat, untextured, nonporous surfaces), other surfaces in a healthcare facility are more prone to harbor bacteria and are more difficult to decontaminate. Several innovations may decrease MDRO contamination of the environment and make cleaning and disinfection more efficient and effective.

In response to an outbreak of *A. baumannii*, an ICU in the United Kingdom implemented deep cleaning and disinfection, replaced items that were difficult to clean, and devised strategies to prevent contamination of regularly used medical equipment. For example:

- Patient binders were replaced with plastic-coated binders that could be wiped with disinfectant;
- Dressing trolleys—movable storage cabinets—were replaced with trolleys that had sealable doors to ensure they were only externally decontaminated; and
- Single-use bags were used to store equipment that was previously exposed. No additional cases of *A. baumannii* occurred after these interventions.[14]

Although not statistically rigorous, this study demonstrates that innovative strategies that replace everyday objects and tools can reduce MDRO transmission and make environmental disinfection simpler and more efficient.

Textiles, especially those frequently touched by infected or colonized patients (e.g., gowns, bed sheets, and blankets), can become contaminated and may be overlooked during standard cleaning operations. Two studies evaluated interventions that included replacing, decontaminating, or improving the antimicrobial properties of textiles found in patient rooms.

One before-and-after trial by Lee et al. (2017) disinfected all textiles and nurses' clothing in addition to other objects and surfaces with Bio-Kil (3-[Trimethoxysilyl] propyloctadecyldimethyl ammonium chloride), and found a statistically significant decline in the environmental bacterial burden compared with control rooms without this extra disinfection.[21]

Copper-oxide-impregnated woven linens were tested in six hospitals in a before-and-after study (the only textile intervention that was not combined with other interventions).[46] This fabric was used to produce patient gowns, pillowcases, sheets, washcloths, towels, and blankets. Compared with a prior period, after 180 days, there was a statistically nonsignificant 36.4 percent reduction in HAIs caused by MDROs ($p>0.05$). Using the combined metric of HAIs from both MDROs and *C. difficile,* the intervention had a statistically significant 39.9 percent reduction ($p<0.05$).

The use of antimicrobial materials for environmental surfaces was mentioned in one systematic literature review. Copper or silver ion surfaces were found by Tacconelli et al. (2014) to have ambiguous support in the literature reviewed in their study.[1]

5.4.4 Implementation

Overall, many of the studies reviewed included environmental cleaning and disinfection as part of a multicomponent intervention. With the use of multicomponent interventions, it is difficult to attribute the success of the intervention to any one component. However, in general, multicomponent

interventions have been demonstrated to be very effective when measuring reductions in a variety of MDRO-related clinical outcomes. In one systematic review, researchers found that environmental cleaning interventions were most effective when implemented in conjunction with antimicrobial stewardship, evaluation of standard care, and source control for reducing acquisition of several MDROs.[47]

5.4.4.1 No-Touch Disinfection Implementation

In a cross-sectional survey of healthcare workers and patients in a hospital testing UV-C disinfection, 84 percent responded that the purpose of UV-C room decontamination was well explained to them. However, 39 percent of responding patients had at some time refused UV-C disinfection in their room or bathroom due to not feeling well (25%), wanting to sleep (13%), not wanting to be bothered (11%), and not liking the smell (5%).[48] This survey demonstrates the importance of educating patients that may be affected by no-touch disinfection interventions that take place in occupied patient rooms.

Time requirements need to be considered when selecting no-touch disinfection methods. HPV requires sealing off rooms and vents and can take as long as 1 hour and 45 to run. However, HPV is a favored no-touch method for some who cite its advantages of portability, lack of harmful residue, and low vapor temperature.[38]

5.4.4.2 Environmental Screening Methods

Detecting the presence of MDROs in the environment can be helpful as a tool to audit the thoroughness of cleaning and disinfection, determine a source of contamination and targeted cleaning and disinfection during outbreaks,[49] and test or compare methods of cleaning and disinfection.

Healthcare facilities can monitor the thoroughness and efficacy of cleaning and disinfection by testing for MDROs on environmental surfaces using fluorescent gel, microbial culturing, UV detectable powder, or ATP detection. For example, fluorescent gels and powders are visible only with UV light and can be applied to a variety of surfaces before environmental cleaning to illuminate surfaces that are missed.

We reviewed six studies that used one of these methods to monitor cleaning and disinfection thoroughness. Five studies used microbial cultures to monitor cleaning [7,20,49-51] and three studies used UV-detectable powders or gels for monitoring purposes.[22,49,50]

In outbreak and endemic settings, environmental screening may be useful in some situations, for example, to help determine a point source of contamination contributing to new cases or to enhance general cleaning and disinfection to prevent additional cases. One systematic review recommends environmental screening only if standard infection control practices (e.g., contact precautions, enhanced cleaning and disinfection) fail to stop an ongoing outbreak.[1]

Microbial culturing as a method of environmental screening is helpful in endemic situations where the environmental strain must be compared with the outbreak strain to understand their relatedness. ATP testing can also differentiate between bacterial species, although it does not provide an isolate that can be sequenced to compare strains. Five studies in this review used microbial culturing in outbreak or endemic situations to locate point sources contributing to new cases, or gaps in routine cleaning, and target those surfaces for disinfection.[7,11,20,52,53]

In addition, two studies used environmental screening to inspect rooms for bacterial contamination before new admissions. If any samples were positive, new patients were not admitted to those rooms. These studies used microbial culturing[27] and ATP detection[9] for this purpose. However, microbial culturing can take hours to complete after collection of environmental samples, and although fluorescent substances provide a real-time method of monitoring cleaning practices, they are not as useful in detecting the presence of bacteria.

5.4.4.3 Unintended Outcomes

Deep environmental cleaning of patient rooms, cleaning or replacement of equipment, and other major changes or interventions can impact daily activities within healthcare facilities. During an outbreak, one ICU had to relocate all patients for 1 week during an intensive cleaning, with accompanying logistical challenges and inconveniences.[14]

The implementation of no-touch technology for room decontamination has budget and staffing implications. As mentioned by Haas et al. (2014), the regular use of technology such as UV disinfection requires planning to ensure that resources are not depleted, staff are trained and available, and attention is not diverted from other tasks and responsibilities.[54]

It is important to assess the appropriateness of a cleaning or disinfection strategy for the specific pathogens of concern in a facility. One report by Passaretti et al. (2013) noted that HPV demonstrated "incompatibility" with the paint in some hospital rooms. It may be prudent to investigate compatibility of new disinfection methods with paint or other sensitive surfaces in rooms where they will be used.[55] Testing could also be done in a small number of rooms before widely implementing a new technique, to avoid widespread damage.

In general, efficacy against MDROs should not be the only outcome of interest in laboratory or preliminary clinical studies. Biodegradability, toxicity, and phenotypic changes to pathogens of interest should be studied and considered when introducing new chemicals or technologies.

A cross-sectional study of environmental service workers in U.S. hospitals found that only 60 percent of respondents reported "always" knowing the type of isolation precautions to be followed when entering a room to perform terminal cleaning; 27 percent also responded that they were "often" or "always" worried that cleaning products might be harmful to them.[56] These responses highlight the importance of the health and safety of staff performing environmental cleaning and disinfection.

5.4.4.4 Education, Monitoring, and Feedback

Education, reeducation, monitoring, and feedback all contribute to successful interventions. One before-and-after study examined a monitoring and feedback program for 27 facilities and their environmental cleaning staff. After an initial education period and several feedback cycles of analysis and objective performance feedback, thoroughness of cleaning improved from 50 percent of surfaces cleaned to 85 percent of surfaces cleaned.[57]

In another before-and-after trial, staff were reeducated with detailed instructions for cleaning and disinfection. This approach resulted in decreased incidence of carbapenem-resistant *K. pneumonia*e.[10] Reeducation was also featured in other studies found in this review.[12,52] A modeled intervention study also found that improving terminal cleaning thoroughness reduced patient acquisition of MDROs.[58]

Monitoring and feedback can help address any confusion that environmental cleaning workers may have. In a cross-sectional study of U.S. hospital environmental workers, 28 percent reported "never" or "sometimes" knowing when to use UV disinfection, 37 percent reported that it was "always" clear what items they were responsible for cleaning, 39 percent reported that they "often" or "always" avoided cleaning near patients to avoid disturbing them, and 40 percent reported that the over-bed table was "often" or "always" too cluttered to clean properly during daily cleaning.[56]

Monitoring and feedback of daily cleaning and disinfection practices could help identify and change these simple lapses in cleaning procedures and reduce HAIs. Unannounced audits were implemented in one outbreak study to encourage ongoing, thorough cleanliness.[14] After a pass rate was achieved for 3 consecutive weeks, auditing was stopped. This strategy could be useful for improving thoroughness of cleaning and during the initial phase of implementing new practices or policies.

Specific staff training to target problematic practices has also been studied in effective before-and-after study interventions. One study in a U.S. hospital used an initial observation period to identify problem areas, then educated staff on hemodialysis-related cleaning and disinfection and avoiding cross-contamination with personal objects.[49] Paired with other changes, this intervention significantly reduced colonization with *K. pneumoniae carbapenemase*-producing isolates.

Monitoring and auditing can be done via visual inspection of cleaning and disinfection practices or with the use of any of the environmental screening methods described above. Fluorescent markers and ATP detection are more commonly used for cleaning and disinfection auditing than are microbial cultures.[45,49,59]

5.4.4.5 Facility Policies

Policy changes in healthcare facilities can also help reduce environmental contamination and improve patient outcomes. In endemic or outbreak situations, some facilities have implemented policies requiring that rooms be certified as clean either by inspection[10] or by a series of negative environmental cultures before new patients can be assigned to the vacated room.[27] Some facilities also may determine that current cleaning and disinfection practices are insufficient and choose to revamp entire policies for environmental cleaning and disinfection. This approach is most common in outbreak situations when traditional practices have not been enough to stem transmission.[51,53]

With the implementation of no-touch disinfection technologies or other labor-intensive interventions, management may need to readjust staffing and assignments[49,60] and otherwise ensure appropriate staffing levels. These changes in policies may require additional staff education (e.g., how to set up a room and use an HPV machine) or additional funding for new staff or equipment purchases.[54,59]

5.4.4.6 Resources To Assist With Implementation

The following resources include information on environmental cleaning, monitoring, program implementation, and other infection control:

- The Agency for Healthcare Research and Quality's Effective Health Care publication *Environmental Cleaning for the Prevention of Healthcare-Associated Infections* is available at https://www.ncbi.nlm.nih.gov/books/NBK311016/pdf/Bookshelf_NBK311016.pdf.
- The CDC's *Guidelines for Environmental Infection Control in Health-Care Facilities* is available at https://www.cdc.gov/infectioncontrol/pdf/guidelines/environmental-guidelines-P.pdf.

- The CDC's Options for Evaluating Environmental Cleaning web page includes links to toolkits for evaluating environmental cleaning and monitoring terminal cleaning and instructions for creating an environmental cleaning program, available at https://www.cdc.gov/hai/toolkits/evaluating-environmental-cleaning.html.
- The CDC's *Chemical Disinfectants—Guideline for Disinfection and Sterilization in Healthcare Facilities* is available at https://www.cdc.gov/infectioncontrol/guidelines/disinfection/disinfection-methods/chemical.html.
- The Association for Professionals in Infection Control and Epidemiology provides Environmental Services resources at https://apic.org/resources/topic-specific-infection-prevention/environmental-services/.
- The U.S. Environmental Protection Agency, Office of Pesticide Programs, publishes a list of recommended cleaning products, "List H: EPA's Registered Products Effective Against Methicillin Resistant *Staphylococcus aureus* (MRSA) and/or Vancomycin Resistant *Enterococcus faecalis* or *faecium* (VRE)," available at https://www.epa.gov/sites/production/files/2018-01/documents/2018.10.01.listh_.pdf.

5.4.5 Gaps and Future Directions

Most of the evidence presented above is taken from outbreak studies and before-and-after interventions or from in vitro studies, and the evidence is weak to draw conclusions about efficacy and implementation. Randomized studies are a more rigorous approach and should ideally be designed with one or two variable changes between the study and control groups. Multicomponent interventions make it difficult to understand which specific elements are responsible for success. More single intervention studies on environmental cleaning for MDROs would be useful.

Of particular importance for future research is comparing disinfectants for use in environmental disinfection. A handful of studies have found that QACs reduce environmental contamination with MDROs and provide residual antimicrobial properties. Although they are low toxicity to humans, evidence is mixed to support their usefulness in disinfecting high-touch surfaces and textiles that are in close contact with HCWs and patients. In addition, they cannot be used for spore-forming organisms, such as *C. difficile*, and are not yet used or studied as commonly as sodium hypochlorite. Lastly, many of the no-touch disinfection technologies are relatively new and have not been rigorously compared with traditional cleaning methods in clinical settings to determine which are most advantageous.

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5.5 PSP: Minimizing Exposure to Invasive Devices and Reducing Device-Associated Risks

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Key Findings

- Using devices minimally and appropriately and practicing hygiene and infection control precautions when inserting them are basic steps that can be taken to reduce device-associated infections.
- Further research is needed to determine the safest and most effective uses of antimicrobial locking solutions and catheter materials.
- Antimicrobial resistance has not been eliminated as a concern when using antibiotics in antibiotic locking solutions, impregnated catheters, or prophylactic treatment to prevent infections.
- Ongoing implementation education, monitoring, and feedback for medical staff, patients, and caregivers are recommended for improving adherence to recommended PSPs.

An invasive device is any medical device that is introduced into the body, either through a break in the skin or an opening in the body. Invasive devices include catheters, such as urinary catheters or central venous catheters, and endotracheal tubes used for mechanical ventilation. Medical catheters are tubes that serve purposes such as administering fluids, blood products, medications, and nutritional solutions; providing hemodynamic monitoring; and collecting urine and measuring urinary output.[1,2,j] Endotracheal tubes are inserted into a patient's trachea to provide an unobstructed passageway for oxygen and other gases (e.g., anesthesia) while a patient is mechanically ventilated.

The use of invasive devices in patients, while often medically necessary, has been associated with increased risk of invasive infections (e.g., bloodstream infections) and overall mortality.[3] From 2011 to 2014, catheter-associated urinary tract infections (CAUTIs), central-line associated blood stream infections (CLABSIs), and ventilator-associated pneumonias (VAPs) accounted for 38 percent, 24 percent, and 2 percent of all healthcare-associated infections, respectively.[4] The treatment of these infections is often complicated by resistance to commonly used antibiotics. Within these three categories of infections (i.e., CAUTIs, CLABSIs, and VAPs), the percentage of pathogens that exhibited drug resistance varied depending on species and antibiotic, but an estimated 14 percent were caused by an antibiotic-resistant pathogen.[4]

5.5.1 Practice Description

Because medical devices provide direct access for bacteria to enter the human body, they pose a significant risk for invasive MDRO infections. Although many of the studies in this review focus on infections that are not specifically MDROs, they were included for their relevance to the prevention and control of MDROs. This review identifies and discusses opportunities to reduce device-associated risks during a patient's care in a health facility. Key findings are presented in the box above.

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[j]The most recent recommendations for catheter use (as of June 2019) from the CDC's HICPAC generally recommend against using indwelling urinary catheters to manage urinary incontinence in place of nursing care. However, the committee also acknowledges that further research is needed for non-indwelling (e.g., condom-style) catheters and for patients at risk of skin breakdown. This approach is in keeping with the overarching recommendation for appropriate indwelling urinary catheter use: only when necessary and only for as long as needed. For more information, refer to Gould C, Umscheid C, Agarwal E, Kuntz G, Pegues D. Guideline for prevention of catheter-associated urinary tract infections Atlanta, GA: Centers for Disease Control and Prevention; 2009. https://www.cdc.gov/infectioncontrol/pdf/guidelines/cauti-guidelines-H.pdf.

5.5.2 Methods

To answer the question, "What are the best device reduction and harm minimization practices?" three databases (CINAHL, MEDLINE, and Cochrane) were searched for "catheter-related infections," "endotracheal tubes," and synonyms in combination with "infection control," "microbial drug resistance," and associated phrases. Articles from 2009 to December 2018 were included.

The initial search yielded 396 results; after duplicates were removed, 342 were screened for inclusion, and 139 full-text articles were retrieved. Of those, 17 were selected for inclusion in this review. Articles were excluded if they were outside the scope of this review, included insufficient detail on a PSP, were unable to be retrieved, or were used in the review of another PSP.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report appendixes A through C.

5.5.3 Review of Evidence

The resulting 17 studies that were selected for review include 6 systematic reviews, 4 laboratory studies, 3 before-and-after intervention studies, 3 retrospective cohort studies, and 1 randomized control trial. The six systematic reviews included studies from various international settings. Of the 11 individual studies, 5 took place in the United States or its territories, and 6 took place abroad.

The settings for these individual studies include patient homes, surgical wards, ICUs, dialysis units, tertiary care hospitals, teaching hospitals, and laboratories. The settings covered in this review span community and primary care, long-term acute care hospitals, rehabilitation centers, hospitals, and general healthcare settings.

5.5.3.1 Least Harmful Device Use—Catheters

To reduce the harms associated with catheter use (intravascular or urinary catheters), interventions can target several stages of their use:

- Avoiding unnecessary and inappropriate catheter use,
- Ensuring aseptic placement of catheters,
- Maintaining awareness and proper care of catheters in place, and
- Promptly removing unnecessary catheters.[5]

A systematic review by Patel et al. (2018) reviewed 102 studies with interventions aiming to reduce CAUTIs and CLABSIs. The review determined that the most successful interventions targeted multiple stages. For both CAUTIs and CLABSIs, successful interventions included protocols to remove by default based on certain criteria (e.g., time).[5] Other aspects of successful interventions (e.g., monitoring, auditing, and staffing) will be addressed in section 5.5.4.

The CDC also has a published set of guidelines for reducing both intravascular catheter-related infections and CAUTIs.[1,6] These guidelines have various recommendations for reducing harm throughout the phases of the patient's care, including:

- Timing of catheter placement,
- Selection of the appropriate catheter device,
- Use of hand hygiene,
- Aseptic technique strategies,
- Barrier precautions during device placement and care, and
- Use of systemic antibiotics (not recommended) and antibiotic lock solutions.

Several of these interventions will be addressed below, with additional information provided in section 5.5.4.4.

5.5.3.1.1 Urinary Catheters

Specific to urinary catheters, Mody et al (2017) conducted a large-scale before-and-after intervention study of 404 nursing homes that implemented a multicomponent strategy that included targeting multiple stages of device use. This study of community-based nursing homes used the Comprehensive Unit-based Safety Program (CUSP) toolkit for CAUTI, developed as part of the Agency for Healthcare Research and Quality Safety Program for Long-Term Care. The intervention targeted urinary catheter removal, aseptic insertion, incontinence care planning, and various training programs for staff, patients, and family.

The intervention reduced UTIs, perhaps indicating success in aseptic techniques, but did not reduce overall catheter utilization. The authors theorized that catheter utilization in nursing homes across the country was already relatively low at the start of the study, leaving little room for further reductions.[7]

The low utilization of urinary catheters in nursing homes was also confirmed in a systematic review by Meddings et al. (2017). The same review found that nursing home interventions involving improving hand hygiene, reducing catheter use, and enhancing barrier precautions were all effective at reducing UTIs in nursing home residents.[8] In an ICU setting, Patel et al. (2018) assessed that many successful interventions included a focus on removing a urinary catheter.[5]

Another systematic review compared methods of short-term (14 days or less) bladder catheterization (indwelling urethral catheterization, intermittent urethral catheterization, and suprapubic catheterization) in hospitalized adults.[9] For the outcome of UTI, evidence was not sufficient enough to support the use of one route of catheterization over the others to reduce infections.

Meddings et al. (2015) used the RAND/UCLA Appropriateness Method, a method for evaluating the appropriateness of medical technology, to refine criteria for the use of urinary catheters (indwelling Foley catheters, intermittent straight catheters, and external condom catheters) in hospitalized medical patients. Using the literature, the authors developed a list of potential indications for each catheter type and created different scenarios illustrating their use. A multidisciplinary panel of subject matter experts ranked the scenarios as appropriate, inappropriate, or uncertain; appropriateness is defined as use for which benefits outweigh risks. The authors conclude that Foley catheters should only be used to measure urine or manage incontinence if other methods have been exhausted or if there are medical indications where nonbarrier methods would increase harm (e.g., to improve healing of sacral ulcers).[10]

5.5.3.1.2 Intravascular Catheters

With respect to intravascular catheters, certain patient safety practices can be used to reduce the risk of infection when vascular access cannot be avoided. The practices included in our review focus on the use of antibiotics or specialized catheters that contain antimicrobial substances. The section below discusses these practices in further detail and their implications for antimicrobial resistance and other potential patient harm.

The CDC guidelines for preventing intravascular catheter-related infections provide recommendations for antibiotic and antiseptic use.[6] In general, for intravascular catheters, the CDC does not recommend the use of systemic antimicrobial prophylaxis. Instead, the CDC recommends the use of certain antiseptic ointments at the catheter exit site for dialysis catheters and recommends antibiotic locking solutions (discussed below) in certain situations.[6] For details on the strength of the evidence for each of these recommendations, please view the CDC guidelines referenced in section 5.5.4.

Regarding site placement of central venous catheters (CVCs), one systematic review of published ICU infection outbreaks found strong evidence to support the use of subclavian insertion sites compared with jugular or femoral sites to reduce the risk of CLABSI.[11] This practice is strongly supported by the CDC guidelines to avoid use of jugular or femoral insertion sites.[6]

As with most medical procedures that are physically invasive, sanitary practices are necessary and may reduce the risk of infected wounds and invasive infections. While no study in this review specifically addressed sanitary practices as an intervention, the CDC guidelines include detailed instructions on appropriate infection control procedures for intravascular catheters.[6] The strongest CDC recommendations include:

- Using sterile gloves when inserting arterial, central, and midline vascular catheters;
- Frequently performing hand hygiene,
- Using sterile gauze or sterile, transparent, semipermeable dressing to cover the catheter site; and
- Using chlorhexidine antisepsis for insertion sites in specific cases (see guidelines for details).[6]

One method of combating invasive infections associated with catheters is to reduce and restrict the growth of bacteria within the catheter itself. Bacteria often form biofilms within catheters that can inhibit catheter function and increase the risk of infection. In addition to preventing bacterial infections and biofilm formation, antibiotic lock (ABL) therapy reduces costs and vein damage associated with device replacement. ABL therapy is the insertion of a concentrated antibiotic solution into a catheter lumen (its internal channel or tube) to prevent the development of microbial biofilm on catheter surfaces.

In a study by Dixon et al. (2012), ABL therapy, as an adjunct to systemic antibiotic therapy, vs. systemic antibiotic therapy alone in patients with tunneled hemodialysis catheters, reduced CLABSI incidence by over 50 percent (RR 0.50 +/- 0.03; $p<0.0001$) and reduced treatment failure and relapses in the study group compared with the control group.[12] The CDC recommends that ABL prophylaxis only be used for hemodialysis patients with long-term catheters who have a history of multiple CLABSIs despite appropriate aseptic techniques during catheter care and insertion.[6]

In two studies identified in this review, no antibiotic resistance was found to be associated with their use in ABLs. One retrospective cohort study in the homes of patients in the Netherlands found taurolidine to be safe for up to 702 days.[13] Another retrospective cohort study in a dialysis unit in the United Kingdom found no increased risk of drug resistance when using vancomycin and gentamicin ABL solutions paired with systemic vancomycin and gentamicin.[12] However, increased prevalence of *S. aureus* and antimicrobial-resistant Enterobacteriaceae was found.

5.5.3.1.3 Catheter Innovations To Reduce Risk of Infection

Various catheter materials have been studied to determine their effectiveness at reducing biofilm formation and preventing catheter-related infections. Urinary catheters can be made of hydrophilic materials—which reduce friction during insertion, thus reducing the need for lubrication and the risk of urethral damage—or impregnated with antimicrobial chemicals to prevent colonization of the catheter with bacteria or fungi. Catheters can be constructed of latex, silicone, or other components; however, antimicrobial silver alloys may bind more readily to latex than to other materials.[14]

Table 7 summarizes the evidence found in two systematic reviews and five studies regarding the use of alternative urinary and intravascular catheter materials and antimicrobial-impregnated catheters. Three technologies were found to be successful in laboratory experiments: gum arabic capped-silver nanoparticle-coated devices[15]; catheters impregnated with rifampicin, triclosan, and trimethoprim[16]; and CVCs impregnated with minocycline and rifampicin (M/R) + chlorohexidine (CHX).[17] One review found gel reservoir and hydrophilic catheters to be safer than traditional sterile noncoated catheters.[18]

Silver-impregnated catheters were determined to have mixed evidence.[11] Catheters impregnated with both silver and chlorohexidine have been demonstrated to reduce colonization and CLABSIs, especially in settings with high background rates of CLABSIs[11] and are highly recommended by CDC if the CVC is expected to stay in place for more than 5 days.[6]

Lastly, M/R-impregnated catheters were the most well studied, cumulatively mentioned in five different abstracted articles. Use of these antimicrobial catheters was backed by one laboratory study[19] and one retrospective cohort study.[20] One systematic review concluded that evidence was mixed to support the use of M/R catheters.[11] Another innovation for increasing catheter safety is the use of needleless connectors, which were mentioned in one review as having mixed evidence regarding their efficacy.[11]

While some studies found a reduction in catheter contamination with needleless connectors, others observed an increase in infection rates temporally associated with their introduction. If needleless connectors are used, the CDC strongly recommends that an antiseptic be used to scrub the access port and that it be accessed only with sterile devices.[6]

The CDC guidelines previously referenced also include recommendations on urinary catheter materials. The CDC acknowledges the benefits of antibiotic-impregnated or antiseptic-impregnated urinary catheters in certain situations but also addresses a mix or lack of evidence demonstrating that they reduce UTI. The CDC also states that silicone and hydrophilic catheters may be preferable in certain situations (e.g., hydrophilic catheter use for intermittent catheterization).[1]

Table 7: Studies of Alternative Materials and Antimicrobial-Impregnated Catheters

Author, Year	Study Type	Patient Safety Practice	Evidence
Ansari et al., 2014[15]	Laboratory study	Use of gum arabic capped-silver nanoparticles (GA-AgNPs), as an antimicrobial surface coating material for surgical implants and instruments	The results of this laboratory experiment found that GA-AgNPs successfully penetrated biofilms, reduced biofilm formation, reduced biofilm coverage, and reduced bacterial colonization overall. The lowest minimum inhibitory concentration for extended spectrum beta-lactamase (ESBL), non-ESBL, and metallo-beta-lactamase *P. aeruginosa* was determined to be 11.25 mg/mL, indicative of a very strong bacteriostatic activity. The minimum bactericidal concentration was found to be in the range of 11.25–45mg/mL. At a concentration of 30 mg/mL, it arrested the biofilm formation without affecting the cell viability, whereas at a concentration of 60 mg/mL, the biofilm formation was completely blocked and the bacterial growth completely ceased.
Bayston et al., 2009[16]	Laboratory study	Impregnation of continuous peritoneal dialysis catheters using rifampicin, triclosan, and trimethoprim	Long-lasting ability to kill ~99% of pathogens associated with infection was seen in patients on continuous ambulatory peritoneal dialysis, even after very large challenge doses. In vitro challenge tests confirmed that this long-lasting activity could prevent colonization of the catheters in flow conditions for prolonged periods. Catheters stopped growth with no signs of resistance for 30 days, had a >98.9% reduction after 280 days' release of antimicrobials from the material, and after 72 hours failed to show bacterial migration down the track.
Bermingham et al., 2013[18]	Systematic review	Use of various materials and practices for urinary catheters, including: clean versus sterile noncoated intermittent self-catheterization, hydrophilic catheters, gel reservoir catheters, and clean noncoated catheters	People using gel reservoir and hydrophilic catheters were significantly less likely to report one or more UTIs compared with those using sterile noncoated catheters (absolute effect for gel reservoir = 149 fewer per 1,000 (95% CI, −7 to 198, p=0.04); absolute effect for hydrophilic = 153 fewer per 1,000 (95% CI, −8 to 268, p=0.04). However, the confidence intervals for these values were wide and overlapping. There was no significant difference in the incidence of symptomatic UTI for people using clean versus sterile noncoated catheters for long-term intermittent self-catheterization.
Doyle et al., 2011[11]	Systematic review	M/R and silver or chlorohexidine-silver sulphadiazine (CHX/SS) impregnated CVCs	This systematic review of outbreak studies reported a reduction in colonization and CLABSIs with both technologies, especially in settings with high background rates of CLABSIs.
Raad et al., 2008[19]	Laboratory study	CVCs impregnated with M/R, silver-platinum and carbon (SPC), and CHX/SS	M/R-CVCs were superior in antiadherence activity and prolonged antimicrobial durability against MDR *S. aureus* and other MRD Gram-negative bacteria.
Raad et al., 2012[17]	Laboratory study	Second-generation CVCs impregnated with M/R and CHX	CHX-M/R-coated catheters have unique properties in completely inhibiting biofilm colonization of MRSA, VRE, *P. aeruginosa*, and *Candida* spp. in a manner superior to that of M/R- or CHX-treated catheters.
Ramos et al., 2011[20]	Retrospective cohort study	CVCs coated with M/R	The incidence of CLABSI per 1,000 patient-days in the medical ICU significantly and gradually decreased from 8.3 in 1998 to 1.2 in 2006 (p<0.001) during the course of the intervention.

5.5.3.2 Reducing Ventilator-Associated Infections

A small number of articles identified and abstracted in this literature review focused on ventilator-associated infections, mainly referring to pneumonia. This is not an intensive review of ventilator-

associated infection reduction, but several PSPs were identified as well-supported or somewhat supported by the current literature to reduce risk of infection. The references listed below have up-to-date recommendations.

Supraglottic suction refers to suctioning that removes bacteria-laden secretions to reduce the risk of aspiration pneumonia or upper-respiratory tract pneumonia. A systematic literature review by Doyle et al. (2011) found that the current literature supported the PSP of supraglottic suction in a patient's endotracheal tube. Doyle et al. (2011) also found overall support in the literature for bed elevation of 30 to 45 degrees for mechanically ventilated patients. Finally, Doyle et al. (2011) found supporting evidence for selectively decontaminating patients' digestive tract to prevent VAPs. All three of these PSPs—supraglottic suction, bed elevation, and selective decontamination—aim to reduce aspiration of bacteria in respiratory fluid and thus reduce pneumonia in ventilated patients.[11]

Subglottic secretion suctioning is a similar method to reduce ventilator-associated infections and was found by one randomized control study to be associated with lower rates of VAP and overall lower length of required ventilation.[21]

The same systematic literature review found only mixed evidence to support using topical antibiotics to decontaminate the oropharynx of patients on mechanical ventilation.[11] A before-and-after intervention study of 925 patients in an ICU administered polymyxin/tobramycin/ amphotericin B in the oropharynx and the gastric tube plus a mupirocin/chlorhexidine regimen in all intubated patients. This regimen lowered the incidence rates of intubation-related pneumonia (5.1 vs. 17.1 per 1,000 ventilator-days; $p<0.001$) in the experimental group.[22]

The Society for Healthcare Epidemiology of America (SHEA) and Infectious Diseases Society of America (IDSA) guidelines, "Strategies to Prevent Ventilator-Associated Pneumonia in Acute Care Hospitals," includes several recommendations covering the topics addressed by this literature review, as well as other PSPs. The recommendations are delineated for different populations (e.g., adults vs. neonates) and can be viewed at the link referenced in section 5.5.4.4 below.

The SHEA/IDSA guidelines state that there is moderate evidence to support the use of endotracheal tubes with a subglottic suction catheter for patients ventilated for more than 2 to 3 days but do not recommend closed/inline endotracheal suctioning. These guidelines also note that the quality of evidence was low to support the bed elevation discussed by Doyle et al. and that the quality of evidence was high for selective oral or digestive decontamination.

Additional guidelines from the SHEA/IDSA publication suggest additional PSPs for adult patients. PSPs with high quality of evidence include:

- Assessing the readiness to extubate daily,
- Interrupting sedation daily,
- Performing spontaneous breathing trials with sedatives turned off, and
- Changing the ventilation circuit only if visibly soiled or malfunctioning.

PSPs with moderate quality of evidence include managing patients without sedation whenever possible, facilitating early mobility, administering regular oral care with chlorhexidine, and providing prophylactic probiotics.[23]

5.5.3.3 Evaluation and Monitoring of Device Use

To reduce duration of device use, clinicians often must regularly reevaluate the need for the device and monitor any changes (e.g., the patient's dependence on the device). In the previously referenced systematic review, Patel et al. (2018) found that successful interventions aiming to reduce CLABSIs and CAUTIs often used checklists, auditing, and monitoring and focused on removal of devices. These checklists and monitoring procedures help reduce human error during the maintenance and removal of devices.[5]

The CDC guidelines for intravascular catheters also provide recommendations on device removal and care. These include assessment of an insertion site infection, removal of unnecessary catheters, quick replacement of catheters when aseptic technique cannot be ensured, and appropriate length of time to use certain types of catheters (e.g., up to 14 days for umbilical venous catheters).[6]

The CDC also has various recommendations on the evaluation and monitoring of device use for urinary catheters. These guidelines include the removing urinary catheters for operative patients as quickly as possible (<24 hours if possible), reducing kinking and obstruction of catheter tubes, and implementing guidelines to advise on proper catheter maintenance.

Lastly, the SHEA/IDSA guidelines include several recommendations on evaluation and monitoring of ventilator use. Some of these recommendations include changing the ventilator circuit if it is visibly soiled or malfunctioning, minimizing breaks in the ventilator circuit, and assessing the readiness to extubate daily. These recommendations are expanded on and delineated for certain populations in the full report, which can be viewed at the link provided in section 5.5.4.4 below.[23]

5.5.4 Implementation

5.5.4.1 Unintended Outcomes

Some of the above interventions, such as ABL solutions, topical skin ointments, and oropharynx decontamination involve the use of antibiotics. As with any antimicrobial use, overuse and inappropriate use can lead to increased drug resistance and increased risk of MDRO colonization or infection.

Regarding ventilator-associated antibiotic use, one before-and-after study discussed the effectiveness of selective digestive decontamination using polymyxin, tobramycin, and amphotericin B in the oropharynx and the gastric tube plus a mupirocin and chlorhexidine regimen in intubated patients. This study maintained that use of antibiotics in this scenario did not confer antibiotic resistance, but evidence showed that this practice increased the risk of MRSA infection and tobramycin resistance in aerobic Gram-negative bacilli such as *P. aeruginosa* and Enterobacteriaceae.[22] The SHEA/IDSA guidelines recommend that facilities with high levels of antimicrobial resistance not use digestive decontamination until higher quality, long-term studies are performed to assess the risks.[23]

Regarding ABL solutions, a retrospective cohort study in a dialysis unit found that after vancomycin and gentamicin catheter lock solutions were used, there was no statistically significant evidence of increased antimicrobial resistance. However, there was some change in the antimicrobial resistance profiles of

monitored pathogens, showing that the drug pressure did influence microbial flora and may need to be studied for longer periods.[12]

Another study investigated resistance to the antibiotic taurolidine and found that it was safe for use for up to 1,394 days. Resistance to the drug was most commonly seen in *Candida albicans*, although bloodstream infections were more commonly caused by *S. aureus* and other *Staphylococcus* species.[13] Although there is some evidence of the interaction of antibiotics in locking solutions and a patients' microflora, the CDC suggests (as a lower priority guideline) ABL prophylaxis, antimicrobial catheter flush, and catheter lock prophylaxis only for high-risk patients. High-risk patients have long-term catheters, have a history of CLABSI, and already adhere to maximal aseptic precautions.[6]

For intravascular catheters, the CDC states that antibiotic ointments and creams should not be used on insertion sites (other than dialysis catheters) because of the risk of conferring antimicrobial resistance and fungal infections. Chlorhexidine dressings are appropriate in some cases.[6]

In summary, this review highlighted potential increases in the antimicrobial resistance prevalence of clinically important pathogens. When considering the use of antibiotics to prevent CLABSIs, CAUTIs, or VAPs, clinicians should exercise caution and be diligent about referencing the existing guidelines, which specifically warn against or promote antibiotics for certain uses and populations. Further research is needed on long-term effects of antibiotic use for selective digestive decontamination and long-term use of locking solutions.

5.5.4.2 Cost-Effectiveness

Although not the focus of this section, two articles touched on cost-effectiveness of interventions discussed above. Doyle et al. (2011) found evidence that antibiotic-impregnated catheters were cost-efficient compared with standard catheters in high-risk populations.[11]

In a systematic review of the evidence to support gel catheters or hydrophilic catheters versus clear noncoated catheters, Bermingham et al. (2013) found that clear noncoated catheters were more cost-effective than single-use gel reservoir catheters. The review identified evidence that these clear noncoated catheters were less effective in preventing UTIs, so this information on cost-effectiveness will be important when considering the implementation of alternative materials.[18]

5.5.4.3 Interventions and Education To Reduce Device-Related Infection Risk

Ongoing education of patients, staff, and caregivers can also help reduce the harms associated with device use. The CDC recommends several education and implementation interventions for staff and patients to help improve outcomes associated with device use. Further, the CDC advises allowing only individuals (including family and at-home caregivers) trained in appropriate techniques for catheter insertion and maintenance to perform these tasks. Other agency recommendations include quality improvement programs to provide ongoing training for staff on all the PSPs discussed above: automated alerts to reassess the need for device use, written guidelines, auditing and feedback of staff practices, and periodic training on insertion, maintenance, and removal.[1]

The SHEA/IDSA guidelines also state that staff education can help maintain high levels of compliance with recommended practices. Staff educational activities include workshops, hands-on training, and use of multiple modalities to convey information. Making information accessible in pocket pamphlets,

posters, flowsheets, and other readily available modalities is also suggested. Finally, these guidelines state that educating patients and family on ventilator-associated guidelines can help them engage with and support the medical team's care.[23]

Within this review, two studies addressed education interventions for preventing CAUTIs. In a multifacility intervention within U.S. nursing homes, Mody et al. (2017) found success in reducing CAUTIs with a multicomponent intervention that included patient training on catheter care and a socioadaptive bundle emphasizing leadership, resident and family engagement, and effective communication.[7]

Lastly, Saint et al. (2016) performed a multifacility before-and-after study of implementation of the CUSP for CAUTI protocol (also known as On the CUSP: Stop CAUTI) to reduce CAUTIs in 603 hospitals across the United States. The multicomponent intervention included staff education on technical and socioadaptive factors, providing feedback to the units on CAUTI rates and catheter use, and addressing gaps in knowledge of urinary management processes.[24]

5.5.4.4 Resources To Assist With Implementation

The following resources include information on prevention of device-related infections; proper catherization use, duration, and removal; insertion site assessment and infection prevention; and other precautions to be taken when using catheters:

- AHRQ Toolkit To Reduce CAUTI and Other HAIs in Long-Term Care Facilities is available at https://www.ahrq.gov/professionals/quality-patient-safety/quality-resources/tools/cauti-ltc/index.html.
- AHRQ Toolkit for Reducing CAUTI in Hospitals is available at https://www.ahrq.gov/professionals/quality-patient-safety/hais/tools/cauti-hospitals/index.html.
- AHRQ Toolkit for Reducing Central Line-Associated Blood Stream Infections is available at https://www.ahrq.gov/professionals/education/curriculum-tools/clabsitools/index.html.
- The Ann Arbor Criteria for Appropriate Urinary Catheter Use in Hospitalized Medical Patients: Results Obtained by Using the RAND/UCLA Appropriateness Method includes guidelines for uses of various urinary catheters, a summary of their most common uses, and a daily ICU checklist for appropriateness of Foley catheter use (Meddings et al., 2015).
- CDC Guideline for Prevention of Catheter-Associated Urinary Tract Infections 2009 is available at https://www.cdc.gov/infectioncontrol/pdf/guidelines/cauti-guidelines-H.pdf.
- CDC Guidelines for the Prevention of Intravascular Catheter-Related Infections, 2011, is available at: https://www.cdc.gov/infectioncontrol/pdf/guidelines/bsi-guidelines-H.pdf).
- AHRQ Toolkit To Improve Safety for Mechanically Ventilated Patients is available at https://www.ahrq.gov/professionals/quality-patient-safety/hais/tools/mvp/index.html.
- TAP Catheter-Associated Urinary Tract Infection (CAUTI) Implementation Guide: Links to Example Resources is available at https://www.cdc.gov/hai/prevent/tap/cauti.html.
- SHEA/IDSA Strategies to Prevent Ventilator-Associated Pneumonia in Acute Care Hospitals: 2014 Update is available at

https://www.jstor.org/stable/pdf/10.1086/677144.pdf?refreqid=excelsior%3A71370b2e020eaf1ce0b6a59683810314.

5.5.5 Gaps and Future Directions

Gaps in evidence are listed within the guidelines cited above (e.g., CDC, SHEA/IDSA), and this review identified several gaps that require further research. In addition, further research is needed on the safety and efficacy of novel technologies such as GA-AgNPs,[15] the triple antibiotic combination discussed by Bayston et al. (2009),[16] and the newly developed M/R + CHX impregnated catheter discussed by Raad et al. (2012).[17] Further study is also needed on ABL solutions. Specifically, long-term studies on antibiotics in ABLs are needed to determine the risk of conferring drug resistance and increasing risk of infection.[12]

Kidd et al. (2015) stated larger sample sizes are needed to create adequately powered studies on alternative catheterization methods, such as suprapubic catheterization and intermittent self-catheterization compared with indwelling urinary catheters.[9] These methods are often cited as reducing risk of infections, but further research is needed to confirm and repeat the results of preliminary studies.

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5.6 PSP: Communication of Patients' MDRO Status

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A patient's positive MDRO status must be promptly communicated to patient care staff to ensure proper infection control practices are implemented and to protect patients against improper treatment (e.g., inappropriate antibiotic use). The timely and accurate dissemination of this information to all clinicians, visitors, and others in the facility who interact with those patients protects these individuals against MDRO transmission. Communication of an individual's past MDRO infections, documented asymptomatic carriage, and relevant high-risk healthcare exposures (such as transfer from a facility with a suspected or identified MDRO outbreak) should occur at every admission or transfer.

Effective communication also requires decisions about who needs to be notified, what information they need, and what privacy concerns exist in sharing this information. As soon as positive laboratory testing results are available, the laboratory should notify key clinicians and infection control personnel. These personnel should then communicate the appropriate precautions to all other staff, visitors, and others whose interaction with patients puts them at increased risk of MDRO acquisition. By implementing effective communication and infection control strategies, each healthcare facility can play a role in preventing local and ultimately global spread of MDROs. Key findings are presented in the box to the right.

Key Findings

- Communication failures have been linked to poor patient outcomes, especially for vulnerable patient populations (e.g., immunosuppressed patients).
- Multimodal and redundant communication policies can improve communication compliance in settings with complex communication (e.g., organ donation) or with multiple care providers (e.g., transfers). Modes of communication can include checklists, brightly colored leaflets attached to medical records, and electronic or automated communication.
- Revisiting policies to ensure they are meeting a facility's needs, performing ongoing monitoring and feedback of policy compliance, and involving staff from multiple disciplines in policymaking are all important for improving patient status communication.

5.6.1 Practice Description

The CDC recommends that all facilities have a system in place to communicate a patient's MDRO status to all necessary personnel before transfer of the patient.[1] Communicating a patient's MDRO status occurs at several points during the patient's interaction with the healthcare system. Intrafacility communication must begin when a positive laboratory test occurs or is highly suspected based on a patient's risk or previous exposures. The information must be disseminated to all clinicians interacting with the patient, visitors, and anyone whose patient interaction increases his or her exposure risk.

When patients are transferred between facilities, interfacility communication of patient status is required. Special care and attention to patient status communication must be taken in situations where patients are immunosuppressed and vulnerable to infection and where facilities may not have preexisting relationships or communication channels. Examples of information sharing strategies from case studies include electronic communication, a highlighted or annotated medical record or patient file, a transfer form, a brightly colored leaflet, verbal communication, and an automated alert.

5.6.2 Methods

The question of interest for this review is: What are the methods of MDRO status communication in a healthcare setting?

To answer this question, we searched three databases (CINAHL, MEDLINE, and Cochrane) for "information dissemination," "information sharing," "patient transfer," or "communication" in combination with "cross-infection," "prevention and control," "drug resistance," and relevant synonyms or similar phrases. Articles from 2009 to December 2018 were included.

The initial search yielded 140 results (including 8 from other sources). After duplicates were removed, 128 were screened for inclusion, and 54 full-text articles were retrieved. Of those, we selected 12 for inclusion in this review. Articles were excluded if they were out of scope or had insufficient detail about the topic of status communication or if the full article was not accessible.

General methods for this report are described in the Methods section of the full report.

For this patient safety practice, a PRISMA flow diagram and evidence table, along with literature-search strategy and search-term details, are included in the report appendixes A through C.

5.6.3 Review of Evidence

Of the 12 articles were selected for review, 2 were case studies, 2 were outbreak studies, 2 were cross-sectional studies, 2 were retrospective cohort studies, 1 was a systematic review, 1 was a prospective interrupted time series study, 1 was a prospective observational study, and 1 was a randomized controlled trial. Nine of the 13 included studies that took place in the United States, 1 took place in Australia, 1 took place in Italy, and 1 took place in Denmark. The systematic literature review was a review of German studies.

5.6.3.1 Intrafacility Communication

Timely and accurate dissemination of a patient's MDRO infection or carrier status is the first step that should be taken to control transmission within a healthcare facility. If a patient is high risk or highly suspected to harbor an MDRO, or if a positive test is received from a clinical laboratory as the result of active screening or routine clinical testing, steps should be taken to communicate the patient's status to all necessary staff. Examples of ways to communicate a patient's MDRO status include:

- Physical signs at the entrance to a patient's room or at the foot of the bed,
- Documentation in a patient's file (e.g., a brightly colored leaflet or note in the front of the file), and
- Checklists, policies, or electronic notifications that prompt providers to check patients' MDRO laboratory test results before interacting with and treating them.

In a prospective observational study of 101 inpatient transfers to radiology, Ong and Coiera (2010) identified and quantified the errors that occurred during intrafacility transfer. The Australian teaching hospital used a transfer form for continuity of care and a patient identity verification process when transferring a patient's care from one individual to another. The most common error that occurred during this process was "inadequate handover," which occurred 43.1 percent of the time and included a missing transfer form or omitted or incorrect information on the form.

While the results did not specifically report on communication of patient MDRO status, these lapses and inaccuracies in communication demonstrate weaknesses or failures in current practices that likely impact the transfer of knowledge about a patient's infectious status. This problem is reinforced by the fact that 2.9 percent of transfers had inappropriate infection control precautions, such as contact

precautions.[2] This study demonstrates that despite an existence of facility policy, implementation and compliance were inadequate, even though four redundant stages of the communication process were identified. Strategies for improving implementation will be discussed in section 5.6.4.

A randomized crossover study in the same hospital compared the use of a checklist with the use of a colored cue card to communicate that a patient was highly infectious. Both strategies improved compliance with infection control precautions similarly compared with the control group (38% compliance). The colored cue card increased compliance to 73 percent, and the pretransfer checklist increased compliance to 71 percent. However, adherence to the checklist was low at 40 percent and was anecdotally reported to be criticized by staff as annoying or redundant.[3]

One Danish university hospital used a leaflet in the front of each patient file and distributed it to the patient's visitors, as well as positioning a sign at the patient's bedpost so that anyone reviewing the file or entering the patient's room was alerted to the patient's status and appropriate precautions.[4] This hospital placed patients on contact isolation precautions if they were positive for an MDRO, putting the patient in rooms only with other MDRO-positive patients, and using personal protective equipment (PPE) when in direct contact with the patient. This intervention of leaflets and signs contributed to a decrease in the number of patients needing isolation per 1,000 occupied bed-days, which declined from 0.94 (95% CI 0.74 to 1.14) to 0.65 (95% CI 0.43 to 0.87; p=0.021) for ESBL-*K. pneumoniae* (ESBL-KP). Researchers also noted a reduction in the rate of isolated ESBL-KP from 39.5 percent to 22.5 percent, although this finding was not statistically significant.[4]

This study showed that improved signage and documentation within a patient's file can improve compliance with contact precautions, thus reducing transmission and the need for additional patients to be put on contact precautions. Ultimately, reducing the number of patients on contact precautions can allow hospitals to conserve resources, such as single-use gowns, gloves, and individual patient rooms. It can also conserve the time of staff who would otherwise need to don and doff PPE and thoroughly decontaminate surfaces and equipment.

Intrafacility communication can be crucial during an outbreak situation, when communicating a patient's infection with a highly transmittable pathogen is necessary to implement proper infection control and prevent further spread. Enhanced communication was part of a multicomponent intervention implemented to stem an outbreak of carbapenem-resistant *K. pneumoniae* among severely immunocompromised ICU patients at the NIH Clinical Center in Maryland.[5] An interdisciplinary team held daily staff meetings to discuss the outbreak investigation and control methods, held weekly meetings to share new findings or developments, and provided email notifications with updates and infection control reminders. An information sheet about transmission of MDROs was also given to patients upon admission.

This successful multicomponent intervention included educating staff, patients, and families on proper infection control practices and keeping everybody updated and informed about the selected infection control practices to ensure understanding and compliance. This intervention involved thorough and constant intrafacility communication using electronic, paper-based, and person-to-person communication.[5] This case study demonstrates that redundant communication and education through multiple modes were effective at reducing transmission.

The studies above demonstrate several methods of intrafacility communication that contributed to successful interventions. These methods included a visual cue (leaflets, signage), electronic record alerts,[6] continuity of care checklists (examples of which can be found in section 5.6.4, and intensive staff involvement and daily communication to heighten awareness during an outbreak among high-risk patients.

5.6.3.2 Interfacility Communication

Patients may be transferred between healthcare facilities for a variety of reasons, including a need for specialty care not offered at the current facility, cost or insurance coverage of medical procedures, or a shift from needing acute care to long-term care. These transfers become moments of vulnerability and possible failed communication regarding the status of a patient who may have an MDRO infection or colonization. Steps should be taken to strengthen communication between facilities in these situations to ensure that transmission does not occur. Specifically, the Council of State and Territorial Epidemiologists recommends that interfacility communication include information on patients' infection or colonization status, the organism with which they are infected, the recent and current antibiotic treatments used, and risk factors (e.g., invasive medical devices).[7]

Several outbreaks have been associated with lapses of communication during patient transfers. One outbreak study in Oregon[8] identified 21 cases of extensively drug-resistant *A. baumannii* in patients transferred between several skilled nursing facilities, acute care hospitals, and long-term acute care hospitals. Despite Oregon Health Department's recommendations for interfacility status communication, diagnosed cases were transferred between facilities with no communication of the patients' diagnosis. Transmission of the extensively drug resistant pathogen at other facilities was ultimately only detected due to voluntary surveillance and detection of other cases and a subsequent epidemiological investigation. This outbreak was the direct result of ineffective interfacility communication and the resulting failure to implement appropriate infection control practices.[8]

Oregon's example cautions that despite policies on interfacility communication, implementation was not adequate and an individual facility's own active surveillance program was needed to halt an outbreak. Implementation strategies such as periodic audits and monitoring and feedback may help improve compliance with existing facility guidelines.

Medicare and Medicaid require long-term care facilities (LTCFs) to communicate specific information when a patient is transferred to another facility or discharged.[9] While this requirement is only for LTCFs, it can be used as an example for other healthcare facilities to ensure proper continuation of care, especially infection control precautions such as contact precautions.

5.6.3.3 Communication During the Process of Organ Transplantation

A unique infection prevention challenge is posed by organ donation. Several organ donation-associated transmissions have been documented, despite existing policies that require communication of positive culture results by organizations such as the United Network for Organ Sharing (UNOS) and the Organ Procurement and Transportation Network (OPTN).[10]

A retrospective cohort study by Miller et al. (2015) found that poor communication could be implicated in several adverse outcomes after organ transplantation. The researchers investigated 56 infection events due to donor-derived transmission over a 2-year period and found that 18 were associated with

errors in communication. Of these 18 infection events, 12 resulted in poor patient outcomes, including 6 deaths.

The communication errors included:

- A delay in communication of suspected donor-derived infection from the transplant center to the organ procurement organization (OPO) or OPTN,
- A failure to communicate positive laboratory results from the laboratory to the OPO or OPTN,
- A delay in communication from the OPO to the OPTN or transplant center, and
- Incomplete communication or erroneous test results.

This study points out the many complexities of communication in the organ donation process due to the many organizations and players involved. To improve communication during organ transplantation, the authors recommend continuous education of all involved clinicians on communication policies, evaluation and monitoring of compliance and failures in the system, safeguards to prevent errors in medical records or lab result reporting, and expedited donor autopsies and lab results.[11]

Ariza-Heredia et al. (2012) documented a successful case of interfacility status communication, where four organ recipients were exposed to *K. pneumoniae* carbapenemase from a donor's kidney, liver, and heart. The positive culture result of the donor was communicated before the transplants occurred, and appropriate antibiotics and contact precautions were implemented for the two recipients who developed infections. The donor's institution initially contacted OPTN, who then facilitated the prompt interinstitutional communication.[10]

In another U.S. case study,[12] two kidney transplants failed when the donor's positive *E. coli* infection was miscommunicated. The donor's laboratory results were incorrectly entered into the chart accompanying the donated organ, and no procedure was in place to ensure that the information was correct and communication of those results occurred. To prevent such failures in the future, the authors recommended multiple redundant communication strategies. These strategies include:

- The donor facility highlighting any positive MDRO results in the charts that accompany an organ,
- The donor facility noting expected dates of pending test results in documentation accompanying an organ, and
- Both the donor and recipient facilities following up to obtain any pending test results.

Doublechecking the donor's medical records for MDRO information is also a prudent step the OPO could take. These interfacility communication procedures and redundancies would protect organ donation recipients from life-threatening infection and failed organ transplants due to improper antibiotic administration or other inappropriate medical care.[12]

A retrospective cohort study performed in Italy (Mularoni et al., 2015) found that from 2012 to 2013, four organ recipients acquired a carbapenem-resistant Gram-negative bacterial infection due to donor infection that was not communicated, unrecognized, or underestimated.[13] This error delayed the appropriate antibiotic treatment for these recipients. In one example, a patient was discharged from an ICU and antibiotic treatment was discontinued due to failed communication of the patient's positive

blood culture result. In another case, a donor had an unrecognized UTI that was detected with a positive urine culture but not communicated to the recipient's caregivers. Lastly, underestimation of the risk of transmission from the donor's MDR infection resulted in inappropriate medical treatment of the recipient.

Lapses in communication during organ transplants may pose a serious threat to recipients and can result in rejected or failed organs as demonstrated in these reports. By improving this process of communication, clinicians promote patient safety and can improve post-transplant outcomes.

5.6.3.4 Unintended Consequences

Negative outcomes associated with inefficient or inaccurate status communication were observed in a handful of the studies in this review. A statewide registry created for CRE carriers in Illinois demonstrates a resource burden imposed by a communication system. Participants reported that manual data entry and manual queries for patients were burdensome and time consuming, so researchers are working to create an automated notification system.[14]

5.6.4 Implementation

As several examples in this review have pointed out, having policies in place does not guarantee effective implementation of patient status communication, be it during transfers, during organ transplantation, or within a facility itself. Engaging staff in new procedures and educating them on the steps involved are all important when applying new policies.

Methods for engaging staff in implementation could include:

- Performing needs assessments before developing new procedures,[15]
- Hosting multidisciplinary meetings to facilitate collaborative thinking or elicit feedback,[4,5]
- Distributing reports on infection rates and trends since implementation of communication procedures,[4] and
- Informing managers and other leaders of procedural changes.[4]

A cross-sectional survey of 448 infection control professionals in the United States reiterates the findings above. The factors that were found to improve implementation included:

- Distribution of copies of the policy to providers ($p=0.03$),
- Use of forms (i.e., checklists) to enhance infection control adherence ($p=0.0008$),
- Administrator-directed infection control activities ($p<0.0001$),
- A culture of data-driven decision making ($p<0.0001$),
- Communication of antimicrobial resistance trends to physicians ($p<0.0001$), and
- Interdepartmental coordination of patient care ($p<0.0001$).[16]

These tools used for changes in infection control policies can just as easily be applied to interfacility or intrafacility communication of patient MDRO status. Educating providers and staff on new policies by distributing educational resources can be part of continuing education on communication protocols.

Checklists can be used to facilitate more thorough information exchange when patients are transferred within a facility. Improved communication and improved coordination of patient care foster an environment more conducive to continuity of information when interfacility communication occurs. Lastly, the reporting of data to demonstrate improvements in patient outcomes can reinforce making positive changes in facility practices that are connected to patient communication.

When implementing interfacility communication protocols, facilities may benefit from reaching out to State health departments or national organizations such as UNOS. Many already have relationships with healthcare facilities, know the appropriate contacts there, and can facilitate meetings or discussions among facilities. For example, the Oregon Health Department helped create a form and process for facilities to use with newly admitted and transferred patients. State health departments should continue to encourage and facilitate interfacility discussion about MDRO communication practices, and smaller local health departments or healthcare facilities should reach out to these larger organizations to ask for assistance in improving intrafacility communications.

5.6.4.1 Resources To Assist With Implementation

Additional resources and tools to aid in the implementation of patient status communication and infection control are listed below.

- CDC's Inter-Facility Infection Control Transfer Form for States Establishing HAI Prevention Collaboratives is available at https://www.cdc.gov/hai/pdfs/toolkits/Interfacility-IC-Transfer-Form-508.pdf.
- The CDC's Interim Guidance for a Public Health Response To Contain Novel or Targeted Multidrug-Resistant Organisms (MDROs) is available at https://www.cdc.gov/hai/containment/guidelines.html.
- CDC's MDRO Management Guidelines is available at https://www.cdc.gov/infectioncontrol/guidelines/mdro/index.html.
- Oregon's Guidance for Control of Carbapenem-Resistant Enterobacteriaceae: 2016 Oregon Toolkit is available at https://www.oregon.gov/oha/PH/DISEASESCONDITIONS/DISEASESAZ/CRE1/cre_toolkit.pdf.

5.6.5 Gaps and Future Directions

More rigorous research studies in a variety of geographic areas and healthcare settings are needed to evaluate the most effective ways to communicate patient status (e.g., checklists vs. brightly colored leaflets in patient files). Facilities that often exchange patients or are part of larger health systems are encouraged to develop relationships with one another to develop strategies and policies for patient MDRO status communication, if not regulated by the government as in the case of LTCFs.

More research and innovation are needed to promote consistent use of technology-based and paper-based communication of patient MDRO status, such as laboratory results in organ transplantation. Lastly, an iterative review of status communication policies is important to ensure that policies are useful, easy to implement, and meet the needs of the ever-changing world of infection control and prevention.

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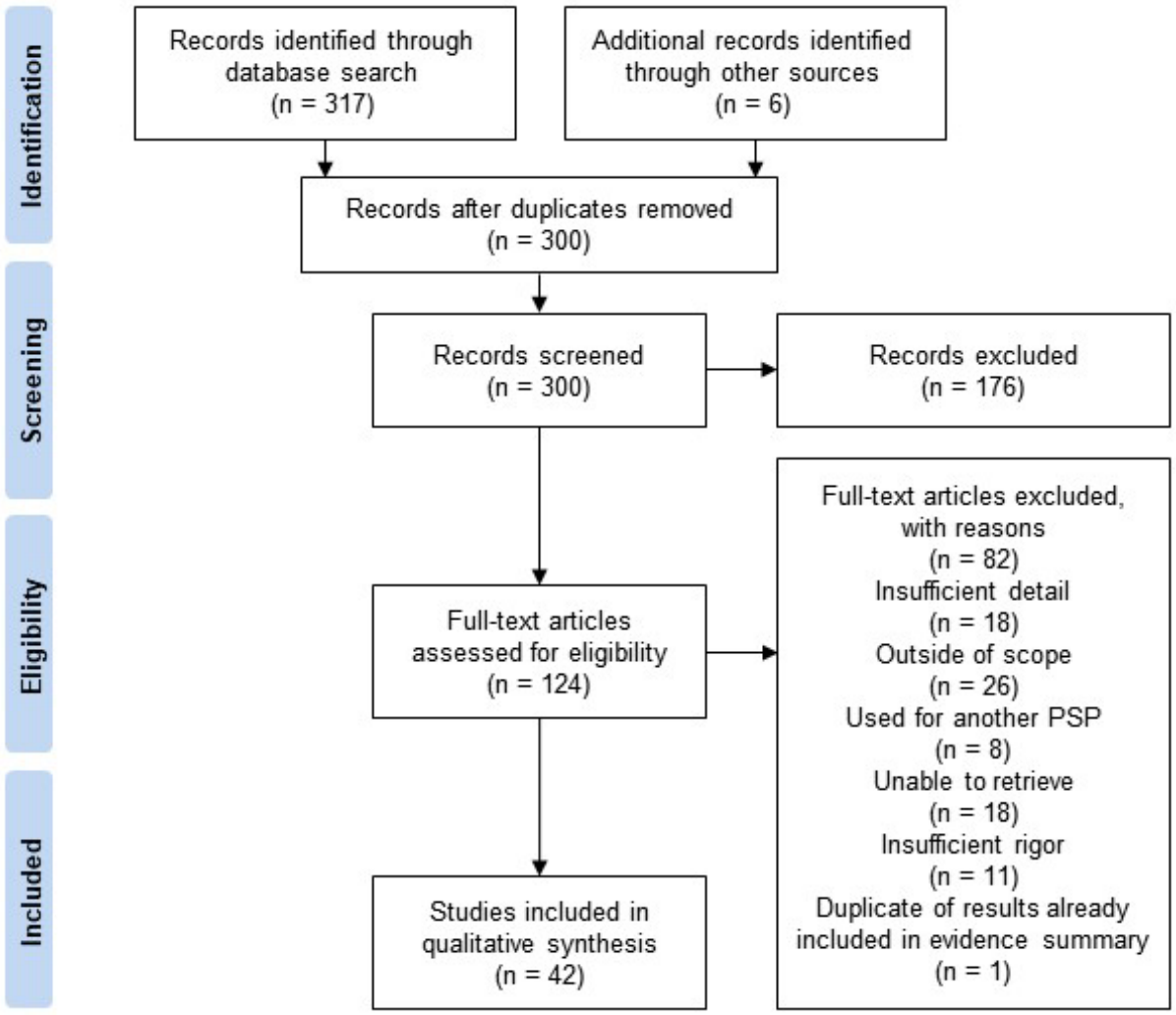
Conclusion and Comment

In this review, we examine the evidence supporting the use of individual safety practices. However, many of the studies on the efficacy of patient safety practices examine bundled approaches or implementation of multiple practices at once, making it difficult to assess the effectiveness of any one practice. Further, improving compliance with one practice (for example, hand hygiene at every opportunity) can reinforce compliance with others, making each practice more successful when combined with others. Understanding the limitations of the available evidence, we make the following recommendations:

- The level of evidence to support hand hygiene for MDRO infection prevention is high. What is needed is further study about the best ways to sustain high compliance with hand hygiene at every opportunity. Increasing compliance may require new technologies, institutional policies, and approaches to reducing the barriers that result in missed opportunities for hand hygiene.
- While active surveillance has evidence to support its use in preventing MDRO acquisition and infection, there is no consensus on the optimal surveillance strategy, due to variation in patient risk factors, local epidemiology, and facility laboratory capability. Some cost-effective suggestions include active surveillance testing of samples (including routine clinical samples) for multiple MDROs and developing risk-based surveillance protocols based on which MDROs are likely to be encountered.
- There is a high level of evidence supporting the use of chlorhexidine bathing, both for preventing MDRO acquisition and as part of decolonization strategy (to reduce transmission opportunities). Chlorhexidine bathing is relatively low cost to implement, and adverse events are rare and resolve when chlorhexidine use is stopped. There is some evidence that the use of chlorhexidine may be selecting for resistance, but no clinical impacts have been documented in the literature reviewed.
- While some evidence supports the efficacy of different solutions for environmental cleaning in laboratory settings, more studies are needed evaluating the relative efficacy of disinfection agents against different MDROs in a clinical setting. These studies should also control for other infection control practices.
- Bundle approaches for reducing device-associated infections have strong evidence to support their use for infection prevention, regardless of the type of pathogen. More evidence is needed to understand the risks of increased resistance introduced by the use of antimicrobial solutions and devices.
- There is strong evidence to suggest that failure to communicate patients' MDRO status can lead to poor patient outcomes, but there are no rigorous analyses or comparisons of optimal communication approaches for MDROs.

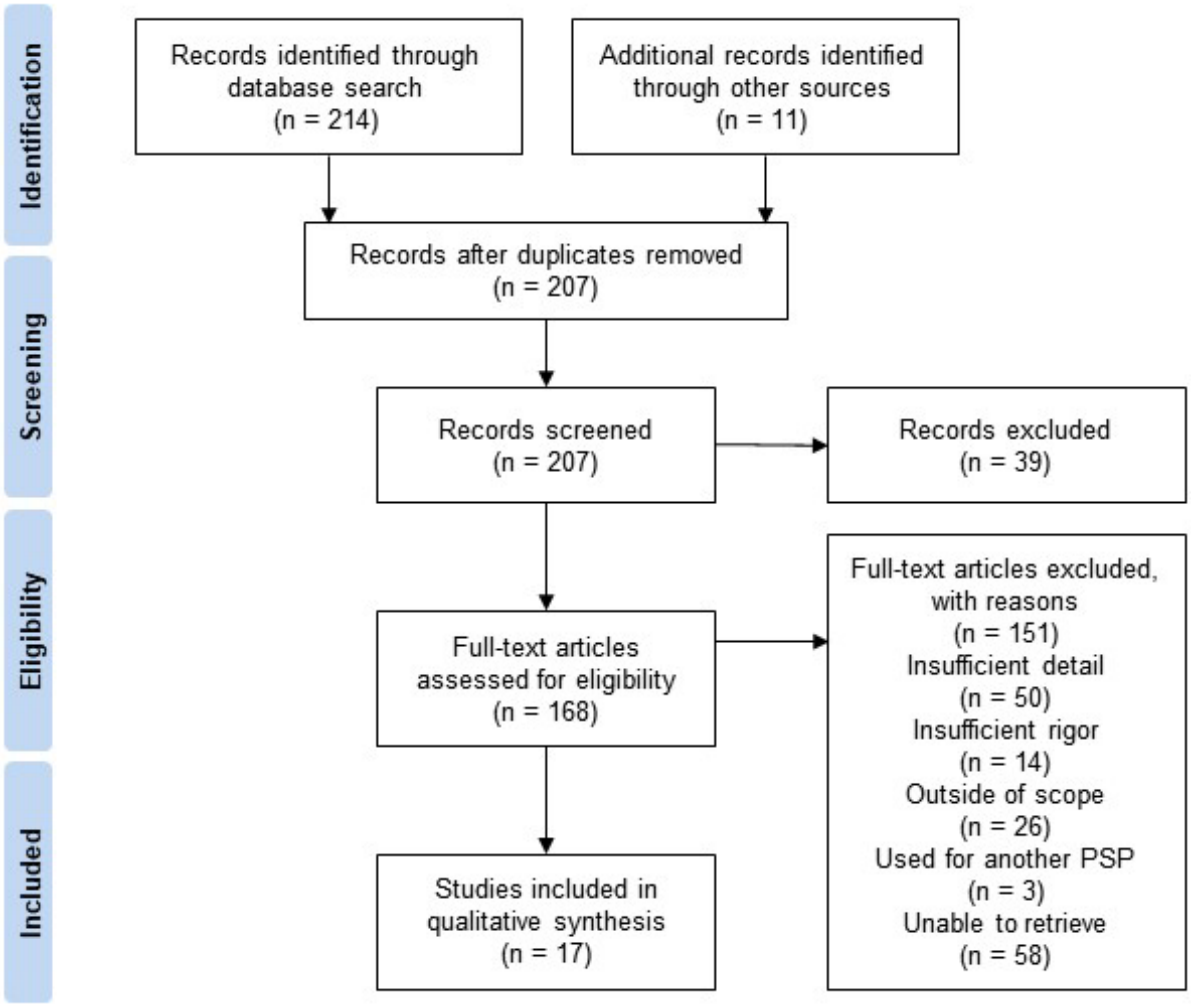
Appendix A. Infections Due to Other Multidrug-Resistant Organisms PRISMA Diagrams

Figure A.1. MDRO, Chlorhexidine Bathing—Study Selection for Review



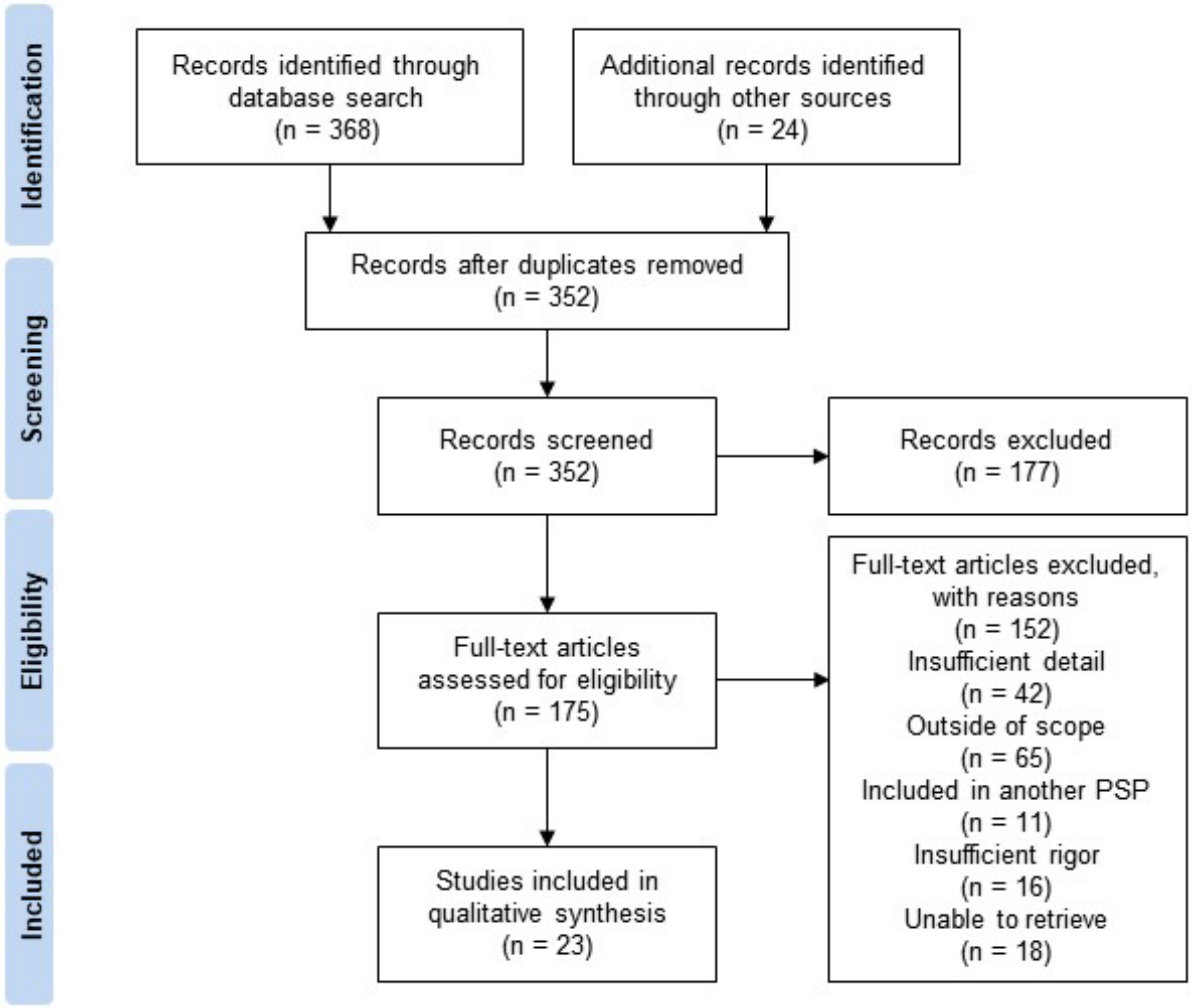
PRISMA criteria described in Moher D, Liberati A, Tetzlaff J, et al.. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7): e1000097. doi:10.1371/journal.pmed1000097.

Figure A.2. MDRO, Hand Hygiene—Study Selection for Review



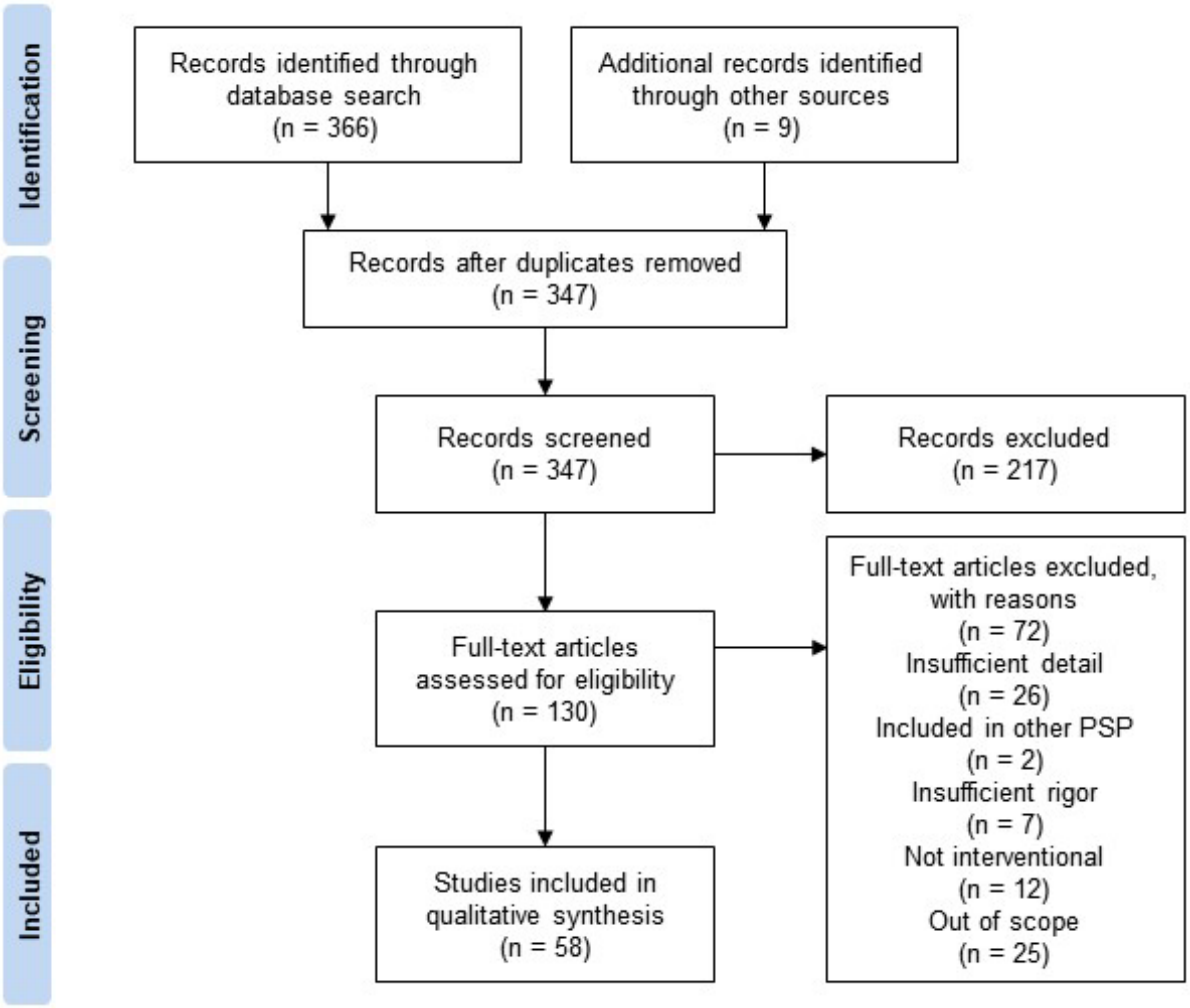
PRISMA criteria described in Moher D, Liberati A, Tetzlaff J, et al.. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7): e1000097. doi:10.1371/journal.pmed1000097.

Figure A.3. MDRO, Surveillance—Study Selection for Review



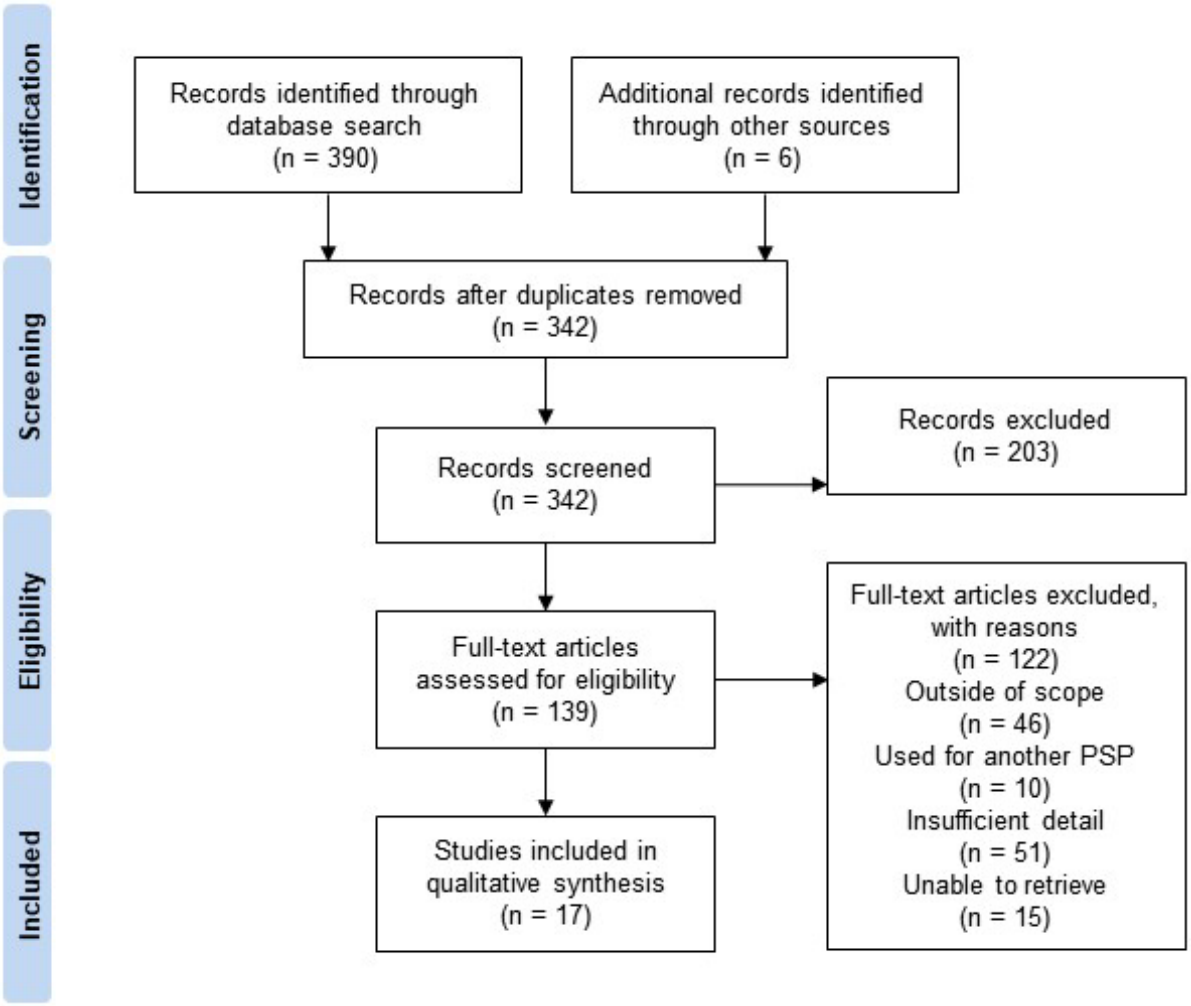
PRISMA criteria described in Moher D, Liberati A, Tetzlaff J, et al.. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7): e1000097. doi:10.1371/journal.pmed1000097.

Figure A.4. MDRO, Environmental Cleaning and Disinfection—Study Selection for Review



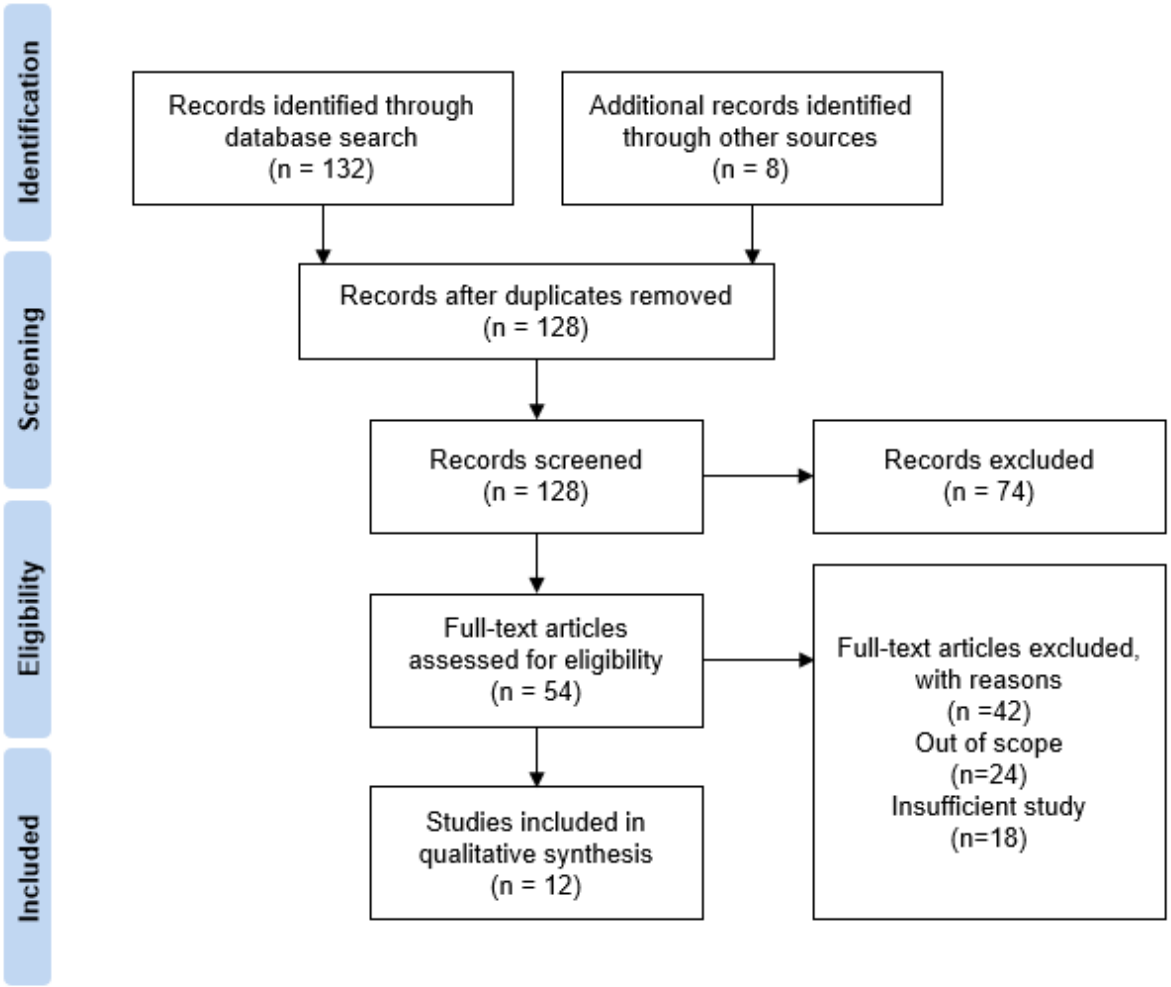
PRISMA criteria described in Moher D, Liberati A, Tetzlaff J, et al.. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7): e1000097. doi:10.1371/journal.pmed1000097.

Figure A.5. MDRO, Minimizing Catheter Use—Study Selection for Review



PRISMA criteria described in Moher D, Liberati A, Tetzlaff J, et al.. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7): e1000097. doi:10.1371/journal.pmed1000097.

Figure A.6. MDRO, Communication of Status—Study Selection for Review



PRISMA criteria described in Moher D, Liberati A, Tetzlaff J, et al.. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7): e1000097. doi:10.1371/journal.pmed1000097.

Appendix B. Infections Due to Other Multidrug-Resistant Organisms Evidence Tables

Table B.1: MDRO, Chlorhexidine Bathing—Systematic Reviews

Note: Full references are available in Section 5.1 reference list.

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Denny and Munro, 2017[5]	Bathing with chlorhexidine gluconate (2%-4%)	General healthcare settings, various countries (including the United States)	A literature search was conducted to identify peer-reviewed studies and meta-analyses that examined the impact of chlorhexidine bathing on HAIs. Generally found good evidence to support incorporating a chlorhexidine bathing regimen to reduce the incidence of CLABSIs, SSIs, and VRE and MRSA infections. MRSA: Several reviewed studies showed a decrease in MRSA transmission or colonization, although not always statistically significant compared with other treatment. VRE: Reduction of colonization on patients' skin and contamination of healthcare workers' hands and environment. Device- and procedure-associated infections (SSI, CLABSI, CAUTI, VAP): Mixed results of success in preventing SSI. Statistically significant reductions in CLABSIs. Reduction in CAUTIs and VAPs as well.	Chlorhexidine gluconate washcloths are more expensive than liquid but require less bathing time. Rinsing is not recommended, to maximize residual contact with skin. Adverse events consist of skin irritation. Accidental or intentional exposure to sensitive areas (eye, esophagus, intestinal lining, inner ear) has caused injury to those areas. Severe anaphylaxis is possible but rare. Future research should include randomized, controlled trials with specific bathing durations/ frequencies; studies of chlorhexidine resistance; and studies of compliance.	Organisms/Outcomes: VRE, MRSA CLABSIs, SSIs, VAPs, CAUTIs Compares level of evidence for studies.

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Derde et al., 2012[6]	Bathing with chlorhexidine gluconate	ICUs, geographic locations not specified	Data from 16 studies were extracted. Chlorhexidine bathing statistically significantly reduced MRSA acquisition in 3 studies; significant reduction in MRSA infection was only observed in 1 of 5 studies. Carriage and bacteremia rates of VRE both significantly declined. Few studies had data on antibiotic-resistant Gram-negative bacteria.	Studies of chlorhexidine bathing also included other prevention practices, such as active surveillance or intranasal mupirocin, and did not control for the impact of these practices when evaluating the effectiveness of bathing.	Organisms/Outcomes: VRE, MRSA Review of seven studies; low risk of bias in individual studies, but also marked difference between the interventions in each study.
Sidler et al., 2014[7]	Chlorhexidine bathing	General healthcare setting, various countries (including the United States)	Swiss literature review on general infection prevention and control practices. Mixed results: one cluster-randomized trial showed a significant reduction (28%) in hospital-acquired BSIs in nine U.S. ICUs with daily washing, but not for MRSA- or VRE-related infections. Another meta-analysis showed significantly reduced MRSA/VRE colonization and infection densities in patients treated with daily washing compared with patients without (incidence rate ratio [IRR] 0.51; 95% CI 0.36–0.73; and IRR 0.57; 95% CI 0.33–0.97 for VRE colonization and VRE infection, respectively). Few studies have addressed the effect of chlorhexidine on extended-spectrum beta-lactamase producing Gram-negative bacteria (ESBL-GNB).	This review found mixed results for VRE and MRSA. Only a few studies addressed the effect of chlorhexidine body washing on ESBL-GNB and *C. difficile.*	Organisms/Outcomes: VRE, MRSA, ESBL-GNB Brief section in a larger literature review on MDR Enterococci.

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Tacconelli et al., 2014[24]	Decolonization with chlorhexidine for MDR-GNB	Healthcare, various countries (including the United States)	European guidelines and systematic review that studied decolonization with chlorhexidine as part of a larger review on managing MDR-GNB. Decolonization with chlorhexidine is well studied and well supported for MRSA. However, for ESBL-producing Enterobacteriaceae, decolonization is short lived. The available evidence for efficacy against MDR-GNB does not support chlorhexidine use for decolonization. Reduced susceptibility to chlorhexidine has been reported among GNB, so sustained use should ideally be accompanied by surveillance for resistance over time.	The authors concluded that the available evidence did not support chlorhedixine use for MDR-GNB, although it is an effective part of decolonization regimens for MRSA, VRE, Gram-positive bacteria, and (temporarily) for ESBL-producing Enterobacteriaceae.	Organisms/Outcomes: VRE, MRSA, MDR GNB

Table B.2: MDRO, Chlorhexidine Bathing—Single Studies

Note: Full references are available in Section 5.1 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Abboud et al., 2016[16]	Enhanced control measures for ICU patients: providing alcohol gel at the bedside, daily bathing with no-rinse 2% chlorhexidine-impregnated washcloths, and disinfection of surfaces around the patient three times per day (provided in addition to the usual measures of screening and cohort nursing)	Observational pre-post cohort study; 543 patients; 1,120 cultures collected, 239 in the pre-intervention period and 881 in the post-intervention period.	40-bed post-operative adult cardiac surgery intensive care unit (ICU), Brazil	For carbapenem-resistant Enterobacteriaceae (CRE) isolation, 64 of 239 (26.8%) positive cultures were found in the pre-intervention period compared with 82 of 881 (9.3%) in the post-intervention period (p<0.001). The median time from CRE infection to colonization increased from 8 days to 14 days (statistical significance not assessed). The incidence of central line-associated bloodstream infections (CLABSIs) with CRE fell from 2.07 per 1,000 central-line-days in the pre-intervention period to 0.23 per 1,000 central-line-days in the post-intervention period (p<0.002). The rate of surgical site infections (SSIs) from CRE decreased from 2.4% in the pre-intervention period to 0.8% in the post-	A statistically significant increase in multidrug resistant (MDR) *P. aeruginosa* was observed post-intervention (p=0.0348).	The study demonstrated that the enhanced control measures—alcohol-based hand rub and chlorhexidine bathing (CHB)—were associated with a significant decrease in SSIs, CLABSIs, and CRE colonization. This finding is consistent with other studies showing the efficacy of using alcohol-based hand rub and CHB for reducing patient and environmental MDR organisms' rates. Due to study design, the relative effects of hand hygiene vs. CHB could not be assessed.	Moderate Compliance with hand hygiene using alcohol-based hand rub was not assessed, and the study did not include a control group of patients not receiving CHB.	Organisms/ Outcomes: CRE, *P. aeruginosa* Colonization, CLABSI, SSI, VAP and UTI rates, mean time to colonization

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				intervention period (p<0.003). Other CRE infections such as ventilator-associated pneumonia (VAP) and urinary tract infections (UTIs) decreased, but the decreases were not statistically significant.				
Alotaibi et al., 2017[41]	In vitro evaluation of vancomycin-resistant *Enterococcus faecium* (VRE) resistance to benzalkonium chloride, chlorhexidine and hydrogen peroxide biocides	In vitro study of VRE and vancomycin-susceptible *Enterococcus* (VSE) isolates' susceptibility. 12 VSE *faecium* and 37 VRE *faecium* isolates obtained from Danish patients and chosen to represent an extended time period and cover major subtypes.	Isolations collected from hospitals, Denmark	Both VRE and VSE *faecium* strains displayed equal susceptibility to hydrogen peroxide, but a higher minimal bactericidal concentration (MBC, the lowest concentration required to kill a bacterium over 48 hours) was found for the former: 75% of VRE *faecium* showed MBC values of 70 mg/L or higher compared with only 25% of VSE *faecium.* (The difference was statistically significant, but p-values were not reported for this measure.)	For benzalkonium chloride, 89% of VRE *faecium* strains had a minimal inhibitory concentration (MIC) of 8 mg/L (the highest level reported in the article) whereas for VSE *faecium* strains, only 25% of the strains had an MIC of 8 mg/L. Almost all VRE strains (97%) showed a higher MBC of 8 mg/L or higher. Both the higher MIC and MBC of VRE strains compared with VSE strains were statistically significant (p<0.0001; chi-square test). For chlorhexidine, the MIC of 95% of VRE *faecium* strains was 4 mg/L or higher, while only	VRE *faecium* strains isolated from Danish hospitals demonstrated decreased susceptibility toward benzalkonium chloride and chlorhexidine compared with VSE strains, where the use of chlorhexidine is particularly heavy in hospitals. The enhanced tolerance of VRE strains to benzalkonium chloride and chlorhexidine was also reflected in reduced biocidal killing compared with VSE strains. The researchers suggest that these results imply that survival of VRE strains is superior to that of VSE strains with regard to two key	Low to moderate	*Organisms/ Outcomes* *VRE, VSE* *Bactericidal susceptibility of benzalkonium chloride, chlorhexidine, and hydrogen peroxide* Study uses Danish isolates. Well-designed study but tested in vitro only, not in a patient care setting.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
					33% of VSE *faecium* strains displayed MIC values at the same level (p=0.0003; chi-square test). The MBC for 95% of VRE strains was 4 mg/L or higher, compared with 50% of VSE strains (p=0.0013; chi-square test).	cleaning and disinfection agents commonly used in hospitals; and that the selective advantage in the presence of these agents may increase the prevalence of VRE *faecium* strains in hospitals.		
Boonyasiri et al., 2016[19]	Once-daily bathing with 2% chlorhexidine-impregnated wipes, without rinsing, compared with bathing with non-antimicrobial soap	Randomized, open-label controlled trial of 481 patients in 4 Thai ICUs. Patients were randomly assigned either to the control group (bathing with non-antimicrobial soap, n=241) or the chlorhexidine group (n=240).	Intensive care setting, Thailand	Once-daily cleansing of ICU patients with no-rinse 2% chlorhexidine-impregnated washcloths did not prevent or delay MDR Gram-negative bacteria colonization compared with routine twice-daily cleansing with nonantimicrobial soap. Favorable events (all samples negative throughout ICU admission, or initially positive samples with subsequent negative samples) at day 14 were observed in 34.8% of patients in the control group and 28.6% in the chlorhexidine group (p=0.79; not statistically significant).	A 2.5% incidence rate of mild skin reactions.	Use of 2% chlorhexidine-impregnated washcloths was not associated with fewer colonization events or infections by MDR Gram-negative organisms than twice-daily bathing with nonantimicrobial soap. Researchers also found that the time spent using the washcloths was much less than with the soap and it was also low cost and easy to implement, despite not producing desired outcomes.	Low	Organisms/ Outcomes MDR Gram-negative bacteria: extended spectrum beta-lactamase (ESBL) producing *Escherichia coli,* ESBL-producing *Klebsiella pneumoniae,* MDR *P. aeruginosa,* MDR *A. baumannii,* VRE No colonization event or confirmed decolonization; target MDR bacteria colonization-free time; VAP, CLABSI, CAUTI rates; length of

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				No statistically significant reduction in VAP rates (5.0% in control group vs. 5.8% in CHB group; p=0.69), CLABSI rates (2.0% vs 1.1%, p=0.74), or catheter-associated urinary tract infection (CAUTI) rates (7.0% vs. 8.5%, p=0.17). Mean length of ICU stay (16.5 days in control group vs. 14.6 days in CHB group, p=0.42) and mean length of total hospital stay (35.9 days vs. 31.8 days, statistical test not reported) did not differ.				ICU stay and length of hospital stay; and adverse skin reactions.
Camus et al., 2014[20]	Twice-daily bathing with 4% chlorhexidine solution (with rinsing) and 0.5% chlorhexidine mouthwash (4 times daily), as part of a decontamination protocol that also included:	Nonrandomized, pre-post study (1 year before and 1 year after intervention) with placebo control. The control group had 925 patients and the intervention group had	21-bed hospital ICU, France	The pre- and post-period groups were similar, except for a statistically significant difference in the distribution of the main diagnosis,[k] a lower Glasgow coma score (p=0.005), and a lower proportion of healthcare-associated infections at admission (p=0.02). All-cause infection rates were lower in	According to the article, the main concern with selective digestive decontamination (SDD) is the potential induction of antibiotic resistance, especially increased MRSA and VRE acquisition rates. The authors did not observe this occurrence in their study but noted that the number of	The intervention was associated with a reduction in acquired infections in all ICU patients, for all types of infections (including those related to MDR organisms.)	Low to moderate CHB was also combined with a chlor-hexidine mouthwash and with antibiotic treatment. The effect of each component	Organisms/ Outcomes Methicillin-susceptible *Staphylococcus aureus* (MSSA) Methicillin-resistant *S. aureus* (MRSA) MDR Gram-negative rod bacteria, including: *Enterobacter* species, *P.*

[k]The authors provide a *p*-value of 0.009, but it is not clear how it was calculated for the distribution of diagnoses.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
	1. Mupirocin (applied to nostrils 3 times daily); and 2. A mixture of polymyxin/ tobramycin/ amphotericin B administered to oropharynx and through gastric tube.	1,022 patients.		the intervention group, with adjusted odds ratios of 0.45 (0.31 to 0.63) in all patients; 0.43 (0.30 to 0.61) in those with a length of stay ≥48 hours; and 0.35 (0.2 to 0.54) in those intubated for ≥48 hours (all p< 0.001). Those in the intervention group with a shorter intubation period were also less likely to have an infection, but this difference was not statistically significant (adjusted odds ratio = 0.77, 0.35 to 1.71; p=0.52). The intervention group had lower rates of all acquired infections (9.4 vs. 23.6 per 1,000 patient-days; p<0.001), intubation-related pneumonia (5.1 vs 17.1 per 1,000 ventilator-days; p<0.001), and catheter-related BSIs (1.0 vs. 3.5 per 1,000 catheter-days; p=0.03). Fewer patients acquired infections due to MDR aerobic Gram-negative bacteria (p=0.008). Time to	acquired MRSA infections was too small from which to draw conclusions about any change in rates.		was not assessed. Rates for specific healthcare-associated infections (HAIs) caused by MDR Gram-negative bacteria were not provided.	*aeruginosa,* and ESBL-producing *K. pneumoniae*

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				first acquired infection was the same in both groups, as was length of stay. Antibiotic consumption was reduced in the intervention group, however.				
Camus et al., 2016[28]	Twice-daily bathing with 4% chlorhexidine solution (with rinsing) and 0.5% chlorhexidine mouthwash (4 times daily), as part of a decontamination bundle that also included: 1. Mupirocin (applied to nostrils 3 times daily); and 2. A mixture of polymyxin/ tobramycin/ amphotericin B administered to oropharynx and through gastric tube.	Observational time series: prospective, single-center study of ICU patients admitted over 5 years. 5,250 patients in intervention group over a 4-year period. Long-term assessment of impact of intervention on acquired infections from MDR aerobic Gram-negative bacilli (GNB) and acquired episodes of ESBL-producing Enterobacteri-aceae rectal carriage (see Camus et al., 2014)	Hospital ICU, France	The incidence rate of infections from MDR aerobic GNB was 5.43% during the 1-year pre-intervention period. It was significantly lower during the entire 5-year study period (1.59%, p<0.0001) and during each study year (2.02% [2008]; 2.50% [2009]; 2.13% [2010]; 0.77% [2011]; 0.50% [2012]; all p<0.01). The proportion of those who acquired rectal carriage of ESBL-producing Enterobacteriaceae during their ICU stays gradually declined with time (trend test using the Cox regression model: odds ratio = 0.92 [0.86 to 0.99], p=0.03).	No harms observed (no additional resistance or colonization with resistant organisms).	A multiple decontamination regimen did not lead to the emergence of MDR aerobic GNB. Infection and colonization rates declined with time.	Low to moderate Well-designed study but unable to speak to efficacy of only the chlor-hexidine bathing and mouthwash components of the regimen.	Organisms/ Outcomes Methicillin-susceptible *Staphylococcus aureus* (MSSA) Methicillin-resistant *S. aureus* (MRSA) MDR Gram-negative rod bacteria, including: *Enterobacter* species, *P. aeruginosa,* and ESBL-producing *K. pneumoniae*

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Cho et al., 2018[43]	Evaluation of chlorhexidine tolerance genes among MRSA isolates in a surgical intensive care unit (ICU) where MRSA-colonized patients are decolonized via CHB	Retrospective, genetic study of chlorhexidine and mupirocin resistance in MRSA isolates (n=119) from 135 ICU patients	Hospital ICU, South Korea	None assessed.	Among the isolates, 39 (32.8%) carried the quaternary ammonium compound (QAC) A/B genes, and 23 (19.3%) exhibited mupirocin resistance. Patients with QAC A/B-positive isolates were more likely to have ICU-acquired MRSA (p<0.001), longer ICU stays (p=0.030), and long hospital stays (p<0.001) than did patients with QAC A/B-negative isolates. QAC A/B-positive isolates were more likely than were QAC A/B-negative isolates to exhibit mupirocin resistance (p<0.001), a chlorhexidine MIC greater than 8mg/L (p=0.005), and the vancomycin-intermediate *S. aureus* phenotype (p<0.001).	QAC A/B-positive strains will require higher concentrations of chlorhexidine for successful environmental cleaning and have implications for decolonization strategies using CHB and mupirocin.	Low Based on isolates from a single Korean hospital; may not be applicable to the United States. Researchers did not evaluate the epidemio-logic link between MRSA-colonized patients and subsequent infection.	*Organisms/ Outcomes: MRSA Chlorhexidine resistance*
Climo et al., 2013[8]	Daily bathing with no-rinse 2% chlorhexidine-impregnated washcloths	Multicenter, cluster-randomized, nonblinded crossover trial of 7,727 patients	Nine intensive care and bone marrow transplant units in six	MDRO acquisition (MRSA, VRE): 23% lower rate of MDRO acquisition for chlorhexidine bathing: 5.10 cases per 1,000 patient-days with	No serious skin reactions related to bathing noted during either study period.	Daily 2% chlorhexidine bathing reduced MRSA and VRE acquisition rates, without indications of increased	Low to moderate Two ICUs with low compliance with study protocol were	Organisms/ Outcomes: Hospital-acquired bloodstream infections Chlorhexidine resistance

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
		randomly assigned bath with no-rinse 2% chlorhexidine-impregnated washcloths or with nonantimicrobial washcloths for a 6-month period, exchanged for the alternate product during the subsequent 6 months. Susceptibility testing on 1,106 isolates (713 MRSA and 393 VRE).	hospitals, United States	chlorhexidine bathing versus 6.60 cases per 1,000 patient-days with nonantimicrobial washcloths (p=0.03). CLABSI: 28% lower rate with chlorhexidine bathing: 4.78 cases per 1,000 patient-days with chlorhexidine bathing versus 6.60 cases per 1,000 patient-days with nonantimicrobial washcloths (p=0.007). In vitro tests of susceptibility showed chlorhexidine was more active against MRSA isolates (4 micrograms/mL) compared with VRE isolates (8 micrograms/mL). Chlorhexidine was slightly more active against MRSA isolates, with a minimum inhibitory concentration required to inhibit the growth of 90% of organisms of 4 µg/mL, compared with 8 µg/mL for VRE isolates.		chlorhexidine resistance over a 6-month period.	excluded from the analysis.	
DeBaun, 2008[46]	Bathing with alcohol-free 2% chlorhexidine gluconate solution	In vitro study of MDR *A. baumannii* and *S. aureus* strains	Laboratory, United States	The alcohol-free 2% chlorhexidine solution reduced bacterial counts of drug-resistant *A. baumannii*	None assessed.	The 2% chlorhexidine bathing solution was effective in vitro at 3 minutes exposure in inhibiting	Low to moderate Did not evaluate in vivo.	Organisms/ Outcomes: MDR *A. baumannii* MDR *S. aureus*

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				and MRSA by 99.9% and within 3 minutes of exposure. This effectiveness was maintained even with significant dilutions (between 1:2,048 and 1:8,192).		MDR *A. baumannii*, and *S. aureus* strains, even when diluted.		
Duszynska et al., 2017[21]	Daily bathing with 2% chlorhexidine-impregnated washcloths. No rinsing after application. One cloth used per each of six body areas: neck, thorax, and abdomen; both upper extremities from armpits to hands; hips, followed by groin area; both lower extremities from thighs to toes; back of the body from neck to the waist; buttocks	Observational study of 272 patients; three time periods (3 months each): pre-intervention, intervention, post-intervention	16-bed ICU, Poland	During the intervention, the general incidence rates of infections (p=0.04) and of catheter-related infections (p=0.005) were significantly lower compared with pre-intervention. Reductions in intubation-associated pneumonia and UTIs were not statistically significant. Half of the infections in the study were caused by MDROs, which decreased by 32% in the intervention and post-intervention periods, but this decrease was not statistically significant.	No redness, rash, or other adverse side effects observed. Nursing personal rated chlorhexidine bathing intervention positively.	The intervention was associated with reduced HAIs, was well accepted by nursing staff, and had few adverse and rare effects.	Moderate Excluded anyone with hypersensitivity or a skin reaction (during study) to chlorhexi-dine	Organisms/ Outcomes: MDR *A. baumannii,* ESBL-producing *K. pneumoniae,* MRSA HAIs (catheter-related infection, urinary tract infection, intubation-associated pneumonia)
Ekizoglu et al., 2016[31]	Chlorhexidine digluconate solution (2% and 4% concentration) for use in	In vitro study of chlorhexidine resistance among MDROs—120	Hospital setting, Turkey	A solution of 4% chlorhexidine digluconate was effective against antibiotic-resistant and susceptible bacteria	Concentrations below 4% showed decrease in bactericidal activity, especially for *S.*	The authors state that it is important to use biocides at appropriate concentrations and to perform	Low As an in vitro study, there is limited applicability to use in	Organisms/ Outcomes: *S. aureus* (methicillin susceptible and resistant strains),

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	environmental cleaning and patient bathing	hospital isolated strains of 7 bacterial genera		after 5 minutes of contact time. Only MRSA showed a resistance to 2% chlorhexidine digluconate solution. However, many of the *S. aureus* strains (both methicillin resistant and methicillin susceptible) and *P. aeruginosa* strains were resistant to 0.5% solution.	*aureus* and *P. aeruginosa.*	surveillance studies to trace resistance or low susceptibility patterns of *S. aureus*, *P. aeruginosa*, and other hospital isolates.	patient bathing.	MDR *A. baumannii,* MDR *A. lowoffii,* MDR *P. aeruginosa,* MDR *K. pneumoniae,* MDR *K. oxytoca, Enterobacter* sp., and *Enterococcus* sp. Chlorhexidine resistance
Fritz et al., 2012[47]	Five-day *S. aureus* decolonization protocol consisting of hand hygiene, twice-daily intranasal 2% mupirocin, and daily 4% chlorhexidine body washing, performed by all household members (not just index patient). In addition, all participants were instructed to avoid sharing personal hygiene items (razors, brushes,	Open-label randomized trial of *S. aureus* decolonization in 183 index pediatric patients with a skin or soft tissue infection (SSTI), 92 in the index patient-only decolonization group, 91 in the household decolonization group Study included 1-month, 3-month, 6-month and 12-month analyses; not	Community setting, United States	At 1 month after decolonization, 50% of index patient cases and 51% of household cases had eradicated all *S. aureus* (p=1.00). At 3 months, however, the household group had a higher rate of *S. aureus* eradication (72% vs. 54%, p=0.05). Eradication did not differ between groups at 3 and 6 months. Moreover, when stratified by baseline MRSA colonization, eradication rates between groups did not differ significantly. Recurrent SSTI in the index patient was reported in 15% of the household group and 26% in the index	No serious adverse events were reported; 22% of cases reported side effects, including dry skin (14%), rash (6%), and hives (2%).	Decolonization of household members of index patients with an SSTI caused by *S. aureus* was well accepted, even if it did not statistically significantly reduce index patients' recurrent SSTIs or result in sustained eradication. The authors did not expect to find significantly lower SSTIs in the household members as well as lower rates of recurrent SSTIs in index patients despite a lack of long-term eradication. The authors hypothesize that acquisition of a new *S. aureus* strain	Low to moderate Compliance with decolonization and hygiene protocols was self-reported.	Organisms/ Outcomes: *S. aureus,* including MRSA *S. aureus* eradication at 1, 3, 6, and 12-months; adherence to decolonization measures; SSTIs

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	towels, bar soap, jars of lotion), launder linens in hot water at least weekly, and launder towels and washcloths in hot water after each use.	all cases completed all 12 months of followup.		patient-only group (p=0.12). The household members in the household decolonization group were less likely to report an SSTI than household members in the index patient-only group, at 1 month (2% vs. 7%, p=0.005), 3 months (4% vs. 10%, p=0.01), and 6 months (9% vs 16%, p=0.04). At 12 months, the trend continued but not statistically significantly (16% vs. 22%, p=0.10).		may result in infection; 20% of index patients were not initially colonized with *S. aureus.* The hygiene protocols may have reduced the acquisition of new *S. aureus* strains.		
Grare et al., 2010[45]	Preliminary evaluation of para-guanidinoethylc alix [4] arene or Cx1 (an alternative to chlorhexidine) for patient bathing	In vitro study of an alternative cationic compound to chlorhexidine	General healthcare setting, France	MICs were determined for 69 clinical isolates including MRSA, MSSA, coagulase-negative *Staphylococci* (CoNS), VRE, beta-lactamase-producing Enterobacteriaceae, and nonfermenting bacilli (*P. aeruginosa, A. baumannii, Stenotrophomonas maltophilia*). Cx1 showed comparable bactericidal activity to chlorhexidine and hexamidine against all	Although previous studies have shown Cx1 to be less cytotoxic than chlorhexidine, Cx1 was also less effective against certain types of bacteria.	Emerging compounds such as Cx1 may, in the future, present alternatives for disinfection with reduced potential harms. Past in vitro studies cited by Grare et al. show that chlorhexidine is cytotoxic over long periods (>24 hours) of exposure or to certain cell types (such as osteoblastic cells). However, Cx1 also showed reduced activity compared with chlorhexidine or	Low	Organisms/ Outcomes: MRSA, MSSA, coagulase-negative *Staphylococci* (CoNS), VRE, beta-lactamase-producing Enterobacteriaceae, *P. aeruginosa, A. baumannii, Stenotrophomonas maltophilia*

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				isolates except for nonfermenting bacilli.		hexamidine, showing the importance of balancing potential harms against efficacy.		
Hayashi et al., 2017[42]	Use of 0.1% chlorhexidine gluconate solution, compared with 0.1% benzothium chloride for bathing	In vitro study of MICs of chlorhexidine and benzothium chloride for 137 MDR *A. baumannii* isolates, 99 non-MDR *A. baumannii* isolates, and 69 non-*baumannii* isolates	Laboratory, Japan	None assessed.	The authors investigated whether a specific MDR *A. baumannii* strain (international clone 2) was more or less susceptible to chlorhexidine or benzothium chloride than other *A. baumannii* strains or other types of bacteria. The distribution of MICs of MDR-AB was higher than non-MDR-AB as well as non-*baumannii* isolates, and this difference was statistically significant for both MICs of chlorhexidine and benzothium chloride.	Despite higher MICs for MDR-AB compared with non-MDR-AB and non-*baumannii* isolates, all MICs were below concentrations in typical use. Although some studies have shown resistance to chlorhexidine among other MDROs (*Pseudomonas* and *Klebsiella* species), MDR-AB strains are still susceptible to the concentrations typically used in skin disinfection, as long as appropriate contact times are used.	Low In vitro study, with limited applications for patient use	*Organisms/ Outcomes: MDR-AB Chlorhexidine resistance*
Hijazi et al., 2016[34]	Chlorhexidine gluconate solution (various concentrations, from 0.125 to 64 mg/L), ethidium bromide	In vitro study of chlorhexidine susceptibility of *Staphylococcus* strains (including MRSA) in a	Intensive therapy unit in hospital, Scotland	None assessed.	Of the bacteraemia isolate strains that were found positive for the QAC A/B gene, 20 strains were *S. epidermis* and 2 strains were *S. aureus.* These accounted for 80%	This study found no indication of decreased efficacy of chlorhexidine-based infection control measures against *S. aureus* infections in the setting. The researchers	Moderate Statistical figures for higher MICs not available in this publication	Organisms/ Outcomes: MRSA, other *S. aureus, S. epidermis* This study informs future directions for chlorhexidine

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	(positive control, various concentrations from 4-1,024 mg/L)	setting where chlorhexidine is used for cleaning and patient bathing Isolates were collected over a period of 7 years. Forty strains of MRSA were randomly selected from intensive treatment patients screened at multiple body sites on admission. Forty-one *Staphylococcus* strains were obtained from blood cultures: 16 strains of S. *aureus* and 25 strains of *S. epidermidis.*			and 13%, respectively, of the total *S. epidermidis* and *S. aureus* strains isolated from blood samples. Only 1 of 40 (2%) MRSA strains isolated from screening samples was found positive for the QAC A/B gene. Chlorhexidine and mupirocin susceptibility among *S. aureus* strains (methicillin susceptible and methicillin resistant) was reduced in strains carrying QAC A/B genes, but there was no evidence of decreased susceptibility over the 7-year data collection period. However, *S. epidermis* strains showed a higher prevalence of QAC A/B genes compared with MRSA isolates (74% vs. 2%).	expressed concern over the high proportion of QAC A/B gene carriage in *S. epidermidis*, which in this study was associated with higher chlorhexidine and mupirocin resistance.		bathing (continuing to monitor resistance).
Huang et al., 2019[9]	Daily bathing with chlorhexidine (and targeted nasal mupirocin) for	Cluster-randomized trial comparing routine bathing and	Hospital, non-critical care units, United States	No differences were seen in the relative hazard ratio (HR) for MRSA- or VRE-positive clinical cultures: HR for the	Fewer than 1% of patients experienced an adverse event, related only to the chlorhexidine use.	This study did not find significant improvements in non-critical care patients. In a subgroup of high-risk	Low Very large study	Organisms/ Outcomes: MRSA, VRE, CRE, EBSL-producing Gram-negative

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	MDRO decolonization.	daily chlorhexidine bathing (with targeted nasal mupirocin) 12-month baseline period, followed by 2-month phase-in and 21-month intervention period 53 hospitals, including 189,081 patients in the baseline period and 339,902 patients in the intervention period (156,889 in routine care, 183,013 in the decolonization group)		intervention period versus the baseline period was 0.79 (95% CI 0.73 to 0·87) in the decolonization group versus 0.87 (95% CI 0.79 to 0.95) in the routine care group; p=0.17. HRs for secondary outcomes were also not statistically significant: for MDR Gram-negative clinical cultures, routine care HR was 0.81 (95% CI 0.72 to 0.91) and decolonization HR was 0.91 (0.82 to 1.00; p=0.16); and HRs for all-pathogen BSIs were 0.96 for routine care (95% CI 0.85 to 1.08) and 0.90 for decolonization (0.80 to 1.01; p=0.43). For high-risk patients (those with medical devices), however, the differences were statistically significant: The HR for the decolonization was 0.8 (95% CI 0.69 to 0.96) compared with the routine care group's HR of 1.17 (95% CI 1.00 to 1.37) for MRSA- or VRE-positive culture		patients (those with medical devices), chlorhexidine bathing offered reduced risk of MRSA- or VRE-positive cultures or all-cause BSI. The authors note that this finding is consistent with findings among ICU patients with devices and suggest further study of targeted decolonization protocols among non-critical care patients with medical devices.		bacteria, *Acinetobacter* and *Pseudomonas* species resistant to 3rd and 4th generation cephalosporins Clinical cultures, BSIs (all-pathogen), *C. difficile* infections, UTIs, 30-day infectious readmissions, chlorhexidine or mupirocin resistance

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				(p=0.0004). Similarly, the all-cause BSI HR for the decolonization group was 0.81 (95% CI 0.70 to 0.94) compared with 1.13 (95% CI 0.96 to 1.33) for the routine care group (p=0.0032).				
Huang et al., 2013[10]	5-day MRSA decolonization day regimen of 2% nasal mupirocin and daily bathing with 2% chlorhexidine-impregnated washcloths	Cluster-randomized trial of three approaches for preventing MRSA in 43 hospitals, with a total of 74 ICUs and 74,256 patients Three strategies: group 1, MRSA screening and isolation; group 2, targeted decolonization (i.e., screening, isolation, and decolonization of MRSA carriers); and group 3, universal decolonization (i.e., no screening,	Hospital, ICU, United States	Universal decolonization resulted in a significantly greater reduction in the rate of all BSIs than either targeted decolonization or screening and isolation. Reductions in rates of MRSA-related BSIs were similar to those of all BSIs, but the difference was not significant. In the intervention period versus the baseline period, modeled hazard ratios for MRSA clinical isolates were 0.92 for screening and isolation (crude rate, 3.2 vs. 3.4 isolates per 1,000 days), 0.75 for targeted decolonization (3.2 vs. 4.3 isolates per 1,000 days), and 0.63 for universal	Seven patients experienced mild pruritus or rash after chlorhexidine bathing that resolved on discontinuation of the use of chlorhexidine-impregnated cloths.	Universal decolonization resulted in the greatest reduction of BSIs by reducing environmental burden and by being implemented quickly (without needing to wait for screening results). Decolonization (both targeted and universal) had a high compliance rate (over 80%). If universal decolonization is implemented, it should be accompanied with surveillance for resistance.	Low Unable to separate the effectiveness of chlorhexidine bathing alone (always combined with mupirocin use)	Organisms/ Outcomes: MRSA MRSA colonization, MRSA-related BSIs, all BSIs

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		and decolonization of all patients) 12-month baseline period; 4-month phase-in period; and 18-month intervention period		decolonization (2.1 vs. 3.4 isolates per 1,000 days) (p=0.01 for test of all groups being equal). In the intervention versus baseline periods, hazard ratios for bloodstream infection with any pathogen in the three groups were 0.99 (crude rate, 4.1 vs. 4.2 infections per 1,000 days), 0.78 (3.7 vs. 4.8 infections per 1,000 days), and 0.56 (3.6 vs. 6.1 infections per 1,000 days), respectively (p<0.0001 for test of all groups being equal).				
Kengen et al., 2018[18]	Daily washing with 2% chlorhexidine-impregnated cloths	Single-site retrospective, open-label, sequential period, nonrandomized interrupted time series analysis in a 31-bed ICU, enrolling a total of 6,634 patients. Two periods—baseline: 32 months,	ICU, Australia	The incidence of clinically significant positive blood cultures during the chlorhexidine period compared with the water and soap period was 3.6 vs. 4.7 per 1,000 patient-days (p=0.37). Blood culture contamination rates were 11.8 vs. 9.5 (p=0.56); incidence rates of new ICU-associated MDRO acquisitions were 3.22 vs. 3.69	Although the rate of new ICU-associated CDI cases was observed to be higher after implementation of chlorhexidine washing compared with water and soap, it was not statistically significant. Potential confounders such as changes in surveillance may have impacted results. Compliance not measured.	Compared with washing with soap and water, daily washing with chlorhexidine-impregnated cloths was not associated with a statistically significant reduction in rates of ICU-associated clinically significant positive blood cultures, blood culture contamination, newly acquired MDRO isolates, or CDIs.	Low to moderate Nursing staff compliance was not measured, and the study included no patient-level data on the extent of application.	Organisms/ Outcomes: MRSA, VRE, MDR Gram-negative bacteria, *C. difficile* Clinically significant positive blood cultures attributable to the ICU stay; contaminated blood cultures; newly acquired MDROs

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		intervention: 26 months		(p=0.27); incidence rates of new CDIs were 2.01 vs. 0.79 (p=0.16). Outcomes after adjustment for confounders were similar.				attributable to ICU from clinical and screening cultures; and newly acquired C. difficile infections
Marolf et al., 2017[40]	Regular hospitalwide bathing with 4% chlorhexidine solution (frequency not specified)	In vitro study of chlorhexidine susceptibility of *S. aureus* strains before and after periodic use of chlorhexidine bathing in a 689-bed teaching hospital. Of 122 *S. aureus* strains meeting the study's nosocomial criteria, 104 were available for testing.	689-bed academic medical center, United States	Of the isolates from the four testing periods (before bathing, after a period of bathing, after bathing had been stopped, and after a second period of bathing), more strains in the period before bathing showed higher MICs (>0.25 µg/mL) than in any of the following periods. The mean MIC for isolates collected before bathing was introduced was greater than for those collected after bathing was introduced at Time 1 and Time 2 (p=0.048 and p=0.024, respectively).	None assessed.	Low-level resistance to chlorhexidine is known, but the study found no evidence over a 7.5-year period of increasing resistance nor any evidence that would suggest 4% chlorhexidine was no longer effective.	Low	Organisms/ Outcomes: *S. aureus* (methicillin susceptibility not specified)
Maxwell et al., 2017[26]	Daily chlorhexidine bath with twice-daily application of mupirocin ointment on	Prospective, randomized control trial on 90 trauma patients admitted to the ICU at a	Intensive care hospital setting, United States	Compared to a protocol of soap and water baths plus placebo ointment, there was no statistically significant difference in all-cause	Subsequent invasive MRSA infections were typically caused by the endogenous colonization strain, which chlorhexidine	Although the study did not show a statistically significant difference in MRSA colonization and infection between the	Moderate The study was terminated before reaching the number of	Organisms/ Outcomes: MRSA MRSA-related infections

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	nares for 5 days	Level I trauma center		Gram-negative or positive infections for chlorhexidine vs. soap, 12 (54.5%) vs. 7 (70%), p=0.467. The days to the onset of first MRSA infection was 2.5 for the treatment group and 4.0 for the placebo group. This difference was not significant.	plus mupirocin did not eradicate. No mupirocin resistance was identified by polymerase chain reaction testing in patients with both colonization and infection by the same strain, but seven tested positive for *smr*, a gene that can confer chlorhexidine resistance.	treatment and control groups, the authors noted that the study was underpowered for the planned objectives. The authors also speculated that a single 5-day treatment may not be sufficient for successful and sustained decolonization.	enrolled patients needed for sufficient predictive power. Study patients may be sicker, given the requirement for a >5-day ICU stay to complete intervention treatment.	
McNeil et al., 2014[37]	Topical antiseptics in general use for prevention and treatment of skin and soft tissue infections caused by MRSA: retapamulin, mupirocin, chlorhexidine	In vitro study of resistance in *S. aureus.* Two hundred isolates from patients with a single skin and/or soft tissue infection and 200 isolates from patients with >3 previous episodes from the years 2010 to 2012 were selected from an *S. aureus* surveillance study.	*S. aureus* isolates from a pediatric hospital setting, United States	*Smr*-positive *S. aureus* accounted for 14% of isolates. The proportion of *smr*-positive organisms increased during the study (p<0.005). MICs were twice as high for *smr*-positive *S. aureus*, and MBCs were 8 to 16 times higher for bactericidal effect in 50% and 90% of isolates, respectively.	In the study, the prevalence of resistant *S. aureus* increased over time.	While the reasons for the relatively high prevalence of *smr*-positive *S. aureus* in the study population are unclear, the researchers suggest it may reflect the dissemination of drug-resistant strains into the community from the healthcare setting.	Low to moderate	Organisms/ Outcomes: MRSA and other *S. aureus* strains
Mendes et al., 2016[15]	Daily bathing with 2%	Quasi-experimental	Hemato-poietic stem	The VRE colonization and infection rates	MDR Gram-negative bacteria infection and	Chlorhexidine bathing was	Low	Organisms/ Outcomes:

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	chlorhexidine gluconate and use of 2% chlorhexidine gluconate antisepsis for central venous catheter insertion, surgery, biopsies	observational study of VRE colonization/ infection and in vitro study of chlorhexidine resistance after an intervention The pre-intervention period (2005-2009) included 870 patients, and the intervention period (2009-2013) included 523.	cell transplant unit in a hospital, Brazil	were significantly reduced among unit patients post-intervention: colonization change in trend: Beta-3=–0.040, p=0.001; infection change in trend: Beta-3= –0.086, p=0.001.	colonization rates in the unit increased in the last years of the study. The chlorhexidine MICs for VRE increased during the exposure period to the antiseptic (by 2 dilutions for MIC_{50}). A higher MIC at baseline period was observed in MDR Gram-negative strains. A monoclonal *P. aeruginosa* clone emerged in the second period.	associated with decreased incidence of VRE colonization and infection; no similar results were found with MDR Gram-negative bacteria.		MDR Gram-negative bacteria, including *A. baumannii, K. pneumoniae,* and *P. aeruginosa,* VRE MDRO colonization and infection rates
Musuuza et al., 2017a[11]	Daily bathing with 2% chlorhexidine gluconate-impregnated washcloths	Pre-post-implementation test study of 619 patients with a total of 6,490 patient-days	24-bed intensive care unit, United States	Prevalence decreased in the immediate aftermath of daily chlorhexidine bathing implementation and generally remained at that level throughout the observation period. The authors observed low rates of incidence of MDRO colonization with VRE, MRSA, and fluoroquinolone-resistant Gram-negative bacilli (FQR-GNB). Monthly prevalence of colonization and	Rare but potentially serious chlorhexidine reactions were not encountered in this study, but the authors recommend eliciting in patient history when implementing bathing.	The authors observed an immediate drop in MDRO prevalence and incidence (except MRSA) once bathing was implemented. Initial enthusiasm for daily chlorhexidine bathing was high but waned over time, posing a barrier to long-term implementation.	Low to moderate The study did not include a control group, and fidelity to daily chlorhexidine bathing was not assessed.	Organisms/ Outcomes: VRE, MRSA, fluoroquinolone-resistant Gram-negative bacilli MDRO colonization

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				incidence for the composite of MRSA, VRE, and FQR-GNB was 1.9%-27.9% and 0-1.1 per 100 patient-days, respectively. Prevalence of VRE and FQR-GNB was significantly reduced; MRSA prevalence was reduced, but not significantly.				
Musuuza et al., 2017b[25]	Daily bathing with 2% chlorhexidine gluconate-impregnated washcloths	In vitro study of chlorhexidine gluconate susceptibility following a daily bathing intervention among 619 patients with a total of 6,490 patient-days	24-bed intensive care unit, United States	Both admission and discharge median MICs for MRSA and FQR-GNB did not differ between the pre- and post-implementation periods. For paired samples, the median MIC for MRSA did not significantly change between admission and discharge. The highest overall MIC was 0.5 µg/mL, and none of the MICs reached the threshold that defines reduced susceptibility to chlorhexidine.	None assessed.	Daily chlorhexidine bathing interventions do not appear to reduce the effectiveness of chlorhexidine, but this study only observed 9.5 months of time.	Low	Organisms/ Outcomes: VRE, MRSA, FQR-GNB
Naparstek et al., 2012[32]	Chlorhexidine digluconate solutions ranging from 0 to 256 mg/mL	In vitro study of susceptibility of extremely drug-resistant *K. pneumoniae*	Hospital setting, Israel	Extremely drug-resistant *K. pneumoniae* is still susceptible to the concentrations used in hospitals for skin preparation, bathing,	*K. pneumoniae* appears to be able to survive the residual effects of chlorhexidine.	Although chlorhexidine-resistant *K. pneumoniae* strains in this study were not resistant to the full concentration	Low	Organisms/ Outcomes: *K. pneumoniae*

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		to chlorhexidine		handwashing, and environmental cleaning.		typically used for skin antisepsis and disinfection, these organisms appear to be resistant to the residual antimicrobial effect of chlorhexidine on skin. The authors theorize this situation could create an opportunity for recolonization with resistant bacteria.		
Noto et al., 2015[17]	Daily bathing with 2% chlorhexidine gluconate-impregnated washcloths	Pragmatic, cluster-randomized, crossover study of 9,340 patients in 5 ICUs	Hospital setting, United States	After adjusting for baseline variables, no statistically significant difference was detected between groups in the rates of CLABSI, CAUTI, VAP, and CDI. Chlorhexidine bathing did not change rates of infection-related secondary outcomes, including hospital-acquired BSIs, blood culture contamination, or clinical cultures yielding MDROs. In a prespecified subgroup analysis, no statistically significant difference in CLABSI, CAUTI, VAP, or CDI was detected in any individual ICU.	None assessed.	Daily chlorhexidine bathing over a 10-week period did not appear to reduce device-associated HAIs or CDI rates, in contrast to Climo and colleagues' (2013) 24-week intervention. However, this study did not conduct active surveillance for MDRO colonization, only observed in clinical cultures.	Low to moderate	Organisms/ Outcomes: Organisms not specified (beyond *C. difficle*) CLABSI, CAUTI, VAP, CDI, MDRO-positive cultures, hospital-acquired BSI

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Otter et al., 2013[38]	Decolonization protocol of 1%-4% chlorhexidine bathing and nasal mupirocin	In vitro study of susceptibility of MRSA to chlorhexidine after implementation of a chlorhexidine-based decolonization protocol	Intensive care unit, United Kingdom	None assessed.	Typing identified two dominant clones: CC22 (n=224) and CC30 (n=197). Annual MRSA BSI rates declined from 2004 (the start of the chlorhexidine bathing program) to 2009, although the rate of decline for CC22 was slower than for CC30. Carriage of QAC A/B and *smr* genes and having a chlorhexidine MIC ≥2 mg/L did not increase overall among MRSA BSI isolates; however, QAC A/B gene carriage increased in CC22 compared with CC30 (OR, 7.21; 95% CI, 1.32 to 39.17). Also, QAC A/B+ CC22 isolates were more likely to have a chlorhexidine MIC ≥2 mg/L than QAC A/B+ CC30 isolates (OR, 21.67; CI, 2.54 to 185.20).	A successful infection control program was associated with the selection of genes linked to higher chlorhexidine MICs in one dominant endemic MRSA clone (CC22), but not another (CC30). The slower reduction in the CC22 MRSA BSI rate suggests that carriage of the QAC A/B gene confers a selective advantage, with potential implications for the sustainability of decolonization practice.	Low	Organisms/ Outcomes: MRSA MRSA-related bloodstream infections
Pedreira et al., 2009[27]	Oral care (toothbrushing) twice daily with 0.12% chlorhexidine digluconate	Randomized controlled study of 56 patients	Pediatric ICU, Brazil	A total of 26 samples contained pathogenic bacteria, and 24 (92%) of the 26 were antibiotic resistant, such as *K. pneumoniae* strains	None assessed.	In children in a PICU, the effects of mechanical oral care plus chlorhexidine did not differ from the effects of mechanical oral care alone.	Low to moderate Small number of patients in study.	Organisms/ Outcomes: MRSA, ESBL-producing *K. pneumoniae,* carbapenem-resistant *P.*

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				resistant to beta-lactamase, MRSA, carbapenem-resistant *P. aeruginosa* and *A baumannii,* and cephalosporin-resistant *Enterobacter* species. The number of children with an increase in the number of samples positive for pathogenic flora was greater in the control group than in the experimental group, but the difference was not statistically significant. Similarly, the colonization of the oral cavity by normal flora did not differ between the two groups of children.				*aeruginosa*, *A baumannii,* cephalosporin-resistant *Enterobacter* species MDR-positive cultures, MDRO colonization
Peterson et al., 2016[12]	Decolonization with 4% chlorhexidine body wash and nasal mupirocin, for 5 days Initial decolonization followed by screening and second decolonization as needed	Prospective, cluster-randomized study in 12 units at 3 long-term care facilities (LTCFs). 274 long-term and 115 short-term beds in intervention units; 299 long-term and 174 short-term	Three LTCFs, United States	The overall rate of MRSA infections significantly decreased between the baseline and Year 2, a 65% reduction of MRSA clinical infection (reduced by 0.78 infections per 10,000 patient-days; $p<0.001$). A significant reduction ($p\leq0.022$) in MRSA clinical infection also was	Costs of running this intervention include cost per decolonization ($10), MRSA testing (as high as $50), and expense of healthcare worker time to apply mupirocin. (Bathing is done routinely, and the substitution of chlorhexidine for soap has negligible impact on cost.)	The authors concluded that this study demonstrates a successful proof of concept that, with chlorhexidine bathing, it is possible to reduce MRSA infections without isolation and other contact precautions in the LTC setting.	Low to moderate The cluster-randomized approach failed to perform adequately in this study: the amount of resident intermingling during daily gathering made it too	Organisms/ Outcomes: MRSA MRSA colonization (nasal), MRSA-related clinical infections

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
	Second decolonization: 4% chlorhexidine body wash for 2 weeks, 2% mupirocin ointment twice daily for 5 days, and 100 mg of minocycline and 600 mg of rifampin (both orally) for 5 days	beds in control units.		observed at each of the three LTCFs. Mupirocin resistance rates were significantly different between the LTCFs in March 2011 (chi-square, 2 df=12.7, p=0.002). There was a significant downward trend in resistance between March 2011 and March 2013 (chi-square, 1 df=4.1, p=0.042), and this trend was not significantly different between LTCFs (interaction chi-square, 2 df=3.9, p=0.145). The authors hypothesize that use of oral antibiotics in the second decolonization reduced all strains of MRSA, including mupirocin-resistant ones.			difficult to separate treatment and control units within a single facility.	
Roode and Bütow, 2018[30]	Single application of chlorhexidine rinse solution for 2 minutes	Observational study of 50 cleft palate surgical patients	Hospital setting, China	Over half of pathogens isolated (61 of 113, 54%) survived after 2 minutes of disinfecting the surgical and surrounding area with chlorhexidine. In addition, two-thirds (76 of 113, 67.3%)	None assessed.	This small study demonstrated significant resistance to preoperative chlorhexidine disinfection, with implications for preventing surgical site infections, as well as	Moderate Small number of patients in this study.	Organisms/ Outcomes: *K. pneumoniae, H. influenza*, *S. aureus*

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				showed resistance to different antimicrobials in vitro. *K. pneumoniae* (n=13), *H. influenza* (n=11), and *S. aureus* (n=9) were the most prevalent pathogens after disinfection.		chlorhexidine's effectiveness as a decolonization agent.		
Ruiz et al., 2017[13]	Daily bathing with 2% chlorhexidine gluconate-impregnated wipes	Prospective cohort study with an intervention of 11 months 1,657 patients admitted during observation period, 430 (25.7%) bathed with chlorhexidine wipes	ICU in hospital setting, Spain	A significant decrease was observed in the incidence of MDRO colonization over the intervention period (β=−0.209; r^2=0.549; p=0.027), and in the number of patients colonized compared with the equivalent period of the previous year (22.0% vs. 18.4%; p=0.01). No statistically significant decrease was observed in the incidence of nosocomial infection (whether or not they were caused by MDROs) between the two periods (4.11% vs. 4.57%; p=0.355).	No dermatologic problems were observed in treated patients.	While the use of chlorhexidine wipes reduced MDRO colonization, it did not lead to a statistically significant reduction in the rate of HAIs (whether or not they were caused by MDROs). The authors concluded chlorhexidine could be helpful as part of a strategy but may not be sufficient on its own, especially for critically ill patients with extended ICU stays.	Low to moderate No environmental sampling was performed, which could have identified MDRO reservoirs. Chlorhexidine resistance was also not studied.	Organisms/ Outcomes: *K. pneumoniae, P. aeruginosa, A. baumannii, E. cloacae,* MRSA, *E. coli* MDRO colonization, HAIs (catheter-related bacteremia, mechanical VAP, mechanical ventilator-associated tracheobronchitis, UTIs)
Smith et al., 2013[39]	Oral care with mouthwashes containing one of the following active components: aloe vera and	In vitro study of effectiveness of commercial, over-the-counter chlorhexidine	Laboratory, Scotland	None of the biofilm isolates were completely eradicated by the compounds tested, with a maximal killing of only approximately 70%	None assessed.	MRSA biofilms are more prevalent in older and long-term patients. Over-the-counter mouthwashes have limited effect on	Moderate/ Low This study did not assess actual mouthwash use by	Organisms/ Outcomes: MRSA and other *S. aureus*

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
	tea tree oil; cetylpyridium chloride (concentration not specified); 0.2% chlorhexidine gluconate; 1% chlorhexidine gluconate; 1.5% hydrogen peroxide; 0.03% triclosan	mouthwashes against MRSA isolates. Oral isolates were collected from dental hospital patients and bloodstream isolates from a reference laboratory		(shown by two mouthwashes). Maximum activity of all compounds tested was observed after 30 seconds.		MRSA biofilms, making oral colonization an infection reservoir.	people, so unclear of the efficacy of mouthwashes when used as directed.	
Suwantarat et al., 2014[35]	Daily bathing with 2% chlorhexidine gluconate-impregnated cloth	Observational, in vitro study of chlorhexidine susceptibility of MDROs in a single hospital, 8 ICUs MDROs cultured from CLABSIs 122 isolates tested for chlorhexidine susceptibility, 28 from patients in units with daily chlorhexidine bathing and 96 from units with no chlorhexidine bathing	ICUs, United States	None assessed.	*Enterococcus* species were the most common organisms causing CLABSIs (n=30) and had a high prevalence of reduced chlorhexidine susceptibility (90%). Other organisms with a high prevalence of reduced susceptibility included coagulase-negative *Staphylococcus* species (51%), *K. pneumoniae* (88%), and *P. aeruginosa* (100%). Patients with daily chlorhexidine bathing were more likely to have an organism with reduced susceptibility (86%	Units that bathed patients with chlorhexidine daily were more likely to have CLABSIs caused by organisms with chlorhexidine resistance, compared to CLABSIs in units that did not conduct daily bathing. In this study, the data do not suggest that chlorhexidine bathing is changing the microbial ecology of which organisms cause CLABSIs (that is, the percentage of CLABSI caused by each organism), although those organisms are showing more chlorhexidine resistance in units	Low Relatively small number of isolates, and no isolates were available for chlorhexidine bathing units from the period before bathing began.	Organisms/ Outcomes: MRSA, *K. pneumoniae* (including ESBL-producing), *P. aeruginosa,* VRE CLABSIs

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
					vs. 64%; p=0.028) and to have infection with Gram-positive bacterial isolates (81% vs 52%; p=0.036) than patients with no bathing. Of 30 Enterococcal isolates, 10 were VRE. All VRE isolates (100%) and 17 vancomycin-susceptible Enterococci (85%) had reduced susceptibility. Reduced chlorhexidine susceptibilities were found in 15 isolates of methicillin-resistant coagulase-negative *Staphylococcus* species (60%), 3 ESBL- producing *K. pneumoniae* isolates (100%), and 1 MRSA isolate (33%).	where regular chlorhexidine bathing occurred.		
Taheri et al., 2016[33]	Benzalkonium chloride, benzethonium chloride, and chlorhexidine digluconate for surface and skin disinfection (patients and	In vitro study of chlorhexidine resistance in isolates from a hospital setting. Three biocides were tested in	Laboratory, Iran	None assessed.	Chlorhexidine was more effective than benzalkonium chloride and benzethonium chloride, with an MIC_{50} of 1 µg/mL, and MIC_{90} = 2 µg/mL against MRSA, and MIC_{50} = 0.5 µg/mL to	When used at the directed concentrations, the biocides should kill 100% of bacteria. However, persistent effects on skin and environmental surface are at lower concentrations, and	Low	Organisms/ Outcomes: MRSA, MSSA, coagulase-negative Staphylococci Chlorhexidine resistance

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
	healthcare workers)	dilutions ranging from 0.25 to 128 µg/mL.			MIC_{90} = 1 µg/mL against both MSSA and coagulase-negative Staphylococci.	theoretically could be a selective pressure for resistant strains. Previous studies have also shown that biofilms on surfaces can provide a 10- to 1,000-fold higher tolerance, although this is more of a consideration for environmental cleaning.		
Urbanic et al., 2018[23]	Daily bathing with 2% chlorhexidine-impregnated wipes, compared to daily bathing with 1% triclosan	Sequential, before-and-after observational study of 4,262 ICU admissions, 2,117 before and 2,145 after chlorhexidine bathing implementation	ICU, Australia	Aside from a reduction in MRSA acquisitions, there were no statistically significant changes in the measurements before and after the intervention. There were no significant changes in the rates of CLABSI (from 1.69 per 1,000 catheter-days [95% CI, 0.68 to 3.48] to 1.33 [95% CI, 0.49 to 2.90]; p=0.68), or ICU-acquired positive blood cultures (from 5.14 per 1,000 patient-days [95% CI, 3.45 to 7.39] to 4.45 [95% CI, 3.00 to 6.36]; p=0.58). MRSA acquisition incidence was lower during the chlorhexidine-bathing period (mean difference,	None assessed.	Chlorhexidine bathing is no worse than use of triclosan in this study and may be more effective at reducing MRSA acquisition. However, effects on infection may only be seen with a large number of patients due to the high number needed to treat HAIs such as CLABSI.	Moderate Single-site study	Organisms/ Outcomes: MRSA, VRE ICU-acquired CLABSIs

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				–2.13 [95% CI, –3.65 to –0.60] per 1,000 patient-days; p=0.007). No statistically significant difference was seen in the rate of isolates involving other pathogens, including VRE.				
Warren et al., 2016[36]	Daily bathing with 4% chlorhexidine aqueous solution (final dilution 1,250 µg/mL)	Retrospective cohort in vitro study of chlorhexidine susceptibility of MRSA isolates from an ICU with daily chlorhexidine bathing	ICU, United States	None assessed.	A nonlinear change in prevalence of QAC A/B genes associated with chlorhexidine tolerance changed in MRSA nasal isolates over the 8-year study period of daily patient bathing with chlorhexidine soap (an increase in years 5 and 6 of the study, then decrease in the remaining 2 years). Increase trends were significant for QAC A/B genes (p=0.02; highest prevalence, 16.9% in 2009 and 2010) and Staphylococcal cassette chromosome *mec* type IV (p<0.001; highest prevalence, 52.4% in 2012). The latter is associated with community-	In this study, long-term daily chlorhexidine bathing at the concentration used did not result in sustained, widespread dissemination of chlorhexidine-resistance genes; however, pre-exposure during previous admissions may result in patients having hospital-acquired, chlorhexidine-resistant strains present on readmission. A cited study on chlorhexidine-resistance gene prevalence among community-dwelling individuals showed a prevalence rate similar to what was found in this study, suggesting that	Low to moderate Single-site study; MIC testing of the MRSA isolates was not conducted.	Organisms/ Outcomes: MRSA Chlorhexidine resistance

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
					acquired MRSA strains.	chlorhexidine-resistance genes are circulating in community-acquired MRSA strains.		
Wesgate et al., 2016[44]	Worst-case dilutions of biocidal solutions under typical use (1% and 0.001% hydrogen peroxide-based solutions, 0.0004% triclosan solution, and 0.00005% chlorhexidine gluconate solution)	In vitro study of resistance of *S. aureus* and *E. coli* to low concentrations of antimicrobials (including chlorhexidine)	Laboratory, United Kingdom	None assessed.	Exposure to triclosan (0.0004%) was associated with a high risk of developing microbicide resistance and antibiotic cross-resistance in *S. aureus* and *E. coli*. Neither exposure to chlorhexidine (0.00005%) nor a hydrogen peroxide-based biocidal product were associated with developing resistance. Persistent exposure to a low concentration of hydrogen peroxide (0.001%) carried a risk of emerging resistance to antibiotics. Unstable clinical resistances to antibiotics occurred after exposure to the cationic biocide and oxidizing agents, specifically tobramycin and	These data suggest that persistent low concentrations of some types of antimicrobials on skin and other surfaces have potential to select for increasingly resistant MDROs. Chlorhexidine was not one of them in this study, but some common alternatives to chlorhexidine have resistance concerns.	Low In vitro study only; did not examine effects in actual clinical practice.	Organisms/ Outcomes: *S. aureus, E. coli* Chlorhexidine resistance, antibiotic resistance

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
					ticarcillin–clavulanic acid.			
Whitman et al., 2010[29]	Daily bathing with 2% chlorhexidine gluconate-impregnated cloths	Cluster-randomized, double-blind, controlled effectiveness trial of chlorhexidine bathing for MRSA decolonization in 1,562 healthy military recruits	Community setting, United States	The compliance rate (defined as application of 50% or more of wipes) at 2 weeks was similar in both groups (chlorhexidine group, 63%; control group, 67%) and decreased over the 6-week period. The estimated difference in soft skin and tissue infection rate between the chlorhexidine group and the control group was 0.025 (±0.016, p=0.14). Rates of colonization were lower in the chlorhexidine group than in the control group at followup (0% to 2% lower for MRSA and 8% to 12% lower for MSSA across sampling visits). The mean incidence of colonization was also significantly lower in the chlorhexidine group, compared to the control group: MSSA, 49.9% vs. 60.8% (p=0.03);	Chlorhexidine bathing caused no serious adverse reactions in the treatment cohort but did cause infrequent, mild, self-limited skin irritation.	Daily bathing with 2% chlorhexidine cloths was ineffective in reducing soft skin and tissue infection in a healthy population, supporting only targeted use of chlorhexidine bathing.	Low	Organisms/ Outcomes: MRSA, MSSA *S. aureus* colonization, infection Not a healthcare setting but may have implications for long-term care setting where common areas are shared.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				MRSA, 2.6% vs. 6.0% (p=0.03).[l]				
Wittekamp et al., 2018[22]	Oral care with 2% chlorhexidine mouthwash (applied 4 times daily, until end of mechanical ventilation)	Randomized trial of effectiveness of chlorhexidine mouthwash, selective oropharyngeal decontam-ination (SOD), and selective digestive tract decontam-ination (SDD) on BSI from MDR-GNB. 8,665 ICU patients receiving mechanical ventilation	ICU, Nether-lands	ICU-acquired BSI with MDR-GNB occurred among 144 patients (154 episodes) in 2.1%, 1.8%, 1.5%, and 1.2% of included patients during the baseline, chlorhexidine, SOD, and SDD periods, respectively. Absolute risk reductions were 0.3% (95% CI, −0.6% to 1.1%), 0.6% (95% CI, −0.2% to 1.4%), and 0.8% (95% CI, 0.1% to 1.6%) for chlorhexidine, SOD, and SDD, respectively, compared with baseline. Adjusted hazard ratios were 1.13 (95% CI, 0.68 to 1.88), 0.89 (95% CI, 0.55 to 1.45), and 0.70 (95% CI, 0.43 to 1.14) during the chlorhexidine, SOD, and SDD periods, respectively, versus baseline.	Oromucosal lesions in a total of 29 (9.8%) of 295 patients treated with 2% chlorhexidine in two of the centers. No serious adverse events.	Among ICU patients receiving mechanical ventilation in settings with moderate to high MDRO prevalence, use of chlorhexidine mouthwash, SOD, or SDD did not reduce BSIs caused by MDR-GNB (compared to usual care).	Low Study may have been under-powered to detect difference in BSIs.	Organisms/ Outcomes: ESBL-producing Enterobacteriaceae, MDR Gram-negative bacteria ICU-acquired BSI, 28-day mortality

[l]No confidence interval was provided for these statistical tests.

Table B.3: MDRO, Hand Hygiene—Systematic Reviews

Note: Full references are available in Section 5.2 reference list.

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Ellingson et al., 2014[16]	General hand hygiene guidelines: what to use, in which circumstances, and how to incentivize hand hygiene compliance	General healthcare settings Multiple countries included in reviewed studies and policies	Opportunities for hand hygiene include: before touching the patient, before a clean/aseptic procedure, after body fluid exposure, after touching the patient, and after touching patient surroundings. Many studies and policies compress this list to two moments: entry and exit of a patient room. The main method for measuring hand hygiene compliance is direct (overt or covert) observation, but using multiple methods (such as product volume, technological systems for automatic monitoring, or even self-report) can strengthen measurement against any single mode's limitations. Alcohol-based hand rubs are generally superior to soap and water, with the major exception being spore-forming organisms such as *C. difficile*. The main drawback of hand rubs is contact dermatitis, which is positively associated with the number of hand hygiene events. For *C. difficile* and other spore-forming organisms, soap and water is the preferred method. Hot water, which can irritate skin, should be avoided. Artificial and long nails are recommended against, on the basis of microbial carriage and risk of glove puncture.	Recommendations for increasing hand hygiene compliance include: 1. Choose the appropriate products: alcohol-based hand rub with at least 62% alcohol, antimicrobial and nonantimicrobial soak, and antisepsic solutions specifically formulated for surgical use. 2. Provide convenient access to hand hygiene equipment and ensure it is refilled routinely. 3. Involve healthcare personnel in choosing products. 4. Perform hand hygiene at the five moments mentioned above (before touching the patient, before a clean/aseptic procedure, after body fluid exposure, after touching the patient, and after touching patient surroundings). 5. Perform hand hygiene when hands are visibly soiled. 6. Assess unit- or institution-specific barriers to hand hygiene. 7. Implement multimodal ("bundle") approaches to address those barriers. 8. Educate, motivate, and ensure competency of healthcare personnel. 9. Measure hand hygiene by direct observation and one other method (product volume, automatic monitoring). 10. Provide feedback to healthcare personnel on hand hygiene compliance.	Organisms/ Outcomes General bacteria and viruses, with specific instructions for *C. difficile*

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Graveto et al., 2018[8]	Cell phone use and hand hygiene	Hospitals, ICUs, operating theaters, dialysis units, burn centers Multiple countries included in reviewed studies	An integrative review of the literature was carried out following the PICOD Method. Thirteen studies met the defined criteria for this review. Cell phones from health care personnel working in ICUs showed a higher rate of bacterial contamination than those working in other units. Cell phones used by doctors posed the highest risk of contamination and of infection rates, compared with nurses or other health technicians, but one study showed that administrative/clerical professionals had higher contamination rates than those of personnel involved in patient care. One study found that 96.7% of health care professionals never disinfected their phone. Another found that 45% of professionals "never" washed their hands before and after using their cell phones, 38% "occasionally" and only 17% said "consistently," and (from a third study) 97% never washed their hands after using their phone. The most common organisms isolated in the reviewed studies were coagulase-negative *Staphylococcus* species (from 48.7% to 95.6% of all samples tested), *S. aureus* species (from 6.7% to 66.7% of all samples), and *Acinetobacter* species (1% to 33% of all samples). Between 9.5% and 52% of *S. aureus* samples across studies were resistant to methicillin, and a high percentage of Gram-negative bacteria (31.3%) was resistant to ceftazidime. Larger phones were associated with a larger number of colonies and a higher probability of pathogenic organism colonies. However, there is a lack of data about the connection between contaminated phones and health care-associated infections (HAIs).	Cell phone use represents a threat to successful hand hygiene, but the ubiquity and utility of cell phones does not support their ban in health care settings. (There is also limited data on the connection between cell phone contamination and HAIs.) Instead, the authors recommend that cell phone use be incorporated into hand hygiene promotion, including handwashing before and after use and regular, standardized disinfection of cell phones. Technological innovation can be a strong ally for healthcare personnel and organizations by creating new equipment such as antibacterial covers and films or ultraviolet light for sanitary purposes.	Organisms/ Outcomes *Staphylococcus aureus, Acinetobacter* species, multidrug-resistant Gram-negative bacteria (MDR-GNB) Hand hygiene compliance after using cell phones, HAIs

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Luangasanatip et al., 2015[26]	Hand hygiene compliance	Hospitals Multiple countries included in reviewed studies	Search of databases for studies published between 2009 and February 2014. Included studies were studies implementing an intervention to improve compliance with hand hygiene among healthcare workers in hospital settings and measuring compliance or appropriate proxies that met predefined quality inclusion criteria. Forty-one met the inclusion criteria (6 randomized controlled trials, 32 interrupted time series, one nonrandomized trial, and two controlled before-and-after studies). Meta-analysis of two randomized controlled trials showed the addition of goal setting to WHO "5 Moments" was associated with improved compliance (pooled odds ratio 1.35, 95% confidence interval 1.04 to 1.76; I2=81%). Nineteen studies reported clinical outcomes; data from these were consistent with clinically important reductions in rates of infection resulting from improved hand hygiene for some but not all important hospital pathogens. Reported costs of interventions ranged from $225 to $4,669 (£146-£3,035; €204- €4,229) per 1,000 bed-days. There is strong evidence supporting the efficacy of the WHO "5 Moments" multicomponent intervention. The clinical outcomes of hand hygiene interventions are not always consistent across all MDROs, and the authors hypothesize that this variation is due to the epidemiology of the organisms and whether strains are acquired outside or inside the care setting. To further increase compliance, the authors also suggest adding supplemental elements such as goal setting, reward incentives, and ways to increase staff accountability (e.g., direct observation).	The WHO "5 Moments" campaign effectively increases hand hygiene compliance among health care workers. Specifically, goal setting, incentives, and accountability can increase compliance and support it over time.	Organisms/ Outcomes: Hand hygiene compliance

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Tacconelli et al., 2014[6]	Contact precautions, environmental cleaning, hand hygiene, antimicrobial stewardship	General healthcare setting Multiple countries included in reviewed studies	Articles presenting data pertaining to the control of the spread, in hospitalized patients, of MDR-*Pseudomonas aeruginosa*, *A. baumannii*, and Enterobacteriaceae and organisms intrinsically resistant to broad-spectrum antimicrobial agents, such as *Stenotrophomonas maltophilia* and *Burkholderia cepacia*, were identified through computerized literature searches. The search was restricted to full articles published in English up to November 2011 and including adult patients (>16 years of age). Hands of any healthcare worker are vulnerable to colonization, although the type and count of MDR Gram-negative bacteria (MDR-GNB) are related to exposure from patients and their environment, as well as the ability of the microbe to successfully colonize on transient contact. Many MDR-GNB can also survive several hours on healthcare workers' hands, depending on the species. Both soap and water as well as alcohol-based hand rubs are equally effective in reducing carriage of MDR-GNB. However, alcohol-based hand rubs are less effective at removing MDR-GNB from artificial nails compared to natural nails. The use of gloves in place of hand hygiene is not sufficient, as one study found contamination of a sizable percentage (29.3% for MDR-*A. baumannii* and 17.4% for MDR-*P. aeruginosa*) after glove removal but before hand hygiene.	Correct hand hygiene before and after patient contact, as well as before and after contact with patient environment (regardless of gown and glove use), is strongly recommended for preventing MDR-GNB transmission in both epidemic and endemic settings.	Organisms/ Outcomes MDR-GNB MDR-GNB carriage

Table B.4: MDRO, Hand Hygiene—Single Studies

Note: Full references are available in Section 5.2 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Barnes et al., 2014[17]	Handwashing on entrance to and exit from patient room (details not specified in the model, just whether or not handwashing was done at both opportunities)	Mathematical model (agent-based modeling) Simulation of the transmission of *A. baumannii,* methicillin-resistant *S. aureus* (MRSA), and vancomycin-resistant Enterococci (VRE) for 1 year using data from the literature and observed data to inform model input parameters compared the effects of hand hygiene and environmental cleaning on rates of MDRO acquisition.	Model based on 20-patient hospital ICU, United States	Baseline rates for hand hygiene compliance of nurses were set at 70% and 85% on entry and exit, respectively, and at 57% and 67% on entry and exit for physicians, respectively, based on observation data from a single facility in the mid-Atlantic region. The mathematical simulation model found that MDR- *A. baumannii* (MDR-AB), MRSA, and VRE acquisition rates increase substantially more if hand hygiene compliance falls than if cleaning thoroughness decreases. In general, a 2:1 improvement in thoroughness of terminal cleaning compared to hand hygiene compliance is required to achieve an equal reduction in MDRO acquisition rates.	None assessed.	This model found hand hygiene to be a more efficient strategy for preventing transmission of MDROs than terminal cleaning. However, if terminal cleaning is easier to improve than hand hygiene, then improving thoroughness may be the more effective strategy in that facility.	Low to moderate Mathematical model only, based on rates at a single hospital. Does not account for other facilities' baselines.	Organisms/ Outcomes: MDR-AB, MRSA, VRE Transmission of MDROs

Cheng et al., 2015[20]	Strict contact precautions (including single-room isolation) for MDR-AB-colonized patients and directly observed hand hygiene in conscious patients immediately before they received meals and medications	Pre-post study of 5,058 patients cultured positive with MDR-AB between January 1, 2004, and June 30, 2014	A university-affiliated hospital and three extended-care hospitals, with a total of 3,200 beds, Hong Kong	The first case of multiple-drug- resistant MDR-AB bacteremia emerged in 2009, with an incidence that increased from 0.27 (1 case) in 2009 to 1.86 (14 cases) per 100,000 patient-days in 2013 (p<0.001). Following implementation, in July 2013, the incidence of MDR-AB bacteremia decreased from 14 cases in 2013 to 1 case in the first 6 months of 2014 (p<0.001). Nonbacteremic MDR-AB also decreased from 106 to 34 cases over that same period (p<0.001). Patients from long-term care facilities for older adults (odds ratio [OR] 18.6, confidence interval [CI] 2.1 to 162.4, p=0.008) and history of carbapenem (OR 7.0, CI 1.7 to 28.0, p=0.006) and beta-lactam/ betalactamase use (OR 5.6, CI 1.1 to 28.7, p=0.038) 90 days prior to admission were independent risk factors for MDR-AB bacteremia by logistic regression compared with carbapenem-susceptible *A. baumannii* bacteremia. The overall compliance of hand hygiene of healthcare workers has gradually increased from 23% in 2007 (baseline) and maintained at 75% to	None assessed.	This study presents a novel hand hygiene approach—reducing MDR-AB bacteremia through patient hand hygiene. Despite increases in staff hand hygiene, direct observation of patient hand hygiene and patient isolation were followed by a reduction in MDR-AB bacteremia. This MDRO is known for widespread environmental contamination, and hand hygiene of patients may protect against MDR-AB acquisition and subsequent bacteremia.	Moderate Single site study; other parts of the multicomponent intervention (increased staff hand hygiene, contact precautions) may have contributed to results.	Organisms/ Outcomes: MDR-AB MDR-AB-related bacteremia

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				79% between 2011 and 2013.				

Cheng et al., 2018[21]	Direct observation of hand hygiene with alcohol-based hand rub (ABHR) performed at 2-hourly intervals during daytime, before meals and medication rounds by a trained nurse in each intervention site. The hand hygiene ambassador delivered 3 mL ABHR to the hands of residents per occurrence of observed hand hygiene, either at the communal areas or at the bedside. A pocket-sized 60 mL ABHR container was used by the research nurse, and standard-sized 500-mL ABHR containers were placed in the cubicle, corridor, and communal areas of sites for the residents, staff, and visitors.	One month, cluster-randomized controlled study of 10 (five intervention, five control) long-term care facilities in Hong Kong	Ten residential care homes for older adults, Hong Kong	After implementation, the number of organism-positive environmental cultures showed a significant reduction in MRSA (79 of 600 [13.2%] vs. 197 of 600 [32.8%]; p<0.001) and carbapenem-resistant *A. baumannii* (CR-AB) (56 of 600 [9.3%] vs. 94 of 600 [15.7%]; p=0.001) contamination in the intervention arm compared with the nonintervention arm during the study period. The volume of hand rub consumed per resident per week was three times as high in the intervention arm compared with the baseline (59.3 ± 12.9 mL vs. 19.7 ± 12.6 mL; p<0.001) and was significantly higher than the nonintervention arm (59.3 ± 12.9 mL vs. 23.3 ± 17.2 mL; p=0.006).	None assessed.	Observed resident hand hygiene before meals and promotion of use of ABHRs reduced environmental contamination with MRSA and CR-AB and was well received by residents.	Low	Organisms/ Outcomes: MRSA, carbapenem-*resistant Acinetobacter* species, extended-spectrum beta-lactamase (EBSL)-producing Enterobacteriaceae MDRO colonization, MDRO environmental contamination

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
D'Agata et al., 2012[9]	Mathematical model of infection control approach, including hand hygiene decolonization, contact precautions, active surveillance, and screening (for VRE and MRSA)	Mathematical model extending data from clinical individual-level studies to quantify the impact of hand hygiene, contact precautions, reduction of antimicrobial exposure, and screening of surveillance cultures in decreasing the prevalence of MDRO colonization and infection	Model based on a 600-bed tertiary care hospital, United States	Improving compliance with hand hygiene from 60% to 80% and from 80% to 100% decreases the colonization prevalence by 12% and 8%, respectively. Each improvement interval decreased MDRO infections by 8%. Comparatively, similar improvement in compliance with contact precautions (from 60% to 80% and from 80% to 100%) decreases the prevalence of colonization by 10% and 6% respectively, and decreases MDRO infections by 6% and 4%, respectively. Screening patients for asymptomatic colonization also reduces MDRO prevalence, but only among patients receiving antimicrobials.	None assessed.	Improving hand hygiene is essential because it prevents transmission regardless of whether the patient's colonization status is known and requires fewer supplies and processes to consistently implement than contact precautions.	Moderate Not a real-world test, but the methodology for the model is based on epidemiologic results of a 600-bed teaching hospital over 1 year.	Organisms/ Outcomes: MRSA, VRE MDRO colonization, MDRO-related infections

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
De la Rosa-Zamboni et al., 2018[11]	A multimodal, hospitalwide hand hygiene program with alcohol-based hand rubs, periodic education, leadership support, and monthly feedback "Let's Go for 100" involved all healthcare workers and encompassed education, awareness, visual reminders, feedback, and innovative strategies. Monthly hand hygiene monitoring and active health care-associated infection (HAI) surveillance were performed in every ward.	Prospective time series analysis. Intervention implemented in 2013. Baseline period: (January-August 2013); intervention and followup period (September 2013 through October 2016). Population: between January 2013 and October 2016, 27,975 patients were discharged from the hospital, yielding a total of 266,524 patient-days, 111,642 central line-days, 30,218 ventilator-days, and 26,327 urinary catheter-days.	349-bed public teaching and referral pediatric hospital, Mexico	Baseline hand hygiene adherence was 34.9% (SD 3.52) and increased significantly (p<0.0001) over the study period to 80.6% (SD 6.3) during the last 3 months. The increase was statistically significant for use of alcohol-based products (z=2.78 and p=0.005) but not for washing hands (z=0.32 and p=0.745). Adherence increased across all healthcare staff groups. The HAI rate decreased from 7.54/1,000 patient-days (SD 1.82) to 6.46/1,000 patient-days (p=0.004)). The authors observed a negative correlation between hand hygiene adherence and attack rate for: • MRSA (coef. -17.10, 95% CI -30.67 to -3.53, p=0.019) • VRE (coef. -54.87, 95% CI -73.28 to -36.46, p=0.001) • *Enterobacter* species (coef. -33.04, 95% CI -51.14 to -14.94, p=0.002) • Overall MDR-ESKAPE[m] group (-7.76, 95% CI -15.08 to 0.37, p=0.059)	N/A	This study shows the impact of a sustained hand hygiene promotion campaign that was associated with reductions in all studied MDROs (MRSA, VRE, and MDR-ESKAPE). The authors note that there are few hand hygiene studies in pediatric settings. Some of the innovative approaches to hand hygiene included messaging for pediatric patients and siblings using a mascot and holding contests among healthcare staff for the most innovative ways to improve hand hygiene compliance.	Low to moderate Single study, but long study period. No other policy changes during study period.	Organisms/ Outcomes: MRSA, VRE, MDR-ESKAPE group HAIs

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Harris et al., 2017[18]	Mathematical model based on an infection control intervention that included directly-observed hand hygiene on entry/exit of patient room (method not specified) and gown and glove use with patients known to be colonized with MDROs	Mathematical model of the relative effects of hand hygiene, glove and gown use, and dedicated staff on MRSA and VRE acquisition rates.	Hospital ICU, United States	This model was based on a previous study that looked at gown and glove use for MRSA and VRE acquisition, which found no effect on VRE acquisition rates but a large effect on MRSA acquisition rates. This study also found that ICUs in the glove and gown intervention had higher hand hygiene compliance rates than control ICUs (78.3% vs. 62.9%). Based on the model, the authors estimate that 44% of the decrease in MRSA acquisition was due to universal glove and gown use, 38.1% was due to improved hand hygiene, and 14.5% was due to the reduction in contact rates (a known side effect of contact precautions).	N/A	This model was able to break down a multicomponent intervention and assess the relative impact of hand hygiene in a multicomponent study. In a separate universal gown and gloving study, hand hygiene had almost as much impact as gown and glove use.	Low to moderate Mathematical model study but based on the data from a "real world" implementa-tion in several ICUs.	Organisms/ Outcomes: MRSA, VRE MDRO acquisition rates

[m]*Enterococcus faecium, S. aureus*, *Klebsiella pneumoniae, A. baumannii, P. aeruginosa*, and *Enterobacter* species.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
McLaws et al., 2009[15]	Regional hand hygiene promotion campaign, "Clean hands save lives" Campaign consisted of placing alcohol-based hand rub dispensers at the point of care (near patient locations), observing hand hygiene compliance, using promotional campaign posters for all audiences, and distributing brochures to encourage patients to confirm hand hygiene compliance.	Pre-post study of a hand hygiene promotion campaign to stop MRSA infections. Sample size not provided. Campaign included all public hospitals in the New South Wales State of Australia.	11 hospital, general wards, and ICUs, Australia	Between the pre- and post-campaign periods, there was a 25% fall in MRSA-related non-ICU sterile site infections, from 0.60/10,000 bed-days to 0.45/10,000 bed-days (p= 0.027), and a 16% fall in MRSA-related ICU non-sterile site infections, from 36.36/10,000 bed-days to 30.43/10,000 bed-days (p=0.037). The pre- and post-campaign rates of MRSA infection from ICU sterile sites (5.28/10,000 bed-days vs. 4.80/10,000 bed-days; p=0.664) and non-ICU, non-sterile sites (5.92/10,000 bed-days vs. 5.66/10,000 bed-days; p=0.207) remained stable. Australia-wide MRSA data reported to the Australian Council on Healthcare Standards showed a 45% decline in infections from ICU non-sterile sites, from 25.89/10,000 bed-days to 14.30/10,000 bed-days (p<0.001), and a 46% decline in infections from non-ICU non-sterile sites, from 3.70/10,000 bed-days to 1.99/10,000 bed-days (p<0.001) over the period 2005–2006.	None assessed, beyond failure to reduce MDROs in certain sites.	Although hand hygiene increased markedly in the intervention hospitals, there was no consistent reduction in all MDROs and in all observation sites. However, focusing only on clinical outcomes with hand hygiene does not reflect potential environmental or systemic factors that need to change (e.g., environmental contamination or a workflow at odds with hand hygiene).	Low Large sample size, and control group available (all other public hospitals outside New South Wales). May have unobserved differences between NSW hospitals and those in other areas.	Organisms/ Outcomes: MRSA Hand hygiene compliance rates, MRSA infections

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Pires dos Santos et al., 2011[13]	Alcohol-based hand rub use (coincidental with antibiotic stewardship initiatives)	Pre-post study of association between CR-*P. aeruginosa* (CR-PA) infection rates and alcohol-based hand rubs through three study periods: period 1, before ertapenem use (17 months); period 2, during ertapenem use (33 months); and period 3, after exclusion of ertapenem (15 months). Sample size not provided.	749-bed hospital, Brazil	CR-PA decreased over the period of ertapenem use as well as during the period of ertapenem restriction. The mean incidence of CR-PA infections per 1,000 patient-days was 0.51 (95% CI, 0.41 to 0.60) in period 1; 0.43 (95% CI 0.36 to 0.49; p=0.33) in period 2; and 0.33 (95% CI 0.26 to 0.41; p=0.34) in period 3. Between period 1 and period 3, this decrease was statistically significant (p=0.04). There was no significant correlation between CR-PA infection and ertapenem use throughout the study periods. However, by multiple regression analysis, the reduction in the rate of CR-PA infection correlated significantly with the increase in the volume of alcohol used as hand sanitizer (p<0.01; Spearman correlation r=-0.40), which increased from 660.7 mL per 100 patient-days in period 1 to 2,955.1 mL per 100 patient-days in period 3.	None assessed.	The natural experiment in this study (increased hand hygiene due to the H1N1 influenza pandemic) allowed the author to evaluate the relative impact of increased hand hygiene (as measured through hand rub consumption) on CR-PA. In this study, the association between alcohol-based hand rub use and increased CR-PA cases was stronger than the association with ertapenem (a type of carbapenem) restriction.	Moderate Single-setting study that initially sought to evaluate the impact of antibiotic stewardship; the hand hygiene component was an incidental finding.	Organisms/ Outcomes: CR-PA CR-PA-related infections

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Rupp et al., 2008[22]	Alcohol-based hand rub (62% ethyl alcohol and 0.3% triclosan) in the intervention group, compared to soap and water (antimicrobial soap with 0.3% chloroxylenol). Hand rub dispensers were installed inside and outside patient rooms in the first unit, with the same in the second unit during the crossover period.	Prospective crossover controlled trial Hand hygiene was covertly observed every 60 days by trained individuals; hand hygiene adequacy not assessed, only performance/nonperformance. Trial included 17,994 minutes of observation, which included 3,678 opportunities for hand hygiene between August 2001 and September 2003.	Two 12-bed ICUs in a single hospital, United States	Hand hygiene adherence rates improved dramatically after the introduction of alcohol-based hand rubs, from 37% to 68% in one unit and from 38% to 69% in the other unit ($p<0.001$). Hand hygiene rates were also better at higher workloads when the hand rub was available in the unit ($p=0.02$). However, no significant changes in MDRO, *C. difficile*, or device-associated infection rates were observed. (The authors noted that the infection rates were generally low during the study periods.)	Having fingernails longer than 2 mm, wearing rings, and lacking access to hand gel were associated with increased microbial carriage.	This study demonstrates that hand hygiene compliance can improve dramatically when the equipment is provided in the right place. When this study was conducted, the recommendations against alcohol-based hand rub for CDI had not yet been made, which likely accounts for the lack of effect on CDI rates. In addition, the authors note that active surveillance for MRSA was not done; given dramatic spread of MRSA throughout healthcare facilities and the community, colonization from outside the units may have been the cause of unchanged MRSA rates.	Low to moderate Process outcome focus	Organisms/ Outcomes: MRSA, VRE, MDR-PA, *C. difficile* Hand hygiene compliance, *C. difficile*-associated diarrhea, MDRO-associated infections, device-associated infections (central venous catheter–related bacteremia, urinary catheter–associated urinary tract infection, and ventilator-associated pneumonia)

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Sickbert-Bennett et al., 2016[23]	Hand hygiene upon entering and exiting patient rooms, observation and immediate feedback from all staff members, and covert observation from trained infection prevention and nursing staff Other PSPs: HAI surveillance	Longitudinal observational study; over 140,000 observations made over a 17-month period	A single 853-bed acute care hospital, United States	Hand hygiene compliance increased significantly by 10% (p<0.001) and HAIs (including those caused by MDROs) decreased significantly by 14% (p=0.0066). This decrease is estimated to have prevented 22 deaths and saved approximately $5 million. The association between hand hygiene compliance and health care associated-*C. difficile* infection, adjusting for unit-level data, showed a 10% improvement in hand hygiene, associated with a 14% infection reduction (p=0.070).	No association was noted between hand hygiene compliance and MDRO infections (p=0.7492).	Although an improvement in hand hygiene was associated with reduction in overall HAIs and produced cost savings, the authors found that this decrease was mostly driven by *C. difficile* infection and was not seen in MDROs. While hand hygiene was helpful in cost saving and is necessary to support other infection prevention practices, it alone may not be sufficient to control MDROs.	Low to moderate Single-site study. No other specific hospitalwide infection prevention goals were adopted during the period of analysis.	Organisms/ Outcomes: MDROs, *C. difficile* Hand hygiene compliance, HAIs, HAIs related to MDROs

Sopirala et al., 2014[12]	Hand hygiene promotion campaign using nurse liaisons to observe and give feedback on compliance with alcohol-based hand rub or soap and water washing on entry and exit of patient rooms Staff nurses were trained to be liaisons to infection prevention personnel. "Link nurses" would observe hand hygiene, give immediate feedback to staff, identify and report on infection prevention issues in their units, and conduct hand hygiene education with staff. Independent audits were done by graduate students, and compliant units would receive recognition (e.g., plaque, celebratory lunch or dinner).	Pre-post quality improvement study at a single 1,191-bed hospital Baseline period: January 1, 2006– March 31, 2008 Intervention period: April 1, 2008– September 30, 2009	Hospital, United States	Hand hygiene gradually increased from 30% in 6 months prior to the intervention to 93% in the 6 months after starting the intervention. Healthcare-associated MRSA incidence rates dropped by 28% from 0.92 cases per 1,000 patient-days to 0.67 (IRR=0.72 [95% CI 0.62 to 0.83], p<0.001). Overall MRSA rates dropped from 4.83 to 4.25 per 1,000 patient-days. Overall MRSA bacteremia decreased from 0.49 to 0.34 per 1,000 patient-days (IRR=0.59 [95% CI 0.42 to 0.84], p=0.003) and health care-associated MRSA bacteremia from 0.18 to 0.10 per 1,000 patient-days (IRR=0.68 [95% CI 0.56 to 0.84], p<0.001).	None assessed.	Hand hygiene promotion and feedback on compliance audits resulted in very high compliance rates that successfully reduced both health care-associated infections and total MRSA cases and bacteremia.	Moderate Single-site study, and other components were not controlled for in estimating clinical outcomes.	Organisms/ Outcomes: MRSA Hand hygiene compliance, health care-associated (HCA) and non-HCA MRSA incidence (infection or colonization), HCA and non-HCA MRSA bacteremia

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Vernaz et al., 2008[14]	Two hand hygiene promotion campaigns using alcohol-based hand rubs: "VigiGerme®" in spring 2003 and "Clean care is safer care" in autumn 2005 (including hand hygiene observations of healthcare personnel). Other protocols included universal MRSA on-admission screening from January to August 2003 in the entire hospital, and from October 2004 to May 2006 in selected surgical wards.	Interventional time series analysis of the temporal relationship between increased use of alcohol-based hand rubs, antibiotic use, and MRSA and *C. difficile* rates. All hospital patients between February 2000 and September 2006; mean hospitalization days, 51,524 per month	2,200-bed primary and tertiary care teaching hospital, Switzerland	Over the study period, the average monthly MRSA incidence was 0.15 clinical isolates per 100 patient-days, varying from 0.09 to 0.21 with no overall trend (p=0.71). The monthly incidence of *C. difficile* was 0.027 isolates per 100 patient-days, varying from 0.004 to 0.054, without any trend (p=0.82). Consumption of hand rubs increased over the study period, from an average of 1.303 L per 100 patient-days in 2001 to 2.016 L per 100 patient-days in 2006, and the effect of the education intervention on increased hand rub use was statistically significant. Only MRSA showed a temporal association between the increase in hand rub use and a decrease in MRSA rates.	The campaign had no significant effect on MRSA reduction in the multivariable analysis.	This study demonstrated a temporal association between increased hand rub use and MRSA, although a multivariable analysis showed no effect of the hand hygiene promotion campaign on MRSA rates. As confirmed by later studies, alcohol-based hand rubs are less effective for reducing *C. difficile* transmission. The average antimicrobial use over the study period was 33 defined daily dose/100 patient-days and did not change over time (p=0.29).	Low to Moderate	Organisms/ Outcomes: MRSA, *C. difficile* Consumption of alcohol-based hand rubs

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Wares et al., 2016[19]	Mathematical modeling of the role of hand hygiene in reducing environmental contamination by MDROs and MDRO transmission	Mathematical simulation model looking at antimicrobial use and environmental contamination and other strategies	Modeled on a hospital dialysis unit serving 120 patients, United States	In this model, when hand hygiene compliance was at 0%, the estimated rate of MDRO acquisition almost doubled, from 14.5% at baseline to 23.1%.	Even with 100% compliance, 13.4% of patients still remained colonized.	In the dialysis setting, MDRO colonization is caused by many factors, although hand hygiene is an important one. Simultaneous improvements in hand hygiene, judicious antimicrobial use, and environmental decontamination are needed to reduce MDRO colonization.	Moderate	Organisms/ Outcomes: Hand hygiene, MDRO transmission Mathematical model—will need validation in actual dialysis setting

Table B.5: MDRO, Surveillance—Systematic Reviews

Note: Full references are available in the Section 5.3 reference list.

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
McKinnel et al., 2013[18]	Active surveillance using risk-based screening for methicillin-resistant *Staphylococcus aureus* (MRSA)	Hospitals	Factors associated with MRSA colonization at admission screening include: • History of MRSA carriage, especially in the last 6 months. • History of hospitalization in last 12 months. • Transfer from a nursing home. • History of CDI, or VRE carriage. • Any infection in past 3 months. • Antibiotic use in past 3 months. • Comorbidities (congestive heart failure, diabetes, chronic obstructive pulmonary disease, renal failure, immunosuppression). Factors *not* associated with MRSA colonization at admission screening include: • Transfer from another hospital. • HIV infection. • Use of intravenous drugs. • Cirrhosis. • ICU admission.	By knowing risk factors associated with MRSA colonization, hospitals and other facilities can develop risk-based testing approaches for screening on admission, reducing costs in time and materials.	Organisms/ Outcomes: MRSA MRSA colonization

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Siegel et al. and the Healthcare Infection Control Practices Advisory Committee, 2006[33]	Active surveillance, including both cultures and testing, for multidrug-resistant organism (MDRO) prevention	General healthcare settings, United States	More research is needed on when it is most beneficial to implement active surveillance for MDRO prevention, but it should be considered when other control methods have failed. Implementing active surveillance requires personnel to collect cultures, adequate laboratory facilities for processing cultures, a mechanism for communicating results to caregivers, decisions or policies for additional measures triggered by culture results, and mechanisms for ensuring measure adherence. Decisions about which populations to screen and which MDROs to screen for vary based on the facility and patient risk factors (e.g., overall patient health, average length of stay, prevalence at other institutions from which the facility receives patients). Recommendations for screening sites: • MRSA: Cultures of the nares identify most patients with MRSA and perirectal and wound cultures can identify additional carriers. • VRE: Stool, rectal, or perirectal swabs are generally considered a sensitive method for detection of VRE. While one study suggested that rectal swabs may identify only 60% of individuals harboring VRE, and may be affected by VRE stool density, this observation has not been reported elsewhere in the literature. • MDR-GNBs: Several methods for detection of MDR-GNBs have been used, including use of perirectal or rectal swabs alone or in combination with oropharyngeal, endotracheal, inguinal, or wound cultures. Rapid detection methods allow facilities to quicker implement contact precautions, if that implementation is pending surveillance culture results. Chromogenic enzyme substrates (CHROMagar) have been shown to have high sensitivity and specificity for identification of MRSA as early as 16 hours after inoculation. In addition, real-time polymerase chain reaction (PCR)-based tests for rapid detection of MRSA directly from culture swabs (<1-2 hours) are commercially available.	Using surveillance to successfully prevent MDRO infection and colonization requires: 1. Obtaining the needed resources for that facility (personnel to collect samples, laboratory capabilities for rapid detection, policies for other practices based on culture results, mechanisms for ensuring adherence to other practices) 2. Understanding the risk factors for the facility and its patients to determine which organisms should be screened for and choose the correct sampling method for the organisms.	Organisms: MRSA, vancomycin-resistant Enterobacteriaceae (VRE), multidrug-resistant Gram-negative bacteria (MDR-GNB)

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Tacconelli et al., 2014[4]	Active surveillance, including both cultures and testing, for MDR-GNB Molecular testing using PCR	Hospital, ICUs, various countries included in review	The search was restricted to full articles published in English up to November 2011 and including adult patients (>16 years of age). Active screening for MDR-GNB is recommended in epidemic settings only. Surveillance of clinical samples will undercount MDR-GNB. The proportion of clinically evidence-based cases also varies by organism and susceptibility of the patient population. PCR-based methods are still in development for MDR-GNB, so culture-based tests are still the "gold standard." Rectal swabs, urine, or respiratory secretions are sufficient for almost all MDR-GNB, with rectal swabs being the most sensitive and groin being most specific (best for confirming negative results). However, one study showed that sensitivity of screening is low (29%) even when six body sites are included. No consensus exists on frequency of screening or timing, although several observational studies of outbreaks have used weekly screening until no cases of colonization/infection or cross-transmission were observed. Mean colonization times for MDR-GNB are 144 days (range, 41 to 349 days), so this period represents a significant time. The efficacy of screening is linked to the level of compliance, so screening must be maintained over time. There are no recommendations for screening for MDR-GNB in a nonoutbreak setting. In epidemic settings, targeted screening on admission for high-risk patients is recommended. Screening can also be used to reinforce other prevention practices in the outbreak response. In the endemic setting, surveillance should be used as an additional measure to control the spread of MDR-GNB, not a basic one.	"One size fits all" approaches do not apply to MDR-GNB. There is a strong link between the efficacy of screening and the level of compliance with screening, meaning that screening fatigue has implications for successfully detecting and preventing MDR-GNB colonization and infection. This situation is easiest to avoid in an epidemic situation yet less so in an endemic situation or where MDR-GNB are not prevalent.	Organisms: MDR-GNB

Table B.6: MDRO, Surveillance—Single Studies

Note: Full references are available in the Section 5.3 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Ahern & Alston, 2009[58]	Longitudinal surveillance data to assess the impact of infection control interventions and antibiotic use. Implementation of a resistance index. The surveillance system was used to measure associations of multiple interventions on health care-associated infection (HAI) rates. Only isolates recovered more than 48 hours after hospital admission are included.	Descriptive implementation case study that examined two 4-year periods before and after implementation of the interventions. The resistance index (a measure of nosocomial infection and colonization) and the rate of antimicrobial use were compared using the Poisson distribution. Two-sided p values of less than 0.05 were considered to be statistically significant.	562-bed academic medical center, United States Hospital with a 26-bed surgical ICU (SICU) and 22-bed medical ICU (MICU), each with a five-bed open ward, and a four-bed pediatric ICU in the SICU	The resistance index was developed to quantify nosocomial infection and colonization. The index, calculated monthly, consists of a numerator of the number of nosocomial isolates and a denominator of the number of patient-days for each nursing unit and for the hospital. Surveillance data suggest that infection control initiatives successfully reversed an upward trend in the six study MDROs, despite increasing antibiotic use. During the pre-intervention period, the resistance index was increasing in both units. The overall resistance index decreased in both units during the post-intervention period. The overall rate of antimicrobial use in the SICU was higher during the post-intervention period than during the pre-intervention period (366 vs. 352 defined daily doses per 1,000 patient-days; p<0.01). The overall rate of antimicrobial use in the MICU was higher during the post-intervention period than during the pre-intervention period (603 vs. 436 defined daily doses per 1,000 patient-days).	None assessed.	The paper describes a surveillance method to measure associations between multicomponent intervention and HAI rates. Keeping track of MDRO isolates over time and between different units allows hospitals to evaluate the effectiveness of their infection control protocols and to show reduction in MDROs despite increased rates of antibiotic prescription.	Moderate to high Authors did not differentiate between infection and colonization. Also, unable to determine which infection control strategy was most effective. The resistance index database required 8–12 hours of maintenance per month.	Organisms/ Outcomes MRSA, *C. difficile,* VRE, *P. aeruginosa,* MDR-GNB *Stentro-phomonas matlophilia Infections related to these six pathogens*

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Almyroudis et al., 2016[21]	Discontinuation of systematic surveillance (weekly perianal swabs) for VRE and contact isolation of colonized patients on the incidence of VRE bacteremia	Pre-post study (comparing two 3-year periods) to assess the incidence of VRE bacteremia and the incidence of bacteremia due to MRSA and *C. difficile*	125-bed hospital hematology/oncology unit with high prevalence of VRE coloniza-tion, United States	The incidence of VRE bacteremia remained stable after discontinuation of VRE surveillance and contact precautions (reduction of 2.32 to 1.87 per 1,000 patient-days; p>0.05). The use of levofloxacin prophylaxis during neutropenia and daily chlorhexidine bathing had no effect on the incidence of VRE bacteremia (p>0.05). The incidence of MRSA bacteremia and *C. difficile* infection for which the facility continued contact precautions also remained stable. Aggregated antibiotic utilization and nursing hours per patient-days were similar between the two study periods. Antibiotic use also remained stable during the two periods (p>0.05, not significant). Nursing hours per patient per day decreased from 13.99 during the control period to 12.86 during the second period (p>0.05, not significant).	None assessed.	The authors found that MRSA bacteremia, *C. difficile* infection, and VRE bacteremia rates remained stable after discontinuation of an active surveillance and contact isolation protocol. Active surveillance and contact precautions for VRE colonization did not appear to prevent VRE bacteremia in patients with hematologic malignancies and recipients of hematopoietic stem cell transplantation with high prevalence of VRE. Based on the inefficiency of the contact isolation and the molecular epidemiology data, a decision was made to discontinue the systematic surveillance for VRE and contact isolation of colonized patients.	Moderate	Organism/ Outcomes: VRE, MRSA, *C. difficile* Colonization, bacteremia due to MRSA or VRE, *C. difficile* infection (CDI)

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Banach et al., 2014[23]	Active surveillance for carbapenem-resistant Enterobacteriaceae (CRE) using stool samples collected for CDI	Pre-post study for two hospitals. Before the study period, hospital A performed active surveillance for CRE among patients on high-risk units using perianal swab sampling at admission and weekly thereafter. There was no active surveillance program at hospital B prior to the intervention. Nested case-control study design was used to identify risk factors for CRE.	Two large academic hospitals, United States	CRE was isolated from 27 (2.6%) of 1,047 specimens. CRE prevalence was 2.9% (25/854 unique patients), with 4.0% (11/272 patients) at hospital A and 2.4% (14/582 patients) at hospital B (p=0.18). Among patients with CRE-positive samples, 10 (40%) had been previously identified as carriers (64% at hospital A, 21% at hospital B). CRE isolates included *Klebsiella pneumoniae* (n=23), *K. oxytoca* (n=1), and *Enterobacter cloacae* (n = 1). The KPC gene was detected in 21 (84%) isolates and 21 (91%) *K. pneumoniae* isolates. CRE-colonized patients were older (median age, 66 vs. 59 years; p=0.05). Rates of CRE positivity did not differ by negative and positive *C. difficile* tests (2/90 [2.2%] and 25/955 [2.6%], respectively; p=0.82) or by patient sex (p=0.97). Bivariate analyses of case-control study data identified characteristics associated with colonization: length of stay >1 week (p=0.04), admission from a skilled nursing facility (p=0.01), percutaneous tube feeding (p<0.01), prior ICU admission (p<0.01), and mechanical ventilation (p=0.01).	This intervention may not be as cost-effective in hospitals with lower prevalence of CRE (more testing required to identify an unrecognized case). Also does not include patients who are not displaying signs of CDI (and thus would not have a stool sample collected).	CRE colonization and CDI share risk factors. In this study, active surveillance for CRE using stool specimens submitted for *C. difficile* testing detected previously unrecognized CRE carriage. Although not comprehensive, this active surveillance strategy may be of value because of its convenience and relative low cost. The estimated average cost of surveillance testing was $8.53 per specimen, including technical support and supplies but not molecular testing. At the study prevalence, 76 and 68 specimens had to be tested at hospitals A and B, respectively, in order to identify one previously undetected CRE carrier. Total cost of detecting one CRE-colonized patient ranged from $580 (hospital B) to $649 (hospital A).	Low to moderate	Organisms/ Outcomes: CRE, *C. difficile* (as a risk factor)

Barbadoro et al., 2017[11]	Active surveillance to identify patients colonized/infected with MDROs for isolation. Skin, blood, respiratory, and urine samples were taken, and compared for relative efficacy in identifying MDRO colonization/ infection. Feedback: Reporting MDRO incidence (number of isolates/ 1,000 days of stay). Other components of the intervention included: operational planning on contact precaution strategies; educational/training initiative on infection prevention practices; checklist for contact precautions; routine surveillance; and reporting of incidence rates.	Time series analysis before and after a multicomponent infection prevention intervention at a single, 900-bed teaching hospital in Italy 149,251 patients totaling 909,706 patient-days included in 2011-2013 study period	Hospital, Italy	Sampling from skin (β=0.08, p=0.001, 95% CI 0.06 to 0.10), blood (β=0.05, p=0.001, 95% CI 0.03 to 0.07), and respiratory samples (β=0.02, p=0.031, 95% CI 0.02 to 0.06) were significantly likely to initially identify MDRO-positive status; sampling from urine was not (β=-0.01, p=0.413, 95% CI -0.03 to -0.01). Overall, the study period after the implementation of a multicomponent intervention showed a month-over-month decrease in MDRO rates.	The authors speculate that results may be more pronounced (i.e., a greater reduction) in hospitals with high transmission rates, compared to hospitals where transmission rates are already low.	In widespread surveillance, skin, blood, and respiratory samples performed better at initially identifying the presence of an MDRO than did urine samples.	Moderate One study site, limited detail about the surveillance methods or how feedback was conducted. Patient case mix over the course of the study was not assessed.	Organisms/ Outcomes: *K. pneumoniae* *K. pneumoniae* infection/ colonization

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Beneson et al., 2013[35]	Active surveillance: Weekly fecal cultures for extended-spectrum beta-lactamase-producing *K. pneumoniae* (ESBL-KP). Rectal swab if stool sample not available. Molecular typing of samples performed to identify strains.	Observational study of 1,763 neonate admissions (7 days or longer) during the 4-year study period across two neonatal ICUs (10-bed and 25-bed) in two academic hospitals	Hospital neonatal ICU, Israel	Surveillance cultures were obtained from 1,482/1,763 (84%) neonates over 4 years. ESBL-KP acquisition decreased continuously from 94/397 (24%) neonates in 2006 to 33/304 (11%) in 2009 ($p<0.001$, hazard ratio 0.75, 95% CI 0.66 to 0.85, $p<0.001$ for comparison of years). Hospitalwide ESBL-KP acquisition did not decrease outside the NICU. Pulsed-field gel electrophoresis identified identical ESBL-KP strains from multiple neonates on six occasions and different strains from single neonates on seven occasions. Continuous long-term surveillance with cohorting of neonates with positive cultures was associated with a significant decrease in ESBL-KP acquisition within the NICU.	Weekly screening would not include neonates whose admissions were <7 days, and so may miss some patients who are colonized (either before or after admission).	Neonates with positive cultures were managed with contact precautions by dedicated nurses separately from other neonates. ESBL-KP acquisition among neonates staying 17 days was compared for the consecutive years. In addition to demonstrating the impact of surveillance on MDRO acquisition, this study shows the importance of molecular testing to identify whether the MDROs identified are being spread within a unit or imported from outside.	Low to moderate Only two sites; no control group. The study did control for the effects of current infection control practices by adding active surveillance to an already established infection prevention protocol.	Organisms/ Outcomes: ESBL-KP ESBL-KP acquisition

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Bryce et al., 2015[38]	Risk-based, active weekly screening of patients (and contact precautions) in high-risk units for VRE (as opposed to VRE screening in *all* units at baseline) to make screening more cost-neutral. Risk-based surveillance was added to a horizontal implementation of environmental cleaning (decluttering) and antimicrobial stewardship program.	Pre-post study and economic analysis of targeted screening and contact precautions for VRE in a 728-bed adult acute care facility, starting in the 2012–2013 year	728-bed adult tertiary care hospital, Canada	In high-risk units, VRE bacteremia decreased significantly the first year after a spike in VRE infection cases in 2013 (p=0.009), as did facilitywide *C. difficile* and MRSA infection cases (by 46% [p<0.001] and 25% [p=0.02], respectively). VRE bacteremia rates outside the high-risk units remained unchanged after switching to risk-management surveillance approach. Cost avoidance for targeted surveillance comes in the form of reduction in VRE isolations (costs for gloves and gowns and hospital linen, as well as lost revenue due to reserving private rooms) and decreased laboratory reagent consumption. Although the project experienced net costs in the first 2 years of implementation (2012–2013 and 2013–2014), by the third year (2014–2015), the project had saved an estimated $14,655.	None assessed.	Risk-management surveillance can be as effective in reducing the target MDRO (as well as others) although it was unclear what the unique impact was of each intervention: risk management surveillance, antimicrobial stewardship, and environmental cleaning.	Low to moderate Single-site study; efficacy results may differ depending on VRE prevalence and risk factors.	Organisms/ Outcomes: VRE, MRSA, *C. difficile* VRE prevalence and bacteremia, CDI, MRSA infection

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
D'Agata et al., 2012[39]	Active surveillance: screening for asymptomatic MRSA and VRE colonization Other PSPs included in model: hand hygiene, contact precautions, reducing antimicrobial exposure	Mathematical model simulation Modeled on a 600-bed tertiary care hospital	Hospital	Screening patients for asymptomatic colonization reduces the overall prevalence of MDRO, but only among patients already receiving antimicrobials. Improving screening has less effect on the prevalence of MDRO compared to improving compliance with hand hygiene or contact precautions, since a smaller population size is targeted. In addition, the model only incorporates screening for VRE and MRSA.	This model also highlights the importance of vulnerability to infection: even modest increases (5-10%) in MDRO infection rate among colonized patients can negate all the beneficial effects of infection prevention interventions.	Universal screening for asymptomatic colonization of MRSA and VRE did not reduce MDROs in this model; however, targeted screening for MRSA and VRE for patients already receiving antimicrobials (a known risk factor for MDRO acquisition) should theoretically reduce MDRO acquisition in the clinical setting.	Moderate Mathematical study, not in situ; only included screening for MRSA and VRE (other MDROs may have different results).	Organisms/ Outcomes: MRSA, VRE, MDR Gram-negative bacteria (MDR-GNB) MDRO colonization
Friere et al., 2017[10]	Screening cultures from inguinal-rectal area, axilla, and throat swabs immediately before liver transplant, and weekly thereafter for carbapenem-resistant *P. aeruginosa* (CR-PA), carbapenem-resistant *A. baumannii* (CR-AB), ESBL-producing *K. pneumoniae.*	Sensitivity study of different methods for collecting surveillance cultures Prospective cohort study of all patients who underwent liver transplant from November 2009 through November 2011 (n=181); 4,110 samples collected	Hospital transplant ward, Brazil	The MDRO positivity rate was highest among the inguinal-rectal collection site samples. However, if only samples collected from this area were considered, surveillance would fail to identify 34.9% of the cases of CR-AB colonization. The sensitivity of active surveillance for EBSL-KP was 92.5%. The performance of screening cultures was poorest for CR-AB (sensitivity, 80.6%).	Routine screening has costs associated with materials, time, and patient isolation (once carriage is identified).	The sensitivity and specificity of a sample collection site or type varies by type of MDRO. Given the costs associated with surveillance and subsequent patient isolation, universal surveillance may make the most sense in facilities where the incidence of MDROs is moderate to high, and for patients for whom the rate of conversion from colonization to infection is high (e.g., transplant patients).	Moderate Single study, observational study design	Organisms/ Outcomes: CR-PA, CR-AB, ESBL-producing *K. pneumoniae,* and EBSL-producing *Escherichia coli* MDRO colonization, MDRO infection, health care-associated infections

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Fujitani et al., 2011[20]	Active surveillance of VRE colonization in patient stool samples positive for *C. difficile* colonization	Prospective laboratory analysis of stool samples from all inpatients with CDI in a single hospital from July 2006–October 2006, comprising 158 CDI cases.	Hospital, United States	Of the 158 cases of CDI evaluated, 88 (55.7%) involved VRE colonization. Independent risk factors for VRE colonization were admission from long-term care facilities (p<0.013), dementia (p=0.001), and hospitalization in the previous 2 months (p=0.002). No statistically significant difference between CDI cases with and without VRE colonization in terms of previous receipt (within 1 month) of antibiotics, including metronidazole and vancomycin, was found on multivariate analysis. CDI cases with VRE colonization had a higher prevalence of coinfection with MRSA (p=0.002) and *Acinetobacter* species (p=0.006).	None assessed.	Given the high rate of CDI associated with VRE colonization, active surveillance of VRE in patients with CDI is reasonable in high-risk settings.	Moderate	Organisms/ Outcomes: VRE, *C. difficile,* MRSA, *Acinetobacter* species VRE colonization

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Huskins et al., 2011[22]	Active surveillance for MRSA (nasal swabs) and VRE (perianal swabs and stool cultures) within 2 days of admission to ICU and 2 days before or after discharge Control ICUs used existing hospital procedures (not specified) to identify MRSA and VRE. Results were reported to health care personnel in the intervention ICUs, but not the control ICUs.	Cluster-randomized trial of an active surveillance and reporting intervention in 10 intervention ICUs (5,434 admissions) and 8 control ICUs (3,705 admissions)	Hospital ICUs, United States	Patients who were colonized or infected with MRSA or VRE were assigned to contact precautions more frequently in intervention ICUs than control ICUs (median of 92% of ICU days with either contact precautions or universal gloving [51% with contact precautions and 43% with universal gloving] in intervention ICUs vs. a median of 38% of ICU days with contact precautions in control ICUs, p<0.001). The change in incidence of MDRO colonization varied widely between ICUs, but mean ICU incidence (of events of MDRO colonization/infection per 1,000 patient-days at risk), adjusted for baseline incidence, did not differ significantly between intervention and control ICUs (40.4 ± 3.3 and 35.6 ± 3.7, respectively; p=0.35). MDRO colonization/infection incidence was not significantly associated with the percentage of patient-days of contact precautions for colonized/ infected patients (p=0.26) or correct hand hygiene compliance (including gloves when recommended) (p=0.61).	In intervention ICUs, health care providers used clean gloves (82% of the time), gowns (77%), and hand hygiene (69%) less frequently than required for contacts with patients assigned to barrier precautions.	Although active surveillance identified a number of colonized patients who had previously been missed, the intervention did not reduce MRSA and VRE colonization or infection compared to usual care. The authors hypothesize that this unexpected result may be due to the lag between culture results and assignment to contact precautions, and the gaps in compliance with the required components of contact precautions and universal gloving. “Identify and isolate” approaches alone may not be enough, since closing one gap in surveillance did not close the gap in compliance.	Low	Organisms/ Outcomes: MRSA, VRE MRSA and/or VRE colonization or infection

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Jones et al., 2015[17]	Active screening at hospital admission for MDR-GNB: nasal screening, screening of clinical cultures Cultures tested for relatedness using PCR	Retrospective cohort study of all patients with both a nasal screen and clinical culture, admitted to a Veterans Affairs (VA) facility between January 2009 and December 2012 (759,759 total). Assessed how often patients with MDR-GNB in clinical cultures obtained within 30 days following admission would have been in contact precautions because of a positive MRSA admission screen	All VA acute care medical facilities, United States	Of patients with MDR-GNB-positive cultures within 30 days following admission, up to 44.3% (dependent on bacterial species) would have been in contact precautions because of a clinical positive admission MRSA nasal screen. Admissions with a positive MRSA screen had odds for MDR-GNB in a culture 2.5 times greater than those with a negative screen (95% confidence interval [CI], 2.4 to 2.6). Odds ratios were 2.4 (95% CI, 2.3 to 2.5) for MDR Enterobacteriaceae, 2.7 (95% CI, 2.5 to 2.9) for MDR *P. aeruginosa*, and 4.3 (95% CI, 3.8 to 4.8) for MDR *Acinetobacter* species.	None assessed.	Evidence supports an association between MRSA status at admission and later discovery of MDRO colonization. This association was strongest for *Acinetobacter* species. Therefore, when patients are placed in contact precautions because of a positive MRSA screen, there may be a collateral benefit of isolating patients at increased risk for transmitting MDR-GNB to others within the hospital. However, it is not clear from this study if the MDR-GNB were present on admission or acquired in the facility. Still, in places where universal MRSA screening is already in place, a positive result may be considered a risk factor for other MDROs.	Moderate VA population may not be representative of general population (more likely to be older, male); unable to determine if MDR-GNB were present on admission or acquired.	Organisms/ Outcomes: MDR-GNB (Enterobacter-iaceae, *P. aeruginosa, Acinetobacter* species), MRSA Positive screening for any of the above organisms

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Karampatakis et al., 2018[24]	Active surveillance was added to an infection prevention study also consisting of hand hygiene; contact precautions, patient and staff cohorting; environmental cleaning; antimicrobial stewardship; staff education; compliance monitoring audits and feedback. Active surveillance consisted of (1) weekly rectal swabs; and (2) environmental surface samples.	Quasi-experimental study of all patients (300 total) in a 9-bed ICU with CR-GNB infection (n=34, retrospectively studied for 6 months) and those in an active surveillance program (n=266, prospectively studied for 22 months)	Hospital ICUs, Greece	The downward trend of average incidence, prevalence, and colonization pressure for all CR-GNB during the active surveillance program mostly occurred due to the reduction of CR-*K. pneumoniae* (CR-KP) and CR-*P. aerguinosa* (CR-PA) infections and resistance rates. Despite enhanced infection control, CR-*A. baumannii* infections were not reduced. Total CR-GNB infections decreased from 29.9 to 25.2 infections per 1,000 bed-days (p>0.05). CR-KP infections decreased from 19.6 to 8.1 per 1,000 bed-days (p=0.001), and CR-PA infections decreased from 5.1 to 1.8 per 1,000 bed-days (p=0.043).	None assessed.	A multicomponent intervention including active surveillance successfully reduced certain rates of CR-GNB (*K. pneumoniae* and *P. aeruginosa*) but not others (*A. baumannii).*	Low to moderate Single-site study but quasi-experimental design with case mix analyzed	Organisms/ Outcomes CR-KP, CR-PA, CR-AB CR-GNB infection and colonization

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Lin et al., 2018[16]	Active surveillance for MRSA (nasal and inguinal swabs, pulsed-field gel electrophoresis to distinguish community-associated strains from others) followed by contact precautions for any patients whose culture tested positive, as mandated by Illinois legislation at the start of the study period. Hospitals also reported if daily chlorhexidine bathing and mupirocin were used.	Observational study of 25 hospitals, including 51 ICUs and 3,909 patients in point prevalence surveys; 5-year study period	Hospital ICUs, United States	In this study, 93% of patients in received active surveillance for MRSA on hospital admission. The overall admission prevalence of MRSA colonization as reported was 9.7% (95% CI, 8.8% to 10.8%) and did not change over time (p=0.95 for trend). The number of hospitals using daily chlorhexidine bathing in at least one ICU grew from 5 to 17 over the study period. The percentage of study patients who were in an ICU using chlorhexidine bathing grew from 28% to a peak of 59% by year 3 (p<0.001 for trend). No hospital ICUs routinely used mupirocin for decolonization. No significant change in MRSA colonization (as measured by the point prevalence survey) was observed after legislation of mandatory active MRSA. MRSA colonization prevalence was unchanged during the study period: year-over-year relative risk for colonization was 0.97 (95% CI, 0.89 to 1.05; p=0.48). This trend remained nonsignificant after adjusting for chlorhexidine bathing and rapid results testing use over time.	Only 54% of patients with MRSA-positive cultures during the point prevalence surveys (n=184) were on contact precautions. Fifteen (8%) were not screened at admission; 16 (9%) had a positive admission MRSA screen but contact precautions had not yet been initiated; 27 (15%) had a pending admission culture that eventually became MRSA positive; and 126 (69%) had a negative admission MRSA culture, representing either admission MRSA screen insensitivity or ICU acquisition.	Despite high compliance with mandatory active surveillance, almost 4 of 10 patients identified as MRSA-colonized by the point prevalence survey were not on contact precautions. In addition, few hospitals were using recommended decolonization protocols (chlorhexidine bathing and nasal mupirocin) at the start of the study, limiting the effectiveness of active surveillance to reduce MRSA colonization. For patients with results available for both nose and groin sites, nasal culturing alone identified 84% (327/ 388) of MRSA-positive patients; 61 patients (16%) were nasal culture negative and groin culture positive. Nasal MRSA screening had a negative predictive value of 98% (95% CI, 97.6% to 98.5%).	Low No control group, as the legislation affected all hospitals in the State of Illinois	Organisms/ Outcomes: MRSA MRSA colonization

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Mawdsley et al., 2010[42]	Active surveillance: process surveillance for compliance with contact precautions for MDRO-flagged patients Infection preventionists conducted weekly rounding to identify whether patients whose electronic medical record (EMR) had electronically flagged them as MDRO-positive (i.e., positive clinical cultures for MRSA, VRE, and MDR-GNB) were put on appropriate contact precautions.	Case study: Surveillance rounding project for a 22-week period	500-bed academic medical center, United States	The program significantly improved the percentage of patients with appropriate isolation (p<0.001). Overall point prevalence of appropriate implementation of precautions was 70% on the first day of the program rollout period, 74% for the first month, and 82% overall for the entire period. The percentage of patients isolated at the first surveillance encounter ranged from 40% to 77%. For those patients still hospitalized 1 week later (for a second surveillance encounter), 97% were appropriately isolated. Patients with MDR-GNB were significantly less likely to be isolated appropriately at the first surveillance encounter than those with MRSA or VRE (p=0.03), with VRE patients having the highest percentage appropriately isolated (66%). Non-ICU patients were less likely to be isolated (p<0.001).	None assessed.	Weekly surveillance rounding alone was successful in improving compliance with contact isolation initiation and required minimal resources (two person-hours of work per week, split among six infection preventionists). However, this approach does not ensure that contact precautions will be consistently followed, and MDROs may require surveillance apart from measure compliance.	Moderate Single-site case study	Organisms/ Outcomes: MRSA, VRE, MDR-GNB Compliance with contact precautions based on EMR flagging

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Mayer et al., 2016[26]	Mandatory surveillance reporting, which was initiated in New York State in July 2013	Retrospective validation of CRE cases reported to the National Healthcare Safety Network using retrospective laboratory report audit of all CRE infections between July 2013 and December 2014 in acute care hospitals in New York State; 1,151 CRE laboratory reports were audited.	178 acute care hospitals, New York, United States	None assessed.	Of CRE laboratory reports audited, 13.6% were not reported (as required by New York State law) and 4.6% were reported in error. Some underreporting was due to lapses in surveillance. Other, systematic underreporting was due to misinterpretation of surveillance definitions.	Lapses in surveillance, misunderstanding or misinterpretation of surveillance definitions can result in under- or overreporting of CRE cases. In this study, underreporting was far more frequent than overreporting. Cases of misinterpretation of surveillance definitions included: not reporting community-onset cases, not reporting specimens from all body sites, not reporting intermediate susceptibilities, changing overall carbapenem susceptibility interpretation based on ertapenem results, and only reporting carbapenemase-producers.	Low to moderate Retrospective study	Organisms/ Outcomes: CRE Mandatory surveillance reporting rates

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Palmore et al., 2011[43]	Infection control adherence monitors were placed in MDR-AB cohort areas to observe and correct staff infection control behavior. Surveillance reporting was done in weekly stakeholder meetings. Other PSPs in outbreak response included active surveillance cultures, hand hygiene, enhanced contact isolation, patient cohorting with dedicated staff, and enhanced environmental cleaning.	Outbreak response (two outbreaks) in an 18-bed medical-surgical ICU	Hospital, ICU, United States	All but two of the patients included in the outbreak had overlapping stays with other MDR-AB patients. Nearly all (90%) of case patients were infected or colonized with outbreak strains. Post-ICU-discharge screenings had low yield rates, and thus were discontinued in the second outbreak. Few of the environmental samples in either outbreak (three and five, respectively) had positive culture results, and all but one were from patient rooms. Based on the evidence from environmental sampling and adherence monitoring, the authors concluded that MDR-AB in these outbreaks were spread by transmission from health care worker to patient (due to insufficient adherence to contact precautions). Collaborative team meetings were critical to halting the outbreak.	Physicians were responsible for more infection control violations than other staff categories, although most all-staff observations showed compliance (95.7% of 4,781 observations).	Extensive surveillance of patients and environment, combined with adherence monitoring, can home in on the transmission patterns of MDR-GNB and expose areas for improvement (in this case, hand hygiene and gown and glove compliance among physicians).	Moderate Single-site outbreak response. Unable to assess the relative effectiveness of each of the components.	Organisms/ Outcomes: MDR-AB Infection prevention practice adherence

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Quan et al., 2015[53]	Automatic surveillance system for flagging patients for contact precautions, with physician-ordered discontinuation.	Case study of a single hospital The system automatically reviewed daily positive laboratory results for 110,212 patient-days involving 20,000 historical admissions.	410-bed academic hospital, United States	In this case study, an automated system surveyed microbiology results for positive cultures for MRSA, VRE, CRE, ESBL pathogens, MDR-AB, and *C. difficile.* Physicians could order discontinuation of contact precautions as appropriate (e.g., negative cultures). Automation saved 43 infection preventionist hours per 1,000 admissions, as well as unmeasured hours spent reviewing MDRO history for each admission.	Discontinuation protocols were too complex to be fully automated.	Automated systems can support enforcement of contact precautions and save considerable infection preventionist time in identifying MDROs. Point prevalence assessment showed that all precautions were appropriate.	Moderate Single-site case study; time savings may vary at other sites.	Organisms/ Outcomes: MRSA, VRE, CRE, ESBL-producing pathogens, MDR-AB, *C. difficile.* Appropriateness of automatic flagging for initiating and discontinuing contact precautions
Rosenman et al., 2014[54]	Active surveillance using EMR evidence of positive culture for MRSA, VRE, CRE, ESBL-producing Enterobacteriaceae, or other MDR-GNB	Retrospective analysis of 80,180 patients (in 12 hospital systems) with microbiology data between October 1, 2013, and December 31, 2013; includes subsequent healthcare encounters (through February 6, 2014).	Hospitals in a shared geographic region, United States	This project created standardized data collection across 12 hospital systems that used clinical data to create MDRO alerts (based on a pre-existing MRSA/VRE alert system). For infection preventionists, the most important alerts were ones at other facilities (identifying which patients may be colonized with organisms and then transferred to other institutions).	Here, 2% of alerts were internally inconsistent (alert email titles did not match the results in the body of the email).	The authors created a regional surveillance system for MDROs, through which they observed several transmissions between institutions.	Moderate Single case series	Organisms/ Outcomes: MRSA, VRE, CRE, ESBL-producing Enterobacter-iaceae, MDR-GNB (*P. aeruginosa, A. baumannii,* and others) Accurate MDRO alerts using positive culture results captured in EMRs

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Silwedel et al., 2016[32]	Routine microbiological screening, including: examination of ear swabs and gastric fluid immediately after birth. Surveillance of intestinal colonization of preterm infants comprised the weekly microbiological examination of anorectal swabs or stool samples in all infants. Infants admitted from external NICUs were screened on admission and isolated until receipt of results. Other PSPs in outbreak response: hand hygiene; glove, gown, and apron use; shared equipment disinfection; patient isolation; dedicated staff.	Retrospective case study. All infants in a single neonatal ICU during a 35-day outbreak. Outbreak affected 13 infants.	Two neonatal ICUs at 113-bed children's hospital, Germany	Routine stool sampling revealed MDR-*E. coli* detected in a total of 35 infants using active surveillance of anorectal or stool samples. Despite infection prevention precautions, ongoing transmission occurred in the NICU. Control was ultimately achieved by relocating all preterm infants from NICU-1 to NICU-2 and moving NICU-1 into a temporary ward. NICU-1 was reopened at the beginning of 2015 after thorough disinfection and extensive reconstruction work.	Although environmental surveillance revealed no MDR-*E. coli,* the outbreak only ended after closure of the original NICU for extensive decontaminatio n and construction of isolation rooms.	Although the environmental sampling turned up no MDR-*E. coli*, the change of environment was what was needed to eventually end the outbreak. Relocation and reconstruction improved the NICU's structural layout, focusing on isolation capacities.	Moderate Outbreak study, single site.	Organisms/ Outcomes: MDR-*E. coli* MDR-*E. coli colonization*

Zarpellon et al., 2018[45]	Active surveillance protocol consisting of: (1) Rectal swab on admission for VRE/CP-*K. pneumonia* in adult and pediatric patients hospitalized for >48 hours in preceding 30 days, had stayed in ICU in preceding 6 months, or were on dialysis; (2) Nasal swabs for MRSA for pediatric patients; (3) Nasal and rectal swabs for all admitted neonates; and (4) Weekly rectal swabs for all adults and nasal swabs for MRSA in pediatric and neonatal patients. PCR molecular testing Other PSPs: patient isolation, contact precautions, two terminal cleanings	Prospective study; all patients in a 123-bed teaching hospital	Hospital, Brazil	The study found significant decreases in infections from MDROs after implementing a multicomponent infection prevention program, including routine surveillance on admission. The overall hospital infection rate in the pre-intervention period (2005–2010) was 5.35% (range: 4.58% to 6.12%). The same rate in the post-intervention period (2011–2016) was 3.62% (range: 3.0% to 4.24%). The overall rate of HAIs decreased by 1.73%. Statistically significant differences in the HAIs rate were observed between the pre- and post-intervention periods (p=0.00198).	Implementing surveillance programs can be costly in both labor and materials, and the cost-benefit comparison of implementation should be considered.	This implementation was successful, but the authors note that this may not always be the case. Cost-effectiveness of surveillance interventions depends on how many infections are reduced (or are likely to be reduced) by the intervention, which varies by facility and even within facilities. For example: in this hospital, MRSA is considered endemic (except in pediatric and neonatal wards). Accordingly, the authors only screened for MRSA in patients where the MDRO was not yet endemic (and thus could be prevented from establishing).	Moderate Single site, observational study design	Organisms/ Outcomes: VRE, MRSA, *K. pneumoniae* carbapenemase-producing bacteria All hospital infections, all health care-associated infections

Table B.7: MDRO, Environmental Cleaning—Systematic Reviews

Note: Full references are available in the Section 5.4 reference list.

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Marra et al., 2018[29]	Use of no-touch disinfection methods, including: ultraviolet light (UVL), hydrogen peroxide mist, hydrogen peroxide vapor (HPV), and traditional environmental cleaning methods	Healthcare settings, multidrug-resistant organism (MDRO) healthcare-associated infections (HAIs), United States and United Kingdom	When the results of the UVL studies were pooled, statistically significant reduction in *C. difficile* infection (CDI) (pooled risk ratio, 0.64; 95% confidence interval [CI], 0.49 to 0.84) and vancomycin-resistant *Enterococci* (VRE) infection rates (pooled risk ratio, 0.42; 95% CI 0.28 to 0.65) were observed. No differences were found in rates of methicillin-resistant *Staphylococcus aureus* (MRSA), or Gram-negative multidrug-resistant pathogens. UVL and hydrogen peroxide mist or vapor should be used to augment traditional cleaning methods. Using UVL no-touch technology to enhance environmental hygiene can decrease HAIs for specific pathogens, specifically CDIs and VRE infections. For CDI prevention, there seems to be 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.	Two studies on UVL performed a cost-effectiveness evaluation of using no-touch technology after terminal cleaning, 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. The authors determined that randomized trials and cost-effectiveness studies are needed.	Organisms/Outcomes: *C. difficile,* MRSA, VRE, other MDROs Systematic review included many studies that were before-and-after quasi-experimental studies, which are subject to multiple biases.

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Nikitovic-Jokic et al., 2018[61]	Use of no-touch disinfection method: portable UVL surface-disinfecting devices	Hospitals, United States	The researchers were not certain of the effectiveness of UVL disinfection in reducing HAIs, given the very low to low quality of evidence, using the GRADE rating system. The intervention was effective in reducing the rate of the composite outcome of HAIs (combined) and colonization (but quality of evidence was low). The authors estimated that the typical cost for a hospital that purchased two portable devices would be $586,023 over 5 years for devices that use pulsed xenon technology and $634,255 over 5 years for devices that use mercury technology.	More rigorous evidence is needed to support the use of portable UVL surface disinfecting technologies in reducing HAIs and environmental MDRO contamination to justify the high cost.	Organisms/Outcomes: *C. difficile* and "combined HAIs" that varied per reviewed article but included MRSA, carbapenem-resistant Enterobacteriaceae (CRE), VRE, multidrug-resistant *Acinetobacter* (MDR-A), *Acinetobacter baumannii, Klebsiella pneumonia*e, MDR Gram-negative bacteria, extended-spectrum beta lactamase-producing Enterobacteriaceae (ESBL-E), MDR *Pseudomonas aerigunosa,* and *Stenotrophomonas maltophilia*

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Tacconelli et al., 2014[1]	Use of environmental screening during outbreaks, use of education, monitoring (e.g., fluorescent gel markers), feedback to improve quality of environmental cleaning, use of antimicrobial surfaces, reduction of shared equipment, and use of disinfectants versus detergents	Hospitalized patients, International	Environmental cleaning is often assessed as a bundle of interventions in an endemic situation and thus does not have strong studies assessing its efficacy. The authors recommend environmental screening when infection control practices fail to stem an outbreak. Cleaning inspections, education, monitoring and feedback, and observation of staff can also improve performance and thoroughness. Bacteria within biofilms may display greater capacity for antimicrobial resistance and can tolerate chlorine and other disinfectants. Disinfectants are more effective at killing pathogens than detergents, but some hospital pathogens can resist the bactericidal effect of particular agents. Disinfectant solutions themselves can become contaminated with bacteria, so containers used should also be cleaned. There is ambiguous support for antimicrobial surfaces (i.e., silver surfaces). Epidemic settings: Vacate rooms and monitor cleaning and adherence to policies; reduce sharing of equipment if a patient is colonized or infected. Endemic settings: Have cleaning procedures and policies; reduce sharing of equipment if a patient is colonized or infected.	Methods for assessing cleanliness are needed, both for scientific studies and to reassure staff and patients. Such methods can be defined within two main categories: process evaluation, where the cleaning process is monitored by visual inspection or with a fluorescent gel marker; and outcome evaluation, where cleanliness is evaluated with the use of adenosine triphosphate (ATP) bioluminescence systems or microbial cultures.	Organisms/Outcomes: MDR Gram-negative bacteria

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Teerawattana-pong et al., 2017[47]	Multicomponent interventions including environmental cleaning, antimicrobial stewardship, decolonization methods, source control, and combinations of the above	Adult ICU patients, Belgium, Brazil, Canada, China, Europe, France, Germany, Hungary, Israel, Italy, Netherlands, Spain, South Korea, Thailand, Vietnam, United States	Of 3,805 publications retrieved, 42 met inclusion criteria (5 randomized controlled trials and 37 observational studies). These 42 studies included 62,068 patients (median age, 58.8 years). Environmental cleaning bundled with antimicrobial stewardship, evaluation of standard care, and source control was the most effective intervention for reducing MDR *A. baumanii* (MDR-AB), ESBL-E, and CRE acquisitions. Compared with standard care, a four-component strategy composed of the same standard care combined with antimicrobial stewardship, environmental cleaning, and source control was the most effective intervention (rate ratio [RR], 0.05; [95% CI, 0.01 to 0.38]). When environmental cleaning was added to a program of standard care with antimicrobial stewardship, or when source control was added to standard care with environmental cleaning, there was a significant reduction in the acquisition of MDR-AB (RR, 0.28 [95% CI 0.18 to 0.43] and 0.48 [95% CI 0.35 to 0.66], respectively).	Environmental cleaning bundled with antimicrobial stewardship, evaluation of standard care, and source control was the most effective intervention for reducing MDR-AB, ESBL, and CRE acquisitions.	Organisms/Outcomes: MDR-AB, CRE, and ESBL-Enterobacteriaceae

Table B.8: MDRO, Environmental Cleaning—Single Studies

Note: Full references are available in the Section 5.4 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Adams et al., 2011[14]	Multicomponent intervention including unannounced decontamination audits and monitoring using an ATP luminometer, twice-daily cleaning and terminal cleaning with 1,000 ppm hypochlorite or 70% alcohol wipes, replacement of hard-to-clean equipment, cleaning of ICU ventilation with biocide fog, and disinfection of ICU with hydrogen peroxide vaporization.	Outbreak intervention study, three cases (ICU patients)	12-bed ICU, small acute hospital in the United Kingdom	The Infection Control Nurses Association (ICNA) audit (2004) demonstrated 96% compliance (pass rate defined as 85%); issues noted were largely attributable to dusty ventilation grills, ward clutter, and poor documentation. A score between 0 and 66 relative light units (RLUs) was reported on the first assessment following confirmation of MDR-AB. A score of 0 to 45 RLUs was recorded before environmental disinfection with HPV. Both sets of results were acceptable against the risk assessment undertaken for these items of equipment. No more cases after second phase of decontamination.	Phase 2 of the decontamination strategy required that ICU be relocated to recovery room for 1 week, which required relocating 12-bed ICU, reviewing surgical admissions, reviewing staffing levels, informing staff/patients/ family of changes, and putting up new signs.	Initial environmental audit using the ICNA audit tool, and cleanliness monitoring using an ATP luminometer, unannounced weekly audit, required pass rate of 90% for 3 consecutive weeks to stop audit, and identification of dirty equipment resulted in a failed audit. A general declutter of the environment was undertaken and twice-daily environmental and equipment decontamination was initiated with either 1,000 ppm hypochlorite or 70% alcohol wipes. The facility replaced hard-to-disinfect equipment (i.e., exposed equipment placed into single-use sealable bags, new trolleys with sealed door system, new binders), cleaned ICU ventilation system by “fogging” with Klercide-CR Biocide B, performed HPV of ICU, used ATP luminometer to find and clean any contaminated surfaces, and performed terminal cleaning with wall washing and curtain changes.	High	Organisms/ Outcomes: MDR-AB outbreak

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Alotaibi et al., 2017[23]	Use of benzalkonium chloride 10 mg/L, chlorhexidine 20 mg/L, and hydrogen peroxide 30 mg/L for environmental disinfection	Cross-sectional study, 12 vancomycin-susceptible (VS) *E. faecium* and 37 vancomycin-resistant (VR) *E. faecium* isolates, Danish patients	Statens Serum Institute Hospital, Denmark	For benzalkonium chloride, 89% of VR *E. faecium* strains had a minimal inhibitory concentration (MIC) of 8 mg/L whereas for VS *E. faecium*, only 25% of the strains had an MIC of 8 mg/L. For chlorhexidine, the MIC of 95% of VR *E. faecium* strains was 4 mg/L or higher, while only 33% of VS *E. faecium* strains displayed MIC values at the same level. In contrast, both VR and VS *E. faecium* displayed equal susceptibility to hydrogen peroxide, but a higher minimal bactericidal concentration (MBC) was found for the former. The efflux activity was also assessed and was generally higher for VR strains than for VS strains.	VR *E. faecium* was found to have decreased susceptibility toward benzalkonium chloride and chlorhexidine compared with VS *E. faecium.*	VR *E. faecium* from Danish hospitals demonstrated decreased susceptibility toward benzalkonium chloride and chlorhexidine compared with VS *E. faecium*. Biocide tolerance may be common in these settings.	Moderate to high Samples were taken over an undefined period.	Organisms/ Outcomes: VR and VS *E. faecium* strains

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Anderson et al., 2017[18]	Terminal cleaning interventions with either quaternary ammonium compound (QAC) disinfectant, UVL, bleach, or bleach and UVL	Cluster-randomized crossover study, 21,395 patients, patients infected or colonized with target organism	Nine hospitals in south-eastern United States	Strategies were implemented at every hospital for 4 consecutive 7-month periods. The primary outcome was not statistically lower with bleach (n=101; 41.6 cases per 10,000 exposure-days; RR 0.85, 95% CI 0.69 to 1.04; p=0.116), or bleach and UVL (n=131; 45.6 cases per 10,000 exposure-days; RR 0.91, 95% CI 0.76 to 1.09; p=0.303) among exposed patients. Incidence of CDI among exposed patients was not changed after hospitals added UV to cleaning with bleach (n=38 vs. 36; 30.4 cases vs. 31.6 cases per 10,000 exposure-days; RR 1.0, 95% CI 0.57 to 1.75; p=0.997).	None assessed.	The incidence of target organisms (MRSA, VRE, *C. difficile*, and MDR-AB) among exposed patients was significantly lower after hospitals added UVL to standard cleaning strategies (n=76; 33.9 cases per 10,000 exposure-days; RR 0.70, 95% CI 0.50 to 0.98; p=0.036). The quaternary ammonium-containing disinfectant in this study was delivered with microfiber cloths, which the authors found removed more bacteria than cotton and synthetic fiber cloths.	Low to moderate	Organisms/ Outcomes: MRSA, VRE, MDR-AB, *C. difficile*

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Apisarn-thanarak et al., 2008[16]	Multicomponent intervention including contact isolation, hand hygiene, active surveillance, cohorting, and environmental cleaning with 1:100 sodium hypochlorite. In Phase 3, environmental cleaning was instead done with detergent and phenolic agents.	Three-year prospective, controlled, quasi-experimental study, n=4,071 patients admitted to three ICUs during study period: medical ICU (MICU), surgical ICU (SICU), and coronary care unit (CCU)	Thammasat University Hospital's three ICUs (MICU, SICU, CCU), each of which has 8 beds, Thailand	Before the intervention, the rate of pan-drug-resistant *A. baumannii* colonization or infection was 3.6 cases per 1,000 patient-days. After the intervention, the rate of pandrug-resistant *A. baumannii* colonization or infection decreased by 66% in period 2 (to 1.2 cases per 1,000 patient-days; p<0.001) and by 76% in period 3 (0.85 cases per 1,000 patient-days; p<0.001). The monthly hospital antibiotic cost of treating pandrug-resistant *A. baumannii* colonization or infection and the hospitalization cost for each patient in the intervention units were reduced by 36% to 42% (p<0.001) and 25% to 36% (p<0.001), respectively, during periods 2 and 3.	None assessed.	Phase 3 was the most effective in reducing colonization and infection rates. Overall, the intervention resulted in sustained reductions in colonization and infection, reduced cost of antibiotic therapy, and reduced cost of hospitalization among ICU patients.	Moderate During the study period, hand hygiene and contact precautions were standard practice.	*Organisms/ Outcomes:* Pan-drug-resistant *A. baumannii* (PDR-AB) PDR-AB colonization, infection

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Apisarn-thanarak et al., 2014[8]	Twice-daily environmental cleaning with detergent-disinfectant (Phase 1) or sodium hypochlorite (Phase 2), preceded by a deep environmental cleaning with bleach after flooding of the MICU	Before-and-after study (multiphase), 1,365 patients, all patients admitted to MICU	MICU (8 beds) in a university hospital, Thailand	Compared with Phase 1 (11.1 cases per 1,000 patient-days), the rate of extensively drug-resistant (XDR) *A. baumannii* clinical isolates declined in Phase 2 (1.74 cases per 1,000 patient-days; p<0.001) and further in Phase 3 (0.69 cases per 1,000 patient-days; p<.0.001). Compared with Phase 1 (12.15 cases per 1,000 patient-days), the rate of XDR *A baumannii* surveillance isolates also declined in Phase 2 (2.11 cases per 1,000 patient-days; p<0.001) and Phase 3 (0.98 cases per 1,000 patient-days; p<0.001). Incidence of nosocomial infections remained stable.	None assessed.	Phase 1: Intervention included twice-daily environmental cleaning with detergent-disinfectant. Phase 2: Sodium hypochlorite was substituted for detergent-disinfectant. All interventions except cleaning with sodium hypochlorite were continued during the 12.5-month followup period.	Moderate	Organisms/ Outcomes: XDR *A. baumannii* (XDR-AB) Clinical isolates of XDR-AB, XDR-AB infections Authors suggest that bleach was only necessary when infection rates and colonization rates were high.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Apisarn-thanarak et al., 2017[5]	Facility-level compliance with a MRSA prevention bundle, use of HPV for MDR-AB prevention, environmental cleaning of patient room and surroundings, and presence of a facilities maintenance division and microbiology laboratory	Cross-sectional survey, n=212 hospitals	Hospitals with ICUs and ≥250 beds, Thailand	Most hospitals regularly used environmental cleaning of patient room and surroundings (85.4%). HPV for MDR-AB was used by 21.2%. Facilities with ≥75% compliance with the MRSA prevention bundle experienced a 17.4% reduction in MRSA rates (p =0.03). Although the presence of environmental cleaning services department (41.3% reduction, p=0.01) was among characteristics associated with decreases in MDR-AB rates, greater compliance with the MDR-AB prevention bundle did not lead to reductions in MDR-AB rates.	None assessed.	Hospitals reporting high compliance with the prevention bundle for MRSA were more successful at reducing MRSA but not MDR-AB, which may be better controlled though enhanced environmental cleaning practices. Hospitals better equipped to limit transmission routes due to better facility infrastructure and resources (e.g., having a facilities maintenance department division and microbiology laboratory) will likely achieve better infection control for MDR-AB than hospitals with limited resources.	High	Organisms/ Outcomes: MRSA and MDR-AB MRSA and MDR-AB rates

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Bagattini et al., 2015[43]	Use of an overheated dry-saturated steam vapor disinfection system compared with 5% sodium hypochlorite	In vitro lab tests on glass surfaces	Micro-biology laboratory, Italy	To reduce *Candida parapsilosis* and *Aspergillus fumigatus* counts (from 107 colony-forming unit [CFU]/mL), a longer contact time was necessary (7 minutes). In vitro tests with sodium hypochlorite at 5% in the absence of an organic substance resulted in an overall reduction in bacterial counts (from 109 CFU/mL) after 5 minutes of treatment. In the presence of an organic substance, after 5 minutes, the hypochlorite reduced the viable count from 109 to 105 CFU/mL for all bacterial strains except *Enterococcus faecalis.* That organism showed a reduction of 2 log units (109 to 107 CFU/mL). For *C. parapsilosis* and *A. fumigatus*, a 2-log unit reduction was observed after 7 minutes.	None assessed	Testing was done using glass surfaces, which are easy to contaminate and highly resistant to chemical products and heat. A portable vapor disinfection system is a viable alternative to available chemical disinfectants, including chloride derivatives, for the disinfection of hospital environmental surfaces.	Moderate to high	Organisms/ Outcomes: XDR-AB*, P. aeruginosa,* carbapenemase-producing *K. pneumonia,* MRSA, high-level aminoglycoside-resistant *E. faecalis, C. parapsilosis,* and *A. fumigatus* Colony-forming units in vitro

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Barnes et al., 2014[58]	Improved terminal cleaning thoroughness and compliance and improved hand hygiene compliance	Simulated before-and-after intervention study, 20 ICU patients	Simulated 20-patient ICU, United States	From the baseline, a 2:1 improvement in terminal cleaning compared with hand hygiene was required to match an equal reduction in acquisition rates (e.g., a 20% improvement in terminal cleaning reduced infections comparably to a 10% improvement in hand hygiene compliance).	None assessed.	The baseline level for thoroughness of terminal cleaning (i.e., surfaces being appropriately cleaned) was set at 40%. Increasing hand hygiene compliance was a more efficient intervention than increased terminal cleaning efficiency by a 2:1 ratio for reducing MDRO acquisition.	Moderate to high	Organisms/ Outcomes: VRE, MRSA, *A. baumannii* Hand hygiene, MDRO acquisition The study used existing literature for parameters.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Bernstein et al., 2016[56]	Environmental service workers (ESW) knowledge, practice, and attitude toward environmental cleaning and other infection prevention strategies	Cross-sectional online survey, n=327 ESWs at 5 hospitals in New York	Two large, tertiary-care academic hospitals, a free-standing academic pediatric and women's hospital, and two community hospitals within a single hospital network in New York, United States	ESWs who reported being trained to properly perform daily cleaning (90%) and discharge cleaning (93%) and were "very confident" in their abilities to do so (72% and 86%, respectively). Reported "often" or "always" using the hospital-approved cleaner-disinfectant to clean surfaces around the patient bed during daily (91%) and discharge (95%) cleaning.	Sixty percent reported "always" knowing the type of isolation precautions to be followed when entering a room to perform discharge cleaning, and 45% reported that it was "always" easy to identify the type of precautions required for a room without a sign posted at the time of discharge cleaning. Twenty-seven percent of respondents reported "often" or "always" worrying that cleaning products may be harmful to them, while 20% reported "often" or "always" worrying that they might get sick due to exposure to patients while cleaning.	Systemic issues can impair the effectiveness of ESWs: 43% reported "never" or "sometimes" receiving useful feedback about their work and 28% reported "never" or "sometimes" knowing when to use ultraviolet light (UVL) disinfection. Some ESWs reported "never" or "sometimes" having enough time to perform daily cleaning (30%) and discharge cleaning (20%) properly, and 26% reported "often" or "always" being interrupted to assist with another task. Thirty-seven percent reported that it was "always" clear what items ESWs were responsible for cleaning. Thirty-nine percent reported "often" or "always" avoiding cleaning near patients to avoid disturbing them, and 40% reported that the over-bed table was "often" or "always" too cluttered for daily cleaning. Most respondents (86%) agreed that their work was "very important" to keep patients safe, and 54% reported that clinicians "never" or "sometimes" showed appreciation for their work.	Moderate to high	Organisms/ Outcomes: ESWs' knowledge, training, and opportunities to carry out environmental cleaning

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Blazejewski et al., 2015[40]	Use of hydrogen peroxide disinfection following routine terminal cleaning, and comparison of an HPV device with a hydrogen peroxide and paracetic acid aerosolizer (aHPP)	Cluster-randomized crossover study; 182 ICU rooms disinfected (51% disinfected with HPV and 49% with aHPP system)	Five medical and surgical ICUs in a university hospital in France. The units included three 10-bed, one 12-bed, and one 4-bed unit. All units were single bed.	Routine terminal cleaning reduced environmental bacterial load (p<0.001) without effect on MDROs (15/182 [8%] rooms at T0 vs. 11/182 [6%] at T1; p=0.371). Hydrogen peroxide technologies were effective for environmental MDRO decontamination (6% of rooms contaminated with MDRO at T1 versus 0.5% at T2, p=0.004). No significant difference was found between aHPP and HPV regarding the rate of rooms contaminated with MDRO at T2 (p=0.313).	Hydrogen peroxide decontamination devices are associated with a longer waiting time between two subsequent admissions in the same room, approximately 1 hour 40 minutes for HPV and three hours for aHPP. They are also associated with increased hospital costs.	No difference was found in the reduction of MDRO room contamination with aHPP versus HPV. Both hydrogen peroxide methods reduced the rate of rooms contaminated with MDROs.	Moderate	Organisms/ Outcomes: MDROs, including ESBL-Gram-negative bacteria, imipenem-resistant *A. baumannii* (IR-AB), MRSA, and MDR *P. aeruginosa* (MDR-PA) Environmental bacterial load Future studies are needed to determine cost-efficiency and toxicity of aHPP techniques.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Butler, 2018[46]	Use of copper-oxide impregnated woven linens (e.g., gowns, pillowcase, blankets)	Before-and-after study, all patients admitted to hospital	Six hospitals, United States	Compared with the three before periods, there was a 61.2% ($p<0.05$), 41.1% ($p<0.05$), and 42.9% ($p<0.01$) reductions in *C. difficile*-related HAIs per 10,000 patient-days in periods B1, B2, and B3, respectively. There was also a 48.3% ($p>0.05$), 36.4% ($p>0.05$), and 19.2% ($p>0.05$) reductions in all HAIs caused by MDROs per 1,000 patient-days. Finally, the decreases in the combined total of MDRO- and *C.* difficile-*related* HAIS per 1,000 patient-days were 59.8% ($p<0.01$), 39.9% ($p<0.05$), and 37.2% ($p<0.05$) for periods B1, B2, and B3.	None assessed.	Linens included patient gowns, pillowcases, fitted and flat sheets, washcloths, bath towels, bath blankets, and thermal blankets. The use of biocidal copper oxide-impregnated linens resulted in significant reduction in both HAIs caused by *C. difficile*, and the combined metric of *C. difficile* or MDRO infection.	Moderate Study did not control for continuous education efforts undertaken to reinforce best practices for disinfection, which may have also contributed to the reduction of the HAI rates.	Organisms/ Outcomes: *C. difficile* and MDROs, which included MRSA, VRE, ESBL-E, MDR-AB, and CRE *C. difficile*-related HAIs

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Cadnum et al., 2018[32]	Mobile ultraviolet-C (UV-C) light room decontamination at a 10-minute exposure time and 5 feet of distance	Laboratory experiment, four different organisms	Laboratory, United States	Generally, larger surface areas were decontaminated more effectively (lower density of pathogens). The reduction in MRSA was significantly greater than the reduction in each of the *Candida* species and *C. difficile* spores (P <0.001). For each of the *Candida* species and for *C. difficile* spores, increasing the cycle time to 20 or 30 minutes resulted in significantly greater reductions in recovery (p<0.001).	None assessed	UV-C room decontamination reduced MRSA contamination at a statistically significant greater rate than *Candida* and *C. difficile* spores. For the latter two organisms, increased cycle time resulted in increased deactivation of the organisms. Larger surface areas with lower densities of pathogens were decontaminated more effectively with all other factors remaining equal.	Moderate to high	Organisms/ Outcomes: *Candida auris, C. albicans, C. glabrata, C. difficile,* MRSA Surface decontaminati on Further studies are needed to evaluate efficacy of UV-C devices in patients' rooms.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Carling et al., 2010[57]	A fluorescent targeting method was used to objectively evaluate the thoroughness of terminal room cleaning and provide feedback and education to environmental cleaning workers.	Before-and-after study, n=3,532 environmental surfaces	260 ICU rooms in 27 acute care hospitals, ranging from 25 beds to 709 beds (mean: 206 beds), United States	Only 49.5% (1,748) of surfaces were cleaned at baseline (95% CI 42% to 57%). After intervention and multiple cycles of objective performance feedback to environmental services staff, thoroughness of cleaning improved to 82% (95% CI, 78% to 86%).	None assessed.	Thoroughness of cleaning at baseline did not correlate with hospital size, patient volume, case-mix index, geographic location, or teaching status. After initial analysis of the thoroughness of cleaning, identical structured educational programs were developed for the environmental services staff of each hospital. Subsequently, the thoroughness of cleaning was reevaluated and the results were used to direct further programmatic and educational interventions (referred to as a feedback cycle). High-risk objects include floors, walls, and other surfaces not regularly cleaned by housekeeping. Additional interventions took place in some facilities, such as addition of staff, education of environmental staff, and personnel resource allocation.	Moderate	Organisms/ Outcomes: General MDROs (organisms not specified) Fluorescent targets used to measure cleaning thoroughness

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Casini et al., 2017[19]	Use of chlorine sodium hypochlorite (1,400 mg/L) with reusable cotton cloths or chlorhexidine—60% isopropyl alcohol with disposable cloths, standard cleaning, and twice-daily cleaning of high-touch surfaces with disposable cloths moistened with a ready-for-use solution of 0.5% chlorhexidine-60% isopropyl alcohol	Before-and-after intervention study, n=103 surfaces	Burn ICU with seven beds in a tertiary care teaching hospital, Italy	During the standard cleaning regimen, 3 of 23 samples (13%) gave results over the AFNOR (French standard that classifies four zones based on the level of risk of infection to which a patient is exposed) limit, and 5 (21.7%) showed unacceptable ATP levels with 100 relative light units/100 cm^2 as the benchmark limit (sensitivity 86.4%, specificity 92.2%). Following improvement of the cleaning procedure, only 2 samples of 50 (4%) did not satisfy the microbiological criteria and 7 (14%) exceeded the ATP limit. In a successive phase, 8 of 30 samples collected showed unacceptable results (27%).	None assessed.	The addition of disinfection with a chlorhexidine solution to the standard sodium hypochlorite solution reduced environmental contamination, infection, and colonization rates, as well as ATP assay detection (a monitoring method).	High	Organisms/ Outcomes: Carbapenem—resistant *A. baumannii (CR-AB)* Microbial growth

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Cheon et al., 2016[11]	Multicomponent intervention including environmental cleaning and disinfection policy enforcement, cleaning of contaminated medical equipment and infected/ colonized patient environments three times per day with bleach or quaternary ammonia, monthly environmental cultures followed by targeted cleaning, antimicrobial stewardship, staff education, contact precautions, staff education, and hand hygiene promotion	Before-and-after intervention study with a 1-month baseline period, a 9-month intervention phase, and a 1-month followup phase, ICU patients	South Korean university teaching hospital ICUs: MICU (19 bed), SICU (20 bed), and a second SICU (7 bed)	The incidence density rate of hospital-onset MDR-AB decreased from 22.82 cases per 1,000 patient-days to 2.68 cases per 1,000 patient-days after the interventions were implemented (odds ratio [OR], 0.12; 95% CI 0.03 to 0.4; p<0.001).	None assessed	Contaminated medical equipment was meticulously disinfected. The nursing staff wiped the environments surrounding colonized or infected patients at least three times per day, with a cloth that was soaked with 1:100 diluted bleach or quaternary ammonium chloride wipes. Monthly environmental cultures were in the ICUs, followed by targeted cleaning focused on any near-patient hand-touch sites and sites that tested positive for MDR-AB.	Moderate to high	Organism: MDR-AB MDR-AB cases, environmental cultures

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Choi et al., 2010[27]	Multicomponent intervention including terminal and environmental cleaning with sodium dichloro-isocyanurate, environmental culturing before new admissions to room, and introduction of closed-suctioning system for ventilators	Outbreak intervention study, 57 ICU outbreak cases (42 MICU patients and 15 SICU patients), 135 environmental samples of patients, 65 samples of hands of HCWs	Korean university hospital ICUs (18-bed MICU and 18-bed SICU)	The number of newly diagnosed cases per month increased to a maximum of 17 in March 2008 and began to decrease after the introduction of outbreak control measures. By August 2008, there were no new cases of CR-AB colonization or infection in either ICU.	None assessed.	Terminal cleaning followed by environmental sampling. New admissions were allowed only if cultures were negative. The environment of the ICU and the surrounding areas was cleaned thoroughly with 100 ppm sodium dichloroisocyan-urate. A higher concentration (200 ppm) was used to clean the environment in which the CR-AB patients were hospitalized. A closed-suctioning system was introduced for all patients receiving mechanical ventilation, and for those who did not receive mechanical ventilation, aseptic techniques were implemented. Strict contact precautions, massive environmental decontamination, and a closed-suctioning system can be effective for controlling CR-AB outbreaks.	Moderate to high	Organisms: CR-AB CR-AB cases, environmental samples, HCW hand samples

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Chojecka et al, 2015[28]	Use of glucoprotamin (GP) for environmental disinfection	Laboratory minimum inhibitory concentrations (MICs) of GP and minimum bactericidal concentrations (MBCs) against tested strains evaluated by serial broth-dilution technique	Laboratory, Poland	Gram-negative strains were more tolerant to GP than Gram-positive strains among tested strains. MRSA and methicillin-susceptible *S. aureus* exhibited similar susceptibility to GP. Tetracycline-resistant *P. aeruginosa* (PAO-LAC) had significantly lower susceptibility to GP than *P. aeruginosa* ($p \leq 0.05$). There were no differences in GP efficiency against these strains based on GP phenol coefficient (GP-PC).	None assessed.	The researchers found that variation in susceptibility of reference strains and antibiotic-resistant standard strains to GP had no meaning at clinically used concentrations, which were higher than concentrations causing bactericidal activity of GP.	Moderate	Organisms/ Outcomes: MRSA and PAO-LAC In vitro bacterial growth

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Ciobataro et al., 2011[10]	Multicomponent intervention including retraining of environmental cleaning staff, inspection of rooms after cleaning by nurse, cleaning of stations that had been used for cases or carriers, guidelines for patient isolation, cohorting, environmental cleaning, and a computerized notification system that flagged of carbapenem-resistant *K. pneumoniae* (CR-KP) carriers and provided instructions	Before-and-after study; facility level	Acute-care university hospital (553-bed hospital and 230-bed rehabilitation facility), Israel	The incidence of CR-KP decreased by 16-fold ($p<0.001$), and this decrease was sustained for 30 months. The rate of cross-infection decreased from 6% during 2007-2008 to 2.7% in 2009-2010 ($p<0.05$). This period saw an increased rate of active surveillance for carriers, from 20% to 89%.	None assessed.	Detailed instructions for cleaning and disinfecting CR-KP-positive patients' units during the hospital stay and after discharge, emphasizing the use of hypochlorite 1,000 ppm, were provided to all housekeeping staff. Vacated rooms had to be certified for reuse by the infection control nurse. The same cleaning procedure was applied to any station that had been used by CR-KP cases/carriers.	Moderate to high	Organisms/ Outcomes: CR-KP CR-KP case, CR-KP carriage

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
De Giglio et al., 2014[25]	Hydrogen peroxide (5%) and silver ion (0.1%) disinfection via direct surface application	Laboratory study	Laboratory, Italy	The disinfecting action of hydrogen peroxide and silver ions was effective after 5 minutes for ATCC® (drug sensitive) strains and after 10 minutes for multidrug-resistant isolates. In the presence of 0.3 g/L bovine serum albumin (BSA; organic matter), the disinfectant appears effective after 5 minutes of contact with ATCC strains, and after 10 minutes with multidrug-resistant isolates. Moreover, it was more effective when used in the absence or in presence of a low concentration of biological materials. In the presence of 3 g/L of BSA, the required contact time became 10 minutes for the ATCC strains and 20 minutes for multidrug-resistant isolates.	None assessed.	There were no differences in the effectiveness of these disinfectants for the two organisms studied. Hydrogen peroxide and silver ions may be a quick and easy disinfectant for occasionally contaminated small surfaces.	Moderate	Organisms/ Outcomes: *S. aureus* ATCC 6538, *P. aeruginosa* ATCC 15442 Surface disinfection

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Galvin et al., 2013[42]	Use of helium and helium air plasma for room decontamination	Laboratory	Laboratory, Ireland	Both plasma types exhibited bactericidal effects on *S. aureus* (log3.6 to >log7), with increased activity against methicillin-resistant strains but had a negligible effect on *C. difficile* spores (<1 log).	None assessed.	A glass surface was used for study.	Moderate to high	Organisms/ Outcomes: *S. aureus* and *C. difficile* Bactericidal effects on glass surface

Gan et al., 2017[45]	Multicomponent intervention including patient zone cleaning with a single microfiber cloth, patient zone cleaning with three microfiber cloths, and audit and feedback using ATP assay and fluorescent markers	Before-and-after intervention study, ICU surfaces	General ICU (25 bed), China	The study comprised a baseline period (period 1) and four sequential tiered interventions: daily wiping of patient zone (high-touch surfaces) with a single clean microfiber cloth (period 2), fluorescent markers and ATP assay to monitor and provide feedback on the effectiveness of cleaning (period 3), daily wiping of a single-patient zone with three clean microfiber cloths (period 4), and withdrawal of the feedback (period 5). The first cloth was used for the bedside table and supply cart rail. The second cloth was used for high-touch surfaces such as buttons and touch screens of ventilators. The third cloth was used for high-touch surfaces in direct contact with patients, such as bed rails. Compared with period 1, the cultures of MDROs from high-touch surfaces were reduced by 41.0% (prevalence ratio [OR]=0.59, p<0.001), 70.8% (OR=0.29, p<0.001), 82.6% (OR=0.17, p<0.001),	None assessed.	Use of three cleaning cloths for one patient zone was more effective compared with a single cloth.	Moderate	Organisms/ Outcomes: MDROs *(*not specified further) Fluorescent markers, and bioluminescent ATP markers

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				and 70.8% (OR=0.29, p<0.0001) in the subsequent sequential interventions, respectively.				
Gavalda et al., 2016[44]	Implementation of a microfiber cleaning system that involves cleaning high-touch surfaces six times a day, using one wipe per room, and soaking clean cloths in 0.1% chlorine	Four-year quasi-experimental, before-and-after study, 1,058 rectal swabs, ICU patients during screening periods	ICUs in teaching hospital (800 bed), Spain	The percentage of carriers at admission was significantly lower during the second screening period (8.9% vs. 0.8%, respectively; p<0.001), after the intervention bundle was implemented.	None assessed.	By only using one wipe per room, the hospital reduced cross-contamination during environmental cleaning as measured by ICU XDR-AB incidence. The authors also attributed the reduction in cases to a one-time in depth cleaning and prompt isolation of cases. Improved cleaning techniques were equally as important as a good organizational strategy to determine the regularity with which certain items and equipment needed to be disinfected.	Moderate to high	Organisms/ Outcomes: XDR-AB Positive XDR-AB screening

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Gupta et al., 2016[9]	Multicomponent intervention including daily high-touch point cleaning, terminal cleaning, ventilator cleaning, environmental cleaning, disposable microfiber cloths, bleach, and environmental auditing twice a day of cleaning processes using a luminometer and ATP testing prior to admitting a patient to a room	Before-and-after study, 26 cases during study period, SICU patients	Surgical ICU (14-bed unit) in tertiary care hospital (1,170 bed), United States	During the 5-month period before the intervention, there were 17 MDRO infections in 16 patients in the SICU at a rate of 9.09 per 1,000 patient-days. During the 7-month period after protocol implementation, there were 9 MDRO infections in 9 patients. The SICU MDRO infection rate decreased by 65% to 3.27 per 1,000 patient-days (p=0.02). In addition to MDROs, during the pre-intervention period, there were 15 cases of *Burkholderia cepacia complex* (BCC) infection. Following the protocol implementation, the number of BCC infection cases fell to 2 cases during the first month and then remained undetectable (p=0.0008) for the remaining 6 months.	None assessed.	A prolonged reduction in infection rates was seen after the intervention and throughout the 6-month followup period. The authors attribute the multifaceted approach to the success of the intervention, including the focus on environmental cleaning and incorporation of dry and wet mopping to reduce organic material, additional disinfection with UV while the ICU was closed, and ongoing monitoring using ATP markers.	Moderate to high Limitation: Lack of true controls	Organisms/ Outcomes: MDROs and BCC MDRO and BCC infections

Haas et al., 2014[54]	Ultraviolet environmental disinfection (UVD) for patient rooms	Retrospective before-and-after study; UVD performed 11,389 times	Tertiary care hospital (643 bed), United States	UVD was used 11,389 times; 3,833 (34%) uses were for contact precaution discharges. UVD was completed for 76% of contact precaution discharges. UVD was used after end of day cleaning in the operating rooms, weekly in the dialysis unit, and for all burn unit discharges. UVD could be requested for rooms of long-stay patients or for discharges in units with high prevalence of MDRO or *C. difficile*. In rooms with more than one occupant, UVD was deferred until the room was no longer occupied. There was a significant 20% decrease in hospital-acquired MDRO plus *C. difficile* rates during the 22-month UVD period compared with the 30-month pre-UVD period (2.14 cases/1,000 patient-days vs. 2.67 cases per 1,000 patient-days, respectively; rate ratio, 0.80; 95% confidence interval 0.73 to 0.88, p<0.001).	Staff are not primarily budgeted to run UVD; rather, this task is added onto the existing role of the staff or supervisor and may divert staff from other essential functions.	Labor cost and availability must be considered in the budget and implementation plan for UVD. Missed contact precaution discharges were discussed weekly to assess flaws.	Low to moderate The study did not evaluate antibiotic use, which can clearly affect acquisition rates of MDROs and *C. difficile*. In addition, many component s occurred simultaneou sly.	Organisms/ Outcomes: MDROs, *C. difficile* MDRO and *C. difficile* rates A cost-benefit analysis of UVD use that includes labor costs is also needed.
Hess et al., 2013[22]	Multicomponent intervention	Cluster-randomized	Four ICUs (one 29-bed	The mean proportion of contaminated HCW	None assessed.	Intervention was a single, supplementary cleaning of	Low to moderate	Organisms/ Outcomes:

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
	including enhanced daily cleaning with QAC of ICU room surfaces frequently touched by HCWs, and feedback on intervention implementation using fluorescent gel markers	controlled trial, 4,444 cultures collected from 132 rooms with patients colonized by MRSA or MDR-AB	medical ICU and three 12-bed surgical ICUs) in a 757-bed tertiary care teaching hospital, United States All ICUs with single-bed, single-occupant rooms	gowns and gloves following routine care provision and before leaving the rooms of patients with MDR-AB was 16% among control rooms and 12% among experimental rooms (RR: 0.77, 95% CI 0.28 to 2.11, p=0.230). For MRSA, the mean proportions were 22% and 19%, respectively (RR: 0.89, 95% CI 0.5 to 1.53, p=0.158).		high-touch surfaces using quaternary ammonium. Surfaces were chosen based on a Centers for Disease Control and Prevention (CDC) list. Implementation of the intervention was verified using an invisible fluorescent gel, which was done in 10% of rooms. Enhanced cleaning was associated with a nonsignificant reduction in HCW gown and glove contamination.		MRSA and MDR-AB Contaminatio n of HCW gowns and gloves

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
La Forgia et al., 2010[4]	Flooding of drainage system with sodium hypochlorite to disinfect sinks	Outbreak intervention study, 16 cases, ICU patients with MDR-AB	Twenty-four ICUs in a university hospital (476 beds), United States	Ten gallons of water were run into each plugged sink in every location in the ICU, followed by slowly pouring 1 gallon of bleach into the water, avoiding splashing. Once all the sinks were filled, the plugs of all sinks were pulled simultaneously, thereby flushing the sink drain piping with the bleach solution. This protocol was continued weekly throughout the observation period. Before this intervention, 18 patients over 10 months had MDR-AB. After the intervention, this rate decreased to 19 patients over 28 months, a statistically significant reduction in infection rate ($p<0.01$).	None assessed.	The authors determined that this one-time comprehensive disinfection of the entire plumbing system was crucial to eliminating all underlying sources of contamination. If they had disinfected each sink individually in a staggered manner, the contamination issue would have persisted. Flooding 100% of the system ensured that bacterial colonization was eliminated and could not return unless from an external source. The weekly repetition of this strategy and the reduction of splashing on surfaces around the sink also contributed to the success of this technique.	Moderate to high No comparison group	Organisms/ Outcomes: MDR-AB MDR-AB cases

Lee et al., 2017[21]	Use of Bio-Kil (3-(Trimethoxysilyl) propyloctadecyl-dimethyl ammonium chloride, a QAC) for environmental cleaning and use of Bio-Kil objects for ongoing antimicrobial action	Prospective before-and-after study, n=77 patients, patients in four study rooms in ICU (two study rooms, two control rooms)	Medical and surgical ICUs in 750-bed Thai teaching hospital	Environmental samples were collected from room surfaces and patients twice weekly during pre-intervention period. The room walls, ceilings, and air-conditioning filters, surfaces of instruments, textiles, and nurses' clothing were all decontaminated or replaced with Bio-Kil products. Sampling was repeated. After application of Bio-Kil, the bacterial burden declined in both groups, although the reduction was greater in the study rooms compared with the control rooms ($p<0.001$). During the pre-intervention period, 16 patients were admitted to control rooms and 18 patients to study rooms. After the intervention, 22 patients were admitted to control rooms and 21 patients to study rooms. The number of cases of new-onset sepsis declined in the intervention group (from 33% to 23.8%) but increased in the control group (from 25% to 40.9%);	None assessed.	The use of Bio-Kil to disinfect and provide ongoing microbial activity reduced environmental bacterial contamination and sepsis incidence in the ICU compared with manual surface cleaning with 500 ppm sodium hypochlorite. Bio-Kil has little to no toxicity to humans and therefore may be a useful disinfectant for textiles and other items that are regularly in direct contact with humans and at high risk of carrying fomites.	Moderate to high	Organisms/ Outcomes: MRSA, VRE, CRE, carbapenem-resistant *P. aeruginosa* (CR-PA), and CR-AB Environmental bacterial samples, new-onset sepsis cases

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				however, there was no significant difference in incidence of new-onset sepsis between the study and control rooms after intervention.				
Lemmen et al., 2015[35]	Use of HPV room decontamination for common MDROs and spores	Before-and-after study, 4 cultures (2 representative MDR Gram-positive and 2 MDR Gram-negative bacteria) and 7 spore indicators (times three trials)	Operating rooms, Germany	Stainless steel and cotton carriers containing viable organism cultures were placed around. HPV was then used to decontaminate the operating room. This process was repeated three times. HPV inactivated all spore biological indicators and no MRSA, VRE, or MDR-AB were recovered from the stainless steel and cotton carriers. HPV was equally effective at all carrier locations.	None assessed.	No identified difference in efficacy for microbes dried onto stainless steel or cotton surfaces, indicating that HPV may have a role in the decontamination of both porous and nonporous surfaces.	Moderate	Organisms/ Outcomes: MRSA, VRE, MDR-AB Spore biological indicator

Levin et al., 2009[52]	Educational intervention on radiograph machine decontamination and hand hygiene education	Before-and-after trial of decontamin-ation protocol, radiographs during observation (173), intervention (112), and followup periods (120).	Academic tertiary care hospital ICU, Israel	The radiology technicians were told that infection control performance was inadequate, that multidrug-resistant bacteria were being cultured from the radiograph machine, and that this situation could be detrimental to patient safety. They were requested to improve infection control measures using alcohol hand rub and changing gloves before and after each contact with the patient or radiograph machine. Adequate infection control was practiced during 2/173 observation period radiographs (1%), 48/113 intervention period radiographs (42%; p<0.001), and 12/120 followup period radiographs (10%; (p<0.001). Radiograph machine surface culture samples yielded positives on 12/30 occasions (40%), 0 of 29 occasions, and 7 of 14 occasions (50%) for the respective periods.	The researchers observed a statistically significant decrease in the use of adequate infection control during radiographs in the followup period compared with the intervention period. Positive cultures were highest in the followup period.	The intervention was heavily focused on the education of radiologist technicians and hand hygiene compliance, while the outcome of interest was environmental contamination of the radiograph machines. Short-term results were shown, but long-term infection control practices resulted in continuing contamination of the machines. The authors recognized that their study was the first study to focus on contaminated radiology equipment, which is very likely to contribute to cross-contamination and transmission of bacteria. However, further studies will be needed to assess which types of interventions can maintain more long-term results.	Moderate	Organisms/ Outcomes: Gram-negative bacteria resistant to ceftazidime, ceftriaxone, or imipenem; MRSA, VRE Surface sample cultures
Liu et al., 2014[7]	Multicomponent intervention including hypochlorite	Outbreak intervention study, 22 patients	Regional hospital, 16-bed medical ICU, Taiwan	Nine environmental specimens, including five specimens collected after	None assessed.	A correction to the preparation of disinfectant solutions was found to eradicate IR-AB, whereas	Moderate to high	Organisms/ Outcomes: IR-AB

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
	disinfection, environmental sampling, contact precautions, patient isolation, and hand hygiene education	colonized with imipenem-resistant *A. baumannii* (IR-AB) and 18 infected with IR-AB, outbreak cases		terminal disinfection, were positive for IR-AB. The low-concentration 0.08% sodium hypochlorite was inadequate. After the facility corrected the environmental cleansing methods, the surveillance study showed no further IR-AB isolates on the control panel surfaces of the medical equipment or in patients in the ICU. In vitro study showed that 0.5% sodium hypochlorite eradicates IR-AB after 30 seconds of inoculation, but 0.08% sodium hypochlorite only reduces the bacterial load.		the more diluted 0.08% hypochlorite was only somewhat reducing the bacterial load. The study demonstrates that education of environmental cleaning staff and auditing of environmental disinfection practices can be crucial for reducing environmental contamination and subsequent disease transmission.		Environmental sample cultures

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Manian et al., 2011[36]	Use of routine terminal cleaning and disinfection (C/D) with quaternary ammonium and sodium hypochlorite compared with HPV room disinfection	Before-and-after study, approximately 20 sample sites per room for 483 rooms, newly vacated by multidrug-resistant *Acinetobacter baumannii* complex (MDR-ABC)- and MRSA-positive patients. ABC and MRSA samples collected from 312 rooms following four rounds of C/D, 37 rooms following one round of C/D before and after HPV treatment, and 134 rooms following one round of C/D and HPV treatment.	900-bed tertiary care teaching hospital, United States	Following four rounds of C/D, 83 (26.6%) rooms had one or more culture-positive sites. Following one round of C/D and HPV treatment, six (4.5%) rooms were culture positive for ABC, MRSA, or both. The addition of HPV treatment to one round of C/D resulted in a significant drop in ABC- and MRSA-positive room sites (odds ratio, 0 [95% CI 0 to 0.8]; for both organisms, p=0.04).	Several culture-negative sites became culture positive after C/D, indicating potential recontamination of surfaces during the C/D process. This change was not found after HPV treatment.	The addition of HPV to multiple rounds of cleaning and disinfection was shown to reduce positive environmental cultures. Even four rounds of routine cleaning and disinfection were insufficient in eradicating environmental cultures. The authors attributed the insufficiency of routine environmental cleaning to the suboptimal cleaning and not to the ineffectiveness of the sodium hypochlorite. Thus, the use of HPV to supplement routine C/D may be a useful alternative or supplement to staff education and monitoring of cleaning and disinfection practices.	Moderate	Organisms/ Outcomes: ABC, MRSA Environmental sample cultures

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Mathew et al., 2016[33]	Use of enclosed UV-C radiation for decontamination of mobile handheld devices (MHDs)	Laboratory, 50 MHDs of healthcare staff	Laboratory, United States	An enclosed UV-C device designed for decontamination of MHDs was effective in rapidly reducing MRSA, and to a lesser degree, *C. difficile* spores, in a laboratory setting. Presence of organic matter reduced the efficacy of the decontamination.	None assessed.	There was no significantly different result between species. Time required for disinfection of MHDs was 15 to 77 seconds for cell phones and 50 to 147 seconds for a tablet.	Moderate Study did not compare effectivenes s of the UV-C device with other methods that have been shown to be effective for decontami-nation of MHDs.	Organisms/ Outcomes: MRSA and C. difficile
Munoz-Price et al., 2010a[49]	Multicomponent intervention including enhanced environmental cleaning, daily 2% chlorhexidine gluconate baths for patients, surveillance cultures at admission, serial point prevalence surveillance (PPS), isolation precautions, and training of personnel.	Before-and-after study, n=213 patients screened, patients admitted to the facility	Long-term acute care hospital (LTACH), United States	Baseline PPS performed on June 17, 2008, showed a prevalence of colonization with *K. pneumoniae* carbapenemase (KPC)-producing isolates of 21% (8 of 39 patients screened). After implementation of the intervention, monthly PPS was performed five times, which showed prevalence rates of colonization with KPC-producing isolates at 12%, 5%, 3%, 0%, and 0% ($p<0.001$).	None assessed.	Spray bottles replaced buckets to avoid contamination, assigned cleaning responsibilities were changed due to confusion over previous policies, new curtains were installed, and several additional objects and surfaces were included in disinfection procedures. Staff education included hemodialysis cleaning training and avoidance of cross-contamination with personal objects.	Moderate	Organisms/ Outcomes: KPC-producing *K. pneumoniae* (KPC-KP) KPC colonization

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Munoz-Price et al., 2010b[60]	Multicomponent intervention including environmental cleaning assessments and feedback using UV-detectable powder on high-touch surfaces, cleaning of KPC-patient rooms' high-touch surfaces and ventilators every shift, daily baths with 2% chlorhexidine, PPS, isolation precautions, and staff education	Outbreak intervention study, nine cases, SICU patients with KPC-KP	20-bed surgical ICU in public teaching hospital, United States	Environmental cleaning assessments were done by applying UV-detectable powder to high-touch surfaces and surveying the presence of the powder after 48 hours. Environmental cultures were also done. One staff member per shift was assigned to clean KPC-patient rooms. Bleach-impregnated cloths were used for cleaning. A respiratory therapist cleaned high-touch ventilator surfaces using UV-powder detection; researchers found that nobody was cleaning bed rails or mechanical ventilators and subsequently provided assignments for these tasks. No further spread of the organism or additional cases were seen.	None assessed.	The multicomponent intervention successfully reduced KPC-KP horizontal transmission even with the ongoing admission of colonized patients. While it is difficult to attribute success to any one component, the authors hypothesized that an increased focus on environmental cleaning may have reduced environmental contamination and subsequent contamination of healthcare workers' hands, contributing to the reduction of horizontal transmission.	High	Organisms/ Outcomes: KPC-KP KPC-KP cases

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Munoz-Price et al., 2014[50]	Weekly electronic communication providing feedback on environmental decontamination, environmental cultures, and other factors	Before-and-after study, 1,103,900 patient-days, all admitted patients during 42-month period	1,500-bed public teaching hospital, United States	Hospitalwide, the rate of CR-AB acquisition decreased from 5.13 +/-0.39 to 1.93+/-0.23 per 10,000 patient-days, during the baseline and post-intervention periods, respectively (p<0.0001). This effect was also observed in the medical and trauma ICUs, with decreased rates from 67.15+/-10.56 to 17.4+/-4.6 (p<0.0001) and from 55.9+/-8.95 to 14.71+/-4.45 (p=0.0004), respectively.	None assessed.	Bundled intervention originally failed to reduce CR-AB acquisition rates, so email updates were implemented. Email recipients included the C-suite of the hospital, the Quality and Patient Safety Division, and the nursing and medical directors of inpatient units. Emails included graphic description and interpretation of environmental findings (cultures and UV markers), maps of positive cultures, and action plans.	Moderate	Organisms/ Outcomes: CR-AB CR-AB acquisition

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
O'Connor et al., 2015[6]	Multicomponent intervention including prohibited prescription and use of linezolid, adherence to infection prevention and control practices, enhanced environmental cleaning, isolation of affected patients, and hospitalwide education programs	Outbreak intervention study, nine affected patients	Tertiary care teaching hospital (483 inpatient beds) and ICU, England	Enhanced cleaning of the ICU was instigated in parallel with increased auditing. This process involved twice-daily cleaning of affected areas with detergent, in addition to a deep clean with sodium hypochlorite to decontaminate the area on discharge. The adopted infection prevention intervention was effective, and the outbreak was limited to the affected ICU.	None assessed	Due to the multicomponent nature of the intervention, it is difficult to attribute the halt of the outbreak to any one component. The authors cited lack of resources as a reason for not implementing environmental and staff screening.	High	Organisms/ Outcomes: Linezolid-resistant *S. epidermidis* *S. epidermidis* cases
Otter et al., 2010[37]	HPV decontamination of ICU rooms	Outbreak intervention study, 12-bed spaces covering all hand-contact areas adjacent to bed and mattress	12-bed ICU, Nether-lands	Ten of 21 areas cultured after cleaning but before HPV (47.6%) yielded Gram-negative rods (GNRs). No GNRs were cultured from the 63 sites sampled after HPV, including areas adjacent to the 21 sites sampled before HPV. All 40 biological indicators were inactivated by the process.	None assessed.	HPV decontamination of the unit took approximately 12 hours, including an overnight aeration, and was completed without incident or damage to the materials and equipment in the ICU.	Moderate to high	Organisms/ Outcomes: MDR GNRs Environmental sample cultures

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Park et al., 2015[41]	Use of argon gas-feeding dielectric barrier discharge (Ar-DBD) and nanosecond pulsed plasma (NPP) for disinfection	Laboratory	Laboratory, South Korea	Both plasma sources inactivated both sensitive and resistant bacteria.	None assessed.	No discussion of clinical applications. Paper mostly assessed the mechanisms of plasma inactivation of bacteria.	High	Organisms/ Outcomes: Drug-sensitive *S. aureus,* MDR *S. aureus*

Passaretti et al., 2013[55]	Use of standard cleaning practices with quaternary ammonium and hydrogen peroxide compared with HPV for room decontamination	Prospective cohort intervention study, 6,350 admissions, patients admitted to rooms previously occupied by MDRO-infected patients	994-bed tertiary care teaching hospital, 6 high-risk units, including ICUs and surgical units, United States	Standard cleaning practices included QAC for surfaces and floors and a hydrogen-peroxide-based cleaner for *C. difficile* patients' rooms. Periodic monitoring of cleaning policy compliance was performed (period was not defined). HPV decontamination was performed in common areas of the surgical ICU and terminal cleaning of rooms was performed after colonized patients were discharged. Shared equipment was also decontaminated with HPV. Biological indicators were also used during decontamination. Patients admitted to HPV-decontaminated were 64% less likely to acquire any MDRO (incidence rate ratio [IRR], 0.36; 95% CI 0.19 to 0.70; p<0.001) and 80% less likely to acquire VRE (IRR, 0.20; 95% CI 0.08 to 0.52; p<0.001). The risk of acquiring *C. difficile*, MRSA, and MDR-GNB individually was reduced but not statistically	One brand of paint used on the walls of one of the HPV units showed some incompatibility with the process; once this paint was replaced, there were no reports of damage to materials or equipment. Individual risk of MRSA, MDR-GNR, or *C. difficile* were not reduced by HPV use.	The use of HPV compared with disinfection with quaternary ammonium and hydrogen peroxide was found to reduce environmental contamination and patient acquisition of MDROs. The use of HPV even reduced acquisition of MDROs in patients without neighbors who were infected. The authors attributed the lack of HPV's effect on MRSA, MDR-GNR, and *C. difficile* to their overall low incidence before and during the intervention.	Moderate	Organisms/ Outcomes: VRE, MRSA, *C. difficile,* MDR-GNB, and general MDROs MDRO acquisition Multiple infection prevention initiatives ongoing during study period, including daily chlorhexidine bathing of patients

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				significantly. The proportion of rooms contaminated with MDROs was reduced significantly only on the HPV units (relative risk, 0.65, p=0.03).				
Peterson et al., 2016[13]	Intensive bleach disinfection (bundle), intranasal mupirocin, and chlorhexidine bath, hand hygiene education in addition to active surveillance	Cluster-randomized nonblinded trial, 16,773 tests, all long-term care facility (LTCF) admissions	Three LTCFs, United States	The MRSA infection rate decreased 65% between the baseline (44 infections during 365,809 patient-days) and Year 2 (12 during 287,847 patient-days; p<0.001); significant reduction was observed at each LTCF (p<0.03). Due to the intervention, 23 MRSA infections were avoided when baseline data were compared with the final year of the program, which translates to a saved expense of $552,000.	None assessed.	The researchers implemented the multicomponent intervention without decreasing socialization or activities of daily living for the residents. Active surveillance, targeted decontamination, and environmental cleaning resulted in a decreased infection rate of MRSA in multiple LTCFs.	Low to moderate	Organisms/ Outcomes: MRSA MRSA infections

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Ratnayake et al., 2011[12]	Enhanced terminal and daily cleaning with hypochlorite and staff education	Outbreak intervention study, nine cases, patients in vascular surgery ward	24-bed vascular unit on an acute surgical ward, United Kingdom	Hypochlorite terminal cleaning was done to reduce spore contamination. Cleaning of equipment and high-contact areas was performed daily. Staff were educated on environmental cleaning practices. Outbreak was stopped, and MRSA acquisitions fell as well (no statistical report).	None assessed.	Both *C. difficile* transmission and MRSA acquisitions were reduced by this multicomponent intervention. It is difficult to attribute success to one component of the intervention, as they were implemented simultaneously. The authors do not describe in detail an environmental audit but claim that one was performed and did not identify any issues that could have contributed to the outbreak. However, the authors do restate the importance of hypochlorite disinfection to eradicate the environmental reservoir of *C. difficile* spores.	High	Organisms/ Outcomes: Clindamycin-resistant *C. difficile,* MRSA MRSA and *C. difficile* acquisitions

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Ray et al., 2010[38]	Use of HPV for room disinfection with terminal cleaning	Before-and-after case-control study (outbreak), 13 patients infected or colonized with MDR-AB and 27 control subjects	54-bed LTACH affiliated with a tertiary care hospital, United States	Case patients were more likely to have wounds (odds ratio [OR], 12.92; p=0.01), have tracheostomy tubes (OR, 9.60; p=0.03), and have received intravenous antibiotics on admission to the LTACH (OR, 6.86; p=0.04). Terminal cleaning was performed to remove organic and porous materials. HPV was performed at least once in each room in the facility and chemical and biological indicators were used for quality assurance. After the completion of HPV room decontamination in the LTACH wards, no further cases of nosocomial acquisition of MDR-AB colonization or infection were detected.	None assessed.	The authors also mentioned that "HPV is favorable in part because of its portability, low vapor temperature, and lack of harmful residue."	Moderate to high This is primarily a case study.	Organisms Outcomes: MDR-AB MDR-AB cases

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Rhodes et al., 2016[34]	Use of violet 405 nm light for room decontamination	Laboratory	Laboratory, United States	Here, 405 nm light-emitting diodes were used to treat varying concentrations of a common laboratory *E. coli* K-12 strain transformed with the pCIG mammalian expression vector, which conferred ampicillin resistance via expression of the beta-lactamase gene. Treatment time was 120 minutes at varying intensities. Study showed a statistically significant log_{10} reduction in bacterial concentration ($p<0.001$).	None assessed.	The researchers found that visible light therapy with 405 nm violet light significantly reduced concentration of beta-lactamase-producing *E. coli* on plated growth media. This process has not yet been applied in clinical settings, but the authors hypothesize that it could be used as a novel sterilization method.	High	Organisms/ Outcomes: Ampicillin-resistant *E. coli* Bacterial concentration in plate samples

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Robustillo-Rodela et al., 2017[39]	Intensive chlorine decontamination and HPV decontamination, preceded by an indepth cleaning with a 0.05% chlorine solution	Outbreak intervention study, n=31, ICU patients and outbreak cases	1,200-bed university hospital, ICU, Spain	The cumulative incidence of OXA-48 carbapenemase-producing Enterobacteriaceae (OXA-48-PE) and MDR-AB was 3.48% and 4.81%, respectively. In the period after the intervention, they were 0.8% and 0%, respectively ($p<0.001$). Before the HPV decontamination, 4.5% of environmental samples were positive for OXA-48-PE and none for MDR-AB. After decontamination, 1.4% of samples were positive for OXA-48-PE.	Conventional cleaning by manually applying a disinfectant is difficult to standardize and has a high risk of error. If wipes and dusters are not correctly used, they can be contaminated and allow the spread of pathogens from one surface to another.	Environmental samples were taken before and after HPV. Indepth ICU cleaning was done with a 500 ppm chlorine solution. Air conditioning grilles were covered, and sink drains were left uncovered. Chemical and biological indicators were used for quality assurance.	High	Organisms/ Outcomes: OXA-48-PE and MDR-AB OXA-48-PE and MDR-AB cases, environmental sample cultures

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Rock et al., 2018[48]	UV-C light room decontamination	Cross-sectional survey, n=100, hospital healthcare workers and patients	Teaching hospital, United States	None assessed.	None assessed.	Eighty-four percent of the patients said the purpose of the UV-C light was well explained. Sixty-four percent let staff know when their room was available for UV-C disinfection. Ninety-three percent felt comfortable with the UV-C light operating in the bathroom while they were in the room. Also, 93% reported that the UV-C light did not interfere with their daily schedule. Finally, 39% had at some time refused UV-C light disinfection in their room or bathroom; reasons included not feeling well (25%), wanting to sleep (13%), not wanting to be bothered (11%), and not liking the smell (5%).	High	Organisms/ Outcomes: No organisms specified. Patient attitudes and experiences with UV-C room decontamination. This study was done 8 months after implementation of a UV-C study.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Rodriguez-Bano et al., 2009[51]	Multicomponent intervention: strict environmental cleaning policy, limited sharing of medical devices, ongoing staff education, promotion of hand hygiene, strict contact and isolation precautions, environmental cleaning, and targeted active surveillance in high-risk areas during periods of likely transmission and contamination	Before-and-after study, 971 cases, all patients in 21 wards	Acute care university hospital with 30-bed ICU, Spain	Device sharing was limited between patients. Environmental sampling was performed in each of the three intervention periods. A strict environmental cleaning policy following CDC recommendations for rooms and any object that might have come into contact with colonized patients was implemented. Before the bundle was instituted, the rate of colonization/infection was 0.82 cases per 100 admissions (1994–1995). Colonization and infection rates showed a sustained decrease after implementation of the control program in 1995 to 0.46 in 1996–1997 and to 0.21 in 1998–2003 ($p<0.001$). The rate of bacteremia due to MDR-AB decreased sixfold during the 8-year observation period.	Rate of positivity of environmental samples did not change over the intervention period.	Decreased incidence of MDR-AB, decreased incidence in bloodstream infections, and decreased clonal diversity of MDR-AB were attributed to this multifaceted intervention. However, no decrease in positivity of environmental cultures was found. In total, several important clinical outcomes improved as a result of this multicomponent intervention and stemmed this multiyear outbreak. The authors also added that the active surveillance component was costly and time consuming, and the presence of the infection control practitioner alone may have improved compliance.	High	Organism: MDR-AB MDR-AB colonization/ infection, MDR-AB bacteremia

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Rutala et al., 2012[3]	Use of an improved hydrogen peroxide disinfectant, standard hydrogen peroxide, and quaternary ammonium	Laboratory	Laboratory, United States	The improved hydrogen peroxide disinfectant was superior to all three concentrations of the standard hydrogen peroxide and similar or superior to the quaternary ammonium product in its effectiveness in $\log_{10}$ bacterial reduction.	Hydrogen peroxide is a category IV in the Environmental Protection Agency (EPA) toxicity categories (very low toxicity).	Improved hydrogen peroxide disinfectant includes anionic and nonionic surfactants in an acidic product to augment microbicidal activity. The authors indicate that this product has the lowest EPA toxicity categorization. Also, the improved hydrogen peroxide has a lower contact time than most EPA low-level disinfectants.	Moderate to high	Organisms/ Outcomes: MRSA, MDR-AB Bacterial reduction
Shaikh et al., 2016[31]	Use of low-intensity UV-C radiation for keyboard decontamination	Before-and-after study, n=25, decontamin-ation of in-use keyboards	Hospital rooms, United States	Keyboards were cultured before and after a 6-minute UV-C cycle. The UV-C device significantly reduced total aerobic bacterial counts on in-use keyboards (p=0.0006). In addition, there was a significant reduction in recovery of potential pathogens after use of the device.	Device required four or five cycles to achieve a <1 log reduction in *C. difficile.*	The UV-C significantly reduced total aerobic bacterial counts on in-use keyboards. The device was less effective against *C. difficile* and required four or five cycles to achieve a <1 log reduction.	Moderate	Organisms/ Outcomes: Gram-negative bacilli, *C. difficile, S. aureus,* and *Enterococcus* spp. Bacterial counts

Strassle et al., 2012[20]	Terminal cleaning with QAC, disposable wipes, and mops	Before-and-after study, patients with known history of colonization or infection with organism	University teaching hospital, medical, surgical, and cardiac surgery ICUs, United States	Environmental sampling was done before and after terminal cleaning. Samples were taken from sinks, floors around patient bed, and high-touch areas. Curtains, infusion pumps, and respiratory equipment were removed from the room. Wipes saturated with quaternary ammonium were used to clean all surfaces. A new wipe was used on each surface to avoid cross-contamination. The floor was mopped from back to front with the same disinfectant solution with an 8- to 10-minute dwell time. Fifteen rooms (46.9%) and 41 sites (n=268, 15.3%) were found positive pre-terminal cleaning. Eight rooms (25.0%) were found positive post-terminal cleaning. Overall, a significant reduction in the number of contaminated rooms (p=0.01) and sites (p>0.01) was observed. Twelve sites (n=219, 5.5%) were found positive post-cleaning.	None assessed.	Culturing was performed to isolate areas that were missed during routine terminal cleaning. The rooms were emptied to ensure all hard-to-reach areas were disinfected. There was a focus on replacing cleaning wipes to reduce cross-contamination, as well as adhering to recommended dwell times for the used disinfectants. Cleaning methods and staff were not observed, potential poor cleaning technique or practice may have occurred, and post-cleaning contamination rates may be improved with education and feedback to environmental services.	Moderate to high Molecular typing was not completed; it cannot be proven that the strain of *A. baumannii* is identical between patient and environmental isolates.	Organisms/ Outcomes: MDR-AB Environmental sample cultures
Ushizawa et al., 2016[15]	Multicomponent intervention	Outbreak intervention	Tertiary care	Medical equipment was disinfected three	ER was temporarily	The ER was temporarily closed to prevent ongoing	High	Organisms/ Outcomes:

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
	including: Enhanced environmental cleaning with bleach and QAC, closure of the emergency room and interruption of admission to the CCC, and isolation of patients with MDR-AB colonization or infection within a single room	study, 15 cases, outbreak cases and other hospital patients	hospital, critical care center, Japan	times per day. A QAC, followed by 0.01% sodium hypochlorite, was used for environmental cleaning in the ER and the ward where the MDR-AB strains were isolated. This bundle of intervention led to a decreased isolation rate of MDR-AB and a halt to the outbreak.	closed during the outbreak response.	transmission. Shared medical equipment was determined to be a common source of contamination, and so environmental cleaning policies were enacted to increase their disinfection.		MDR-AB MDR-AB cases
Wendel et al., 2015[53]	Multicomponent intervention including sink trap replacement and a reduction in washbasin use	Outbreak intervention study, 29 cases, outbreak cases	Tertiary care hospital, 40-bed surgical ICU, Germany	Environmental sampling revealed colonization of the wastewater system, several sinks, and a reusable hair washbasin. Use of washbasin was restricted. Sink traps were also replaced. Continued surveillance over a period of 2 years revealed no further case of this outbreak strain GIM-1e carrying *P. aeruginosa.*	None assessed.	Due to the difficulty in cleaning and disinfecting sink traps with biofilms, the researchers opted for replacement of the sink trap systems and an ongoing focus on their cleaning and disinfection. As it is a high-risk area for biofilm growth and bacterial contamination, researchers opted to limit washbasin use entirely to prevent cross-contamination. A 2-year followup period reiterated the success of this intervention in halting the spread of the outbreak strain.	High Colonization or infection status was difficult to assess in the retrospective part of the data analysis.	Organisms/ Outcomes: GIM-1-producing *P. aeruginosa* ST111 GIM-1-producing-PA cases, environmental sample cultures

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Zarpellon et al., 2018[62]	Multicomponent intervention: enhanced terminal cleaning, twice-daily room disinfection, establishment of prevention guidelines, hand-hygiene promotion, isolation of patients colonized or infected by such organisms, and enforced contact precautions	Before-and-after study, all hospitalized patients	123-bed public teaching hospital, Brazil	This intervention included terminal cleaning and disinfection of the rooms, performed twice by different teams on separate days in its bundle. Statistically significant differences were observed between the pre- and post-intervention periods (p=0.00198). Control measures were effective in halting a previously endemic clone of *A. baumannii*. The incidence of VRE, *K. pneumoniae*, and *P. aeruginosa* during the surveillance period was low.	None assessed.	While a policy change and focus on monitoring environmental cleaning was part of this multicomponent intervention, the authors primarily attributed success to an active surveillance program.	High Low incidence of some target MDROs.	Organisms/ Outcomes: *A. baumannii, K. pneumoniae, P. aeruginosa* MDRO incidence

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Zarrilli et al., 2012[26]	Multicomponent intervention: environmental cleaning with 500 ppm chloride derivatives, disinfection of incubators with 4% chlorhexidine, sterilization of ventilation equipment with low-temperature hydrogen peroxide gas plasma, and ongoing monitoring with environmental sampling	Outbreak intervention case-control study, 22 cases, neonates in NICU	Neonatal ICU in university hospital, Italy	The intervention included environmental cleaning procedures with chloride derivatives at 500 ppm and disinfection of incubators with 4% chlorhexidine. All reusable assisted ventilation equipment was sterilized with low-temperature hydrogen peroxide gas plasma technology. Environmental sampling identified several contaminated sites. After intervention, these sites never cultured positive.	None assessed.	The multicomponent intervention successfully stemmed the outbreak, although it is difficult to attribute success to any one component. Extensive environmental investigation and screening were done to identify any ongoing sources of contamination, which was especially crucial due to the sensitivity of the population. Ongoing environmental screening was performed throughout the outbreak.	High	Organisms/ Outcomes: XRD-AB XRD-AB cases, environmental sample cultures

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Zoutman et al., 2014[59]	Environmental services department activities including auditing, training, supply availability, and resource allocation	Cross-sectional survey, n=96 from 103 hospitals, environmental services managers	Hospitals, Canada	Here, 86.3% (82/95) of managers responsible for environmental services reported their staff were adequately trained, and 76.0% (73/96) said supplies and equipment budgets were sufficient.	Here, 36.8% (35/95) of environmental services departments did not audit the cleaning of medical-surgical patient rooms on at least a monthly basis. Cleaning audits of medical-surgical patient rooms frequently included environmental marking methods in only one-third (33.3%, 31/93) of hospitals and frequently included the measurement of residual bioburden in only 13.8% (13/94).	Researchers concluded there is a general need for increased and improved auditing of environmental cleaning in Canadian hospitals, and most hospitals had environmental services staffing deficits.	High	Organisms/ Outcomes: MDROs (not specified) Environmental staff knowledge and self-report of resources for cleaning

Table B.9: MDROs, Minimizing Catheter Use and Reducing Harm—Systematic Reviews

Note: Full references are available in the Section 5.5 reference list.

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Bermingham et al., 2013[18]	The use of various materials and practices for urinary catheters including clean versus sterile noncoated intermittent self-catheterization, hydrophilic catheters, gel reservoir catheters, and clean noncoated catheters	Eight studies of long-term (>28 days) intermittent self-catheterization in community or primary care settings, mostly men with spinal cord injuries; International setting	For the systematic review, the researchers searched MEDLINE, Embase, and Cochrane and CINAHL databases from 2002 to April 18, 2011. Clinical outcomes of interest included symptomatic urinary tract infection (UTI), bacteremia, mortality, patient preference or comfort, and number of catheters used. An economic model was created to determine cost-effectiveness (incremental cost per quality-adjusted life year [QALY] gained) of various interventions and included costs associated with downstream complications of UTI. The final review included eight studies. Most were conducted of patients with spinal cord injuries, and most of the included patients were men. People using gel reservoir and hydrophilic catheters were significantly less likely to report one or more UTIs compared with sterile noncoated catheters (absolute effect for gel reservoir = 149 fewer per 1,000 (95% confidence interval [CI] −7 to 198, p=0.04); absolute effect for hydrophilic = 153 fewer per 1,000 (95% CI −8 to 268, p=0.04). The authors also concluded that there was no difference in the mean monthly number of UTIs (mean difference −0.01; (95% CI −0.11 to 0.09, p=0.84), total number of UTIs at 1 year (mean difference 0.18 (95% CI −0.50 to 0.86, p=0.60), or total antibiotic treatment episodes at 1 year (mean difference −0.88 (95% CI −1.58 to −0.18, p=0.01) for people using hydrophilic coated catheters compared with those using noncoated catheters. There was no statistically significant difference in the incidence of one or more UTIs for people using clean versus sterile noncoated catheters (p=0.86). Although the most effective at reducing UTIs, gel reservoir catheters cost >£54,350 per QALY gained.	The type of catheter used for intermittent self-catheterization seems to make little difference to the risk of symptomatic UTI. The authors concluded that patients should be offered a choice between hydrophilic and gel reservoir catheters due to the limitations and gaps in evidence supporting one over the other. The authors determined that despite the lowered risk of UTI for patients using gel reservoir catheters, these catheters were not cost-effective compared with their counterparts, clear noncoated catheters.	Organisms/ Outcomes: Symptomatic UTI and bacteremia

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Doyle et al., 2011[11]	Multiple patient safety practices: staff education, subclavian central venous catheter (CVC) insertion, alcoholic chlorhexidine gluconate skin antisepsis at insertion site, maximal barrier precautions during CVC care, anti-infective and antimicrobial-impregnated CVC, needleless connectors, biopatch disk, supraglottic suction during ventilation, decontamination of the oropharynx for patients on ventilators, selective decontamination of the digestive tract for patients on ventilators, and semirecumbent positioning during ventilation.	113 ICU outbreak studies from multiple countries, including the United States	Using surveillance data collected in the United States and internationally, article describes contemporary rates, sites, and pathogens responsible for common ICU-acquired infections. Emerging pathogens are outlined, including a systematic review of published ICU infection outbreaks from 2005 to 2010. Multiple PSPs associated with controlling ICU outbreaks are reviewed (see "Description of PSP"). PSPs with mixed evidence: Minocycline-rifampicin and silver or chlorhexidine-silver sulfadiazine-impregnated catheters, and needleless connectors. PSP with supporting evidence: Educating physicians and nurses on central line insertion and care, subclavian insertions versus jugular or femoral sites, maximal barrier precautions at the time of catheter insertion, elevation of beds to 30-45 degrees for patients receiving ventilation, selective decontamination of the digestive tract to prevent ventilator-associated pneumonia, supraglottic suction in endotracheal tubes, chlorhexidine to decontaminate the oropharynx, application of alcoholic chlorhexidine gluconate versus aqueous-based solutions for skin antisepsis at the time of insertion.	The authors identified evidence supporting the use of several PSPs for the control of ICU outbreaks, including those caused by pathogens commonly associated with drug resistance.	Organisms/ Outcomes: Common ICU pathogens, including some commonly associated with drug resistance (e.g., *Staphylococcus aureus, Candida,* and Enterobacteria-ceae species) ICU-acquired infections

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Kidd et al., 2015[9]	Use of urethral (indwelling or intermittent) or suprapubic routes for short-term urinary catheterization	38 studies of hospitalized adults; International setting	This systematic review was conducted by performing a review of trials identified from the Cochrane Central Register of Controlled Trials, and by manually searching journals and conference proceedings. The interventions considered were urethral (indwelling or intermittent) or suprapubic catheterization. Fourteen trials compared indwelling urethral catheterization with intermittent catheterization. Two trials had data for symptomatic UTI and were included in the meta-analysis. Results were not pooled due to inconclusive, poor quality of evidence and clinical and statistical heterogeneity. Suprapubic catheters reduced the number of participants with asymptomatic bacteriuria, recatheterization, and pain compared with indwelling UTI and asymptomatic bacteriuria. The evidence for symptomatic UTI was inconclusive. The evidence was inconclusive for suprapubic versus intermittent urethral catheterization.	The authors determined that adequately powered trials comparing all catheters are required, particularly suprapubic and intermittent urethral catheterization. Some low-quality studies reported increased risk of catheter-associated pain in patients with indwelling urethral catheters compared with suprapubic catheters. The authors could not conclusively determine any increased risk of UTI when comparing indwelling and intermittent urethral catheterization.	Organisms/ Outcomes: No specified organisms Urinary tract infection, adverse events, replacement, duration of use, participant satisfaction, and cost-effectiveness
Meddings et al., 2015[10]	Use of the RAND/UCLA Appropriateness Method to determine the criteria for appropriate use of Foley-catheters, intermittent straight catheters (ISCs), and external condom catheters	30 studies of hospitalized adults and reviews of international guidelines; International setting	The panel rated 105 Foley scenarios (43 appropriate, 48 inappropriate, 14 uncertain), 97 ISC scenarios (15 appropriate, 66 inappropriate, 16 uncertain), and 97 external catheter scenarios (30 appropriate, 51 inappropriate, 16 uncertain). The refined criteria clarify that Foley catheters are appropriate for measuring and collecting urine only when fluid status or urine cannot be assessed by other means; specify that patients in ICUs need specific medical indications for catheters because ICU location alone is not an appropriate indication; and recognize that Foley and external catheters may be pragmatically appropriate to manage urinary incontinence in select patients.	The recommendations and criteria created by this review should be used to inform large-scale collaborative and bedside efforts to reduce inappropriate urinary catheter use.	Organisms/ Outcomes: No specified organisms Any inappropriate use of various types of urinary catheters

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Meddings et al., 2017[8]	Single- or multicomponent intervention including improving appropriate use of urinary catheters, performing aseptic placement, providing maintenance care, and prompting removal of unnecessary catheters, as well as hand hygiene, barrier precautions, infection control strategies, infection surveillance, use of standardized infection definitions, and interventions to improve antibiotic use	20 studies of nursing homes, rehabilitation centers, and spinal cord injury programs, included studies reporting at least one outcome for catheter-associated UTI (CAUTI), UTIs not identified as catheter associated, bacteriuria, or urinary catheter use; International setting	Nineteen studies were included. Many studies were underpowered for the review's outcomes of interest and did not demonstrate any statistically significant change. The only intervention that demonstrated a statistically significant reduction in CAUTI in chronically catheterized patients used a comprehensive program to improve antimicrobial use, hand hygiene (including hand hygiene and gloves for catheter care), and preemptive precautions for patients with devices, along with promotion of standardized CAUTI definitions and active multidrug resistant organism (MDRO) surveillance.	The strength of evidence to motivate catheter avoidance and removal in nursing homes is low compared with other settings. A multicomponent intervention involving antimicrobial use, hand hygiene, and preemptive precautions for patients with devices was the only intervention that statistically significantly reduced CAUTI rates.	Organism/ Outcome: MDROs (general, not specified) Any CAUTI, non-catheter-associated UTI, bacteriuria, or urinary catheter use not associated with an infection

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Patel et al., 2018[5]	For urinary catheters and CVCs, interventions were categorized using a conceptual model, with stages applicable to both CAUTI and CLABSI prevention: avoid catheter if possible (stage 0), ensure aseptic placement (stage 1), maintain awareness and proper care of catheters in place (stage 2), and promptly remove unnecessary catheters (stage 3).	102 randomized and nonrandomized studies that implemented at least one intervention to prevent CLABSI or CAUTI in an adult ICU setting. Review did not include general ward, outpatient/ ambulatory, and neonatal/ pediatric settings. International setting.	The studies that demonstrated the greatest success in preventing CLABSI and CAUTI had several features in common. They often addressed multiple steps within the lifecycle of catheter use (avoidance, insertion, maintenance, and removal). They used auditing to ensure compliance. For CLABSI, they used a checklist as a central quality improvement tool. For CAUTI, engaging a multidisciplinary team including nurse leadership seemed critical to optimize implementation and sustainability efforts. In addition, a focus on stage 3 (removal), including protocols to remove by default, was associated with success in CAUTI studies.	Successful interventions to reduce CAUTI and CLABSI often included multicomponent interventions that addressed all stages of device use, checklists, auditing and monitoring, multidisciplinary teams and nurse leadership, and focus on removal of devices (for CAUTI).	Organisms/ Outcomes: No organisms specified Any CAUTI or CLABSI Studies with interventions that are no longer standard of care in the United States were excluded.

Table B.10: MDROs, Minimizing Catheter Use and Reducing Harm—Single Studies

Note: Full references are available in the Section 5.5 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Ansari et al., 2014[15]	Use of gum arabic capped-silver nanoparticles (GA-AgNPs), as an antimicrobial surface coating material for surgical implants and instruments	Laboratory experiment to assess antimicrobial properties, n=55 isolates	Laboratory, India	The lowest minimum inhibitory concentration (MIC) for extended spectrum beta-lactamase (ESBL), non-ESBL, and metallo-beta-lactamase (MBL) *P. aeruginosa* was determined to be 11.25 µg/mL, demonstrating strong bacteriostatic activity. The minimum bactericidal concentration (MBC) was found to be in the range of 11.25–45 µg/mL, demonstrating bactericidal activity of GA-AgNPs. At a concentration of 30 µg/mL, biofilm formation stopped without affecting the cell viability, whereas at a concentration of 60 µg/mL, the biofilm formation and bacterial growth were stopped.	None assessed.	Results demonstrated that the GA-AgNPs can easily penetrate the biofilm, reduce its formation, and reduce the surface coverage and bacterial colonization.	Low to moderate	Organisms/ Outcomes: Biofilm-forming MDROs (specifically *Pseudomonas aeruginosa*) Bacterial inhibition/ bactericide

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Bayston et al., 2009[16]	Impregnation of continuous peritoneal dialysis catheters using rifampicin, triclosan, and trimethoprim	Laboratory testing of medical-grade silicone sheets and tubing	Laboratory, United Kingdom	The authors concluded that the duration of antimicrobial activity would have lasted longer than 280 days. Bacterial growth was stopped and there were no signs of resistance toward any of the agents for 30 days. Test catheters after 72 hours did not show bacterial migration down the track.	The toxicity of triclosan for anything other than topical use is not well studied, and it may cause inflammation of the peritoneal membrane, leading to adhesions and loss of absorptive capacity. However, this study did not demonstrate any adverse reactions in mice after 7 days or 30 days.	The authors concluded that the antimicrobial substances had a long-lasting ability to kill ~99% of pathogens associated with infection in patients on continuous ambulatory peritoneal dialysis, even after very large challenge doses and that the tested catheters with the tested antimicrobials could resist colonization in flow conditions for prolonged periods.	Moderate to high	Organisms/ Outcomes: Methicillin-resistant/ methicillin susceptible *S. aureus* MRSA/MSSA), *S. epidermidis,* and *E. coli* Bacterial growth

Camus et al., 2014[22]	Administration of polymyxin/ tobramycin/ amphotericin B in the oropharynx and the gastric tube plus a mupirocin/ chlorhexidine body wash regimen in intubated patients and standard care in the other patients	Before-and-after study in ICU patients during two 1-year periods, N=925 before and 1,022 after, ICU patients	21-bed medical ICU at a university-affiliated hospital, France	The comparison of acquired infection rates between groups was adjusted for differences at baseline. Infection rates were lower in the study group compared with the control group (5.3% vs. 11.0%; p <0.001), as were the incidence rates of total acquired infections (9.4 vs. 23.6 per 1,000 patient-days; p<0.001), intubation-related pneumonia (5.1 vs. 17.1 per 1,000 ventilator-days; p<0.001), and catheter-related bloodstream infections (1.0 vs. 3.5 per 1,000 catheter-days; p= 0.03). In the patients who required intubation for less than 48 hours or who were not intubated, infection rates did not decline significantly in the study group (adjusted odds ratio = 0.77, 95% CI 0.35–1.71, p=0.52). Compared with the control group, the study group experienced fewer acquired infections caused by ceftazidime-resistant Enterobacteriaceae (0.8‰ vs. 3.6‰; p<0.001), ciprofloxacin-resistant Enterobacteriaceae (0.8‰ vs. 2.5‰; p=0.02), ciprofloxacin-resistant *P. aeruginosa* (0.5‰ vs. 1.6‰; p=0.05), and colistin-resistant Gram-negative bacilli (0.7‰ vs. 1.9‰; p=0.04). Fewer patients acquired infections due to multidrug-resistant aerobic Gram-negative bacilli (AGNB) (p=0.008 The median length of stay in the ICU was	Other literature suggests there is some increased risk of MRSA with the use of selective digestive decontamination.	In intubated patients, the use of topical polymyxin/ tobramycin/ amphotericin B plus mupirocin/chlorhexidine was associated with the reduction of all-cause ICU-acquired infections. The authors report that the use of selective digestive decontamination (SDD) is still reluctantly accepted due to concerns over the potential induction of antibiotic resistance, which the authors stated is not backed by current evidence. The authors also admitted concerns over the increased risk of MRSA with the use of SDD and over increase in the AGNB tobramycin resistance rate, especially for Enterobacteriaceae and *P. aeruginos*a.	Low to moderate The study controlled for patient characteristics but not antibiotics use.	Organisms/ Outcomes: Ceftazidime-resistant Enterobacteriaceae, ciprofloxacin-resistant Enterobacteriaceae, ciprofloxacin-resistant *P. aeruginosa,* colistin-resistant GNB, and multidrug-resistant AGNB General device-related infections,

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
				similar in the control and study groups (p=0.63).				
Damas et al., 2015[21]	Subglottic suctioning for patients undergoing ventilation	Randomized control trial, n=252, adult patients intubated with a tracheal tube	Five ICUs in a French hospital	Group 1 underwent suction and group 2 was the control group. Ventilator-associated pneumonia occurred in 15 patients (8.8%) of group 1 and 32 patients (17.6%) of group 2 (p = 0.018). In terms of ventilatory days, ventilator-associated pneumonia rates were 9.6 of 1,000 ventilatory days and 19.8 of 1,000 ventilatory days, respectively (p = 0.0076). The total number of antibiotic days was 1,696 in group 1, representing 61.6% of the 2,754 ICU days, and 1,965 in group 2, representing 68.5% of the 2,868 ICU days (p < 0.0001).	None assessed.	Subglottic secretion suctioning resulted in a significant reduction of ventilator-associated pneumonia prevalence associated with a significant decrease in antibiotic use. By contrast, ventilator-associated condition occurrence did not differ between groups and appeared more related to other medical features than ventilator-associated pneumonia.	Low	Organisms/ Outcomes: Organisms not specified Ventilator-associated pneumonia, ICU length of stay, days of antibiotic use, days of ventilation

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Dixon et al., 2012[12]	Use of antimicrobial lock (AML) solutions with systemic antibiotics for patients with tunneled hemodialysis catheters	Retrospective cohort study, controls (n=265) and study group (n=662), all catheter-related blood stream infections (CR-BSI).	Renal and trans-plantation center and its five regional satellite units, United Kingdom	This study analyzed antibiotic sensitivity/ resistance profiles of MRSA, vancomycin-resistant *Enterococci* (VRE), resistant *Escherichia coli*, resistant *Pseudomonas* species, and resistant *Enterobacter* species, and changes in the incidence of infection (chi-square test) and resistant organisms (Fisher's exact test). The incidence of CR-BSI decreased from 8.50/1,000 catheter-days (controls) to 3.80 (study group; p<0.0001), and the incidence of relapses decreased from 13.2% to 6.8% (p=0.0027). The proportion of MRSA (p=0.87) and VRE (p=0.90) did not increase.	The proportion of gram-positive cultures increased (p<0.0001), including *S. aureus* (p=0.03). Gentamicin resistance (relative risk [RR] >15.29; p<0.0001) and ciprofloxacin resistance (RR = 6; p=0.007) increased in *Enterobacter* species, but not *Pseudomonas* or *E. coli* species.	Overall, the incidence of CR-BSI and CR-BSI relapses decreased statistically significantly in the study group compared with the control group. A statistically significant increase in Gram-positive cultures and an increase in gentamicin and ciprofloxacin resistance in *Enterobacter* species was also observed.	Moderate–low The study did not control for patient character-istics or antibiotic treatment.	Organisms/ Outcomes: MRSA, VRE, resistant *E. coli,* resistant *Pseudomonas* species, resistant *Enterobacter* species CR-BSI

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Mody et al., 2017[7]	Multicomponent intervention that included a technical bundle involving urinary catheter removal, aseptic insertion, regular assessments, training for catheter care, and incontinence care planning, as well as a socioadaptive bundle emphasizing leadership, resident and family engagement, and effective communication	Before-and-after study of 404 nursing homes	Community-based nursing homes across 48 States, DC, and Puerto Rico	The unadjusted catheter-associated UTI (CAUTI) rates decreased from 6.78 to 2.63 infections per 1,000 catheter-days. With use of the regression model and adjustment for facility characteristics, the rates decreased from 6.42 to 3.33 (incidence rate ratio [IRR], 0.46; 95% CI 0.36 to 0.58, p<0.001). Catheter utilization dropped from 4.5% at baseline to 4.9% at the end of the intervention. Catheter utilization remained unchanged (4.50 at baseline, 4.45 at conclusion of project; IRR, 0.95; 95% CI 0.88 to 1.03, p=0.26) in adjusted analyses. The number of urine cultures ordered for all residents decreased from 3.49 per 1,000 resident-days to 3.08 per 1,000 resident-days. Similarly, after adjustment, the rates were shown to decrease from 3.52 to 3.09 (IRR, 0.85; 95% CI 0.77 to 0.94; p=0.001).	None assessed.	The intervention, which combined technical and socioadaptive interventions, successfully reduced the incidence of CAUTIs but did not decrease catheter utilization in either the adjusted or unadjusted analysis. Possible explanations for this finding include that utilization rates were already low in the nursing homes at the start of this project. In addition, with catheter use being a CMS publicly reported measure since 1990, nursing homes have had several decades to improve their practice of discontinuing the use of clinically unnecessary catheters.	Low to moderate	Organisms/ Outcomes: Organisms not specified Any CAUTI

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Olthof et al., 2012[13]	Long-term taurolidine catheter locking use in patients on home parenteral nutrition	Retrospective cohort study, n=158, home parenteral nutrition patients	Patient homes, Netherlands	Between January 2009 and April 2011, 14 patients developed at least one CR-BSI episode during long-term taurolidine catheter locking (median [range] = 451 [78-1,394] days). Coagulase-negative *Staphylococcus* species or *S. aureus* were the most common CR-BSI-causing Gram-positive bacteria. Taurolidine MICs were 512 mg/L or less in 50% of these isolates (MIC_{50}). Taurolidine MIC_{50} among CR-BSI-causing *Candida albicans* was 2,048 mg/L.	The effectiveness of taurolidine on the development of biofilms, prevention of Gram-positive bacteria, and prevention of fungi has not been well studied.	Long-term use of taurolidine seems to be safe for up to 1,394 days of taurolidine catheter locking. Increased taurolidine resistance was most notably observed in *C. albicans*. The authors recommended additional research on the mechanism of the antiseptic effect of taurolidine on Gram-positive bacteria to provide insight on why patients who use taurolidine still occasionally develop CR-BSI.	Moderate	Organisms/ Outcomes: CR-BSI-causing Gram-positive bacteria and taurolidine resistance CR-BSI

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Raad et al., 2008[19]	The use of CVCs impregnated with: minocycline and rifampicin (M/R), silver-platinum and carbon (SPC), and chlorhexidine and silver sulfadiazine (CHX/SS)	Laboratory testing using "established biofilm colonization model"	Laboratory, United States	By measuring colony forming units (CFUs)/cm, the authors determined M/R catheters had superior antiadherence activity and more prolonged antimicrobial durability compared with CHX/SS-CVCs, SPC-CVCs, and uncoated control catheters for preventing biofilm formation of MDR and vancomycin-resistant *S. aureus* ($p<0.02$), MDR *S. maltophilia* ($p<0.005$), and MDR *A. baumannii/calcoaceticus* ($p<0.002$). M/R-CVCs and CHX/SS-CVCs did not vary statistically in their antiadherence properties or antimicrobial durability against MDR *E. agglomerans*. However, they were superior to SPC-CVCs and the uncoated control catheters ($p<0.001$).	None assessed.	M/R-CVCs were superior in antiadherence activity and prolonged antimicrobial durability for MDR and vancomycin-resistant *S. aureus*, MDR *S. maltophilia*, and MDR *A. baumannii/ calcoceticus.* For MDR *E. agglomerans*, M/R-CVCs and CHX/SS-CVCs were both statistically significantly superior to SPC-CVCs and uncoated control catheters.	Moderate to high	Organisms/ Outcomes: MDR *S. aureus* and MDR Gram-negative bacteria Bacterial adherence

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Raad et al., 201217	The use of second-generation CVCs impregnated with minocycline and rifampicin (M/R) + chlorohexidine (CHX)	Laboratory testing using "established biofilm colonization model"	Laboratory, United States	CHX-M/R CVCs were the only antimicrobial catheters that completely inhibited the biofilm colonization of all resistant bacterial and fungal organisms tested. In terms of CFUs/cm segment of the catheter, they were superior to uncoated catheters (p<0.003). CHX-M/R-coated CVCs had a significantly more effective and prolonged (up to 3 weeks) antimicrobial activity against MRSA and *P. aeruginosa* than M/R, CHX/SS, and uncoated CVCs (p< 0.0001). CHX-M/R-coated peripherally inserted central catheters (PICCs) also showed statistically significant reductions in biofilm formation compared with M/R-coated and CHX-coated PICCs for MRSA, VRE, *P. aeruginosa*, and *Candida* species (p<0.003).	M/R and CHX/SS CVCs both demonstrated limited effectiveness against MDR *P. aeruginosa* (in this study) and *Candida* (in other literature).	The authors concluded that CHX-M/R-coated catheters more effectively reduced biofilm colonization and had prolonged efficacy against colonization of MRSA, VRE, *P. aeruginosa*, and fungi in a manner superior to that of M/R- and chlorhexidine-treated catheters.	Moderate to high	Organisms/ Outcomes: MRSA, VRE, *P. aeruginosa, C. albicans,* and *C. glabrata* Biofilm colonization
Ramos et al., 2011[20]	Use of CVCs coated with minocycline and rifampicin (M/R)	Retrospective cohort study, n=8,009, all patients admitted between 1999 and 2006	Tertiary care university-affiliated hospital and ICU, United States	The incidence of central line-associated bloodstream infection (CLABSI) per 1,000 patient-days in the medical ICU significantly and gradually decreased from 8.3 in 1998 to 1.2 in 2006 (p<0.001). The resistance *of S. aureus* and coagulase negative *Staphylococci* clinical isolates to tetracycline or rifampin remained stable or decreased significantly during the same period.	None assessed.	There was a statistically significant decrease in CLABSIs over the 8-year study period after the introduction of CVCs coated with M/R. However, other interventions were occurring at the same time. Authors suggest a prospective study in the future.	Moderate	Organisms/ Outcomes: *Staphyloccoci*, *S. aureus* CLABSI and resistance to tetracycline and rifampin in clinically relevant *Staphylococcal* isolates

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Saint et al., 2016[24]	Use of the Comprehensive Unit-based Safety Program, which included education of sponsor organizations and hospitals, data collection, and education on technical and socioadaptive factors for CAUTI prevention.	Before-and-after study, 962 units in 603 hospitals, both ICU and non-ICU units	Hospital units in 32 of the United States, DC, and Puerto Rico	Program recommendations included assessing daily the presence and need for an indwelling urinary catheter, considering alternative urine-collection methods to avoid catheter use, emphasizing the importance of aseptic technique during insertion and proper maintenance after, providing units feedback regarding urinary catheter use and CAUTI rates, and addressing gaps in knowledge of urinary management processes. The unadjusted CAUTI rate decreased overall from 2.82 to 2.19 infections per 1,000 catheter-days. In an adjusted analysis, CAUTI rates decreased from 2.40 to 2.05 infections per 1,000 catheter-days (IRR, 0.86; 95% CI 0.76 to 0.96, p=0.009) Among non-ICUs, catheter use decreased from 20.1% to 18.8% (IRR, 0.93; 95% CI 0.90 to 0.96, p<0.001), and CAUTI rates decreased from 2.28 to 1.54 infections per 1,000 catheter-days (IRR, 0.68; 95% CI 0.56 to 0.82, p<0.001). Catheter use and CAUTI rates were largely unchanged in ICUs. Tests for heterogeneity (ICU vs. non-ICU) were significant for catheter use (p=0.004) and CAUTI rates (p=0.001).	None assessed.	The national prevention program reduced catheter use and CAUTI rates in non-ICUs. Similar effects were not seen in ICUs. One possible explanation is that patients who are ill enough to warrant admission to the ICU require close monitoring of urine output, which is an appropriate criterion for indwelling urinary catheters.	Low to moderate	Organisms/ Outcomes: Any CAUTI

Table B.11: MDRO, Status Communication—Systematic Reviews

Note: Full references are available in the Section 5.6 reference list.

Author, Year	Description of Patient Safety Practice	Setting/s, Population/s	Summary of Systematic Review Findings	Implementation Themes/Findings	Notes
Tacconelli, 2014[6]	Use of an alert code upon admission for carriers of multidrug-resistant Gram-negative bacteria (MDR-GNB)	Acute care facilities, Germany	These evidence-based guidelines were produced after a systematic review of published studies on infection prevention and control interventions aimed at reducing the transmission of MDR-GNB. Recommendations include an alert code for previously known positive patients/known carriers to perform screening and preemptive contact precautions (CPs) (for epidemic settings of MDR *Klebsiella*. There is also a moderate level of evidence to implement alert codes in endemic settings of MDR *Acinetobacter*. Before transferring patients to other healthcare facilities (acute and non-acute care), facilities should ensure communication of infection/colonization status.	Moderate evidence was defined as: We are moderately confident in the effect estimate. The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.	Organisms/ Outcomes: MDR-GNB Includes guidelines and recommendations

Table B.12: MDRO, Status Communication—Single Studies

Note: Full references are available in the Section 5.6 reference list.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Andersen, 2013[4]	Multicomponent intervention: Bedpost sign, leaflet for front page of patient file, ordering procedures with prompt questions about isolation requirements, rapid involvement of infection control nurses with same-day visits of new extended-spectrum beta lactamase (EBSL) cases	Prospective, interrupted time series, all patients in hospital more than 3 years	510-bed Danish university hospital	Reported significant reduction in cefuroxime consumption (74.5%). Other results were not statistically significant: reductions such as ciprofloxacin (8.9%, p=.7); the rate of isolated EBSL *Klebsiella pneumoniae* (ESBL-KP), which decreased from 39.5% to 22.5%; and the incidence of infections with ESBL-KP, which showed a special cause pattern (nonrandom variation) indicative of a decrease. Reduced use of isolation precautions: number of isolated patients per 1,000 occupied bed-days (OBDs) declined from 0.94 (95% CI 0.74 to 1.14) to 0.65 (95% CI 0.43 to 0.87), p=0.021, for ESBL and did not change for non-ESBL causes. Isolation days per 1,000 OBDs decreased from 13.8 (95% CI 8.6 to 19.0) to 7.1 (95% CI 3.4 to 10.8) for ESBL, and from 42.8 (95% CI 30.8 to 54.7) to 28.6 (95% CI 22.0 to 35.3) for non-ESBL, p=0.0032.	None assessed.	Multidisciplinary discussion led to decision that isolation precaution policy and coordination with sections that provide transverse services needed to be improved. It also led to collective learning and collaboration and system thinking. Initial cross-sectional study in three wards determined carrier prevalence. Rollout of changes included informing staff and ward managers of new changes and their goals, newsletters and diagrams of resistance rates, and later CUSUM charts.	Low to moderate	Organisms/ Outcomes: ESBL-KP Cefuroxime consumption, ciproflaxin consumption, EBSL-KP infections

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Ariza-Heredia, 2012[10]	Interfacility communication for organ transplants from MDRO carriers. All interfacility communication occurred before organ transplantation into recipients and appropriate preventive strategies were implemented (contact isolation for those with positive cultures and preemptive pathogen-directed antibiotic treatment in all cases).	Case study on transplant recipients receiving organs/tissue from one donor with *Klebsiella pneumoniae* carbapenemase-producing *K. pneumoniae* (KPC-KP).	Four hospitals, United States	All transplant recipients had good short-term outcomes.	One-half (two of four) recipients developed KPC-KP infections.	Cases were promptly reported to Organ Procurement and Transplantation Network (OPTN) and there was prompt interinstitutional communication. OPTN/United Network for Organ Sharing (UNOS) has a policy requiring the prompt sharing of culture results between centers and organ procurement organizations, and potential donor-derived infections are tracked by the OPTN/UNOS through the Ad Hoc Disease Transmission Advisory Committee.	Moderate to high	Organisms/ Outcomes: KPC-KP KPC-KP infections

Buser, 2017[8]	Interfacility communication upon admission and transfer	Outbreak study, 21 cases, residents and patients in skilled nursing facilities (SNFs), long-term acute care hospitals (LTACHs), and acute care hospitals (ACHs). Reviewed medical records and surveillance surveys and used pulsed-field gel electrophoresis (PFGE) and molecular analysis. Six large, hospital-based, clinical microbiology laboratories processing ~90% of OR clinical microbiology specimens.	Multi-facility outbreak in Oregon	Twenty-one cases were identified that were highly related by PFGE or healthcare facility exposure. Overall, 17 patients (81%) were admitted to either LTACH A (n = 8), or SNF A (n = 8), or both (n = 1) prior to XDR *A. baumannii* (XDR-AB) isolation. Interfacility communication of patient or resident XDR status was not performed during transfer between facilities.	Outbreak attributed to lack of communication among facilities, despite Oregon Public Health Department recommendations.	An outbreak linked to SNF A was suspected, so they launched what became a multifacility investigation to determine the scope of the problem, identify a source, and intervene to prevent further spread. Index case was transferred to SNF A, status was not communicated, and eight more carriers were identified over 25 months. Other hospitalizations and transfers of other cases were associated with additional transmission. OPHD assisted facilities to develop a form and process for interfacility communication during admission and transfer. Outbreak was only detected because of a voluntary surveillance system. Recommend timely and transparent communication to allow rapid contact precautions. Inspired creation of Oregon Administrative Rule 333-019-0052, which mandates written communication of MDRO status for interfacility patient transfer, effective January 1, 2014.	Moderate to high	Organism: XDR-AB XDR-AB cases
Chou, 2008[16]	Implementation of antimicrobial resistance	Cross-sectional survey, 448	Hospitals represented in the	Formalization, standardization, centralization, institutional	None assessed.	Research found formalization and standardization may	Moderate	Organisms/ Outcomes:

	(AMR) prevention and control strategies	infection control professionals	2001 American Hospital Association Annual Survey	culture, provider–management communication, and information technology use were associated with optimal antibiotic use and enhanced implementation of strategies that prevent and control antimicrobial resistance spread (all p<0.001). However, interdepartmental coordination for patient care was inversely related with antibiotic use in contrast to antimicrobial resistance spread prevention and control (p<0.0001). Multiple structural and process factors were associated with the implementation of AMR prevention and control strategies, including feedback on hand hygiene compliance (p<0.0001), distribution of copies of the policy to providers (p=0.03), use of forms to enhance infection control adherence (p=0.0008), administrator-directed infection control activities (p<0.0001), availability of decision support (p<0.0001), a culture of data-driven decision making (p<0.0001), communication of AMR trends to physicians (p<0.0001), and interdepartmental coordination of patient care (p<0.0001).		eliminate staff role conflict, whereas centralized authority may minimize ambiguity. Culture and communication likely promote internal trust, whereas information technology use helps integrate and support these organizational processes. These findings suggest concrete strategies for evaluating current capabilities to implement effective practices and foster and sustain a culture of patient safety.		No organisms specified Self-reported hospital factors associated with implementation of AMR prevention and control strategies
Miller et al., 2015[11]	Accurate and timely (<72 hours)	Retrospective cohort study, n=56 infection	United States organ	None assessed.	Eighteen IEs (48 recipients) were associated with	Communication failures can occur at multiple levels in organ	Moderate to high	Organisms/ Outcomes:

	communication of infections in donated organs from the donor center, to organ procurement organizations (OPOs), to the recipient center	events (IEs), donor-derived transmission events over 2 years	donor centers, OPOs, and recipient centers, United States		communication gaps, of which 12 resulted in adverse effects in 69% of recipients (20/29), including 6 deaths. When IEs and test results were reported without delay, appropriate interventions were taken, subsequently minimizing or averting recipient infection (23 IEs, 72 recipients). Communication errors included: the transplant center delayed contacting the OPO or OPTN with a suspected donor-derived infection, the laboratory failed to relay donor results (including autopsy results) to the OPO and/or transplant center, an OPO delayed contacting OPTN or transplant centers, clerical errors occurred in reporting donor viral serologies, and the OPO provided incomplete communication of test results to transplant centers.	transplant processes. These failures often result in poor patient outcomes, including death. These results warrant education of all involved clinicians on existing communication policies and continuous evaluation of current failures in the communication process to refine the policies. The authors also recommend future actions to require expedited donor autopsies with reporting of findings to OPOs, as well as safeguards to prevent clerical errors in the reporting of donor serologies.		No organisms specified Transplant-related MDR infections
Mularoni, 2015[13]	Communication of MDRO status	Retrospective cohort study,	Italy	Transmission did not occur in high-risk recipients who	In a 2-year period, 30/214 (14%)	The safe use of organs from donors with	Low to moderate	Organisms/ Outcomes:

	during organ donation	214 recipients and 170 deceased donors, all extraintestinal cultures from deceased donors whose organs were transplanted between January 1, 2012, and December 31, 2013; seven case studies		received appropriate and prompt antibiotic therapy for at least 7 days.	recipients received an organ from 18/170 (10.5%) deceased donors with infection or colonization caused by carbapenem-resistant gram-negative bacteria that was unknown at the time of transplantation. Among them, 14/30 recipients (47%) received a transplant from a donor with bacteremia or with infection/colonization of the transplanted organ and were considered at high risk of donor-derived infection at the time of transmission. Also, 16/30 (53%) recipients received an organ from a nonbacteremic donor with colonization of a nontransplanted organ and were considered at low risk of infection transmission. Proven transmission occurred in 4 of the 14 high-risk recipients because donor infection was	multidrug-resistant bacteria requires intra- and interinstitutional communication to allow appropriate management and prompt treatment of recipients to avoid transmission of infection. The authors recommend that donor culture results always be reviewed in the first few days after transplantation to allow prompt antibiotic treatment. Another type of error that contributed to donor-derived infection transmission was the inappropriate treatment resulting from the underestimation of the risk of donor MDR transmission. A thorough review of donor cultures and uniform protocols of antibiotic treatment for recipients of organs from donors infected with MDR bacteria have now been implemented at the studied institution.		Carbapenem-resistant Gram-negative bacteria Donor-derived infections Includes definitions of low and high risk of donor-derived infection transmission in text. Also discusses Italian guidelines for quality and safety of organs for transplantation.

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
					not recognized, was underestimated, or was not communicated. These recipients received late, short, or inappropriate post-transplant antibiotic therapy.			
Ong & Coiera, 2010[2]	Accurate use of transfer form and patient identity verification during transport	Prospective observational study, n=101, inpatient transfers to radiology unit over a 6-month period	Australian teaching hospital	None assessed.	No incidents of patient harm were recorded. Inadequate handover was the most common transfer error (43.1%), followed by failure to perform patient identification checks (41.9%). Inadequate infection control precautions also occurred 2.9% of the time.	Analysis of the transfer process revealed numerous redundancies that safeguard against transfer errors. However, they were relatively ineffective in preventing errors, due to the poor compliance rate. Thus, the authors advocate increasing compliance to existing redundant processes as an improvement strategy, before investing resources on new processes.	Moderate to high	Organisms/ Outcomes: No organisms specified Transfer process measures (handover, infection control practices, patient identification)

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Ong et al, 2013[3]	The use of a pretransfer checklist used by radiology porters to confirm a patient's infectious status or the use of a colored cue to highlight written infectious status information in the transfer form	Randomized crossover trial, 300 transfers over 4 months, inpatient transfers between wards and radiology	Australian teaching hospital	Compliance with infection control precautions in the intervention groups was significantly improved relative to the control group ($p<0.01$). Adherence rate in the control group was 38%. Applying the colored cue resulted in a compliance rate of 73%. The pretransfer checklist intervention achieved a comparable compliance rate of 71%. When the two methods were combined, a compliance rate of 74% was attained. Acceptability of the colored cue was high, but adherence to the checklist was low (40%).	The checklist was not well received by some porters, who rejected its use. The checklist was only implemented 40% of the time.	Both interventions demonstrated an improvement in infection control precautions compared with the control group. However, the colored cue was better received by staff, and the checklist was only implemented in 40% of the transfers.	Moderate to high	Organisms/ Outcomes: No organisms specified Rate of compliance with a pre-transfer checklist

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
Palmore, 2013[5]	Communication of patient status during a carbapenem-resistant *Klebsiella pneumoniae* (CR-KP) outbreak as part of a multicomponent intervention, which also included surveillance, cohorting, hand hygiene, chlorhexidine baths, adherence monitoring, isolation precautions, and attention to the details of environmental decontaminatio n	Outbreak study, n=17 infected or colonized, severely immuno-compromised patients	Clinical research center (NIH Clinical Center), Bethesda, Maryland	Temporal association between implementation of infection control interventions and mitigation of the outbreak.	The authors noted "unintended consequences of publication"—incomplete information was distributed to other NIH staff and the public that created fear and concerns. The strong reaction and "kitchen sink" approach to stemming this outbreak may have contributed to the heightened sense of fear among people who were largely not at risk.	Weekly, multidisciplinary meetings were held to discuss new developments, interventions, and investigative findings. The meetings allowed for comments/questions and education. Daily staff meetings were implemented to discuss outbreak investigation and control. Hospital epidemiologists and infection preventionists made dozens of presentations at a variety of events. Email notifications provided status updates, and infection control reminders were distributed to all clinical staff when new information was available and every few weeks. Information was distributed regarding enhanced contact precautions and active surveillance. An info sheet was included in admission materials about the risk of nosocomial MDROs.	High Small case series; study does not control for each component	Organisms/ Outcomes: CR-KP CR-KP cases

Pfeiffer, 2014[15]	Developing a statewide network for carbapenem-resistant Enterobacteriaecea (CRE) prevention	Implementation case study. Cross-sectional surveys and guidance from interdisciplinary advisory committee, statewide	Oregon infection prevention and microbiology laboratory personnel, including 48 microbiology laboratories, 62 acute care facilities, and 140 long-term care facilities	The DROP-CRE working group, comprising representatives from academic institutions and public health, convened an interdisciplinary advisory committee to assist with planning and implementation of CRE epidemiology and control efforts. The working group established a statewide CRE definition and surveillance plan; increased the State laboratory capacity to perform the modified Hodge test and polymerase chain reaction for carbapenemases in real time; and administered surveys that assessed the needs and capabilities of Oregon infection prevention and laboratory personnel. Results of these inquiries informed CRE education and the response plan, the Oregon CRE Toolkit (a state specific CRE guide booklet). Of 60 CRE cases reported from November 2010 through April 2013, only 3 were identified as carbapenemase producers; the cases were not linked, and no secondary transmission was found. Microbiology laboratories, acute care facilities, and long-term care facilities reported lacking carbapenemase testing capability, reliable interfacility communication, and CRE awareness, respectively.	None assessed.	Needs assessment surveyed microlaboratories and infection preventionists in acute care facilities, and LTCFs. 50% and 78% of laboratories "flagged" carbapenem-resistant organisms and ESBLs in the medical records, respectively; 68% of labs included MICs in the susceptibility report. Actions taken when MDR Enterobacteriaceae were encountered included notifying infection control (44%), notifying the nursing station (44%), generating an automated report on the medical record (42%), notifying the ordering physician (33%), and no further action (14%). For acute care facilities, only 58% of respondents agreed that their facility was made aware of patient MDRO status at admission to the hospital. In contrast, 82% believed that the receiving facility was made aware of patient MDRO status at discharge from the hospital. For LTCFs, 79% of respondents stated that their transfer documents indicated MDRO infection or	Moderate to high	Organisms/ Outcomes: CRE Survey of CRE communication practices

Author, Year	Description of Patient Safety Practice	Study Design; Sample Size; Patient Population	Setting	Outcomes: Benefits	Outcomes: Harms	Implementation Themes/Findings	Risk of Bias (High, Moderate, Low)	Comments
						colonization status upon release to other levels of care, and 75% said MDRO status was documented for residents transferred into their facility.		
Trick, 2015[14]	Use of a statewide web-based registry of XDROs	Cross-sectional survey after implementation of statewide registry, 1,557 reports during the first year, 173 facilities	Illinois, ACHs, LTACHs, LTCFs, reference labs	Here, 55% of 21 hospitals and 43% of 7 LTACHs had queried the status of a CRE-unknown patient. Two (29%) of seven LTACHs queried all patients on admission.	Time-consuming manual queries and entry, no explicit consent required from patients.	Most ACHs did not routinely query (59%) or queried occasionally (32%); none queried every admitted patient. Nearly all (96%) hospitals expressed interest in automated CRE alerts.	Moderate to high	Organisms/ Outcomes: CRE CRE reporting and report review

Appendix C. Multidrug-Resistant Organisms Search Terms

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
Search 2008-Present, English Only MedLine Publication Types: • Clinical Trial • Clinical Trial, Phase I • Clinical Trial, Phase II • Clinical Trial, Phase III • Clinical Trial, Phase IV • Comparative Study • Controlled Clinical Trial • Corrected and Republished Article • Evaluation Studies • Guideline • Journal Article • Meta-Analysis • Multicenter Study	Hand Hygiene	(((MH "Drug Resistance, Microbial"OR MH "Drug Resistance, Multiple") OR (AB "Microbial Drug Resistance" OR "Bacterial Drug Resistance")) AND ((MH Handwashing) OR (AB Handwashing OR "Hand Washing" OR "Hand Sanitization" OR "Hand Hygiene" OR "Hand Disinfection")))	(((MH "Drug Resistance, Microbial" OR MH "Drug Resistance, Multiple, Bacterial") OR (AB "Microbial Drug Resistance" OR "Bacterial Drug Resistance")) AND ((MH "Hand Hygiene" OR MH "Hand Disinfection") OR (AB Handwashing OR "Hand Washing" OR "Hand Sanitization" OR "Hand Hygiene" OR "Hand Disinfection")))

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Practice Guideline • Published Erratum • Randomized Controlled Trial • Review • Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines • Randomized Controlled Trial • Research Review • Systematic Review			

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
Search 2008-Present, English Only MedLine Publication Types: • Clinical Trial • Clinical Trial, Phase I • Clinical Trial, Phase II • Clinical Trial, Phase III • Clinical Trial, Phase IV • Comparative Study • Controlled Clinical Trial • Corrected and Republished Article • Evaluation Studies • Guideline • Journal Article • Meta-Analysis • Multicenter Study • Practice Guideline	Surveillance	(((MH “Infection Control”) OR (AB “Infection Control” OR “Infection Prevention”)) AND ((MH “Drug Resistance, Microbial” OR MH “Drug Resistance, Multiple”) OR (AB “Microbial Drug Resistance” OR “Bacterial Drug Resistance”)) AND (AB “Monitoring” OR “Surveillance” OR "Monitoring and Surveillance")	((MH “Infection Control”) OR (AB “Infection Control” OR “Infection Prevention”)) AND ((MH “Drug Resistance, Microbial” OR “Drug Resistance, Multiple, Bacterial”) OR (AB “Microbial Drug Resistance” OR “Bacterial Drug Resistance”)) AND (AB Monitoring OR Surveillance OR "Monitoring and Surveillance")))

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Published Erratum • Randomized Controlled Trial • Review • Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines • Randomized Controlled Trial • Research Review • Systematic Review			

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
Search 2008-Present, English Only MedLine Publication Types: • Clinical Trial • Clinical Trial, Phase I • Clinical Trial, Phase II • Clinical Trial, Phase III • Clinical Trial, Phase IV • Comparative Study • Controlled Clinical Trial • Corrected and Republished Article • Evaluation Studies • Guideline • Journal Article • Meta-Analysis • Multicenter Study • Practice Guideline	Minimize Use of Devices	(((MH “Infection Control”) OR (AB “Infection Control” OR “Infection Prevention”)) AND ((MH “Drug Resistance, Microbial” OR MH “Drug Resistance, Multiple”) OR (AB “Microbial Drug Resistance” OR “Bacterial Drug Resistance”)) AND ((MH Catheters or MH “Catheter-Related Infections”) OR (AB Catheter* OR “Catheter Related Infection*” OR “Catheter-Related Infection*” OR “Endotracheal Tubes” OR “Cannula*”)))	(((MH “Infection Control”) OR (AB “Infection Control” OR “Infection Prevention”)) AND ((MH “Drug Resistance, Microbial” OR MH “Drug Resistance, Multiple”) OR (AB “Microbial Drug Resistance” OR “Bacterial Drug Resistance”)) AND ((MH Catheters or MH “Catheter-Related Infections”) OR (AB Catheter* OR “Catheter Related Infection*” OR “Catheter-Related Infection*” OR “Endotracheal Tubes” OR Cannula*)))

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Published Erratum • Randomized Controlled Trial • Review • Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines • Randomized Controlled Trial • Research Review • Systematic Review			

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
Search 2008-Present, English Only MedLine Publication Types: • Clinical Trial • Clinical Trial, Phase I • Clinical Trial, Phase II • Clinical Trial, Phase III • Clinical Trial, Phase IV • Comparative Study • Controlled Clinical Trial • Corrected and Republished Article • Evaluation Studies • Guideline • Journal Article • Meta-Analysis • Multicenter Study • Practice Guideline	Chlorhexidine Bathing	((MH "Drug Resistance, Microbial" OR MH "Drug Resistance, Multiple") OR (AB "Microbial Drug Resistance" OR "Bacterial Drug Resistance")) AND ((MH Chlorhexidine) OR AB (Chlorhexidine AND Bathing OR Bath*)))	(((MH "Drug Resistance, Microbial" OR MH "Drug Resistance, Multiple") OR (AB "Microbial Drug Resistance" OR "Bacterial Drug Resistance")) AND ((MH Chlorhexidine) OR (AB Chlorhexidine AND Bathing OR Bath*)))

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Published Erratum • Randomized Controlled Trial • Review • Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines • Randomized Controlled Trial • Research Review • Systematic Review			

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
Search 2008-Present, English Only MedLine Publication Types: • Clinical Trial • Clinical Trial, Phase I • Clinical Trial, Phase II • Clinical Trial, Phase III • Clinical Trial, Phase IV • Comparative Study • Controlled Clinical Trial • Corrected and Republished Article • Evaluation Studies • Guideline • Journal Article • Meta-Analysis • Multicenter Study • Practice Guideline	Communication of MDRO Status	(((MH “Drug Resistance, Microbial” OR MH “Drug Resistance, Multiple”) OR (AB “Microbial Drug Resistance” OR “Bacterial Drug Resistance”)) AND ((MH “Communication”) OR (AB “Information Sharing” “Information Dissemination” OR “Communication”)))	(((MH “Drug Resistance, Microbial” OR MH “Drug Resistance, Multiple, Bacterial”) OR (AB “Microbial Drug Resistance” OR “Bacterial Drug Resistance”)) AND ((MH “Information Dissemination" OR MH “Communication”) OR (AB “Information Sharing” “Information Dissemination” OR “Communication”)))

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Published Erratum • Randomized Controlled Trial • Review • Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines • Randomized Controlled Trial • Research Review • Systematic Review			

Method	Search	Search String for: CINAHL	Search String for: MEDLINE
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Method	Search	Search String for: CINAHL	Search String for: MEDLINE
• Published Erratum • Randomized Controlled Trial • Review • Scientific Integrity Review • Technical Report • Twin Study • Validation Studies CINAHL Publication Types: • Clinical Trial • Corrected Article • Journal Article • Meta-Analysis • Meta Synthesis • Practice Guidelines • Randomized Controlled Trial • Research Review • Systematic Review			