Evidence Report/Technology Assessment
Number 208

6. Prevention of Healthcare-Associated Infections

Closing the Quality Gap: Revisiting the State of the Science

Executive Summary

Background

The Centers for Disease Control and Prevention (CDC) define a healthcare-associated infection (HAI) as:

[A] localized or systemic condition resulting from an adverse reaction to the presence of an infectious agent(s) or its toxin(s). There must be no evidence that the infection was present or incubating at the time of admission to the acute care setting.[1]

The CDC estimates that in 2002 there were 1.7 million HAI and 99,000 HAI-associated deaths in hospitals. The four largest categories of HAI, responsible for more than 80 percent of all reported HAI, are central line–associated bloodstream infections (CLABSI, 14%), ventilator-associated pneumonia (VAP, 15%), surgical site infections (SSI, 22%), and catheter-associated urinary tract infections (CAUTI, 32%).[2]

In a CDC report, national costs of HAI were estimated, based on 2002 infection rates and adjusted to 2007 dollars using the Consumer Price Index for inpatient hospital services. Estimates of the total annual direct medical costs of HAI for U.S. hospitals ranged from $35.7 billion to $45 billion. Using the same adjustment, the estimates of patient hospital costs for the four most common HAI ranged from $3.45 billion to $10.07 billion for SSI, $0.67 billion to $2.68 billion for CLABSI, $1.03 billion to $1.50 billion for VAP, and

Evidence-based Practice Program

The Agency for Healthcare Research and Quality (AHRQ), through its Evidence-based Practice Centers (EPCs), sponsors the development of evidence reports and technology assessments to assist public- and private-sector organizations in their efforts to improve the quality of health care in the United States. The reports and assessments provide organizations with comprehensive, science-based information on common, costly medical conditions and new health care technologies. The EPCs systematically review the relevant scientific literature on topics assigned to them by AHRQ and conduct additional analyses when appropriate prior to developing their reports and assessments.

AHRQ expects that the EPC evidence reports and technology assessments will inform individual health plans, providers, and purchasers as well as the health care system as a whole by providing important information to help improve health care quality.

The full report and this summary are available at www.effectivehealthcare.ahrq.gov/reports/final.cfm.

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Evidence-Based Practice

$0.39 billion to $0.45 billion for CAUTI.[3] It is estimated that the cost savings of preventing 70 percent of HAI would be $25.0 billion to $31.5 billion, using the same adjustments.[3]

The prevention and reduction of HAI is a top priority for the U.S. Department of Health and Human Services (www.cdc.gov/HAI/prevent/prevention.html). A call to action for the elimination of HAI has been issued jointly by the Association for Professionals in Infection Control and Epidemiology, Inc., the Society for Healthcare Epidemiology of America, the Infectious Diseases Society of America, the Association of State and Territorial Health Officials, the Council of State and Territorial Epidemiologists, the Pediatric Infectious Diseases Society, and the CDC.[4] In a consensus statement issued by these groups, a plan for the elimination of HAI includes the promotion of adherence to evidence-based practices through partnering, educating, implementing, and investing.

In 2003, the Institute of Medicine (IOM) published a report, Priority Areas for National Action: Transforming Health Care Quality.[5] The report identified 20 clinical topics for which there are quality concerns because of the gap between knowledge of the topic and integration of that knowledge into the clinical setting. In response to the IOM report, the Agency for Healthcare Research and Quality (AHRQ) initiated a series of technical reviews on quality improvement (QI) strategies focused on improving the quality of care for the IOM's 20 priority areas.[6]

Objectives

This systematic review updates the AHRQ Evidence Report Closing the Quality Gap: A Critical Analysis of Quality Improvement Strategies: Volume 6—Prevention of Healthcare-Associated Infections.[7] From here on, this report is referred to as the 2007 report. The objective of that evidence review was to identify QI strategies that successfully increase adherence to effective preventive interventions and reduce infection rates for CLABSI, VAP, SSI, and CAUTI.

The current review expands the settings to be considered from primarily hospitals to include ambulatory surgery centers, freestanding dialysis centers, and long-term care facilities, where the prevention of HAI needs to be addressed as well.

Where applicable, the current report also applies the recommendation of a report prepared for AHRQ by RAND Health[8] in which the impact of context on the effectiveness of patient safety practices is assessed. The context of an intervention—for example, the type of health care setting, the leadership structure, the safety culture, the openness to innovation—can have an important impact on whether preventive interventions are adopted.

Key Questions for this report follow.

Key Question 1. Which quality improvement strategies are effective in reducing the following healthcare-associated infections?

- Central line–associated bloodstream infections (CLABSI)
- Ventilator-associated pneumonia (VAP)
- Surgical site infections (SSI)
- Catheter-associated urinary tract infections (CAUTI)

a. Which quality improvement strategies are effective in increasing adherence to evidence-based preventive interventions for the four healthcare-associated infections listed above?

b. What is the cost, return on investment, or cost-effectiveness for health care providers, patients, and society as a whole of quality improvement strategies to reduce these healthcare-associated infections?

c. Which factors are associated with the effectiveness of quality improvement strategies, including, for example,

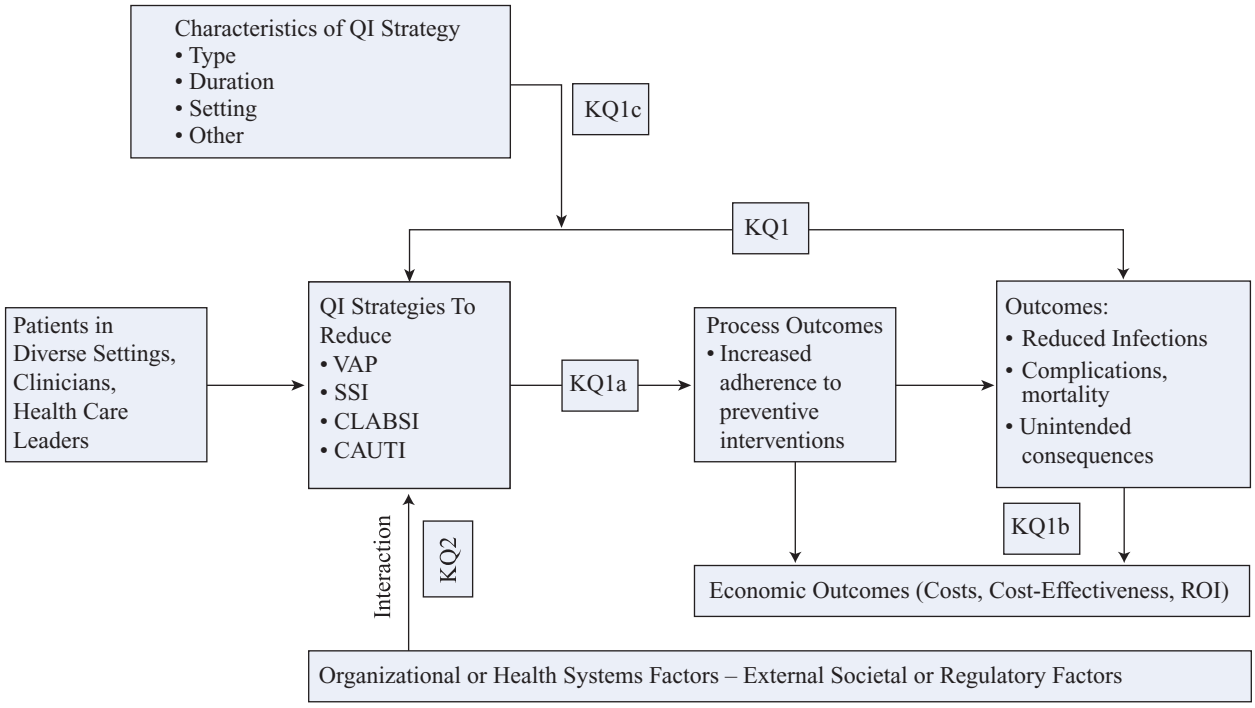
1. Type of quality improvement strategy
   - a. Clinician education
   - b. Patient education
   - c. Audit and feedback
   - d. Clinician reminder systems
   - e. Organizational change
   - f. Financial or regulatory incentives for patients or clinicians
   - g. A combination of the above
2. Duration of intervention
3. Setting, for example, hospitals (intensive care unit, surgical or ventilator-dependent patients), outpatient surgical centers, long-term care facilities, and freestanding dialysis centers, and which kinds of clinicians implement the quality improvement strategies?

Key Question 2. What is the impact of the health care context on the effectiveness of quality improvement strategies, including reducing infections and increasing adherence to preventive interventions?

Analytic Framework

The analytic framework depicts the potential impact of the implementation of QI strategies on reducing the following HAI: CLABSI, VAP, SSI, and CAUTI (Figure A). Key Question 1 shows the link between QI strategies and health outcomes: decreased infection rates, decreased complications and mortality, as well as unintended consequences. Key Question 1a shows the link between QI strategies and process outcomes; that is, adherence to preventive interventions. There are economic implications from both the process outcomes and the health outcomes, as depicted by Key Question 1b. Characteristics of the QI strategies, such as type of strategy, duration of the implementation, and setting, determine the effect of the QI strategies on the outcomes (Key Question 1c). Link Key Question 2 marks the interaction between the implementation of QI strategies and contextual factors of the organization. For example, institutions with an existing patient safety infrastructure may have fewer barriers to implementing QI strategies than other institutions.

Figure A. Analytical framework for systematic review on quality improvement strategies to reduce healthcare-associated infections



CAUTI = catheter-associated urinary tract infection; CLABSI = central line–associated bloodstream infection; KQ = Key Question; QI = quality improvement; ROE = return on investment; SSI = surgical site infection; VAP = ventilator-associated pneumonia.

Methods

Input From Stakeholders

This systematic review was developed and written by the Blue Cross and Blue Shield Association Technology Evaluation Center Evidence-based Practice Center (EPC). Individuals from various stakeholder groups were invited as Technical Experts and/or Peer Reviewers to guide this systematic review. The Technical Expert Panel (TEP) reviewed the research protocol in two phases: (1) initial draft protocol, (2) revised protocol that incorporated the TEP's comments on the draft and findings of a preliminary literature search. The final research protocol was posted on the AHRQ Web site. Peer reviewers were invited to provide written comments on the draft report based on their clinical, content, or methodological expertise. The draft report was also posted for public comment.

All potential Technical Experts and Peer Reviewers were required to disclose any potential conflicts of interest in accordance with AHRQ policy. The AHRQ Task Order Officer and the EPC worked to balance, manage, or mitigate any potential conflicts of interest identified. Writing and editing the report was solely the responsibility of the EPC.

Data Sources and Selection

Articles from the 2007 report[7] that met our inclusion criteria were included in this report. Then the same search strategy used in the prior report[7] was rerun on MEDLINE®, CINAHL®, and Embase®. Duplicate records were deleted. The search covered the time period from January 2006, when the search in the last report ended, to April 2011. The search was updated in January 2012 while the draft report was available for public comment, and relevant articles were added. Additional efforts were made to identify articles on interventions in nonhospital settings, which are likely to be reported less frequently, by querying the TEP and conducting a specific search on relevant studies in nursing homes. (See Appendix A for search strategy details.) We also screened the bibliographies of included articles to identify additional references. Web sites of entities involved in efforts to reduce HAI, such as the Institute for Healthcare Improvement, were scanned to ensure that no relevant peer-reviewed publications were missed and to identify descriptions of implementation strategies for which outcomes have been published in the peer-reviewed literature.

Titles and abstracts from the literature search citations were placed in a Microsoft Access® database for the first round of screening. Three trained reviewers conducted the screening. Each title and abstract was screened and marked as either: (1) retrieve for full-text review, (2) do not retrieve for full-text review, or (3) uncertain. Studies were marked for retrieval for full-text review if the citation reported the outcomes of an intervention for any one of the four specified HAI or a combination of HAI that included at least one of the four. The reasons for excluding an article were noted. Articles deemed uncertain for full-text review were screened by a second reviewer. If both reviewers were uncertain, the article was retrieved for full-text review. Articles were included if the study described an implementation strategy to increase adherence with one or more preventive interventions with the intent of reducing one or more of the four types of infections covered in this report. The following implementation strategies were included: clinician education, patient education, audit and feedback, clinician reminder systems, organizational change, financial or regulatory incentives for patients or clinicians, or a combination of these strategies. Articles also had to include statistical analysis comparing baseline and postintervention infection or adherence rates.

Data Abstraction and Quality Assessment

Following an extensive training process, reviewers abstracted articles selected for inclusion in the review; a second reviewer conducted a fact check on the abstracted items, using a clean copy of the article. The abstracter and the fact checker discussed discrepancies; any unresolved issues were decided through consultation with a third reviewer. Two reviewers independently conducted quality appraisals for each article; discrepancies were resolved by discussion or by the inclusion of a third reviewer, when necessary.

Abstracted data included the following: QI strategies, evidence-based preventive interventions, adherence and infection rates, unintended consequences, costs, savings, and contextual factors. Completeness of reporting was not assessed independently. The criteria to evaluate study quality are as follows:

1. Study design
2. Whether baseline and postintervention adherence rates were reported and analyzed statistically
3. Whether baseline and postintervention infection rates were reported and analyzed statistically
4. Whether the statistical analysis was adequate
    - Were potential confounders (e.g., baseline patient characteristics) assessed?

- If potential confounders existed, were they controlled for in the analysis?
- For interrupted time-series designs, was an interrupted time-series analysis used?

5. Whether the intervention was independent of other QI improvement efforts implemented at the same time
6. Whether the followup period was 1 year or longer

Study design was used for the initial study quality classification so that all controlled trials were assigned higher quality, interrupted time-series analyses were assigned a quality of medium, and all simple before-after studies were assigned a quality of lower. Then, for each study, criteria 2 through 6, listed above, were assigned a plus, minus, or uncertain. Any study with two or more minuses was moved to the next lower quality ranking. The terms "higher" and "lower" are used to indicate the relative ranking of quality in this report.

Data Synthesis and Analysis

As in the previous review,[7] the articles in this review differed greatly in QI targets, QI strategies, preventive interventions and methods of measuring adherence to them, contexts, and study design. Quantitative analyses are not feasible, and the studies are synthesized in a qualitative manner.

The articles included in this review are divided into two categories, those with infection rates or adherence rates that were adjusted for confounding or secular trends and those that adjusted for neither. Because of the extensive challenges to the validity of the latter, they are not included in the detailed description of the body of evidence or assessment of the strength of evidence. They are described briefly under each type of infection in the Results chapter of the full report and enumerated in an appendix.

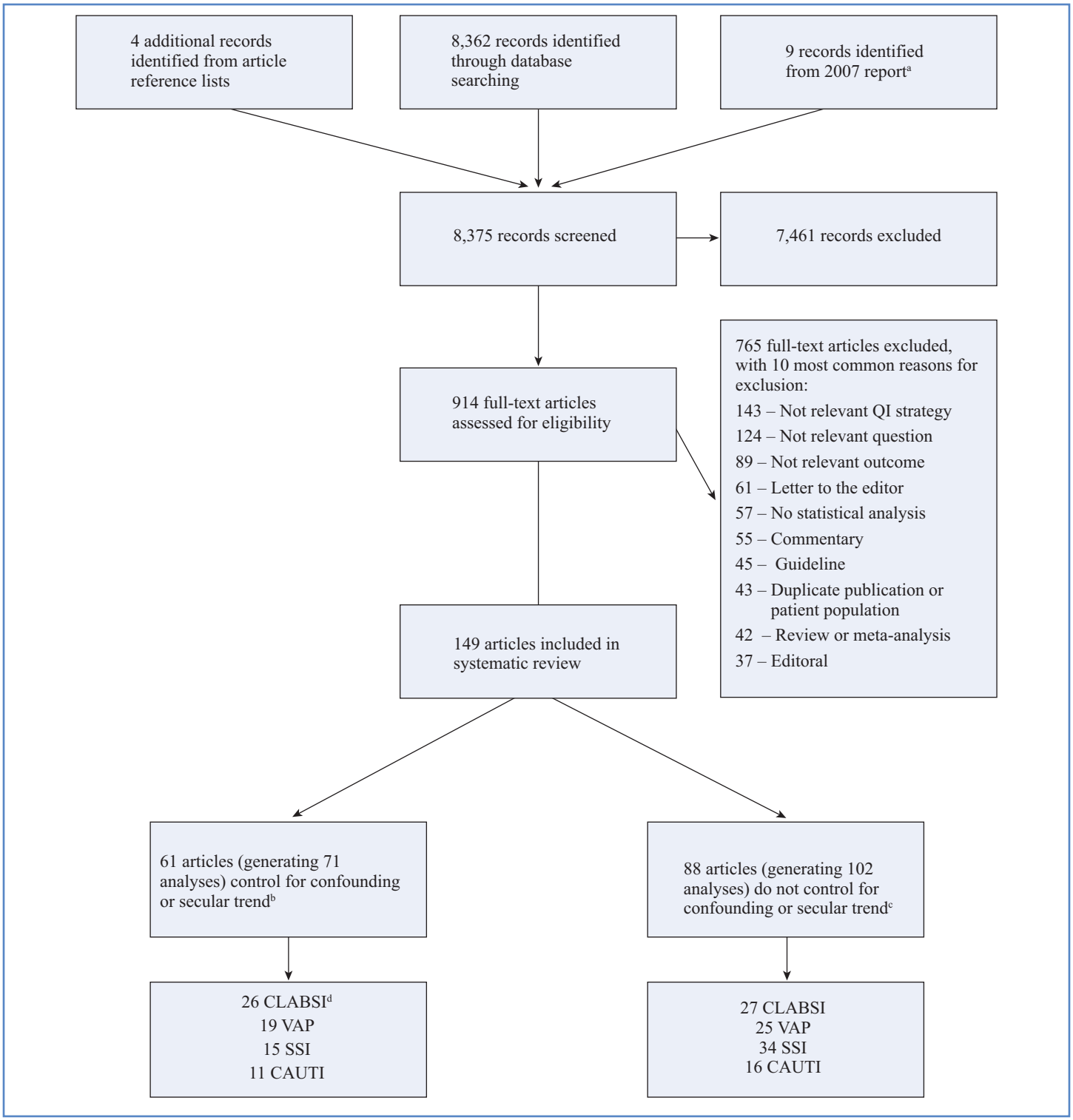
The overall strength-of-evidence grade was determined in compliance with AHRQ's Methods Guide for Effectiveness and Comparative Effectiveness Reviews[9] and is based on a system developed by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) Working Group.[10]

Results

Overview

The literature review yielded 8,362 abstracts. One hundred and thirty-six articles from the literature search met all selection criteria for inclusion in the current report. An additional four articles were identified from a review of article reference lists. Articles from the 2007 report were screened: 9 articles (generating 10 analyses at the infection level) met selection criteria for this report and controlled for confounding or secular trend. See the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) diagram in Figure B for additional details.

Figure B. Search results and article triage



[a]Ranji SR, Shetty K, Posley KA, Lewis R, Sundaram V, Galvin CM, Winston LG. Closing the Quality Gap: A Critical Analysis of Quality Improvement Strategies (Vol. 6: Prevention of Healthcare-Associated Infections). AHRQ Publication No. 04(07)-0051-6. Rockville, MD: Agency for Healthcare Research and Quality; 2007. www.ncbi.nlm.nih.gov/pubmed/20734530.
[b]Eight of these studies reported on two infections and one, on three infections.
[c]Five of these articles reported on two infections; three, on three infections; and one, on four infections.
[d]One of these articles has an updated publication 1 year later. In the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) diagram these studies were cited as a single study.

The 149 articles (generating 173 analyses at the infection level) were divided into two groups. The first group consisted of 61 articles, most of which were quasi-experimental studies that controlled for confounding or secular trend. Eight of these articles reported on two types of infection, and one article report ed on three infections; each infection reported is treated as a separate study from this point forward. Sixty-one articles yielded 71 analyses, including 9 articles (10 analyses) from the 2007 report; these studies evaluated the use of one or more QI strategies to improve adherence or infection rates and also controlled for confounding or secular trend. There were 26 analyses performed on CLABSI, 19 on VAP, 15 on SSI, and 11 on CAUTI. The words "analysis" and "study" are used interchangeably and refer to the infection-level results.

The other 88 articles (102 analyses) did not account for the many potential sources of confounding and for secular trend. Therefore, their results are at high risk of bias. These were simple before-after studies or controlled before-after studies (2 of 88) with two group tests, for example, t-tests and chi-square tests. The two controlled before-after articles were demoted due to lack of between-group comparisons. Of these 88 articles, 5 articles reported on 2 types of infection, 3 articles reported on 3 infections, and 1 article reported on 4 infections, for a total of 102 analyses; each infection is treated as a separate study from this point forward. The characteristics of this second group of studies are summarized in tables for each infection in Appendix F, but they were excluded from the analysis in this report. Table A provides study characteristics of the 71 included studies, as well as the study quality characteristics for all 173 studies (149 articles).

Table A. Number of studies in each category by infection type and overall

Study Characteristic	Category	CLABSI	VAP	SSI	CAUTI	All
Design	Cluster RCT	2	2	1	0	5
	Individual RCT	0	0	1	1	2
	Stepped wedge	1	1	1	1	4
	Controlled study	4	2	1	1	8
	Interrupted time series	3	5	1	2	11
	Simple before-after	16	9	10	6	41
	Total	**26**	**19**	**15**	**11**	**71**
Number of QI Strategies	5 QI strategies	2	0	0	0	2
	4 QI strategies	8	7	2	2	19
	3 QI strategies	7	5	5	2	19
	2 QI strategies	5	7	4	4	20
	1 QI strategy	4	0	4	3	11
Outcomes Reported	Adherence only	1	1	2	3	7
	Infection rates only	16	9	5	2	32
	Both adherence and infection rates	9	9[a]	8	6a	32
Sample Size (Range Across Studies When Reported)[b]	Patients postintervention	50 to 4,671	81 to 4,761	115 to 10,617	93 to 1,794	NA
	Postintervention infection rate	0 to 7.7 per 1,000 catheter-days	0.7 to 22.5 per 1,000 ventilator-days	0% to 7.7%	1.8 to 12.9 per 1,000 catheter-days	NA
	Baseline infection rate	1.84 to 17 per 1,000 catheter-days	1.9 to 39.7 infections per 1,000 ventilator-days	1.1% to 15%	1.7 to 21.5 per 1,000 catheter-days	NA

Table A. Number of studies in each category by infection type and overall (continued)

Study Characteristic	Category	CLABSI	VAP	SSI	CAUTI	All
Length of Followup (Months)	Mean	20	22	14.4	23	20
	Median	23	17	12	17	18
	Range	3.5 to 46[c]	4 to 54	1 to 30[d]	3 to 61	1 to 61
Location	United States	18	9	11	2	40
	Other	8	10	4	9	31
Multisite or Single Site	Multisite	12	4	7	3	26
	Single site	14	15	8	8	45
Study Quality	Higher	1	3	2	1	7
	Medium	9	4	3	3	19
	Lower	16	12	10	7	45
	Did not control for confounding or secular trend	27	25	34	16	102

CAUTI = catheter-associated urinary tract infection; CLABSI = central line–associated bloodstream infection; NA = not applicable; QI = quality improvement; RCT = randomized controlled trial; VAP = ventilator-associated pneumonia; SSI = surgical site infection.
[a]One study compared two sets of QI strategies, and another compared early and later infection rates.
[b]Patients may be defined differently across studies within a given infection category—for example, patients on ventilator or patients on ventilator for at least 48 hours.
[c]Four studies did not report length of followup.
[d]One study did not report length of followup.

Analyzing the impact of QI strategies, the objective of this report, is complicated by the fact that more than one QI strategy was used in most studies (60 of 71). Disentangling the effect of a single QI strategy is not possible with the available body of evidence. With 71 studies, 16 different combinations of QI strategies were used. The following approaches were considered for evaluating the effectiveness of the QI strategies, but all had limitations and were rejected.

- Considering each QI strategy individually within each study. The effect of a strategy cannot be disentangled from the impact of other strategies.
- Using the number of QI strategies. This option was not viable as the types of QI strategies included may have confounded the effect.
- Identifying the incremental impact of a single QI strategy. This approach could be measured only by comparing two combinations of QI strategies in the same clinical context, in which one combination contained the QI strategy of interest and the other did not. None of the studies identified for this report had such a design.

Therefore in this report, QI strategies are grouped together based on the combinations of strategies used in our included studies (Table B). This approach mirrors common practice, which relies on combinations of QI strategies, and can therefore potentially yield practical insights.

To develop a workable classification of QI strategy combinations for the purposes of this report, we hypothesized that organizational change and provider education constitute base strategies. Face validity is the initial rationale for the hypothesis, as 90 percent of the included studies used at least one of these two strategies. While this hypothesis is open to debate, the use of these strategies was ubiquitous, so in practical terms, little distinction could be made between those studies that used these two strategies and those that did not. In addition, it is difficult to imagine how any preventive intervention or QI effort could be implemented without at least some level of organizational change and/or provider education. Further, it is plausible that those studies that did not report using organizational change or provider education may simply have taken these elements for granted. Analyzing the effectiveness of specific components of organizational change would be useful, but the heterogeneity of

organizational change across studies and variations in thoroughness of reporting preclude such an analysis based on current evidence. Scant information is available in this literature comparing different educational strategies.

So, for simplicity, from here on we refer to organizational change, provider education, or the combination of both as base strategies. This concept allowed us to organize our data into categories of strategies used in combination with the base strategies. These additional strategies are: (1) audit and feedback plus provider reminder systems; (2) audit and feedback only; (3) provider reminder systems only. Only two[11,12] studies reported the use of financial incentives, regulation, or policy, and two[13,14] reported on patient education, so these QI strategies are not treated separately despite their potential importance. The main variation across QI strategy combinations, therefore, is in the use of audit and feedback and/or provider reminder systems. For each infection, the QI strategy combinations were grouped into two or three categories in developing the strength-of-evidence tables. The composition of these groups varies to some degree from infection to infection, based on which combinations were reported in the included studies.

Within each study, the intervention period was compared with a period of no intervention (usual care), which refers to the absence of additional QI efforts other than the standard of care already in place. Thirteen studies implemented QI strategies in a stepwise fashion and did not report rates before any intervention in the study was implemented.[11,15-26] The comparator for these studies was defined as a low-intensity intervention. Also, a separate strength-of-evidence evaluation was conducted for studies reporting both adherence and infection rates because studies that report both outcomes have more reliable results than those that do not. This evaluation reported results for each QI combination across all four types of infections.

The strength-of-evidence conclusions rely both on the underlying effect of different QI combinations on outcomes and on the availability of studies to assess the relationship. A low strength of evidence, therefore, does not necessarily mean that there is no relationship between the QI strategy and improved outcomes. It is therefore possible that the strength of evidence will change as additional evidence accumulates.

Table B. QI strategy combinations across infections

Combination of QI Strategies	Organizational Change	Provider Education	Audit and Feedback	Provider Reminder Systems	Patient Education	Financial Incentives	CLABSI[a]	VAP[a]	SSI[a]	CAUTI[a]	All[a]
Variants of Base Strategies (Organizational Change and Provider Education)	•	•					3[b]	3[b]	1	0	**7**
	•						0	0	2[b]	0	**2**
		•					3	1	0	0	**4**
Variants of Base Strategies With Audit and Feedback	•	•	•		([c])		4	4[d]	3[b]	1	**12**
	•		•				0	1	1	0	**2**
		•	•				0	0	1	1	**2**
			•		•		1	1	0	1	**3**
Variants of Base Strategies With Provider Reminder System	•	•		•			2	1	2	1	**6**
	•			•			0	0	1	2	**3**
				•			1	0	2	3	**6**
Variants of Base Strategies With Audit and Feedback + Provider Reminder System	•	•	•	•		([c])	10[b,e]	6[b]	2	2[b]	**20**
	•		•	•			1	1	0	0	**2**
		•	•	•			1	1	0	0	**2**
Total					4			19			***71***

CAUTI = catheter-associated urinary tract infection; CLABSI = central line–associated bloodstream infection; HAI = healthcare-associated infection; QI = quality improvement; VAP = ventilator-associated pneumonia; SSI = surgical site infection.

[a]These columns indicate the number of studies for each HAI or for all HAI that use the variant of QI strategies indicated in each row.

[b]Comparator for one article is low-intensity intervention.

[c]These two strategies did not define the combinations; therefore, a dot is not included in the definition of the combinations.

[d]One study also includes patient education.

[e]Two studies also include financial incentives.

Key Questions 1 and 1a: QI Strategies Used To Improve Adherence and Infection Rates

Central Line–Associated Bloodstream Infection

Twenty-six studies that addressed the prevention of CLABSI and controlled for confounding factors or secular trend met the inclusion criteria.[11,12,14,16,17,19,20,24,27-44] One study was rated higher quality,[19] 9 studies[11,17,20,24,28-32] were rated medium quality, and 16 studies[12,14,16,27,33-44] were rated lower quality. The strength of evidence for the combinations used to target CLABSI is summarized in Table C.

Table C. Strength of evidence for combinations targeting CLABSI

SOE	Combination	Outcome	Number/Type of Studies
Moderate	Base strategies + audit and feedback + provider reminder system	Infection rate	1 controlled study[17] 2 interrupted time series[11,32] 8 simple before-after[12,33,38-41,43,44]
	Base strategies + audit and feedback or provider reminder system	Infection rate	1 interrupted time series[31] 6 simple before-after[14,16,27,35-37]
	Base strategies	Infection rate	3 controlled studies[28-30] 1 simple before-after[42]
Low	Base strategies + audit and feedback + provider reminder system	Adherence: insertion bundle	1 controlled study[24] 1 interrupted time series[11] 1 simple before-after[43]
		Adherence and infection rates	2 interrupted time series[11,32] 1 simple before-after[43]
	Base strategies + audit and feedback or provider reminder system	Adherence and infection rates	1 interrupted time series[31] 4 simple before-after[14,16,35,36]
Insufficient	Base strategies + audit and feedback + provider reminder system	Adherence: maintenance bundle	1 interrupted time series[11]
		Adherence: hand hygiene	1 interrupted time series[11]
	Base strategies + audit and feedback or provider reminder system	Adherence: multiple measures	1 interrupted time series[31]
		Adherence: hand hygiene	1 simple before-after[14]
	Base strategies	Adherence: multiple measures	1 simple before-after[34]
		Risk of infection	1 simple before-after[34]
		Adherence rate and risk of infection	1 simple before-after[34]

CLABSI = central line–associated bloodstream infection; SOE = strength of evidence.

Note: The base strategies are organizational change and provider education.

Moderate Strength of Evidence

All combinations used in studies targeting CLABSI had a moderate strength of evidence for improving infection rates:

- Audit and feedback and provider reminder systems with the base strategies compared with usual care
- Audit and feedback or provider reminder systems with the base strategies compared with usual care
- Base strategies compared with usual care

Ratings of low or insufficient strength of evidence, summarized below for adherence outcomes, reflect the limited number of studies for each of the results.

Low Strength of Evidence

Low strength of evidence was found for audit and feedback and provider reminder systems combined with the base strategies, compared with usual care, for improving adherence to an insertion bundle as well as improving adherence and infection rates. The strength of evidence for the use of audit and feedback or provider reminder systems with the base strategies, compared with usual care, for improving both adherence and infection rates was found to be low.

Insufficient Evidence

The use of audit and feedback and provider reminder systems with the base strategies for improving adherence to a maintenance bundle or hand hygiene was judged to have insufficient strength of evidence. The strength of evidence for the use of audit and feedback or provider reminder systems with the base strategies for improving multiple preventive interventions or hand hygiene was found to be insufficient. Also, the strength of evidence for the use of the base strategies alone for improving adherence to multiple preventive interventions, risk of infection, or both adherence and risk of infection was judged to be insufficient.

Ventilator-Associated Pneumonia

Nineteen studies of implementation of QI strategies to reduce rates of VAP met the inclusion criteria and also controlled for confounding or secular trend.[13-15,19-22,24-27,44-51] Three studies[19,45,46] were ranked of higher quality, 4[,20,24,25,47] of medium quality, and 12 of lower quality.[13-15,21,22,26,27,44,48-51] The strength of evidence for the combinations used to target VAP is summarized in Table D.

Table D. Strength of evidence for combinations targeting VAP

SOE	Combination	Outcome	Number/Type of Studies
Moderate	Base strategies + audit and feedback + provider reminder system	Adherence: overall/summary	1 controlled study[45] 2 interrupted time series[15,47]
		Adherence: HOB elevation	2 controlled studies[24,45] 2 interrupted time series[15,47]
		Adherence: oral care	1 controlled study[45] 2 interrupted time series[15,47]
		Infection rate	1 controlled study[45] 3 interrupted time series[15,20,47] 3 simple before-after[22,44,50]
		Adherence and infection rates	1 controlled study[45] 2 interrupted time series[15,47]
	Base strategies + audit and feedback	Adherence: overall/summary	2 simple before-after[13,27]
		Infection rate	2 interrupted time series[25,26] 3 simple before-after[13,14,27]
		Adherence and infection rates	3 simple before-after[13,14,27]

Table D. Strength of evidence for combinations targeting VAP (continued)

SOE	Combination	Outcome	Number/Type of Studies
Insufficient	Base strategies + audit and feedback + provider reminder system	Adherence: readiness to wean	2 controlled studies[24,45] 1 interrupted time series[15]
	Base strategies + audit and feedback	Adherence: hand hygiene	1 simple before-after[14]
	Base strategies + provider reminder system	Infection rate	1 simple before-after[49]
	Base strategies	Adherence: HOB elevation	1 controlled study[46]
		Infection rate	1 controlled study[46] 2 simple before-after[48,51]
		Adherence and infection rates	1 controlled study[46]

HOB = head of bed; VAP = ventilator-associated pneumonia; SOE = strength of evidence.
Note: The base strategies are organizational change and provider education.

Moderate Strength of Evidence

Moderate strength of evidence was found for the use of audit and feedback and provider reminder systems with the base strategies on improving adherence to an overall bundle, head-of-bed elevation, and oral care. The use of this combination compared with usual care for improving infection rates alone and with adherence rates was also judged to have moderate strength of evidence. Furthermore, the evidence for the use of audit and feedback with the base strategies, compared with usual care, for improving an overall bundle, infection rates, and both infection and adherence rates was determined to be moderate.

Insufficient Evidence

Insufficient evidence was available to make any conclusions about the use of audit and feedback and provider reminder systems with the base strategies for improving readiness to wean. The strength of evidence for the use of provider reminder systems with the base strategies for improving infection rates was also judged to be insufficient. Use of base strategies to improve head-of-bed elevation, infection rates, or adherence and infection rates was found to have insufficient evidence.

Surgical Site Infection

A total of 15 studies were identified from the literature search that used QI strategies to implement preventive interventions aimed at reducing SSI, controlled for confounding or secular trends, and met all other criteria for inclusion in this systematic review.[18,52-65] Two studies were rated higher quality,[18,58] 3 studies were rated medium quality,[52,53,59] and 10 studies[54-57,60-65] were rated lower quality. The strength of evidence for the combinations used to target SSI is summarized in Table E.

Table E. Strength of evidence for combinations targeting SSI

SOE	Combination	Outcome	Number/Type of Studies
Moderate	Base strategies + audit and feedback +/- provider reminder system	Adherence: antibiotic timing	1 interrupted time series[53] 1 stepped wedge[52] 2 simple before-after[55,60]
Low	Base strategies + audit and feedback +/- provider reminder system	Adherence: antibiotic selection	1 stepped wedge[52] 2 simple before-after[55 60]
		Adherence: shaving	2 simple before-after[60,61]
	Base strategies + provider reminder system	Adherence: antibiotic timing	1 controlled study[58] 2 simple before-after[57,62]
		Infection rate	1 controlled study[58] 3 simple before-after[57,62, 63]
Insufficient	Base strategies + audit and feedback +/- provider reminder system	Adherence: antibiotic duration	1 stepped wedge[52] 3 simple before-after[55,60,61]
		Adherence: normothermia	2 simple before-after[55,60]
		Adherence: glucose control	2 simple before-after[55,60]
		Infection rate	1 interrupted time series[53] 4 simple before-after[55,60,61,64]
		Adherence and infection rates	1 interrupted time series[53] 1 stepped wedge[52] 3 simple before-after[55,60,61]
	Base strategies + provider reminder system	Adherence: antibiotic selection	1 simple before-after[54]
		Adherence: antibiotic duration	1 simple before-after[54]
		Adherence: hair removal	1 simple before-after[57]
		Adherence and infection rates	1 controlled study[58] 2 simple before-after[57,62]
	Base strategies	Infection rate	1 controlled study[59] 2 simple before-after[56,65]

SOE = strength of evidence; SSI = surgical site infection.
Note: The base strategies are organizational change and provider education.

Moderate Strength of Evidence

The use of audit and feedback with or without provider reminder systems with the base strategies, compared with usual care, for improving adherence to appropriate antibiotic timing was judged to have moderate strength of evidence.

Low Strength of Evidence

The use of audit and feedback with or without provider reminder systems with the base strategies, compared with usual care, for improving adherence to appropriate antibiotic selection or shaving was judged to have low strength of evidence. The evidence for the use of provider reminder systems with the base strategies to improve antibiotic timing or infection rates was deemed low.

Insufficient Evidence

Insufficient evidence was found to make any conclusions on the use of audit and feedback with or without provider reminder systems with the base strategies to improve antibiotic duration, normothermia, glucose control, infection rates, or both adherence and infection rates. In addition, insufficient evidence was found for the use of provider reminder systems with the base strategies for improving antibiotic selection, antibiotic duration, appropriate hair removal, or both adherence and infection rates. Insufficient evidence was also found for the use of the base strategies alone to improve infection rates.

Catheter-Associated Urinary Tract Infections

The literature search identified 11 studies that addressed the prevention of CAUTI and controlled for confounding factors or secular trend.[14,23,35,61,64,66-71] One study[66] was ranked of higher quality, three[67,69,70] of medium quality, and seven[14,23,35,61,64,68,71] of lower quality. The strength of evidence for the combinations used to target CAUTI is summarized in Table F.

Table F. Strength of evidence for combinations targeting CAUTI

SOE	Combination	Outcome	Number/Type of Studies
Moderate	Base strategies + provider reminder system	Adherence: overall urinary catheterization	3 controlled studies[66,69,70] 1 interrupted time series[67] 2 simple before-after[35,68]
Insufficient	Base strategies + audit and feedback + provider reminder system	Adherence: appropriate urinary catheterization	1 simple before-after[71]
		Infection rate	1 interrupted time series[23]
	Base strategies + audit and feedback	Adherence: overall urinary catheterization	1 simple before-after[61]
		Adherence: hand hygiene	1 simple before-after[14]
		Infection rate	3 simple before-after[14,61,64]
		Adherence and infection rates	2 simple before-after[14,61]
	Base strategies + provider reminder system	Adherence: inappropriate urinary catheterization	1 controlled study[66] 1 interrupted time series[67]
		Adherence: correctly inserted urinary catheters	1 controlled study[70]
		Infection rate	1 controlled study[66] 1 interrupted time series[67] 1 simple before-after[35]
		Adherence and infection rates	1 controlled study[66] 1 interrupted time series[67] 1 simple before-after[35]

CAUTI = catheter-associated urinary tract infection; SOE = strength of evidence.
Note: The base strategies are organizational change and provider education.

Moderate Strength of Evidence

The use of provider reminder systems alone or with the base strategies, compared with usual care, for improving adherence to duration of overall urinary catheterization was found to have moderate strength of evidence.

Insufficient Evidence

The following strategies were used to improve infection rates, but insufficient evidence was found:

- Audit and feedback and provider reminder systems with the base strategies
- Audit and feedback with the base strategies
- Provider reminder systems with the base strategies

Insufficient evidence was also found for the use of both audit and feedback and provider reminder systems with the base strategies to improve appropriate urinary catheterization. Use of audit and feedback with the base strategies to improve overall urinary catheterization, hand hygiene, or simultaneous improvement of adherence and infection rates was also found to have insufficient evidence.

Provider reminder systems with or without the base strategies to improve inappropriate urinary catheterization, correctly inserted urinary catheters, infection rates, and both adherence and infection rates were found to have insufficient evidence.

Key Question 1b: Cost of QI Strategies

Fourteen studies[11,17,36,37,41,44,46,69,70,72-76] were identified that provided information related to the implementation costs and/or savings of QI initiatives to reduce HAI. Ten studies[11,17,36,37,41,44,46,69,70,75] that adjusted for confounding or secular trend reported information on savings. Four studies that did not adjust for confounding or secular trend provided information on the costs of the QI initiative. The literature reviewed for this report identified only one study[69] that provided a detailed analysis for net savings, and no studies provided a comprehensive analysis of return on investment.

Given the limited number of studies that evaluated costs and/or savings and the lack of data on net cost savings, as well as the variation in QI initiatives used in those studies and the varied metrics studied related to costs, the strength of evidence related to the overall cost and savings associated with use of various QI strategies to reduce HAI is insufficient.

Furthermore, no studies were identified that addressed the important questions of the total cost of the QI program or the return on investment of the various QI initiatives.

Key Question 1c: Factors Associated With Effectiveness of QI Strategies

We limit this analysis to studies that reported and analyzed changes in both adherence rates and infection rates because these studies provide the strongest possible causal evidence. To provide a more generalizable and robust synthesis of QI strategies, the analysis in this section combines studies across the four HAI. Because all of the included studies were in hospital settings and there were no direct comparisons between multiple units in a single hospital or across hospitals, we were unable to conduct any setting comparisons. Since length of followup was an aspect of the quality rating, it was not analyzed separately. The focus of this section is on the type or combination of QI strategies, for which there is the most evidence. Twenty-six studies analyzed both adherence and infection rates.[11,13-16,20,27,31,32,34-36,43,45-47,52,53,55,57,58,60-62,66,67] Four of these studies did not separately analyze adherence rates, but adherence was included in the regression analysis for infections.[16,32,36,52] Three studies analyzed adherence and infection rates for multiple individual infections.[14,35,61] These studies are treated as separate studies, one for each infection, as was done for Key Questions 1 and 1a. This brings the total number of analyses included in this Key Question to 30. One study[68] was excluded from this analysis because it differentiated between early versus late infection rates and thus was not comparable with the other studies.

The strength of evidence for the combinations reported to improve both adherence and infection rates across all four infections is summarized in Table G.

Table G. Strength of evidence for combinations of QI strategies

SOE	Combination	Outcome	Number/Type of Studies
Moderate	Base strategies + audit and feedback + provider reminder system	Adherence and infection rates	1 controlled study[45] 1 stepped wedge design[52] 4 interrupted time series[11,15,32,47] 2 simple before-after[43,55]
Moderate	Base strategies + audit and feedback	Adherence and infection rates	1 controlled study[20,a] 2 interrupted time series[31,53] 8 simple before-after[13,14,27,60,61,a,b,c]
Low	Base strategies + provider reminder system	Adherence and infection rates	2 controlled studies[58,66] 1 interrupted time series[67] 6 simple before-after[16,35,36,57,62,d]
Insufficient	Base strategies	Adherence and infection rates	1 controlled study[46] 1 simple before-after[34]

QI = quality improvement; SOE = strength of evidence.
Note: The base strategies are organizational change and provider education.
[a]One study also includes financial incentives.
[b]One study also includes patient education.
[c]Two of these studies report on more than one infection.
[d]One of these studies reports on more than one infection.

Moderate Strength of Evidence

Audit and feedback plus provider reminder systems with the base strategies and audit and feedback with the base strategies were found to have moderate strength of evidence for improving both adherence and infection rates across HAI.

Eight studies reported both adherence and infection rates, and used audit and feedback plus provider reminder systems with the base strategies, compared with usual care.[11,15,32,43,45,47,52,55] Three reported on CLABSI,11,[32,43] three reported on VAP,[15,45,47] and two reported on SSI.[52,55] One[45] was of higher quality, four[11,32,47,52] were of medium quality, and three[25,43,55] were of lower quality.

Eleven studies reported both adherence and infection rates, and used audit and feedback with the base strategies, compared with usual care.[13,14,20,27,31,53,60,61] Two[14,31] reported on CLABSI, four[13,14,20,27] reported on VAP, three reported on SSI,[53,60,61] and two reported on CAUTI.[14,61] Three[20,31,53] were of medium quality and eight (from five articles)[13,14,27,60,61] were of lower quality.

Low Strength of Evidence

Provider reminder systems alone or with the base strategies were found to have low strength of evidence for improving adherence and infection rates.

Nine studies reported both adherence and infection rates, and used provider reminder systems alone or with the base strategies, compared with usual care.[13,35,36,57,58,62,66,67] Three studies[16,35,36] reported on CLABSI, three reported on SSI,[57,58,62] and three reported on CAUTI.[35,66,67] Two[58,66] were of higher quality, one[67] was of medium quality, and six (in five articles)[16,35,36,57,62] were of lower quality. Even though this combination of QI strategies was found to have moderate strength of evidence when used to improve CAUTI rates, there were limited data for this combination for the other three infections. Therefore, this conclusion was not generalizable across all four infections.

Insufficient Evidence

There is insufficient strength of evidence that the use of base strategies improves adherence and infection rates compared with usual care.

Two studies reported both adherence and infection rates and used base strategies, compared with usual care.[34,46] One reported on CLABSI[34] and one reported on VAP.[46] One[46] was of higher quality and the other34 was of lower quality.

Key Question 2: Effect of Context on Effectiveness of QI Strategies

The 71 studies that controlled for confounding or secular trend were also evaluated to address the impact of context on the effectiveness of the QI strategies. Context, generally, can be thought of as the "characteristics of the organization and its environment that influence the implementation and effectiveness of the patient safety practice."[77] Seven contextual factors, in addition to organizational characteristics such as institution size, financial status, and location, were captured in this report, as the authors of the RAND report recommend for use when evaluating the effectiveness of patient safety practices:[8]

- Theory behind patient safety practice
- Existing patient safety infrastructure
- External factors
- Patient safety culture and teamwork at unit level
- Leadership at unit level
- Change in responsibilities at unit level
- Availability of implementation and management tools

While contextual factors impact the effectiveness of QI strategy implementation and the sustainability of the outcomes, reporting these factors is neither standardized nor required. Another barrier to reporting such information is the required brevity of journal articles. Investigators of some studies in this review attempted to control for contextual factors in the analyses, others provided discussions of contextual differences, and still others did not address contextual issues at all. Our synthesis of context is limited to mapping the frequency with which contextual factors were reported and providing examples of how contextual factors were addressed in some of the studies. Table H provides the frequency of reporting of the seven additional contextual factors across the four infections.

Roughly two-thirds of the studies took place in single sizes,[11,13-15,17,21-23,25,26,28-31,33-39,41,42,44-49,51,54-58,62,64,65,67-69] and about half were from the United States.[11-13,18-21,25,27,28,30,32,33,36,40-42,44,45,50,52,54-57,62,63,65,71] The most commonly reported contextual factor was availability of implementation materials, followed by changes in responsibilities at the unit level and leadership at the unit level. The contextual factors that were discussed the least were theory behind patient safety practice and patient safety culture and teamwork at the unit level. Two studies reported no additional contextual factors other than organizational characteristics.[29,53] Twenty-nine studies (four[20,24,27,44] of which reported on two infections each)

reported at least half of the additional contextual factors of interest.[11,12,16-18,20-24,27,36-38,40-44,52,55,56,60,70,71] However, no study reported all seven additional contextual factors. Because all of the included studies were in hospital settings and there were no direct comparisons between multiple units in a single hospital or across hospitals, we were unable to conduct any setting comparisons.

Table H. Frequency of contextual factors used in included studies

Contextual Factor	CLABSI	VAP	SSI	CAUTI	Total
Theory Behind Patient Safety Practice	9	3	4	0	16
Existing Patient Safety Infrastructure	8	6	2	4	20
External Factors	9	7	5	2	23
Patient Safety Culture and Teamwork at Unit Level	14	10	3	4	31
Leadership at Unit Level	17	12	5	3	37
Change in Responsibilities at Unit Level	14	11	12	7	44
Availability of Implementation and Management Tools	19	13	11	6	49

CAUTI = catheter-associated urinary tract infection; CLABSI = central line–associated bloodstream infection; VAP = ventilator-associated pneumonia; SSI = surgical site infection.

Discussion

Key Findings and Strength of Evidence

This report reviews 71 studies (61 articles) of QI strategies targeting healthcare-associated infections, 10 included in the 2007 review and 61 published subsequently. Four HAI were reviewed: CLABSI, VAP, SSI, and CAUTI. We limited our synthesis to studies that had statistical analyses that adjusted for confounding or secular trend, without which no causal inference can be made about the reported results.

Most studies used multiple QI strategies; only 12 studies used a single QI strategy. Outcomes of interest to the review were adherence to various preventive interventions, change in infection rates, and costs and return on investment. Information was also sought on unintended consequences of QI strategies and contextual factors that might influence the success of a strategy, but data were sparse. Only one study, which did not control for confounding or secular trend, was identified that addressed QI strategies to improve adherence to preventive interventions or reduce HAI rates outside the hospital setting. Most comparisons were with usual care; for 13 studies, the comparison was with a period of a low-intensity QI intervention.[11,15-26]

Evidence synthesis of QI strategies presented considerable challenges. It was not possible to disaggregate the data into individual strategies or to systematically assess the incremental effects of adding a particular strategy to a combination of strategies. Moreover, a wide variety of combinations of specific QI strategies were used in the studies, making it challenging to categorize consistent combinations of QI strategies or to compare such combinations with each other.

As discussed in the Results section, to develop a workable classification of QI strategy combinations, we hypothesized that organizational change and provider education constitute base strategies. This simplifying concept allowed us to organize our data into categories of strategies used in combination with the base case. These additional strategies are: (1) audit and feedback plus provider reminder systems, (2) audit and feedback only, (3) provider reminder systems only.

Key Findings and Strength of Evidence Across Infections

Our key findings, shown in Table G, assess the evidence across all four infections, applying the framework for grading strength of evidence described in Methods Guide for Effectiveness and Comparative Effectiveness Reviews, which is based on GRADE.[9,10] Only studies that reported on both adherence and infection rates are included in our key findings across infections: 30 of the 71 studies (42%). All comparisons are with usual care.

- There is moderate strength of evidence that adherence and infection rates improve when these strategies are used with the base strategies:
  - Audit and feedback plus provider reminder systems
  - Audit and feedback alone

- There is low strength of evidence that adherence and infection rates improve when this strategy is used with the base strategies:
    - Provider reminder systems alone
- There is insufficient evidence that the base strategies alone (listed below) improve adherence and infection rates:
    - Organizational change plus provider education
    - Provider education only

We consider these to be our most robust and generalizable findings. Note that the strength-of-evidence analysis describes the evidence for only the specified combination of QI strategies compared with usual care. The conclusions do not imply that one combination is superior to another. We can only describe the strength of evidence that is available for each combination of QI strategies. Furthermore, the finding of moderate strength of evidence, given a heterogeneous incomplete literature, is noteworthy and suggests that these implementation strategies can be effective in reducing HAI, which is the ultimate objective of the QI efforts.

Findings and Strength of Evidence for Each Infection

Table I displays moderate-strength findings for each infection. There were no QI strategy combinations for which the strength of evidence was rated high. For each infection, studies varied in the adherence rates reported and whether significant improvements were found. Thus, Table I shows the specific adherence rates that were improved with each combination of QI strategies.

In general, within-infection results concur with the key results across infections displayed in Table G. There is moderate strength of evidence to support audit and feedback plus provider reminder systems with the base strategies, as well as audit and feedback alone with the base strategies. Two differences are worth noting.

- Studies of CLABSI demonstrate the impact of differing approaches to the QI strategy on the outcome. Two studies compared simulation-based provider education with traditional provider education (lecture and/or video-based education).[28,30] Both studies found the simulation-based approach to provider education to be superior to the traditional method. This finding may warrant further confirmatory research.
- Studies of CAUTI focused on provider reminder systems as the main strategy for reducing duration of urinary catheterization. There was moderate strength of evidence that provider reminder systems alone or used in combination with the base strategies improve adherence related to duration of overall urinary catheterization, compared with usual care. This finding was not generalizable to other infections given the current body of evidence.

Table I. Combinations of QI strategies with moderate strength of evidence for each infection

Infection	Combination	Outcome
CLABSI	Base strategies + audit and feedback + provider reminder system	Infection rate
	Base strategies + audit and feedback or provider reminder system	Infection rate
	Base strategies	Infection rate
VAP	Base strategies + audit and feedback + provider reminder system	Adherence: overall/summary
		Adherence: HOB elevation
		Adherence: oral care
		Infection rate
		Adherence and infection rates
	Base strategies + audit and feedback	Adherence: overall/summary
		Infection rate
		Adherence and infection rates

Table I. Combinations of QI strategies with moderate strength of evidence for each infection (continued)

Infection	Combination	Outcome
SSI	Base strategies + audit and feedback ± provider reminder systems	Adherence: antibiotic timing
CAUTI	Provider reminder systems ± base strategies	Adherence: overall urinary catheterization

CAUTI = catheter-associated urinary tract infection; CLABSI = central line–associated bloodstream infection; HOB = head of bed; QI = quality improvement; VAP = ventilator-associated pneumonia; SSI = surgical site infection.
Note: The base strategies are organizational change and provider education.

Alternative interpretations may account for these CLABSI and CAUTI results, which cannot be empirically verified from the evidence available from this review. Simulation-based provider education may have a greater impact than traditional, more passive teaching techniques. Alternatively, however, simulation may have attributes that are similar to audit and feedback, and may even, under some circumstances, constitute a form of audit and feedback. With respect to CAUTI, might audit and feedback enhance the results of provider reminder systems? Moreover, in the setting of initiating urinary catheterization, which is addressed by only 3[14,23,70] of 11 studies, audit and feedback might be more relevant than provider reminder systems. These alternative interpretations remind us that it is important to understand the potential synergies among QI strategies and that certain QI strategies may be more effective for some preventive interventions than others.

Findings in Relationship to What Is Already Known

2007 Evidence Report

Authors of the 2007 Evidence Report identified several strategies with potential benefit, but for which further research is needed:

1. Printed or computer-based reminders with use of automatic stop orders may reduce unnecessary urethral catheterization.
2. Printed or computer-based reminders may improve adherence to recommendations for timing and duration of surgical antibiotic prophylaxis.
3. Staff education using interactive tutorials (including video and Web-based tutorials) and checklists may improve adherence to insertion practices for placement of central venous catheters.
4. Staff education, including use of interactive tutorials, may improve adherence to interventions to prevent VAP.

The report concluded that the evidence for QI strategies to improve preventive interventions for HAI was generally of suboptimal quality, and therefore they were unable to reach firm conclusions.[7]

Evidence on the results of QI strategies to reduce HAI has shown improvement since the 2007 report. There was improved methodological quality in the included studies of the current report compared with the previous report. Of the 42 studies included in the 2007 report, only 14 (33%) had a control group or more sophisticated statistical analysis than a two-group test. Of the 173 studies included in the current systematic review, 71 (42%) had a control group or more sophisticated statistical analysis. Both the absolute number of studies and the proportion of studies with statistical analysis to control for confounding and secular trend increased. We were therefore able to reach firmer conclusions. We found moderate strength of evidence to support several combinations of strategies across all four infections and for specific infections.

In addition, the number of relevant publications per year has increased. This trend continued while the systematic review was being prepared. An update of the literature search from April 2011 to January 2012 yielded 40 included articles, compared with 103 articles between January 2006 and April 2011.

The 2007 report concluded that:

> Investigators should attempt to perform controlled trials of QI strategies when possible, and should report both adherence rates and infection rates. If performing a controlled trial is impractical, investigators should perform interrupted time series studies, involving reporting data for at least 3 time points before and after the intervention and formal time series statistical analysis.[7]

We are in complete agreement with the authors' conclusions. Relatively small changes in research design and statistical analysis—such as collecting data for three

time points before the intervention and using interrupted time series statistical analysis—could substantially strengthen the body of evidence.

Other Studies and Systematic Reviews

Comparing the results of this systematic review with the published literature is challenging. First, the effectiveness of quality improvement strategies may vary with the context and with the clinical issue being addressed. A number of other studies, including several Cochrane reviews, address efforts to change clinical practice regarding use of preventive services, implementation of guidelines, and prescribing patterns (e.g., Shojania and colleagues,[78] Jamal and colleagues,[79] Grimshaw and colleagues[80]). The impact may also vary with the context, and as this report concludes, the usable information available on context remains sparse. Another recent systematic review of the influence of context on the success of QI in health care concludes that the current body of work is in an early stage of development (Kaplan and colleagues, 2010[81]). The present report relies on the concepts developed by a blue-ribbon panel of experts and reported in the RAND report.[8] The definition and scope of QI strategies also varies (e.g., Scott, 2009;[82] Grimshaw and colleagues, 2004[80]). For example, in this report, provider education is treated as a single entity, in accordance with the categorization used in the 2007 report.[7] A report focusing on education might break it down into distribution of educational materials, educational meetings, and educational outreach visits.[80] As noted, examining the difference between simulation-based provider education and traditional provider education might also be worthwhile.

Finally, the approaches to analyzing individual QI strategies, such as audit and feedback, vary because they often form part of a bundle of QI strategies. Should the focus be on individual strategies, even if they form part of a bundle of interventions that may vary from study to study? The advantage is the ability to focus on specific components that may be critical to the success of an intervention. The disadvantage is the inability to disentangle the effects of different strategies grouped together. The focus on individual strategies was used in the 2007 report and a number of other studies.[7,83] The current report groups combinations of similar strategies, which will help to account for interactions among individual QI strategies. However, because of the large number of different QI strategy combinations, the groupings are not entirely homogeneous and there are fewer studies per combination. The results are also more challenging to present (e.g., base strategies and audit and feedback or provider reminder systems). Nevertheless, we think this approach produces more valid and generalizable conclusions because it allows for interaction effects to a greater degree. Furthermore, in actual practice, bundles of QI strategies are frequently used.

De Vos and colleagues[84] conducted a systematic review of controlled studies on the impact of implementing quality indicators in hospitals. The article included 21 studies from 1994 to 2008, none of which focused on efforts to reduce HAI. Most studies used multiple implementation strategies, and the most commonly used strategy for incorporating information on quality indicators was audit and feedback. Fourteen of the studies adjusted for potential confounders, and the results of these studies appeared to be less effective than those for unadjusted studies. Effective or partly effective studies (defined by the proportion of improved measures) appeared to use audit and feedback together with other implementation strategies. Despite the differences between this article and the current systematic review, the findings appear to be congruent.

The systematic reviews on provider reminder systems tended to focus on specific types of reminder systems, e.g., onscreen point-of-care computer reminders.[78] Given the diversity of provider reminder systems used in the studies included in the current report, the findings for these disparate types of reviews were not compared. One meta-analysis focused on reminder systems to reduce urinary tract infections and urinary catheter use in hospital patients.[85] Based on a review of 14 articles published before September 2008, the authors found that the rate of CAUTI fell by 52 percent ($p < .001$) when reminders or stop orders were used. There was overlap between the studies included in this article and in the current report, but Meddings and colleagues[85] appear to have included simple before-after studies. Their overall conclusion is therefore similar to that in the current report, but the size of the effect is likely to be overestimated.

Comparing the results of the current systematic review with other findings echoes the challenges encountered in conducting this review. Specifically, the heterogeneity encountered in articles on implementation of preventive interventions to reduce HAI is magnified in the literature on QI strategies in general. Overall, however, the results of the current review appear to be congruent with those of other studies and systematic reviews. They suggest that improvements in adherence and infection rates may result from use of audit and feedback as well as provider reminder systems.

Limitations of the Current Review

The limitations of this review are those that are generally encountered in assessments of complex interventions that are used in complex settings. Such studies are typically

heterogeneous in design, setting, measurement, outcomes, and reporting. The resulting data are not amenable to quantitative analysis, thus requiring a qualitative approach. As noted above, evidence synthesis of QI strategies presented considerable challenges. To develop a workable classification of QI strategy combinations, we hypothesized that organizational change and provider education constitute base strategies and categorized other QI strategies that were combined with organizational change and provider education. As is often the case in qualitative research, the validity of the classification must be demonstrated by its application. Is it a useful way to organize the evidence? Most importantly, and as yet unknown, is the issue of whether the classification can be used prospectively to predict success of QI strategies.

Moreover, this review adopted the existing classification system of QI strategies, with whatever limitations may be inherent in this system. One limitation that is apparent to us is that the same strategy may in fact incorporate very different interventions. For example, as noted above, the different provider education methods may vary in intensity, and thus their potential effect on the outcomes of interest may vary. To this end, the recommendations of Shekelle and colleagues to advance the science of patient safety include "more detailed descriptions of interventions and their implementation."[77]

Future Research Needs

We found both critical methodologic weaknesses in the literature and gaps in evidence to address the Key Questions of our review.

Improving Methodologic Quality

Studies selected for this systematic review used either an experimental design with a control group or a quasi-experimental design. Most studies of QI strategies are effectiveness studies rather than efficacy studies. The interventions are implemented in a "real-world" setting rather than using the highly controlled designs that are the standard for efficacy studies. The factors that can confound the results of such quasi-experimental studies are well known. Although 173 studies met initial selection criteria for this review, 102 were excluded from our synthesis because they used statistical analyses that did not control for confounding or secular trend. While these studies reported an association between QI strategy and outcome, they do not support causal inference. To advance the science of using QI strategies to reduce HAI, studies need to demonstrate a causal linkage between improved adherence and reduced infection rates as well. To evaluate this, studies should report both adherence with the preventive interventions and infection rates.

The circumstances under which studies of QI strategies are conducted merit a thoughtful approach to improving the development of evidence. Conducting a rigorous evaluation of a complex intervention is a challenging undertaking. The usual call to improve the quality of evidence by producing randomized controlled trials may not pertain to this issue. A more productive approach would be to improve the quality of quasi-experimental studies through (1) conducting more rigorous study designs, (2) taking into account secular trends and potential confounders, and (3) reporting and analyzing both adherence and infection rates. The enthusiasm of institutions and institutional collaborations might be harnessed by creating toolkits and accessible consultation so that organizations that are engaged in QI initiatives can make a meaningful contribution to the accumulation of knowledge about successful QI strategies.

Methodologic quality would also be improved by systematic collection and reporting of factors that may contribute to the generalizability of QI strategies. Although we abstracted contextual factors from the studies included in this review, the available data were too disparate to be synthesized in a meaningful fashion. This is not surprising, as available studies largely predate the dissemination of recommendations to advance the science of patient safety through emphasis on the effect of context. Presently, the approach to collecting and reporting on factors that may influence generalizability is not sufficiently standardized to produce a robust evidence base. We suggest that availability of toolkits and consultation to organizations undertaking QI evaluation studies could assist this effort.

Adopting more standardized approaches to measuring adherence would strengthen the body of evidence. While preventive interventions are well known, the way in which adherence is measured varied from study to study, thus reducing the comparability of adherence outcomes across studies. Another potential confounder is that studies varied in how preventive interventions were implemented—for example, in the frequency of oral care for ventilated patients or the use of antibiotic-impregnated catheters.

Evidence Gaps

Only one study, which did not control for confounding or secular trend, was found on the use of QI strategies to reduce HAI in nonhospital settings such as ambulatory surgical centers, freestanding dialysis centers, and long-term care facilities. Yet a substantial proportion of health care is delivered outside hospitals.

The studies on using QI strategies to reduce HAI were very limited in providing data about the implementation costs, cost savings from the implementation, and return on investment from implementing the QI strategies. The

data related to savings are weakened by the number of simple before-after studies that present information on cost savings when the impact on infection rates is uncertain. One reason for not adopting successful QI strategies is that they are "too expensive," so the lack of data related to this measure is a major deficiency.

Finally, there are limited data related to the long-term durability and sustainability of the impact of the QI strategies over time. Many studies lasted only 1 year postintervention or less. To eliminate, or at least reduce, HAI, the QI strategies must show sustained effectiveness over several years.

Conclusions

The magnitude of the potential harm caused by HAI and their ubiquity, as well as the recent reduction in infection rates, highlight the importance and feasibility of identifying the most effective ways for health care institutions to address their prevention. Although the practical challenges in measuring the effectiveness of different strategies in a real-world environment are many, the results of this systematic review demonstrate that it can be done and that practical lessons can be gleaned even from a less than ideal evidence base. In this update of the 2007 AHRQ report (Ranji and colleagues, 2007),[7] there is moderate strength of evidence across all four infections examined that both adherence and infection rates improve when either audit and feedback plus provider reminder systems or audit and feedback alone are added to the base strategies of organizational change and provider education. There is low strength of evidence that adherence and infection rates improve when provider reminder systems alone are added to the base strategies. There is insufficient evidence for reduction of HAI in nonhospital settings, cost savings for QI strategies, and the nature and impact of the clinical context. Relatively modest improvements in research approaches have the potential to substantially strengthen the evidence and provide further insight into how to protect patients from healthcare-associated infections.

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