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Original Article

Implementation strategies to reduce surgical site infections: A systematic review

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Abstract

Background: Surgical site infections (SSIs) portend high patient morbidity and mortality. Although evidence-based clinical interventions can reduce SSIs, they are not reliably delivered in practice, and data are limited on the best approach to improve adherence.

Objective: To summarize implementation strategies aimed at improving adherence to evidence-based interventions that reduce SSIs.

Design: Systematic review

Methods: We searched PubMed, Embase, CINAHL, the Cochrane Library, the WHO Regional databases, AFROLIB, and Africa-Wide for studies published between January 1990 and December 2015. The Effective Practice and Organization Care (EPOC) criteria were used to identify an acceptable-quality study design. We used structured forms to extract data on implementation strategies and grouped them into an implementation model called the "Four Es" framework (ie, engage, educate, execute, and evaluate).

Results: In total, 125 studies met our inclusion criteria, but only 8 studies met the EPOC criteria, which limited our ability to identify best practices. Most studies used multifaceted strategies to improve adherence with evidence-based interventions. Engagement strategies included multidisciplinary work and strong leadership involvement. Education strategies included various approaches to introduce evidence-based practices to clinicians and patients. Execution strategies standardized the interventions into simple tasks to facilitate uptake. Evaluation strategies assessed adherence with evidence-based interventions and patient outcomes, providing feedback of performance to providers.

Conclusions: Multifaceted implementation strategies represent the most common approach to facilitating the adoption of evidence-based practices. We believe that this summary of implementation strategies complements existing clinical guidelines and may accelerate efforts to reduce SSIs.

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Surgical site infection (SSI) is a global problem associated with increased mortality, hospital length of stay, hospital readmissions, and costs.[1–5] In the United States, SSIs added >1 million patient days and $1.6 billion in costs in 2005.[6] In Europe, between 2013 and 2014, SSIs varied by surgical procedure from 0.6% to 9.5% per 100 procedures.[7] In low- and middle-income countries (LMICs), SSIs are the most frequent healthcare-associated infection (HAI).[4] Compelling evidence shows that several effective interventions prevent SSIs, and both the World Health Organization (WHO) and the US Centers for Disease Control and Prevention (CDC) recently issued guidelines outlining the most appropriate prevention measures.[8–12] However, evidence-based recommendations are often not delivered at the bedside.[13–15] One possible explanation is limited guidance on translating evidence-based recommendations into routine practice.

Several approaches have been described to improve adherence with evidence-based interventions.[16,17] One practical implementation model used to translate evidence into practice is known as the "Four Es": engage, educate, execute, and evaluate.[18] Use of this model has been associated with significant and sustained reductions in HAIs, including state and national collaborative programs.[19–23] This model also has been used in initiatives to prevent thromboembolic events and to increase early mobility practices among hospitalized patients.[24,25] This model focuses on administrative and clinical stakeholders and has technical and adaptive (cultural) work to foster the translation of evidence into bedside practice. Finally, the Four Es model was recently incorporated into expert guidance documents to support efforts to translate recommendations for HAI prevention into practice and accelerate improvement efforts.[26]

We conducted a systematic review of the literature to identify studies describing implementation strategies to improve adherence with evidence-based SSI-prevention interventions. Our objective was to summarize implementation strategies using

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the Four-E framework and highlight the adaptation of these strategies in LMICs.

Methods

Data sources and search strategy

We searched the following databases: PubMed, EMBASE, CINAHL, Cochrane Library, and WHO Regional databases, including AFROLIB and Africa-wide information on EBSCO for articles published from January 1, 1990, through December 31, 2015. We used a comprehensive database-specific combination of terms, including medical subject headings (MeSH) related to SSI and prevention measures (Appendix 1).

Inclusion and exclusion criteria

Eligible studies described strategies to increase adherence with evidence-based interventions known to reduce SSI during the study period and reported SSI outcomes. For the purpose of our analysis, we used the 1988–2009 CDC guidelines for the prevention of SSI and the 2009 WHO guidelines for safe surgery.[12,27] We included experimental, observational studies, randomized controlled trials (RCT), controlled before-and-after (CBA) studies, interrupted time series (ITS) studies, and quality improvement (QI) initiatives. All surgical patient populations and settings (inpatient or outpatient), and patients of all age groups were included. We excluded systematic reviews, meta-analyses, case reports, editorials or commentaries, and conference proceedings. In addition, we restricted the search to studies written in English, French, and Spanish.

Study selection and data extraction

Articles were selected in several phases (Fig. 1). First, 6 reviewers independently screened titles and generated a list of potential abstracts for inclusion. Second, 4 authors (P.A., V.R., B.A., and B.Z.) independently reviewed the abstracts, identified articles for full-text review, and read the articles for eligibility. Data extracted from each study included author, study year and country, income level of country (low-middle or high, as defined by the World Bank[28]), setting, patient population (pediatric or adult, inpatient or outpatient), surgical specialty, infection prevention measures, compliance data, and SSI outcomes. Study quality was appraised with the Effective Practice and Organization of Care (EPOC) criteria, which considers RCTs, non-RCTs, CBA, and ITS as acceptable quality.[29]

Analysis of implementation strategies

We summarized implementation strategies according to 1 of the Four Es framework categories (ie, engage, educate, execute, or evaluate). These categories were not always mutually exclusive; reviewers decided on the best fit through group consensus. We extracted key stakeholders and compared studies that did and did not demonstrate a decrease in SSI to highlight some differences in implementation approaches.[30–32]

Results

We identified 13,798 records in our initial search and 2 articles from reference lists of the identified studies (Fig. 1). After removing duplicates, 9,823 unique titles remained, of which 7,342 were excluded because inclusion criteria were not met. Of the remaining 2,481 records, 2,106 were excluded because our study objective was not met or an abstract was not provided. The remaining 375 studies underwent full-text review. Of those, 255 were excluded because SSI rates were not reported, leaving 120 studies in our final analysis. An additional 5 studies were identified from another search of systematic reviews, providing 125 studies in our final analysis. The analysis included 124 cohort studies and 1 RCT.

Demographic characteristics

Overall, 105 studies (84%) were conducted in high-income countries and 20 (16%) in LMICs (Appendix 2). Also, 14 studies (12%) evaluated a pediatric population, [33–46] and 111 (88%) evaluated an adult, mixed (adult and pediatric), or undefined population. We quantified the studies by surgical specialty: 21 cardiothoracic,[33,36,37,39,40,46–61] 22 orthopedic,[34,41,42,62–80] 13 obstetrics and gynecology,[81–93] 23 gastrointestinal,[94–116] 3 neurosurgery,[117–119] 2 plastic surgery,[44,120] 28 multiple specialities,[30–32,45,59,121–143] and 13 undefined speciality.[38,43,144–154]

Adherence to SSI prevention measures

Of the 70 studies (56%) that provided data on adherence with SSI preventive measures, 95% reported an increase in compliance with prevention measures. However, 37 studies (28%) did not statistically evaluate the impact of interventions on SSI rates. Of the remaining 88 studies, 61 (69%) reported significant decreases in SSIs,[30,32,33,36,37,41,47–50,54,56,57,59–62,66,68–70,74,75,78,80,83–85,87–91,94,95,97,102,105,108,110,112,113,115,117,118,121,124,126,127,129,132,134,135,138,139,144,145,148,150,152,154] and 21 (24%) reported no change or no statistical decrease in SSIs.[31,34,39,46,55,58,59,77,79,81,99,100,102,107,109,120,123,125,136,140,142] However, 2 studies (2%), including 1 RCT, reported increased SSIs.[96,133]

Overall, 103 studies (82%) used multifaceted strategies to promote adherence to prevention measures. The most common measure was appropriate use of surgical antibiotic prophylaxis, which was reported in 86 of the 125 studies (68%) and in 14 of the 20 (70%) studies conducted in LMICs.[30,37,91,106,121–123,126,129,132,134,138,142,152] Other common prevention measures were surgical site preparation (31%), hair removal techniques (25%), normothermia (20%), glycemic control (18%), wound care (17%), preoperative bathing (16%), operating room discipline/traffic (14%), instrument sterilization (13%), hand hygiene (11%), preoperative cleansing (14%), and gloving techniques (8%) (Table 1).

Implementation of SSI prevention strategies using the Four Es framework

Most studies used multifaceted strategies to improve adherence with evidence-based SSI prevention measures. Moreover, 76 studies (63%) described efforts to engage frontline staff as an important strategy to improve adherence with prevention measures. Also, 65 studies (54%) used some form of education to introduce the measures to frontline staff, compared to only 11% of studies that focused on patient education. Execution strategies to improve adherence were described by 108 studies (86%). In addition, 74 studies (59%) described evaluation activities. Overall, only 8 studies (6%) met the EPOC criteria, which limited our ability to identify best practices in the remaining 117 studies.

Engagement

Among all of the studies, 76 (63%) described efforts to engage frontline staff as an implementation strategy, largely by forming multidisciplinary teams. The range of disciplines included

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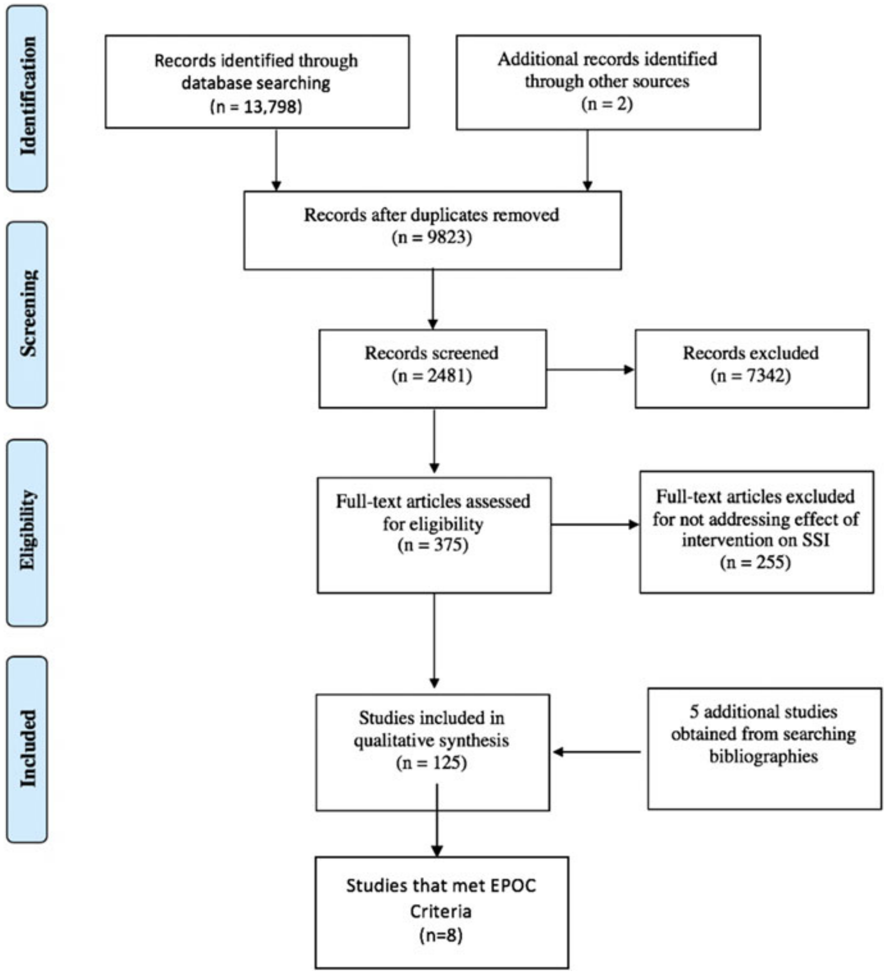

Fig. 1. Systematic review study flow diagram. Note. SSI, surgical site infection; EPOC, Effective Practice and Organization of Care.

surgeons, anesthesia providers, perioperative nurses, pharmacists, and infection prevention control specialists. Multidisciplinary teams reviewed existing SSI prevention practices and identified opportunities for improvement, developed interventions, measured progress, and gave feedback to hospital staff.[33,139,155] In 7 studies, the role of team champions in SSI improvement efforts was described.[37,42,50,73,125,130,131] Team champions were enthusiastic individuals identified across the institution. They included frontline staff such as surgeons, anesthesiologists, nurses, and team members in leadership positions, including administrators and hospital executives. They often provided important leadership to engage and coach teams and managed resources to foster the desired change.[73,100,125,156]

Also, 15 studies highlighted the importance of partnering multidisciplinary teams with senior leaders.[45,51,70,75,81,84,91,111,113,117,130,137,139,147,156] Hospital leadership communicated to clinical staff the goals and expectations to decrease SSIs, and in some studies a designated hospital executive was engaged in the work, met with improvement teams, provided resources, and helped teams overcome organizational barriers.[42,130,156]

Studies in LMICs frequently described multidisciplinary and multidepartmental efforts to prevent SSIs, fostering buy-in and input from providers and encouraging local ownership of the process. These QI initiatives were led and motivated by various groups, including the department of surgery,[91,94,95,106] clinical staff and clinical epidemiologists,[121] hospital management,[81] infection prevention control specialists,[56,129] pharmacists,[142] local investigators and clinical researchers (Table 2).[30,37,44,76,134,138,152] Of 20 LMIC studies, 8 (40%) implemented local teams comprising multiple clinical specialties, administrators, and leadership.[37,56,81,91,106,122,132,152] Also, 2 studies noted that government involvement (Iran and Moldova) from their ministry of health was crucial to uptake of the 2009 WHO checklist.[123,134] Brisibe et al[81] described a written commitment from hospital management to ensure that the Nigerian teaching hospital received a steady supply of sterile medical supplies.

Education

In total, 65 studies (54%) used some form of staff education as an implementation strategy. Traditional teaching methods included large-group workshops, didactics, and grand rounds.[34,50,64,130,131] Other methods included peer education, role playing, briefing and debriefing sessions, webinars, and live simulations.[36,37,43,48,64,100,111] Haycock et al[48] implemented an intensive education program that led to an 86% SSI reduction among cardiac surgery patients. Horst et al[130] had clinical nurse specialists and pharmacists teach the glycemic control protocol to nurses at the bedside. Two studies provided more intensive training, spanning months before intervention implementation.[49,109] Education was reinforced via refresher courses, online videos, and webinars, and brochures allowed for quick reference.[36–38,43,89,121,127,131,144] Singh et al[56] conducted before-and-after test comparisons to evaluate the success of their education.

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Table 1. Common Infection Prevention Measures

IPC Measure	All Studies (n=125), No.	Low and Middle Income Countries (n=20), No.
Surgical antimicrobial prophylaxis	84	14
Skin-prep techniques	37	4
Hair removal techniques	29	3
Temperature control	24	1
Glucose control	22	1
Wound care/sterile dressing	20	3
Preoperative bathing	19	2
OR discipline/traffic/cleaning	17	1
Instrument sterilization	15	4
Hand hygiene	13	4
Preoperative mupirocin/ chlorhexidine	17	0
Gloving technique	10	0
Staphylococcus aureus screening and decolonization	12	0
Method of wound closure	5	0
Hyperoxia	4	0
Bowel preparation practices	7	2
Nutritional support	4	0
Goal-directed intravenous fluid	4	0
Surgical drain placement	3	0
Isolation protocol/contact precautions	3	1
OR ventilation control	3	0

Note. IPC, infection prevention and control; OR, operating room.

Of 125 studies, 15 (11%) focused on patient education and their shared responsibility for infection prevention.[44,69,71,75,78,80,82,85,86,88,101,113,115,117,146] Riley et al[88] gave patients reading material on skin preparation with presurgery instructions. Aiken et al[121] used posters to educate patients about the importance of receiving antibiotics before incision and prompt discontinuation after surgery. Also, 2 studies used a preoperative checklist to educate and prepare patients for surgery.[69,71]

Of 20 studies with LMIC programs, 12 (60%) used staff education to reduce SSI rates.[37,44,56,91,106,121–123,129,132,142,152] A project in Kenya took ~600 hours of staff meeting time to develop and implement antibiotic best practices.[121] Jenkins et al[37] delivered monthly webinars over a 2-year period in 17 LMICs to decrease SSIs among pediatric congenital heart surgery patients. Day-long seminars, [95] one-on-one physician training,[129] and online modules designed for both existing and new staff were also described,[56] all leading to decreases in SSIs. In 1 LMIC study, [44] educating patients on wound care by providing illustrated discharge instructions reduced SSIs among patients undergoing cleft lip and palate repair in India.

Execution

Execution strategies were described by 108 of the 125 studies (86%). Execution often focused on streamlining interventions by simplifying and standardizing the care delivery process and creating verification checks. Furthermore, 57 studies (46%) implemented protocols, pathways, and policies to improve adoption of prevention measures.[31,34,39–41,43,46,53,55–58,61,65,69,74,75,78,79,81,83,85,87,89,94,95,100,102–104,107,109,113,121–123,127,130,131,136,143–145,150–152,154] In addition, 43 studies combined measures into a "bundle" of care practices.[33,40,42,43,46,47,53,54,59,61,66,68,69,75,78,79,83–87,96,98–100,105,107,108,110,112,113,115,116,118,121,135,137,139,140,146,155] In 1 study, SSI were reduced rates by serially introducing a care bundle for cesarean section at a large community hospital.[86] A study involving 24 hospitals in Michigan showed a dose response in which increased bundle compliance resulted in decreased SSIs, suggesting synergy among prevention measures in the bundle.[112]

Among the 125 studies, 26 (21%) used checklists to improve the adoption of evidence-based interventions.[30,36,52,64,66,69,71,75,77,86,97,111,113,120,123,126,132,134,140,143,145,146,157] Other studies used order sets,[75,103,149] electronic reminders,[101,115] and automatic stops for antibiotics[129] to create verification checks and to improve adherence.

Many of the LMIC studies adapted the 2009 WHO Surgical Safety Checklist to local needs, [36,123,126,132,134] protocols,[94,95,122] and policies[81,121] to simplify and standardize care. In a study conducted in Moldova, local ownership and buy-in were promoted by developing an anesthesia preoperative evaluation template that included several SSI prevention interventions to improve workflow.[132] An Argentinean study described an automatic-stop prophylaxis form that empowered pharmacists to stop prolonged postoperative antimicrobials.[129] Both studies showed significantly decreased SSI rates.

Evaluation

Of 125 studies, 74 studies (59%) described evaluation activities, with a general focus on giving feedback to key stakeholders to support improvement efforts. Some studies used a benchmark approach to compare performance among peers.[32,58,107,121] Another strategy reported feedback to the frontline providers and hospital leadership.[113] In that study, providing feedback using a dashboard to compare local data to national benchmarks was associated with a significant decrease in SSI rates and improvement in patient outcomes, including SSI, length of stay, and patient satisfaction. One study posted hospital-based newsletters in public places, such as waiting rooms and elevators, to celebrate staff contributions to decreasing SSIs, [147] and another displayed scorecards of infection rates in patient care areas.[139]

In addition, 5 studies implemented prospective SSI surveillance and performance feedback to surgeons as an unimodal implementation strategy.[32,76,124,148,153] In 1 multicenter study, 34 hospitals participating in a Dutch surveillance network collected SSI data and provided feedback exhibited significant decreases in SSI rates over 5 years.[128] Other studies similarly showed that raising awareness among surgeons about infection rates could lead to practice change and improvements in outcomes.[32,158]

Of 20 LMIC studies, 11 (55%) emphasized evaluation and feedback as an implementation strategy.[37,76,91,94,121,122,126,132,134,138,152] In Brazil, the National Nosocomial Infection Surveillance System was used to evaluate performance and provide feedback to providers.[152] Other evaluation methods included direct observation and immediate feedback of **clinical performance** to create a sense of accountability and motivation for improvement.[134,152] For instance, a tool called the "infectometer" was used in clinical areas to report weekly and monthly HAI rates compared to the expected incidence of infection.[152] In Belgrade, active surveillance with

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Table 2. Included Studies from Low-Middle Income Countries (LMICs)

Author, Year, Country	Design, Setting, Population (No.)	Surgical Specialty	Interventions	IPC Measures	Compliance	SSI Def.	SSI Outcome
Aguilar-Nascimento 2008 Brazil/Middle	Before/After Single hospital Adults (308)	GI surgery	Ex: ACERTO protocol	ACERTO: preoperative nutritional support if malnourished, early postop feeding, no mechanical bowel preparation, Avoidance of excess IVF, drains & nasogastric tubes, early mobilization	Increase	Not reported	Decreased by 66% Pre: 9/78 (11.5%) Post: 9/230 (3.9%) *P* = .01 OR = 3.2 (95% CI, 1.2–8.4)
Aguilar-Nascimento, 2010 Brazil/Middle	Before/After Single unit Adults (117)	GI surgery	Ex: Protocols Ev: Surveillance, audits, and data feedback	ACERTO: preoperative nutritional support if malnourished, early postop feeding, no mechanical bowel preparation, avoidance of excess IVF, drains and nasogastric tubes, early mobilization	Not reported	Not reported	Decrease Pre: 8/42 (19%) Post: 2/75 (2.7%) *P* < .001
Aiken 2013 Kenya/Low	Interrupted time series Single hospital Adults (3,343)	Multiple	Ed: Education materials Ex: Policy Ev: Surveillance, data feedback, audit	SAP policy	Increase	CDC 2008	Decreased for superficial SSI only: Clean, clean-contaminated Pre: 69/1,130 (6.1%) Post: 83/2,046 (4.1%) *P* = .01 Contaminated and dirty: Pre: 10/76 (13.2%) Post: 17/91 (2.2%) *P* = .006 Total SSI (*P* values not provided): Clean, clean-contaminated Pre: 82/1,130 (7.3%) Post: 102/2,046 (5%) Contaminated and dirty: Pre: 18/76 (23.7%) Post: 17/91 (18.7%)
Anchalia 2011 India/Low-middle	Before/After Single hospital Population: not reported	Multiple	En: Multidisciplinary committee Ed: Training Ex: Protocols Ev: Surveillance, data feedback	SAP, preoperative bathing, diabetes control, no/clip hair removal, iodine skin prep, closing operating room doors and limiting staff, instrument sterilization, sterile dressing change, surveillance	Not reported	CDC 1999	Decreased from 13% to 4.4% *P* values not provided.
Askarian 2011 Iran/Middle	Before/After Single hospital Adult (144)	Multiple	Ex: WHO safety checklist Ed: Training	SAP policy	Increase	Not reported	No change Pre: 10.4% Post: 5.3% *P* = .10
Brisibe 2015 Nigeria	Before/After Single unit Adults: number not reported	OB/GYN	En: Commitment of the hospital management Ex: Contract outsourcing, revolving fund scheme, policy	Instrument sterilization	Not reported	Not reported	Overall: No change *P* = 0.230 (Decreased in non-booked CS; *P* = .032)
El Mhamdi 2014 Tunisia/Middle	Before/After Single hospital Mixed population (508)	Multiple	Ex: WHO checklist Ev: Direct observation by senior physician	SAP, instrument sterilization	Increase	Not reported	Decrease Pre: 25/185 (13.5%) Post: 14/323 (4.3%) *P* < .001

(*Continued*)

Table 2. (*Continued*)

Author, Year, Country	Design, Setting, Population (No.)	Surgical Specialty	Interventions	IPC Measures	Compliance	SSI Def.	SSI Outcome
Gomez 2006 Argentina/Middle	Before/After Mixed population (7,478)	Multiple	Ed: Workshops, lectures and discussions Ex: Automatic STOP SAP forms	SAP timing, regimen & duration adequacy	Increase	CDC 1994	Decrease Pre: 111/3,496 (3.2%) After: 75/3,982 (1.9%) $P < .01$
Jenkins 2014 17 LMIC	Prospective Multiple hospitals Pediatrics (15,049)	Cardiac	En: Quality improvement teams. empower nurses Ed: Educational webinars Ex: Congenital heart surgery check list Ev: Worldwide registry	SAP, patient warming, hand hygiene	Not reported	CDC 2008	Decreased over time SIR: for 2012 compared to 2010 was 0.77 (95% CI, 0.68–0.87)
Khan 2006 India/Low	Before/After Single unit Adults (308)	GI surgery	En: Teamwork/ multidisciplinary Ed: Educational materials Ex: Guideline development (nominal group technique	SAP policy, hair removal, patient bathing, skin prep, diabetes control, surgical hand scrub	Increase	CDC Not reported	Decrease Pre: 21/222 (9.45%) Post: 0/56
Kim 2015 Moldova/Low	Before/After Single hospital Adults (2,743)	Multiple	Ex: WHO surgical safety checklist, training, provision of pulse oximeters Ev: Indicators, process measures feedback	Antibiotic prophylaxis timing	Increase	Not reported	Decrease Pre: 22% Short term: 8.5% $P < .01$ Long term: 6%, ($P = .03$)
Kwok 2013 Moldova/Low	Before/After Single hospital Mainly adults (4,357)	Multiple	Ed: Staff training Ex: WHO surgical safety checklist, provision of pulse oximeters Ev: Indicators, process measures feedback	SAP	Increase	Not reported	Decrease Pre: 297/1,993 (14.9%) Post: 98/2,106 (4.7%) $P < .001$
Schönmeyr 2014 India/Low	Before/after Mixed population (mainly pediatrics)(654)	Plastics	Ed: Standardized patient education, nursing education regarding postop care protocols, nurses delivered targeted individual and group education program on wound care protocols, discharge materials provided in local language with pictures Ex: Standardized postoperative care	Wound care, postoperative care was standardized	Not reported	Not reported	Decrease Pre: 8/220 (3.7%) Post: 1/252 (0.4%) $P < .05$
Singh 2012 India/Low	Time series analysis Single unit Adults (2838)	Cardiac	En: Multidisciplinary teamwork Ed: Staff education program (2 training modules and online continuous education) Ex: Protocol Ev: Surveillance	Hand hygiene, isolation precautions, and wound care	Not reported	CDC 1988	Decrease Pre: 46% Post: 3.27% $P < .0001$

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Table 2. (*Continued*)

Author, Year, Country	Design, Setting, Population (No.)	Surgical Specialty	Interventions	IPC Measures	Compliance	SSI Def.	SSI Outcome
Starčević 2015 Serbia/Middle	Prospective (no description of the control group) Single hospital Age not reported (3,867)	Ortho	Ev: Surveillance	Surveillance	Not reported	CDC 1992	Decrease 4.6% to 1.6% *P* value not provided.
Starling 1997 Brazil/Middle	Prospective Multiple hospitals Population unknown	Unknown	En: Multidisciplinary teamwork, cooperative research Ed: Yearly training courses Ex; Policy Ev: Surveillance and data feedback	SAP policy, active surveillance cultures	Not reported	CDC 1992	Decrease CS: 11.6%–5.9% $P < .05$
Suchitra 2009 India/Low	Before/After 3 hospitals Unknown mixed population (2,244)	Multiple	Ed: Staff education program Ev: Surveillance, data feedback	Surveillance, hand hygiene, universal precautions, skin disinfection, SAP policy	Not reported	CDC 1999	Decrease Pre: 136/1,125 (12.1%) Post: 45/1,119 (4%) $P < .001$
Toor 2015 Pakistan/Low	Before/After Single hospital Adults (613)	Multiple	Ex: WHO Surgical Safety Checklist	Preoperative antibiotic use, sterile instruments	Increase	CDC 1999	Decrease Pre: 99/303 (32.7%) Post: 47/310 (15.2%) $P < .001$
Weinberg 2001 Colombia/Middle	TSA Multiple hospitals Adults (16,464)	OB/GYN	En: Leadership, teamwork/ multidisciplinary Ed: Training Ex: CQI tools and principle Ev: Data feedback, accountability	SAP policy, hair removal, and skin prep	Increase	CDC 1992	Decrease Hosp A: $P < .001$ Hosp B: $P = .04$
Yang 2014 China/Middle	Prospective Single hospital Adults (1,543)	Multiple	Ed: Reinforcement by educational sessions delivered by pharmacists every 3 months to include new physicians Ex: SAP guidelines and physician computerized order entry system	SAP type, timing, redosing, and duration	Increase	Not reported	No change $P = .923$

IPC, infection prevention control; SSI, surgical site infection; Ortho, orthopedic; Ed, educate; Ex, execute; Ev, evaluate; SAP, surgical antimicrobial prophylaxis; CDC, Centers for Disease Control; US, United States; En, engage; CHG, chlorhexidine; GI, gastrointestinal (abdominal); ACERTO, Accelerating the Total Recovery; IVF, intravascular fluid; OR, odds ratio; CI, confidence interval; RCT, randomized controlled trial; WHO, World Health Organization; UK, United Kingdom; OB/GYN, obstetrics and gynecology; BMI, body mass index; HPA, Health Protection Agency of United Kingdom; SWI, sternal wound infection; MRSA, methicillin-resistant *Staphylococcus aureus*; CTSW, cardiothoracic surgery sternal wounds; TKA, total knee arthroplasty; SF, spinal fusion; SIR, standardized infection ratio; ACS, American College of Surgeons; TSA, time-series analysis; CS, cesarean section; CQI, continuous quality improvement.

Table 3. Evidence of Included Studies that Met EPOC Criteria (n=8)

Author, Year, Country	Design, Setting, Population (no.)	Surgical Specialty	Interventions	IPC Measures	Compliance	SSI Def.	SSI Outcome
Aiken 2013 Kenya/Low	TSA Single hospital Adults (3,343)	Multiple	Ed: Education materials Ex: Policy Ev: Surveillance, data feedback, audit	SAP policy	Increase	CDC 1999	Decreased for superficial SSI only: Clean, clean-contaminated Pre: 69/1,130 (6.1%) Post: 83/2,046 (4.1%) $P = .01$ Contaminated and dirty: Pre: 10/76 (13.2%) Post: 17/91 (2.2%) $P = .006$ Total SSI (*P* values not provided): Clean, clean-contaminated: Pre: 82/1,130 (7.3%) Post: 102/2,046 (5%) Contaminated and dirty: Pre: 18/76 (23.7%) Post: 17/91 (18.7%)
Anthony 2011 United States /High	RCT Single Adults (211)	Colorectal	Ex: Bundles	No mechanical bowel prep, use of pre-/ intraoperative warming, increased oxygen during and after, reduction of intravenous fluid	NR	CDC 2008	Increase Intervention: 45/100 (45%) Control: 24/97 (25%) $P = .004$
Hadley 2010 United States /High	CBA Single Adults (2,058)	Orthopedic	Ex: Screening and decolonization protocol	Mupirocin and vancomycin	Increase	CDC 2008	Decrease 1.45 vs 1.28 $P = .809$
Rao 2011 United States /High	CBA Single Adults (4,310)	Orthopedic	Ed: Patient education Ex: Screening protocol	Mupirocin and chlorohexidine Antibiotic choice	Increase	NR	Decrease SSI rates: Pre: 2.7% Post: 1.2% $P = .009$
Schweizer 2015 United States	TSA Multiple hospitals Adults (42,534)	Multiple	Ex: Bundle	Screening for *S. aureus* and decolonization, targeted prophylaxis	Increase	CDC 2013	Decrease (*S. aureus* SSI) Pre: 101/28,218 Post: 29/14,316 RR = 0.58 CI = 0.37–0.92
Toltzis 2014 United States	TSA Multiple hospitals Pediatrics	Multiple	En: Administrators, transparency of teams without liability, leadership teams, teleconferences with other teams to share lessons learned Ex: Bundle	Prohibition of razor, chloraprep use, SAP	Increase	CDC 2008	Decrease Pre: 4.48/100 surgical procedures Post: 1.89/100 surgical procedures *P* value not provided.
Van Kasteren 2005 Netherlands	TSA Multiple hospitals Mixed population (3,813)	Multiple	Ex: Policy Ed: Educational sessions Ev: Audits and data feedback	SAP	No change	CDC 1999	No change Pre: 5.4% (95% CI: 4.3–6.5)> Post: 4.6% (95% CI: 3.6–5.4)
Weinberg 2001 Colombia	TSA Multiple hospitals Adults (16,464)	OB/GYN	En: Leadership, teamwork/ multi-disciplinary Ed: Training Ex: CQI tools and principle Ev: Data feedback, accountability	SAP policy, hair removal, skin prep	Increase	CDC 1992	Decrease Hospital A: $P < .001$ Hospital B: $P = .04$

Note. EPOC, Effective Practice and Organization of Care; IPC, infection prevention control; SSI, surgical site infection; Def, definition; TSA, time-series analysis; Ed, educate; Ex, execute; Ev, evaluate; SAP, surgical antimicrobial prophylaxis; CDC, Centers for Disease Control; RCT, randomized controlled trial; NR, not reported; CBA, controlled before-after; CI, confidence interval; En, engage; OB/GYN, Obstetrics and Gynecology; CQI, continuous quality improvement.

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feedback alone resulted in a decrease in SSIs among orthopedic patients.[76]

Application of EPOC criteria

Only 8 studies met EPOC criteria for inclusion in our analysis (Fig. 1). Overall, we observed no clear differences in implementation strategies between studies that met the EPOC criteria and those that did not. Most of these studies described a multifaceted approach that included efforts to define a common goal for improvement, to engage and educate multidisciplinary teams and senior leaders, to simplify and standardize care (bundles, protocols, policies, and briefings), to collect data and offer performance feedback, and to provide opportunities for shared learning.[31,45,59,91,121] Many studies specifically commented on the importance of several important factors when implementing best practices (1) senior leadership support, (2) engaging and educating multidisciplinary teams, (3) locally relevant education materials, and (4) an "enabling infrastructure" to collect data, analyze, and provide feedback.[59,91,121] The remaining 3 studies described efforts to standardize care (ie, bundles, protocols, and policies) but provided little to no information about additional implementation strategies (Table 3).[78,79,96]

Discussion

In this systematic review, we identified 125 studies that described implementation strategies to increase the adoption of evidence-based SSI prevention measures and categorized the strategies according to the Four E framework.[19,20,22,23,159] Most of the studies used a multifaceted approach and addressed change at multiple levels within their healthcare organization. These strategies aimed (1) to build and encourage multidisciplinary teamwork, (2) to obtain leadership buy-in, (3) to increase staff and patient awareness and knowledge about SSIs and prevention practices, (4) to standardize and simplify clinical processes, (5) to create verification procedures, and (6) to provide timely feedback to stakeholders to support improvement efforts. Although strategies varied among studies and we were not able to identify the best approach, lessons learned from successful HAI prevention efforts highlighted the importance of employing multifaceted strategies, including engagement, education, execution, and evaluation.[160]

Globally, SSI prevention is a priority.[3,4,8,9,12] Unfortunately, effective and reliable SSI prevention measures are not consistently implemented in practice, leading to variable success in reducing these infections.[161–163] Several themes emerged from our systematic review.

First, successful strategies often engaged multidisciplinary perioperative staff in leading SSI improvement efforts, highlighting the influential role different specialties have in improving care. Second, leadership participation to champion and support improvement efforts were invaluable and contributed to success. Leadership included senior executives and hospital administrators and sometimes extended to government officials, especially in LMICs.[160,164,165] Although specific leadership actions were poorly described, successful HAI prevention efforts require leadership support to identify and remove implementation barriers, including the adaptive challenges of changing people's priorities, beliefs, habits, and loyalties.[166]

Third, most studies included education to increase knowledge of best practices. Insufficient knowledge of evidence-based recommendations is a significant barrier to adoption of clinical practice guidelines.[167] In addition to traditional learning-based teaching methods, some studies reinforced education by using real-life simulations, [64] monthly coaching calls,[45,111] and yearly training courses.[152] The role of the surgical patient as an important stakeholder in SSI prevention was highlighted in a few studies and is gaining increasing recognition. An expert panel recently published practical ways to engage and educate patients, including educational leaflets translated into multiple languages.[168]

Fourth, most studies used protocols, care bundles, and checklists to simplify and standardize evidence-based interventions as part of their multifaceted approach. Several studies, for example, used checklists to summarize recommended practices. In LMICs, the most common method was to adapt the 2009 WHO surgical safety checklist based on local resources and culture.[30,123,126,132,134] Local ownership of interventions and implementation strategies were especially important in these settings. Nevertheless, protocols and checklists are tools that only work if staff think they add value. Successful implementation requires significant staff engagement that taps into the intrinsic motivation of professionals and uses peer learning to change behaviors and shift social norms.[169]

Finally, almost all studies incorporated an evaluation strategy to monitor performance and provide feedback to frontline staff. Monitoring and feedback can heighten the sense of urgency, promote accountability, and show clinicians how they are performing. For example, in 1 study, patients were surveyed post discharge for SSI, direct feedback was given to the responsible surgeon, and a 31% decrease in the odds of an SSI was achieved.[32] In addition to monitoring outcomes, monitoring process measures and providing feedback may identify additional opportunities to improve.[113]

Feedback can also be used to reframe SSI as a social problem, to foster ownership among staff, and to generate friendly competition.[67] Two studies provided peer-to-peer performance comparisons, [65,139] whereas others made team-to-team and interhospital comparisons within hospital networks.[43,128,147] An important lesson, however, was that monitoring and feedback of outcomes alone may not be sufficient to change behaviors or practices.[18]

Several studies did not reduce SSI rates (Appendix 2). Though it was challenging to understand causality, most of these studies did not describe strategies to address 1 or more of the Four Es (ie, engage, educate, execute, and evaluate). For example, some studies implemented the 2009 WHO surgical safety checklist without describing strategies to engage, educate, evaluate, or provide feedback to staff.[77,120] In the study by Reames et al[111] the investigators implemented a checklist-based initiative to decrease SSI; however, participating organizations lacked the infrastructure to collect data. As a result, improvement teams did not receive feedback on performance or SSI rates. Finally, in the RCT by Anthony et al[96] the authors expressed concerns about the validity of the intervention bundle, as did other commentaries.[96,170]

We acknowledge several limitations of this review. First, most of the studies implemented multifaceted strategies, making it impossible to identify the relative importance of individual strategies or the most effective implementation strategies. Furthermore, our approach to summarizing strategies may be at risk for observer bias. Nevertheless, we identified a broad range of implementation strategies that can be adapted based on local culture and resources and we provide an extensive list of references that hospitals can access for more detailed information. Second, it was sometimes challenging to differentiate between studies designed to evaluate the effectiveness of a clinical intervention (eg, does decolonization improve outcomes?) and studies designed to increase compliance with evidence-based interventions. In addition, our analysis

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included studies conducted prior to the most recent CDC and WHO SSI prevention guidelines. As such, our review will need to be updated as new guidelines, including updated prevention measures are published. Third, we limited our search to studies published in English, Spanish, and French and may have missed important studies published in other languages. Nevertheless, the studies we did identify represented a wide geographic distribution, a variety of surgical procedures, and a range of SSI prevention measures, making our results applicable in diverse settings. Finally, only 8 studies [31,45,59,78,79,91,96,121] met the EPOC criteria of an acceptable-quality study design, limiting our ability to draw causal inferences or definitive conclusions.

Despite these limitations, we believe this review complements clinical practice guidelines and fills an important gap in the existing SSI literature by organizing a broad range of strategies into a practical framework that can be used to enhance the adoption of evidence-based practices and accelerate efforts to reduce SSI.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2018.355

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References

1. Kirkland KB, Briggs JP, Trivette SL, Wilkinson WE, Sexton DJ. The impact of surgical-site infections in the 1990s: attributable mortality, excess length of hospitalization, and extra costs. *Infect Control Hosp Epidemiol* 1999;20:725–730.
2. Gaynes RP, Culver DH, Horan TC, Edwards JR, Richards C, Tolson JS. Surgical site infection (SSI) rates in the United States, 1992–1998: the National Nosocomial Infections Surveillance System basic SSI risk index. *Clin Infect Dis* 2001;33 Suppl 2:S69–S77.
3. Report on the Burden of Endemic Health Care-Associated Infection Worldwide. World Health Organization website. http://apps.who.int.ezp.welch.jhmi.edu/iris/bitstream/10665/80135/1/9789241501507_eng.pdf. Published 2011. Accessed July 2017.
4. Allegranzi B, Bagheri Nejad S, Combescure C, *et al.* Burden of endemic health-care-associated infection in developing countries: systematic review and meta-analysis. *Lancet* 2011;377:228–241.
5. Graf K, Ott E, Vonberg RP, *et al.* Surgical site infections–economic consequences for the health care system. *Langenbecks Arch Surg* 2011;396: 453–459.
6. de Lissovoy G, Fraeman K, Hutchins V, Murphy D, Song D, Vaughn BB. Surgical site infection: incidence and impact on hospital utilization and treatment costs. *Am J Infect Control* 2009;37:387–397.
7. European Centre for Disease Prevention and Control. Healthcare-associated infections: surgical site infections. In: *ECDC. Annual epidemiological report for 2015.* Stockholm: ECDC; 2017.
8. Berrios-Torres SI, Umscheid CA, Bratzler DW, *et al.* Centers for disease control and prevention guideline for the prevention of surgical site infection, 2017. *JAMA Surg* 2017;152:784–791.
9. Global Guidelines on the prevention of surgical site infection, 2016. World Health Organization website. http://www.who.int/infection-prevention/publications/ssi-prevention-guidelines/en/. Published 2016. Accessed August 23, 2017.
10. Allegranzi B, Zayed B, Bischoff P, *et al.* New WHO recommendations on intraoperative and postoperative measures for surgical site infection prevention: an evidence-based global perspective. *Lancet Infect Dis* 2016; 16:e288–e303.
11. Allegranzi B, Bischoff P, de Jonge S, *et al.* New WHO recommendations on preoperative measures for surgical site infection prevention: an evidence-based global perspective. *Lancet Infect Dis* 2016;16:e276–e287.
12. Guidelines for safe surgery, 2009. World Health Organization website. http://apps.who.int/iris/bitstream/handle/10665/44185/9789241598552_eng.pdf?sequence=1&isAllowed=y. Published 2009. Accessed December 15, 2018.
13. Davis D, Evans M, Jadad A, *et al.* The case for knowledge translation: shortening the journey from evidence to effect. *BMJ* 2003;327:33–35.
14. Pronovost PJ, Murphy DJ, Needham DM. The science of translating research into practice in intensive care. *Am J Respir Crit Care Med* 2010; 182:1463–1464.
15. Leaper DJ, Tanner J, Kiernan M, Assadian O, Edmiston CE Jr. Surgical site infection: poor compliance with guidelines and care bundles. *Int Wound J* 2015;12:357–362.
16. Grol R. Improving the quality of medical care: building bridges among professional pride, payer profit, and patient satisfaction. *JAMA* 2001; 286:2578–2585.
17. Gagliardi AR, Brouwers MC, Palda VA, Lemieux-Charles L, Grimshaw JM. How can we improve guideline use? A conceptual framework of implementability. *Implement Sci* 2011;6:26.
18. Pronovost PJ, Berenholtz SM, Needham DM. Translating evidence into practice: a model for large scale knowledge translation. *BMJ* 2008; 337:a1714.
19. Pronovost P, Needham D, Berenholtz S, *et al.* An intervention to decrease catheter-related bloodstream infections in the ICU. *N Engl J Med* 2006;355:2725–2732.
20. DePalo VA, McNicoll L, Cornell M, Rocha JM, Adams L, Pronovost PJ. The Rhode Island ICU collaborative: a model for reducing central line-associated bloodstream infection and ventilator-associated pneumonia statewide. *Qual Saf Health Care* 2010;19:555–561.
21. Hong AL, Sawyer MD, Shore A, *et al.* Decreasing central-line-associated bloodstream infections in Connecticut intensive care units. *J Healthc Qual* 2013;35:78–87.
22. Berenholtz SM, Pham JC, Thompson DA, *et al.* Collaborative cohort study of an intervention to reduce ventilator-associated pneumonia in the intensive care unit. *Infect Control Hosp Epidemiol* 2011;32:305–314.
23. Berenholtz SM, Lubomski LH, Weeks K, *et al.* Eliminating central line-associated bloodstream infections: a national patient safety imperative. *Infect Control Hosp Epidemiol* 2014;35:56–62.
24. Streiff MB, Carolan HT, Hobson DB, *et al.* Lessons from the Johns Hopkins Multi-Disciplinary Venous Thromboembolism (VTE) Prevention Collaborative. *BMJ* 2012;344:e3935.
25. Needham DM, Korupolu R, Zanni JM, *et al.* Early physical medicine and rehabilitation for patients with acute respiratory failure: a quality improvement project. *Arch Phys Med Rehabil* 2010;91:536–542.
26. Septimus E, Yokoe DS, Weinstein RA, Perl TM, Maragakis LL, Berenholtz SM. Maintaining the momentum of change: the role of the 2014 updates to the compendium in preventing healthcare-associated infections. *Infect Control Hosp Epidemiol* 2014;35 Suppl 2:S6–S9.
27. Mangram AJ, Horan TC, Pearson ML, Silver LC, Jarvis WR. Guideline for prevention of surgical site infection, 1999. Hospital Infection Control Practices Advisory Committee. *Infect Control Hosp Epidemiol* 1999;20: 250–280.
28. World Bank countries and lending groups. World Bank website. http://data.worldbank.org/income-level/low-income. Published 2015. Accessed August 21, 2018.
29. What study designs should be included in an EPOC review? EPOC resources for review authors, 2017. Cochrane Effective Practice and Organization of

Care (EPOC) website. http://epoc.cochrane.org/resources/epoc-resources-review-authors. Published July 2017. Accessed December 2018.
30. Toor AA, Farooka MW, Ayyaz M, Sarwar H, Malik AA, Shabbir F. Pre-operative antibiotic use reduces surgical site infection. *J Pak Med Assoc* 2015;65:733–736.
31. van Kasteren ME, Mannien J, Kullberg BJ, *et al.* Quality improvement of surgical prophylaxis in Dutch hospitals: evaluation of a multi-site intervention by time series analysis. *J Antimicrob Chemother* 2005;56:1094–1102.
32. Wilson AP, Hodgson B, Liu M, *et al.* Reduction in wound infection rates by wound surveillance with postdischarge follow-up and feedback. *Br J Surg* 2006;93:630–638.
33. Adler AL, Martin ET, Cohen G, *et al.* A comprehensive intervention associated with reduced surgical site infections among pediatric cardiovascular surgery patients, including those with delayed closure. *J Pediatric Infect Dis Soc* 2012;1:35–43.
34. Ballard MR, Miller NH, Nyquist AC, Elise B, Baulesh DM, Erickson MA. A multidisciplinary approach improves infection rates in pediatric spine surgery. *J Pediatr Orthop* 2012;32:266–270.
35. Dimopoulou A, Kourlaba G, Psarris A, Coffin S, Spoulou V, Zaoutis T. Perioperative antimicrobial prophylaxis in pediatric patients in Greece: compliance with guidelines and impact of an educational intervention. *J Pediatr Surg* 2015;51:1307–1311.
36. Izquierdo-Blasco J, Campins-Marti M, Soler-Palacin P, *et al.* Impact of the implementation of an interdisciplinary infection control program to prevent surgical wound infection in pediatric heart surgery. *Eur J Pediatr* 2015;174:957–963.
37. Jenkins KJ, Castaneda AR, Cherian KM, *et al.* Reducing mortality and infections after congenital heart surgery in the developing world. *Pediatrics* 2014;134:e1422–e1430.
38. Kelly RE Jr, Wenger A, Horton C Jr, Nuss D, Croitoru DP, Pestian JP. The effects of a pediatric unilateral inguinal hernia clinical pathway on quality and cost. *J Pediatr Surg* 2000;35:1045–1048.
39. Murray MT, Corda R, Turcotte R, Bacha E, Saiman L, Krishnamurthy G. Implementing a standardized perioperative antibiotic prophylaxis protocol for neonates undergoing cardiac surgery. *Ann Thorac Surg* 2014;98:927–933.
40. Nayar V, Kennedy A, Pappas J, *et al.* Improving cardiac surgical site infection reporting and prevention by using registry data for case ascertainment. *Ann Thorac Surg* 2016;101:190–199.
41. Ryan SL, Sen A, Staggers K, Luerssen TG, Jea A. A standardized protocol to reduce pediatric spine surgery infection: a quality improvement initiative. *J Neurosurg Pediatr* 2014;14:259–265.
42. Ryckman FC, Schoettker PJ, Hays KR, *et al.* Reducing surgical site infections at a pediatric academic medical center. *Jt Comm J Qual Patient Saf* 2009;35:192–198.
43. Schaffzin JK, Harte L, Marquette S, *et al.* Surgical site infection reduction by the solutions for patient safety hospital engagement network. *Pediatrics* 2015;136:e1353–e1360.
44. Schonmeyr B, Restrepo C, Wendby L, Gillenwater J, Campbell A. Lessons learned from two consecutive cleft lip and palate missions and the impact of patient education. *J Craniofac Surg* 2014;25:1610–1613.
45. Toltzis P, O'Riordan M, Cunningham DJ, *et al.* A statewide collaborative to reduce pediatric surgical site infections. *Pediatrics* 2014;134:e1174–e1180.
46. Woodward CS, Son M, Taylor R, Husain SA. Prevention of sternal wound infection in pediatric cardiac surgery: a protocolized approach. *World J Pediatr Congenit Heart Surg* 2012;3:463–469.
47. Chien CY, Lin CH, Hsu RB. Care bundle to prevent methicillin-resistant *Staphylococcus aureus* sternal wound infection after off-pump coronary artery bypass. *Am J Infect Control* 2014;42:562–564.
48. Haycock C, Laser C, Keuth J, *et al.* Implementing evidence-based practice findings to decrease postoperative sternal wound infections following open heart surgery. *J Cardiovasc Nurs* 2005;20:299–305.
49. Hannan MM, O'ullivan KE, Higgins AM, *et al.* The combined impact of surgical team education and chlorhexidine 2% alcohol on the reduction of surgical site infection following cardiac surgery. *Surg Infect* 2015;16:799–805.
50. Hogle NJ, Cohen B, Hyman S, Larson E, Fowler DL. Incidence and risk factors for and the effect of a program to reduce the incidence of surgical site infection after cardiac surgery. *Surg Infect* 2014;15:299–304.
51. Kles CL, Murrah CP, Smith K, Baugus-Wellmeier E, Hurry T, Morris CD. Achieving and sustaining zero: preventing surgical site infections after isolated coronary artery bypass with saphenous vein harvest site through implementation of a staff-driven quality improvement process. *Dimens Crit Care Nurs* 2015;34:265–272.
52. Lindblom RP, Lytsy B, Sandstrom C, *et al.* Outcomes following the implementation of a quality control campaign to decrease sternal wound infections after coronary artery by-pass grafting. *BMC Cardiovasc Disord* 2015;15:154.
53. Lutarewych M, Morgan SP, Hall MM. Improving outcomes of coronary artery bypass graft infections with multiple interventions: putting science and data to the test. *Infect Control Hosp Epidemiol* 2004;25:517–519.
54. Miyahara K, Matsuura A, Takemura H, Mizutani S, Saito S, Toyama M. Implementation of bundled interventions greatly decreases deep sternal wound infection following cardiovascular surgery. *J Thorac Cardiovasc Surg* 2014;148:2381–2388.
55. Rao N, Schilling D, Rice J, Ridenour M, Mook W, Santa E. Prevention of postoperative mediastinitis: a clinical process improvement model. *J Healthc Qual* 2004;26:22–28.
56. Singh S, Kumar RK, Sundaram KR, Kanjilal B, Nair P. Improving outcomes and reducing costs by modular training in infection control in a resource-limited setting. *Int J Qual Health Care* 2012;24:641–648.
57. Trussell J, Gerkin R, Coates B, *et al.* Impact of a patient care pathway protocol on surgical site infection rates in cardiothoracic surgery patients. *Am J Surg* 2008;196:883–889.
58. Usry GH, Johnson L, Weems JJ Jr. Blackhurst D. Process improvement plan for the reduction of sternal surgical site infections among patients undergoing coronary artery bypass graft surgery. *Am J Infect Control* 2002;30:434–436.
59. Schweizer ML, Chiang HY, Septimus E, *et al.* Association of a bundled intervention with surgical site infections among patients undergoing cardiac, hip, or knee surgery. *JAMA* 2015;313:2162–2171.
60. Walsh EE, Greene L, Kirshner R. Sustained reduction in methicillin-resistant *Staphylococcus aureus* wound infections after cardiothoracic surgery. *Arch Intern Med* 2011;171:68–73.
61. Jog S, Cunningham R, Cooper S, *et al.* Impact of preoperative screening for meticillin-resistant *Staphylococcus aureus* by real-time polymerase chain reaction in patients undergoing cardiac surgery. *J Hosp Infect* 2008;69:124–130.
62. Acklin YP, Widmer AF, Renner RM, Frei R, Gross T. Unexpectedly increased rate of surgical site infections following implant surgery for hip fractures: problem solution with the bundle approach. *Injury* 2011;42:209–216.
63. Douglas P, Asimus M, Swan J, Spigelman A. Prevention of orthopaedic wound infections: a quality improvement project. *J Qual Clin Pract* 2001;21:149–153.
64. Garcia-Paris J, Cohena-Jimenez M, Montano-Jimenez P, Cordoba-Fernandez A. Implementation of the WHO "Safe Surgery Saves Lives" checklist in a podiatric surgery unit in Spain: a single-center retrospective observational study. *Patient Saf Surg* 2015;9:29.
65. Hutzler L, Kraemer K, Iaboni L, Berger N, Bosco JA 3rd. A hospital-wide initiative to eliminate preventable causes of immediate use steam sterilization. *AORN J* 2013;98:597–607.
66. Johnson B, Starks I, Bancroft G, Roberts PJ. The effect of care bundle development on surgical site infection after hemiarthroplasty: an 8-year review. *J Trauma Acute Care Surg* 2012;72:1375–1379.
67. Jordan CJ, Goldstein RY, Michels RF, Hutzler L, Slover JD, Bosco JA 3rd. Comprehensive program reduces hospital readmission rates after total joint arthroplasty. *Am J Orthop (Belle Mead NJ)* 2012;41:E147–E151.
68. Kawamura H, Matsumoto K, Shigemi A, *et al.* A bundle that includes active surveillance, contact precaution for carriers, and cefazolin-based antimicrobial prophylaxis prevents methicillin-resistant Staphylococcus aureus infections in clean orthopedic surgery. *Am J Infect Control* 2016;44:210–214.
69. McDonald LT, Clark AM, Landauer AK, Kuxhaus L. Winning the war on surgical site infection: evidence-based preoperative interventions for total joint arthroplasty. *AORN J* 2015;102:182.e181–182.e111.

https://doi.org/10.1017/ice.2018.355 Published online by Cambridge University Press

70. Mejia E, Williams A, Long M. Decreasing prosthetic joint surgical site infections: an interdisciplinary approach. *AORN J* 2015;101:213–222.
71. Mori C. Implementing evidence-based practice to reduce infections following arthroplasty. *Orthop Nurs* 2015;34:188–196.
72. Morris AJ, Panting AL, Roberts SA, Shuker C, Merry AF. A new surgical site infection improvement programme for New Zealand: early progress. *N Z Med J* 2015;128:51–59.
73. Rovaldi CJ, King PJ. The effect of an interdisciplinary QI project to reduce OR foot traffic. *AORN J* 2015;101:666–681.
74. Sanchez-Hernandez N, Saez-Lopez P, Paniagua-Tejo S, Valverde-Garcia JA. Results following the implementation of a clinical pathway in the process of care to elderly patients with osteoporotic hip fracture in a second level hospital. *Rev Esp Cir Ortop Traumatol* 2016;60:1–11.
75. Sechriest IVF, Carney JR, Kuskowski MA, Haffner JL, Mullen MJ, Covey DC. Incidence of knee sepsis after ACL reconstruction at one institution: the impact of a clinical pathway. *J Bone Joint Surg A* 2013;95: 843–849.
76. Starčević S, Munitlak S, Mijović B, Mikić D, Suljagić V. Surgical site infection surveillance in orthopedic patients in the military medical academy, Belgrade. *Vojnosanit Pregl* 2015;72:499–504.
77. Boaz M, Bermant A, Ezri T, *et al.* Effect of surgical safety checklist implementation on the occurrence of postoperative complications in orthopedic patients. *Isr Med Assoc J* 2014;16:20–25.
78. Rao N, Cannella BA, Crossett LS, Yates AJ Jr, McGough RL 3rd, Hamilton CW. Preoperative screening/decolonization for *Staphylococcus aureus* to prevent orthopedic surgical site infection: prospective cohort study with 2-year follow-up. *J Arthroplasty* 2011;26:1501–1507.
79. Hadley S, Immerman I, Hutzler L, Slover J, Bosco J. *Staphylococcus aureus* decolonization protocol decreases surgical site infections for total joint replacement. *Arthritis* 2010;2010:924518.
80. Kim DH, Spencer M, Davidson SM, *et al.* Institutional prescreening for detection and eradication of methicillin-resistant *Staphylococcus aureus* in patients undergoing elective orthopaedic surgery. *J Bone Joint Surg Am* 2010;92:1820–1826.
81. Brisibe SF, Ordinioha B, Gbeneolol PK. The effect of hospital infection control policy on the prevalence of surgical site infection in a tertiary hospital in South-South Nigeria. *Niger Med J* 2015;56:194–198.
82. Bullough L, Wilkinson D, Burns S, Wan L. Changing wound care protocols to reduce postoperative caesarean section infection and readmission. *Wounds UK* 2014;10:84–89.
83. Corcoran S, Jackson V, Coulter-Smith S, Loughrey J, McKenna P, Cafferkey M. Surgical site infection after cesarean section: implementing 3 changes to improve the quality of patient care. *Am J Infect Control* 2013;41: 1258–1263.
84. Dyrkorn OA, Kristoffersen M, Walberg M. Reducing post-caesarean surgical wound infection rate: an improvement project in a Norwegian maternity clinic. *BMJ Qual Saf* 2012;21:206–210.
85. Hickson E, Harris J, Brett D. A journey to zero: reduction of post-operative cesarean surgical site infections over a five-year period. *Surg Infect* 2015; 16:174–177.
86. Ng W, Brown A, Alexander D, *et al.* A multifaceted prevention program to reduce infection after cesarean section: Interventions assessed using an intensive postdischarge surveillance system. *Am J Infect Control* 2015; 43:805–809.
87. Rauk PN. Educational intervention, revised instrument sterilization methods, and comprehensive preoperative skin preparation protocol reduce cesarean section surgical site infections. *Am J Infect Control* 2010;38: 319–323.
88. Riley MM, Suda D, Tabsh K, Flood A, Pegues DA. Reduction of surgical site infections in low transverse cesarean section at a university hospital. *Am J Infect Control* 2012;40:820–825.
89. Salim R, Braverman M, Berkovic I, Suliman A, Teitler N, Shalev E. Effect of interventions in reducing the rate of infection after cesarean delivery. *Am J Infect Control* 2011;39:e73–e78.
90. Vincent A, Ayzac L, Girard R, *et al.* Downward trends in surgical site and urinary tract infections after cesarean delivery in a French surveillance network, 1997–2003. *Infect Control Hosp Epidemiol* 2008;29: 227–233.
91. Weinberg M, Fuentes JM, Ruiz AI, *et al.* Reducing infections among women undergoing cesarean section in Colombia by means of continuous quality improvement methods. *Arch Intern Med* 2001;161:2357–2365.
92. Witter FR, Lawson P, Ferrell J. Decreasing cesarean section surgical site infection: an ongoing comprehensive quality improvement program. *Am J Infect Control* 2014;42:429–431.
93. Wu M-S, Sun T-B, Shyr M-H, *et al.* Quality improvement of antimicrobial prophylaxis for abdominal hysterectomy in a medical center in eastern Taiwan. *Tzu Chi Med J* 2008;20:112–118.
94. Aguilar-Nascimento JE, Caporossi C, Bicudo AS, Silva RM, Santos TP, Cardoso EA. Enhancing surgical recovery in central West Brazil: the Acerto protocol results. *J Parenter Enter Nutr* 2008;32:322.
95. de Aguilar-Nascimento JE, Bicudo-Salomao A, Caporossi C, Silva RM, Cardoso EA, Santos TP. Enhancing surgical recovery in central West Brazil: the ACERTO protocol results. *e-SPEN* 2008;3:e78–e83.
96. Anthony T, Murray BW, Sum-Ping JT, *et al.* Evaluating an evidence-based bundle for preventing surgical site infection: a randomized trial. *Arch Surg (Chicago)* 2011;146:263–269.
97. Connolly TM, Foppa C, Kazi E, Denoya PI, Bergamaschi R. Impact of a surgical site infection reduction strategy after colorectal resection. *Colorectal Dis* 2016;18:910–918.
98. Crolla RM, van der Laan L, Veen EJ, Hendriks Y, van Schendel C, Kluytmans J. Reduction of surgical site infections after implementation of a bundle of care. *PLoS One* 2012;7:e44599.
99. Hill MV, Holubar SD, Garfield Legare CI, Luurtsema CM, Barth RJ Jr. Perioperative bundle decreases postoperative hepatic surgery infections. *Ann Surg Oncol* 2015;22 Suppl 3:S1140–S1146.
100. Forbes SS, Stephen WJ, Harper WL, *et al.* Implementation of evidence-based practices for surgical site infection prophylaxis: results of a pre- and postintervention study. *J Am Coll Surg* 2008; 207:336–341.
101. Hechenbleikner EM, Hobson DB, Bennett JL, Wick EC. Implementation of surgical quality improvement: auditing tool for surgical site infection prevention practices. *Dis Colon Rectum* 2015;58:83–90.
102. Hedrick TL, Heckman JA, Smith RL, Sawyer RG, Friel CM, Foley EF. Efficacy of protocol implementation on incidence of wound infection in colorectal operations. *J Am Coll Surg* 2007;205:432–438.
103. Hedrick TL, Turrentine FE, Smith RL, *et al.* Single-institutional experience with the surgical infection prevention project in intra-abdominal surgery. *Surg Infect* 2007;8:425–435.
104. Hernández-Navarrete J, Arribas-Llorente JL, Solano Bernad VM, *et al.* Quality improvement program of nosocomial infection in colorectal surgery. *Medicina Clínica* 2005;125:521–524.
105. Keenan JE, Speicher PJ, Nussbaum DP, *et al.* Improving outcomes in colorectal surgery by sequential implementation of multiple standardized care programs. *J Am Coll Surg* 2015;221:404–414.
106. Khan MA, Rao PGM, Rao A, Rodrigues G. Survey and evaluation of antibiotic prophylaxis usage in surgery wards of tertiary level institution before and after the implementation of clinical guidelines. *Indian J Surg* 2006;68:150–156.
107. Larochelle M, Hyman N, Gruppi L, Osler T. Diminishing surgical site infections after colorectal surgery with surgical care improvement project: is it time to move on? *Dis Colon Rectum* 2011;54:394–400.
108. Lavu H, Klinge MJ, Nowcid LJ, *et al.* Perioperative surgical care bundle reduces pancreaticoduodenectomy wound infections. *J Surg Res* 2012; 174:215–221.
109. Miller TE, Thacker JK, White WD, *et al.* Reduced length of hospital stay in colorectal surgery after implementation of an enhanced recovery protocol. *Anesth Analg* 2014;118:1052–1061.
110. Perez-Blanco V, Garcia-Olmo D, Maseda-Garrido E, Najera-Santos MC, Garcia-Caballero J. Evaluation of a preventive surgical site infection bundle in colorectal surgery. *Cir Esp* 2015;93:222–228.
111. Reames BN, Krell RW, Campbell DA Jr, Dimick JB. A checklist-based intervention to improve surgical outcomes in Michigan: evaluation of the Keystone Surgery program. *JAMA Surg* 2015;150:208–215.
112. Waits SA, Fritze D, Banerjee M, *et al.* Developing an argument for bundled interventions to reduce surgical site infection in colorectal surgery. *Surgery* 2014;155:602–606.

https://doi.org/10.1017/ice.2018.355 Published online by Cambridge University Press

113. Wick EC, Galante DJ, Hobson DB, *et al.* organizational culture changes result in improvement in patient-centered outcomes: implementation of an integrated recovery pathway for surgical patients. *J Am Coll Surg* 2015;221:669–677.
114. Wick EC, Gibbs L, Indorf LA, Varma MG, Garcia-Aguilar J. Implementation of quality measures to reduce surgical site infection in colorectal patients. *Dis Colon Rectum* 2008;51:1004–1009.
115. Cima R, Dankbar E, Lovely J, *et al.* Colorectal surgery surgical site infection reduction program: a national surgical quality improvement program—driven multidisciplinary single-institution experience. *J Am Coll Surg* 2013;216:23–33.
116. Bull A, Wilson J, Worth LJ, *et al.* A bundle of care to reduce colorectal surgical infections: an Australian experience. *J Hosp Infect* 2011; 78:297–301.
117. Hover AR, Sistrunk WW, Cavagnol RM, *et al.* Effectiveness and cost of failure mode and effects analysis methodology to reduce neurosurgical site infections. *Am J Med Qual* 2014;29:517–521.
118. Le C, Guppy KH, Axelrod YV, *et al.* Lower complication rates for cranioplasty with peri-operative bundle. *Clin Neurol Neurosurg* 2014;120: 41–44.
119. Lepanluoma M, Rahi M, Takala R, Loyttyniemi E, Ikonen TS. Analysis of neurosurgical reoperations: use of a surgical checklist and reduction of infection-related and preventable complication-related reoperations. *J Neurosurg* 2015;123:145–152.
120. Biskup N, Workman AD, Kutzner E, Adetayo OA, Gupta SC. Perioperative safety in plastic surgery: is the world health organization checklist useful in a broad practice? *Ann Plast Surg* 2016;76:550–555.
121. Aiken AM, Wanyoro AK, Mwangi J, Juma F, Mugoya IK, Scott JA. Changing use of surgical antibiotic prophylaxis in Thika Hospital, Kenya: a quality improvement intervention with an interrupted time series design. *PLoS One* 2013;8:e78942.
122. Anchalia MM, D'Ambruoso L. Seeking solutions: scaling-up audit as a quality improvement tool for infection control in Gujarat, India. *Int J Qual Health Care* 2011;23:464–470.
123. Askarian M, Kouchak F, Palenik CJ. Effect of surgical safety checklists on postoperative morbidity and mortality rates, Shiraz, Faghihy Hospital, a 1-year study. *Qual Manag Health Care* 2011;20:293–297.
124. Brandt C, Sohr D, Behnke M, Daschner F, Ruden H, Gastmeier P. Reduction of surgical site infection rates associated with active surveillance. *Infect Control Hosp Epidemiol* 2006;27:1347–1351.
125. Dimopoulou A, Kourlaba G, Psarris A, Coffin S, Spoulou V, Zaoutis T. Perioperative antimicrobial prophylaxis in pediatric patients in Greece: compliance with guidelines and impact of an educational intervention. *J Pediatr Surg* 2016;51:1307–1311.
126. El Mhamdi S, Letaief M, Cherif Y, Bouanene I, Kallel W, Hamdi A. Implementation of the safe surgery checklist of the World Health Organization at the University Hospital of Monastir (Tunisia). *Tunis Med* 2014;92:385–390.
127. Geubbels EL, Bakker HG, Houtman P, *et al.* Promoting quality through surveillance of surgical site infections: five prevention success stories. *Am J Infect Control* 2004;32:424–430.
128. Geubbels EL, Nagelkerke NJ, Mintjes-De G, Vandenbroucke-Grauls CM, Grobbee DE, De Boer AS. Reduced risk of surgical site infections through surveillance in a network. *Int J Qual Health Care* 2006;18:127–133.
129. Gomez MI, Acosta-Gnass SI, Mosqueda-Barboza L, Basualdo JA. Reduction in surgical antibiotic prophylaxis expenditure and the rate of surgical site infection by means of a protocol that controls the use of prophylaxis. *Infect Control Hosp Epidemiol* 2006;27:1358–1365.
130. Horst HM, Rubinfeld I, Mlynarek M, *et al.* A tight glycemic control initiative in a surgical intensive care unit and hospitalwide. *Jt Comm J Qual Patient Saf* 2010;36:291–300.
131. Kanter G, Connelly NR, Fitzgerald J. A system and process redesign to improve perioperative antibiotic administration. *Anesth Analg* 2006;103: 1517–1521.
132. Kim RY, Kwakye G, Kwok AC, *et al.* Sustainability and long-term effectiveness of the WHO surgical safety checklist combined with pulse oximetry in a resource-limited setting: two-year update from Moldova. *JAMA Surg* 2015;150:473–479.
133. Koch AM, Nilsen RM, Dalheim A, Cox RJ, Harthug S. Need for more targeted measures - only less severe hospital-associated infections declined after introduction of an infection control program. *J Infect Public Health* 2015; 8:282–290.
134. Kwok AC, Funk LM, Baltaga R, *et al.* Implementation of the World Health Organization surgical safety checklist, including introduction of pulse oximetry, in a resource-limited setting. *Ann Surg* 2013;257: 633–639.
135. Liau KH, Aung KT, Chua N, *et al.* Outcome of a strategy to reduce surgical site infection in a tertiary-care hospital. *Surg Infect* 2010;11:151–159.
136. Neumayer L, Mastin M, Vanderhoof L, Hinson D. Using the Veterans Administration National Surgical Quality Improvement Program to improve patient outcomes. *J Surg Res* 2000;88:58–61.
137. Ng WK, Awad N. Performance improvement initiative: prevention of surgical site infection (SSI). *BMJ Qual Improv Rep* 2015;4.
138. Suchitra JB, Lakshmidevi N. Hospital-acquired infections: are prevention strategies matching incidence rates? *Healthcare Infect* 2009;14: 21–25.
139. Thompson KM, Oldenburg WA, Deschamps C, Rupp WC, Smith CD. Chasing zero: the drive to eliminate surgical site infections. *Ann Surg* 2011; 254:430–437.
140. Tillman M, Wehbe-Janek H, Hodges B, Smythe WR, Papaconstantinou HT. Surgical care improvement project and surgical site infections: can integration in the surgical safety checklist improve quality performance and clinical outcomes? *J Surg Res* 2013;184:150–156.
141. Woster PS, Ryan ML, Ginsberg-Evans L, Olson J. Use of total quality management techniques to improve compliance with a medication use indicator. *Top Hosp Pharm Manage* 1995;14:68–77.
142. Yang Z, Zhao P, Wang J, *et al.* DRUGS system enhancing adherence of Chinese surgeons to antibiotic use guidelines during perioperative period. *PLoS One* 2014;9:e102226.
143. Yegge JA, Gase KA, Hopkins-Broyles D, Leone CL, Trovillion EW, Babcock HM. Development of a standardized process improvement protocol to address elevated health care-associated infection rates on an incented quality scorecard. *Am J Infect Control* 2014;42:185–189.
144. Barchitta M, Matranga D, Quattrocchi A, *et al.* Prevalence of surgical site infections before and after the implementation of a multimodal infection control programme. *J Antimicrob Chemother* 2012;67:749–755.
145. Everett BR, Sitton JT, Wilson M. Efficacy and cost-benefit analysis of a global environmental cleaning algorithm on hospital-acquired infection rates. *J Patient Saf* 2017;13:207–210.
146. John H, Nimeri A, Ellahham S. Improved surgical site infection (SSI) rate through accurately assessed surgical wounds. *BMJ Qual Improv Rep* 2015; 4(1):u205509–w2980.
147. Joyce JS, Cioffi GA, Petriwsky JG, Robinson JS. Legacy Health's 'Big Aims' initiative to improve patient safety reduced rates of infection and mortality among patients. *Health Aff (Millwood)* 2011;30:619–627.
148. Marchi M, Pan A, Gagliotti C, *et al.* The Italian national surgical site infection surveillance programme and its positive impact, 2009 to 2011. *Euro Surveill* 2014;19.
149. Pegues DA. Translating and scaling the HHS action plan to prevent health-care-associated infections to the local level: experience of a Los Angeles Health System. *Med Care* 2014;52:S60–S65.
150. Prospero E, Barbadoro P, Marigliano A, Martini E, D'Errico MM. Perioperative antibiotic prophylaxis: improved compliance and impact on infection rates. *Epidemiol Infect* 2011;139:1326–1331.
151. Shea KG, Styhl AC, King HA, Hammons J, Clapp M. Surgical site infection reduction program: challenges and opportunities. *J Pediatr Orthop* 2015; 35:S51–S54.
152. Starling CE, Couto BR, Pinheiro SM. Applying the centers for disease control and prevention and national nosocomial surveillance system methods in Brazilian hospitals. *Am J Infect Control* 1997;25:303–311.
153. Staszewicz W, Eisenring MC, Bettschart V, Harbarth S, Troillet N. Thirteen years of surgical site infection surveillance in Swiss hospitals. *J Hosp Infect* 2014;88:40–47.
154. Takahashi Y, Takesue Y, Nakajima K, *et al.* Implementation of a hospital-wide project for appropriate antimicrobial prophylaxis. *J Infect Chemother* 2010;16:418–423.

https://doi.org/10.1017/ice.2018.355 Published online by Cambridge University Press

155. van der Slegt J, van der Laan L, Veen EJ, Hendriks Y, Romme J, Kluytmans J. Implementation of a bundle of care to reduce surgical site infections in patients undergoing vascular surgery. *PLoS One* 2013;8:e71566.
156. Wick EC, Hobson DB, Bennett JL, *et al.* Implementation of a surgical comprehensive unit-based safety program to reduce surgical site infections. *J Am Coll Surg* 2012;215:193–200.
157. Lepanluoma M, Takala R, Kotkansalo A, Rahi M, Ikonen TS. Surgical safety checklist is associated with improved operating room safety culture, reduced wound complications, and unplanned readmissions in a pilot study in neurosurgery. *Scand J Surg* 2014;103:66–72.
158. Taylor G, Buchanan-Chell M, Kirkland T, McKenzie M, Sutherland B, Wiens R. Reduction in surgical wound infection rates associated with reporting data to surgeons. *Can J Infect Dis* 1994;5:263–267.
159. Pronovost PJ, Watson SR, Goeschel CA, Hyzy RC, Berenholtz SM. Sustaining reductions in central line-associated bloodstream infections in Michigan intensive care units: a 10-year analysis. *Am J Med Qual* 2016;31:197–202.
160. Pronovost PJ, Weaver SJ, Berenholtz SM, *et al.* Reducing preventable harm: observations on minimizing bloodstream infections. *J Health Organ Manag* 2017;31:2–9.
161. Serra-Aracil X, Garcia-Domingo MI, Pares D, *et al.* Surgical site infection in elective operations for colorectal cancer after the application of preventive measures. *Arch Surg (Chicago)* 2011;146:606–612.
162. Awad SS. Adherence to surgical care improvement project measures and post-operative surgical site infections. *Surg Infect* 2012;13:234–237.
163. Arriaga AF, Lancaster RT, Berry WR, *et al.* The better colectomy project: association of evidence-based best-practice adherence rates to outcomes in colorectal surgery. *Ann Surg* 2009;250:507–513.
164. Saint S, Kowalski CP, Banaszak-Holl J, Forman J, Damschroder L, Krein SL. The importance of leadership in preventing healthcare-associated infection: results of a multisite qualitative study. *Infect Control Hosp Epidemiol* 2010;31:901–907.
165. Henderson DM, Staiger TO, Peterson GN, *et al.* A collaborative, systems-level approach to eliminating healthcare-associated MRSA, central-line-associated bloodstream infections, ventilator-associated pneumonia, and respiratory virus infections. *J Healthc Qual* 2012;34: 39–47.
166. Pronovost PJ. Navigating adaptive challenges in quality improvement. *BMJ Qual Saf* 2011;20:560–563.
167. Cabana MD, Rand CS, Powe NR, *et al.* Why don't physicians follow clinical practice guidelines? A framework for improvement. *JAMA* 1999;282: 1458–1465.
168. Tartari E, Weterings V, Gastmeier P, *et al.* Patient engagement with surgical site infection prevention: an expert panel perspective. *Antimicrob Resist Infect Control* 2017;6:45.
169. Dixon-Woods M, Bosk CL, Aveling EL, Goeschel CA, Pronovost PJ. Explaining Michigan: developing an ex post theory of a quality improvement program. *Milbank Q* 2011;89:167–205.
170. Hunt TK, Hopf HW. Selection of bundle components. *Arch Surg (Chicago)* 2011;146:1220–1221.

https://doi.org/10.1017/ice.2018.355 Published online by Cambridge University Press