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Multidisciplinary Prevention and Surveillance of Surgical Site Infections in Orthopedic Surgery: A Systematic Review

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ABSTRACT: Surgical site infections (SSIs) are a major cause of morbidity after orthopedic surgery, and their prevention depends on coordinated work across surgical, anesthetic, nursing, pharmacy, microbiology, and infection-control teams. To synthesize evidence on multidisciplinary strategies for preventing and monitoring SSIs in orthopedic surgery. This review followed PRISMA 2020. PubMed, Scopus, and Web of Science were searched for English-language randomized trials and cohort, case-control, cross-sectional, and case-series studies published from January 2009 to January 2026. Risk of bias was appraised with design-specific tools, and findings were synthesized narratively with an exploratory random-effects meta-analysis. Fourteen studies from ten countries were included (one randomized trial, eight cohort studies, one case series, two case-control studies, and two cross-sectional studies). Across three studies reporting comparable SSI counts, multicomponent bundles were associated with lower SSI risk (pooled risk ratio 0.41, 95% CI 0.22–0.77; I^2 = 0%). Multidisciplinary programs improved antimicrobial prophylaxis adherence (76.7% to 89.9% in one study). Observed hand hygiene compliance was 40.8%, whereas physicians self-reported 88.9% compliance with SSI prevention measures in a separate study. Smoking, prolonged preoperative stay, and iodine-only skin preparation were associated with infection, and SSIs nearly doubled treatment costs. Most nonrandomized intervention studies had serious risk of bias, and certainty was low. Bundle-based, team-delivered prevention coupled with continuous surveillance and feedback is

associated with fewer SSIs and better process adherence, but the evidence is largely observational. Controlled studies with standardized surveillance definitions are needed.

1. INTRODUCTION

Surgical site infection (SSI) is among the most consequential complications of orthopedic surgery. Because orthopedic procedures frequently involve implants, bone, and prolonged operative exposure, infection can compromise fixation or arthroplasty, require revision surgery, and prolong recovery. In older adults with hip fracture, SSI has been linked to excess mortality and a recognizable profile of risk factors (Pollmann et al., 2020), and after joint replacement it adds substantially to the cost of the episode of care (Adeyemi and Trueman, 2019).

A considerable proportion of health-care-associated infections is preventable, which makes SSI a leading target for prevention programs. Systematic reviews estimate that a substantial share of such infections is avoidable with existing measures (Schreiber et al., 2018). The World Health Organization's global guidelines assemble recommendations spanning the preoperative, intraoperative, and postoperative periods, including decolonization, skin antisepsis, antimicrobial prophylaxis, and wound management (WHO, 2018).

Delivering these measures reliably is rarely the work of one profession. Surgeons control technique and operative duration; anesthesiologists administer antimicrobial prophylaxis and manage temperature, glucose, and oxygenation; nurses perform skin preparation, instrument processing, and wound care; pharmacists and stewardship teams govern agent choice and duration; microbiologists provide screening and typing; and infection-prevention teams operate surveillance and feedback. Systematic reviews in orthopedics and traumatology have catalogued the strategies used to translate such measures into daily practice (Marche et al., 2021).

Care bundles, defined as small sets of evidence-based practices applied together, have become the dominant organizing concept. A bundle's value rests on the reliability with which every element is delivered, and its effect has been examined for staphylococcal infections in orthopedic and cardiac surgery (Ma et al., 2017). However, bundles, decolonization programs, and prophylaxis protocols are usually evaluated as stand-alone clinical interventions, and the organizational features that sustain them, such as team structure and feedback, are less often examined together with their outcomes (Ariyo et al., 2019).

Surveillance is the second pillar of prevention. Systematic collection of SSI data, including follow-up after discharge, allows institutions to benchmark performance, detect clusters, and judge whether an intervention has worked, and audit with feedback is among the implementation strategies evaluated in systematic reviews (Ariyo et al., 2019). In orthopedic surgery, where infection may declare itself months after implantation, surveillance design strongly affects measured incidence, and process surveillance, such as observed compliance with hand hygiene, offers a complementary view of whether prevention measures are actually delivered (Marche et al., 2021).

Despite this, evidence on multidisciplinary prevention and surveillance in orthopedic surgery is scattered across trials, quality-improvement reports, cohort studies, and cross-sectional audits. Existing reviews have examined implementation methods (Marche et al., 2021) and pathogen-specific bundles (Ma et al., 2017). The present review brings together evidence on SSI incidence, surveillance, compliance, and risk factors across these designs.

Therefore, this systematic review synthesizes the evidence on multidisciplinary strategies for preventing and monitoring SSIs in orthopedic surgery. The guiding question is: among patients undergoing orthopedic surgery and the teams that care for them, are multidisciplinary prevention and surveillance strategies associated with lower SSI incidence, better process adherence, and more favorable economic outcomes than usual care or no such strategy, and what do observational studies reveal about the gaps and risk factors that these strategies must address?

2. MATERIALS AND METHODS

2.1 Protocol and reporting

This systematic review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021).

2.2 Eligibility criteria

Eligibility was defined using the PICO framework:

Population: patients of any age undergoing elective or trauma-related orthopedic surgery (arthroplasty, arthroscopy, fracture fixation, hemiarthroplasty, spine), and the clinicians and teams delivering perioperative orthopedic care when the study addressed compliance or surveillance.

Intervention/Exposure: multidisciplinary prevention strategies (care bundles, decolonization, antimicrobial prophylaxis stewardship, hand hygiene and aseptic-practice programs, team-based quality improvement) and/or SSI surveillance, audit, and feedback; for observational designs, exposure to patient or perioperative risk factors or to variation in compliance.

Comparator: usual care, a pre-implementation period, uninfected matched controls, or a different professional group; descriptive studies without a comparator were eligible for narrative synthesis.

Outcomes: primary, SSI incidence defined by recognized criteria; secondary, adherence or compliance, length of stay, readmission, cost, microbiological profile, and risk factors.

Eligible designs were randomized controlled trials (RCTs), cohort, case-control, cross-sectional, and case-series studies published in English from 1 January 2009 through 31 January 2026, inclusive. Reviews, meta-analyses, editorials, conference abstracts, laboratory studies, studies of non-orthopedic or mixed surgery without separable orthopedic data, and studies reporting neither SSI nor compliance or process outcomes were excluded.

2.3 Information sources and search strategy

PubMed/MEDLINE, Scopus, and Web of Science were searched, and reference lists of included studies and relevant reviews were screened. A representative PubMed strategy combined three concept blocks: ("surgical site infection"[tiab] OR "surgical wound infection"[MeSH] OR "wound infection"[tiab]) AND (orthop*[tiab] OR arthroplast*[tiab] OR "fracture fixation"[tiab] OR "hip fracture"[tiab] OR spine[tiab]) AND (prevent*[tiab] OR bundle[tiab] OR surveillance[tiab] OR multidisciplin*[tiab] OR interdisciplin*[tiab] OR "infection control"[tiab] OR "antibiotic prophylaxis"[tiab]), limited to English and the date window.

2.4 Study selection and data extraction

Two reviewers independently screened titles, abstracts, and full texts, resolving disagreements by discussion or a third reviewer, and independently extracted data using a piloted form. Screening was performed using Rayyan, and data extraction used a piloted Excel form. Extracted items were country, setting, design, population, intervention or exposure, comparator, surveillance method, outcome definitions, effect measures, and authors' conclusions. Where reports were internally inconsistent, tabulated counts were preferred over narrative percentages.

2.5 Risk of bias and certainty of evidence

Risk of bias was assessed independently by two reviewers using design-appropriate tools: RoB 2 for randomized trials (Sterne et al., 2019); ROBINS-I for nonrandomized studies of interventions (Sterne et al., 2016); the Joanna Briggs Institute checklist for descriptive case-series findings (Munn et al., 2020); the Newcastle-Ottawa Scale for case-control studies and the observational risk-factor cohort (Wells et al., n.d.); and the AXIS tool for cross-sectional studies (Downes et al., 2016). Disagreements were resolved by consensus. Certainty of evidence for the main outcomes was rated independently by two reviewers using the GRADE approach (Guyatt et al., 2008), with final ratings documented in Table 4.

2.6 Synthesis

Studies were synthesized narratively by design and intervention type. Where studies reported SSI counts for a bundle versus a comparator, an exploratory random-effects meta-analysis (DerSimonian and Laird, 1986) pooled risk ratios on the log scale, with a 0.5 continuity correction for zero cells. Heterogeneity was quantified with Cochran's Q and I^2 (Higgins and Thompson, 2002). Studies reporting only rates without counts, or a pathogen-specific outcome, were excluded from the primary pooling, and the MRSA-specific outcome from Kawamura et al. (2016) was examined in a sensitivity analysis. Analyses were run in Python 3 (NumPy, SciPy). Because designs and outcome definitions differed, pooled estimates were interpreted as descriptive rather than confirmatory.

3. RESULTS AND DISCUSSION

3.1 Study selection

The database searches identified 1,500 records (PubMed/MEDLINE n = 620, Scopus n = 480, Web of Science n = 400). After removing 450 duplicates, 1,050 records remained. After screening titles and abstracts, 102 full-text reports were sought and assessed, and 88 were excluded (ineligible study design n = 25, not orthopedic surgery or no separable orthopedic data n = 30, no SSI, compliance, or surveillance outcome n = 20, and other reasons n = 13). Fourteen studies met the inclusion criteria (**Figure 1**).

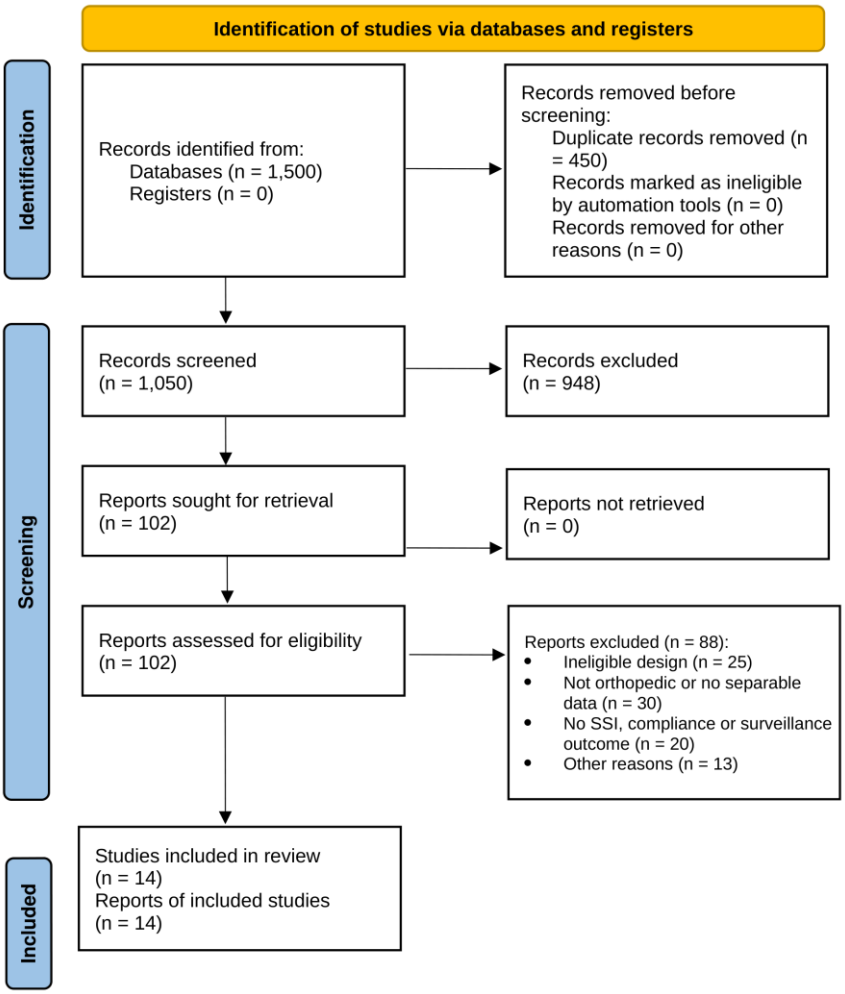


Figure 1. PRISMA 2020 flow diagram of study identification via databases and registers. Database records comprised PubMed/MEDLINE (n = 620), Scopus (n = 480), and Web of Science (n = 400). Adapted from Page et al. (2021), CC BY 4.0.

3.2 Characteristics of included studies

The 14 studies (Table 1) were published between 2015 and 2023. Three were from Germany, two each from India and the United States, and one each from Greece, Japan, Spain, Sweden, Hong Kong, Ireland, and Norway. Nine evaluated interventions: one randomized trial, seven cohort studies (including one quality-improvement study), and one case series. Five observational studies examined risk factors or compliance: two case-control studies, two cross-sectional studies, and one cohort study. Surgical populations spanned arthroplasty and arthroscopy, hip fracture and hemiarthroplasty, orthopedic trauma, spine, and clean implant surgery.

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Table 1. Characteristics of the included studies

Study (ID)	Country; design	Setting and population (N)	Intervention or exposure vs comparator	Outcome ascertainment
Dhawan et al. (2023)	India; RCT (prospective, 3 years)	Clean orthopedic surgery with hardware implants; N = 597 (S. aureus carriers 98, randomized to ICG 50 or NICG 48; non-carriers 499)	Bundled intervention (carrier decolonization with mupirocin and chlorhexidine gluconate) vs non-interventional carriers	PRI/SSI during follow-up; PFGE typing of isolates
Kawamura et al. (2016)	Japan; before–after cohort (2004–2012)	University hospital, clean orthopedic surgery; 3299 operations (period A 1333; period B 1966)	Period B: contact precautions for MRSA carriers and cefazolin-based prophylaxis stewardship added to active surveillance and decolonization (period A)	MRSA SSI rate; antimicrobial use density; alcohol antiseptic use
Kritikou et al. (2019)	Greece; retrospective cohort (2012–2015)	400-bed tertiary hospital; elective knee arthroscopy, knee and hip arthroplasty; N = 1299 (740 old protocol; 559 new protocol)	Three-stage bundle (preoperative risk-factor management, chlorhexidine bathing, nasal mupirocin, alcohol antisepsis, operating-room discipline, education, audits) vs standard care	Continuous surveillance by infection-control nurses; 1-year follow-up
Lustenberger et al. (2020)	Germany; prospective cohort (2015–2019)	Level I trauma center; all surgical procedures (3587 in 2015; 3962 in 2019)	Five-measure complication-avoidance bundle developed from weekly morbidity and mortality conferences; comparison across years	Prospective standardized complication documentation; CDC SSI criteria
Ribed et al. (2020)	Spain; prospective pre–post cohort (2016)	Tertiary teaching hospital; adults having planned spine, total knee, total hip, or hip fracture surgery; N = 83 (40 pre; 43 post)	Multidisciplinary team, updated guidelines, order-entry alerts, education, pharmacist bedside care vs pre-intervention	Prophylaxis adherence; SSI, length of stay, 30-day readmission
Erichsen Andersson et al. (2022)	Sweden; longitudinal observational cohort (5 years)	Large orthopedic university hospital; N = 3553 hip fracture patients	"Safe Hands" bundle across the hip fracture care pathway, built on researcher–manager–clinician partnership; years 1–2 vs years 4–5	Routinely collected outcome data; early (in-hospital) SSI

Study (ID)	Country; design	Setting and population (N)	Intervention or exposure vs comparator	Outcome ascertainment
Conaty et al. (2018)	Ireland; prospective quality-improvement study (June 2016–January 2017)	Joint replacement, hip fracture repair, and fracture fixation; 168 surgeries	Guideline changes, reminders, and tools in rapid improvement cycles; baseline vs end of project	Appropriateness of prophylactic agent, dose, timing, duration
Chow et al. (2020)	Hong Kong; retrospective case series (2008–2018)	Single center; hemiarthroplasty for hip fracture, age > 65 years; N = 527 (242 before; 285 after bundle)	MRSA screening with vancomycin for positives, chlorhexidine bathing, three-stage disinfection, waterproof draping, iodophor drape, adhesive dressing	SSI by CDC criteria (superficial and deep)
Thakore et al. (2015)	United States; retrospective matched case-control	Level I trauma center; 1819 isolated fractures; 78 SSI cases and 78 matched controls	SSI (exposure) vs uninfected controls matched by fracture site, type, and surgical duration	Chart review; treatment costs and risk factors
Suranigi et al. (2021)	India; prospective case-control (2015)	Tertiary hospital; 1023 orthopedic patients; 47 SSI cases and 47 matched controls	Patient, preoperative, and intraoperative factors in infected vs uninfected patients	CDC SSI definition; cultures; length of stay, readmission, cost
Tomsic et al. (2021)	Germany; cross-sectional survey (2019)	University orthopedic clinic; 52 physicians (38 surgeons, 14 anesthesiologists); response rate 73.2%	Self-reported compliance with 26 SSI preventive measures and COM-B determinants	Questionnaire
Baier et al. (2022)	Germany; cross-sectional observational (2020)	Orthopedic university clinic; 1145 hand hygiene opportunities during 16 surgeries	Hand hygiene compliance by occupation and specialty (WHO "5 moments")	Direct observation by trained observer (92.6% concordance)
Schweizer et al. (2015)	United States; multicenter before–after cohort	20 hospitals; 31,701 hip or knee arthroplasties (20,642 before, 11,059 during intervention)	Screening, targeted decolonization and prophylaxis tailored to MRSA status vs preintervention practice	Complex S. aureus SSI using NHSN definitions

Study (ID)	Country; design	Setting and population (N)	Intervention or exposure vs comparator	Outcome ascertainment
Pollmann et al. (2020)	Norway; observational cohort	Akershus University Hospital; 1,709 hip fracture patients	Risk factors for deep SSI and association with mortality	Early deep SSI within 30 days; delayed deep SSI through 1 year for hemiarthroplasty

ID = study identifier used throughout the tables. ICG, interventional carrier group; NICG, non-interventional carrier group; PRI, prosthesis-related infection; PFGE, pulsed-field gel electrophoresis; MRSA, methicillin-resistant S. aureus; CDC, Centers for Disease Control and Prevention; COM-B, capability, opportunity, motivation, behavior. Kritikou et al. report SSI rates of 1.7% vs 0.8% in the text but 1.8% vs 0.7% in the table; table counts are used here.

3.3 Multidisciplinary bundles and ssi incidence

Three studies reported counts suitable for the primary bundle-versus-comparator pooling (Kritikou et al., 2019; Chow et al., 2020; Ribed et al., 2020). Random-effects pooling gave a risk ratio of 0.41 (95% CI 0.22–0.77; Q = 0.62, p = 0.73, I^2 = 0%) (**Figure 2**). Adding the MRSA-specific outcome from Kawamura et al. (2016) gave RR 0.43 (95% CI 0.28–0.66; I^2 = 0%). Schweizer et al. (2015) was synthesized narratively because the main arthroplasty estimate was pathogen-specific. Lustenberger et al. (2020) compared overall surgical complications, and Erichsen Andersson et al. (2022) reported period-specific early SSI rates.

Dhawan et al. (2023) was excluded from pooling because the reported p-value could not be reproduced from the carrier-group event counts. The intervention group had no infections (0/50), and the control group had one MRSA SSI (1/48). The report gave p = 0.002, while a two-sided Fisher exact test using these counts yielded p = 0.490.

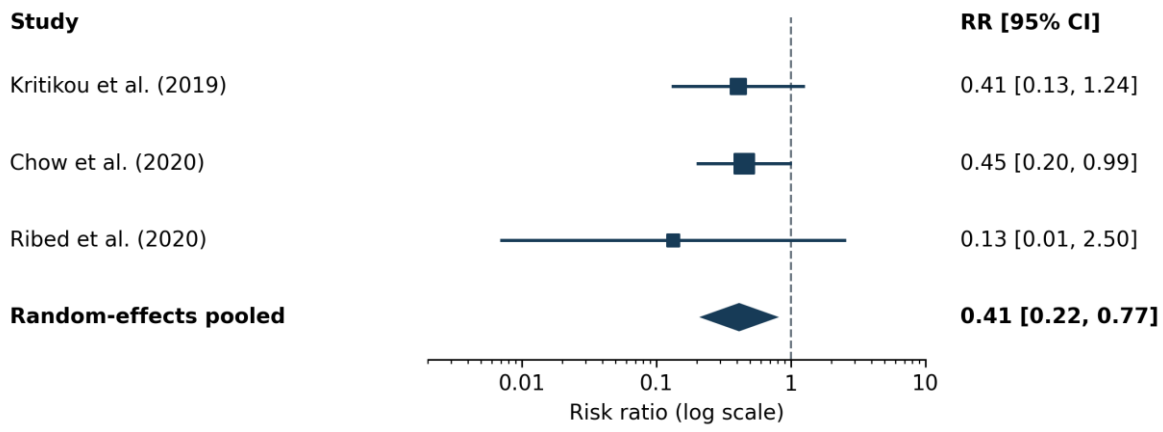


Figure 2. Exploratory random-effects forest plot of SSI risk with multidisciplinary bundles versus comparator (DerSimonian–Laird; 0.5 continuity correction for zero cells).

Table 2. Key quantitative findings and conclusions of the included studies

Study (ID)	Primary outcome(s)	Secondary and other outcomes	Authors' conclusion
Dhawan et al. (2023)	Overall infection 1.1% (PRI 0.3%, SSI 0.8%). Among randomized carriers, 0/50 had an infection with the intervention versus 1/48 (MRSA SSI) in the control group. The paper reported p = 0.002; two-sided Fisher exact p = 0.490 for these counts. PFGE indicated an endogenous source.	S. aureus carriage 16.4% (98/597); non-carriers 1.2% infected, by non–S. aureus organisms	The authors reported a bundle benefit. The carrier comparison contained one infection.
Kawamura et al. (2016)	MRSA SSI 0.97% (19/1966) in period B vs 2.17% (29/1333) in period A; p = 0.003	MRSA SSI rate correlated negatively with cefazolin use density (r = −0.76; p = 0.0002) and alcohol antiseptic use (r = −0.68; p = 0.002)	Contact precautions and prophylaxis stewardship with active surveillance lowered MRSA SSI
Kritikou et al. (2019)	SSI 0.7% (4/559) new protocol vs 1.8% (13/740) old protocol; p = 0.102	Median postoperative stay 2 vs 5 days (p < 0.001); readmission 0.8% vs 1.4% (p = 0.322); median cost hip arthroplasty €3000 vs €4000 and arthroscopy €1500 vs €1585 (both p < 0.001); knee arthroplasty unchanged; SSI odds knee arthroplasty vs arthroscopy OR 5.9 (95% CI 1.75–20.57)	Bundle reduced stay and cost, with a substantial but nonsignificant fall in SSI
Lustenberger et al. (2020)	Overall surgical complication rate 1.14% (2016) to 0.56% (2019), a 51% reduction	Complication rate 0.8% over 5 years; SSI most frequent complication (n = 40; 24.8% of surgical complications)	Multimodal strategy halved complications within 3 years
Ribed et al. (2020)	Global adherence to prophylaxis guidelines 76.7% to 89.9% (p = 0.039)	Duration 75.0% to 97.7%; post-surgery dose 55.0% to 76.7%; timing 57.5% to 72.1%; SSI 3 vs 0 (p > 0.05); stay reduced by 1 day; readmission down 15% (p = 0.038)	Multidisciplinary program improved adherence and appeared to reduce readmission
Erichsen Andersson et al. (2022)	Early SSI 2.5% (years 1–2) to 1.1% (years 4–5)	Sepsis 2.7% to 1.3%; urinary tract infection 14.2% to 4.2%; odds of SSI fell each year; male sex, longer procedure, sepsis, and preoperative skin damage raised odds	Partnership-based bundle effectively reduced infections

Study (ID)	Primary outcome(s)	Secondary and other outcomes	Authors' conclusion
Conaty et al. (2018)	Appropriate prophylaxis prescribing 20% to 78% (168 surgeries)	Junior-doctor changeover required additional education and reminders	Interdisciplinary rapid-cycle approach improved prescribing
Chow et al. (2020)	SSI 3.16% (9/285) after bundle vs 7.02% (17/242) before; p = 0.0411	Hemiarthroplasty bundle launched after unexpectedly high SSI rates in 2010 and 2012	Effective and sustained SSI decrease
Thakore et al. (2015)	Median treatment cost $108,782 (infected) vs $57,418 (controls); p < 0.001	No significant risk factor identified; no single driver of cost	SSI nearly doubled cost; shorter stay and quality programs may help
Suranigi et al. (2021)	SSI 4.6% (47/1023); smoking 17/47 cases vs 5/47 controls (p = 0.0035)	Preoperative stay > 3 days 14 vs 5 (p = 0.0208); iodine-only skin preparation 42 vs 27, compared with iodine plus isopropyl alcohol (OR 6.2, 95% CI 2.09–18.56); readmission more frequent in cases (p = 0.0001); attributable cost Rs 32,542; stay 12.5 vs 10.5 days (p = 0.715); A. baumannii (11 isolates; 10 multidrug resistant) and S. aureus most common	SSI persists despite protocols; better pre-, intra-, and postoperative care needed
Tomsic et al. (2021)	Mean self-reported overall compliance 88.9% (range 53.8–100% across 26 measures)	Surgeons 90.0% vs anesthesiologists 85.9% (p = 0.097); capabilities (β = 0.35; p = 0.015) and planning (β = 0.29; p = 0.041) independently associated; lowest item: removing white coat before patient contact (53.8%)	Capability and planning skills relate to compliance
Baier et al. (2022)	Overall hand hygiene compliance 40.8% (467/1145; 95% CI 37.9–43.6%)	Surgical vs anesthesia staff 28.4% vs 46.1% (p < 0.001); surgeons 19.6% vs anesthesiologists 47.9% (OR 4.8, 95% CI 3.0–7.6); pediatric theater OR 1.9 (95% CI 1.4–2.6)	Compliance needs improvement, with tailored interventions for each group
Schweizer et al. (2015)	Complex S. aureus SSI after hip or knee arthroplasty: rate ratio 0.48 (95% CI 0.29–0.80)	Cardiac surgery estimate 0.86 (95% CI 0.47–1.57)	The bundle was associated with lower complex S. aureus SSI rates after arthroplasty

Study (ID)	Primary outcome(s)	Secondary and other outcomes	Authors' conclusion
Pollmann et al. (2020)	Early deep SSI: 38/1,709 (2.2%); seven delayed deep SSIs after hemiarthroplasty	Longer surgery was associated with deep SSI in univariable analysis only. Early deep SSI was associated with higher adjusted mortality at 90 days (RR 2.4) and 1 year (RR 1.8).	Early deep SSI was associated with excess mortality; surgical duration was not independently associated with deep SSI

Percentages are as reported in the source studies; counts are shown where available.

3.4 Process, resource, and economic outcomes

Programs targeting the prophylaxis process improved adherence markedly, most clearly for duration and dosing (Ribed et al., 2020), and rapid-cycle improvement raised appropriate prescribing several-fold in a second study (Conaty et al., 2018). Reductions in hospital stay and readmission accompanied bundle implementation in two studies, and cost differences were procedure-specific rather than uniform (Kritikou et al., 2019). Conversely, infection imposed a large cost penalty in orthopedic trauma (Thakore et al., 2015) and an attributable cost with excess readmissions in an Indian cohort (Suranigi et al., 2021).

3.5 Surveillance, compliance, and risk factors

Surveillance was integral to most intervention studies, taking the form of continuous infection-control nurse follow-up (Kritikou et al., 2019), active MRSA screening (Kawamura et al., 2016), prospective complication capture reviewed at weekly conferences (Lustenberger et al., 2020), and routine outcome registries (Erichsen Andersson et al., 2022). The two cross-sectional studies revealed a gap between perceived and actual practice: physicians reported high compliance with preventive measures (Tomsic et al., 2021), whereas direct observation found less than half of hand hygiene opportunities were met, with the lowest compliance among surgeons (Baier et al., 2022). The case-control studies identified smoking, prolonged preoperative hospitalization, and iodine-only skin preparation as factors associated with infection (Suranigi et al., 2021), while a matched trauma case-control study found no single dominant risk factor (Thakore et al., 2015). Pollmann et al. (2020) found early deep SSI in 2.2% of hip fracture patients and an association between early deep SSI and higher adjusted mortality.

Table 3. Professional groups, prevention components, and surveillance features by study

Study (ID)	Professional groups or teams documented	Prevention components	Surveillance or monitoring feature
Dhawan et al. (2023)	Orthopedic surgery; clinical microbiology (screening, molecular typing)	S. aureus screening; mupirocin and chlorhexidine decolonization	Follow-up for PRI/SSI; PFGE typing
Kawamura et al. (2016)	Infection control and prevention; orthopedics; antimicrobial stewardship	Contact precautions; cefazolin-based prophylaxis stewardship; alcohol antiseptic	MRSA active surveillance; antimicrobial use density monitoring
Kritikou et al. (2019)	Surgeons; nurses (operating-room head nurse audits); infection-control nurses	Risk-factor management; chlorhexidine bath; nasal mupirocin; alcohol skin antisepsis; closed doors; education	Continuous SSI surveillance; 1-year follow-up; random audits

Study (ID)	Professional groups or teams documented	Prevention components	Surveillance or monitoring feature
Lustenberger et al. (2020)	Trauma surgical team and operating-room staff (weekly morbidity and mortality conference)	Situational awareness; reduced operating-room traffic; preoperative infection screening; adapted prophylaxis; iodine drape	Prospective complication documentation; weekly case review
Ribed et al. (2020)	Surgeons; infectious diseases; preventive medicine; pharmacists	Updated guideline; order-entry alerts for dose and renal function; education; bedside pharmacist care	30-day tracking of SSI, stay, readmission
Erichsen Andersson et al. (2022)	Researchers, managers, clinicians (partnership)	Care-pathway bundle targeting hand hygiene, aseptic technique, catheter-related infection	Routinely collected outcome data over 5 years
Conaty et al. (2018)	Interdisciplinary quality-improvement team	Guideline changes; reminders; supporting tools	Prospective continuous audit in rapid cycles
Chow et al. (2020)	Orthopedic surgical team; microbiological screening	MRSA screening and vancomycin; chlorhexidine bath; three-stage disinfection; drape; dressing	CDC-based SSI classification across 10 years
Thakore et al. (2015)	Orthopedic trauma service; institutional cost data	Not an intervention study	Matched case ascertainment; cost capture
Suranigi et al. (2021)	Orthopedics and microbiology departments	Not an intervention study	CDC definition; culture and susceptibility; prospective data collection
Tomsic et al. (2021)	Orthopedic surgeons and anesthesiologists; hospital hygiene research team	26 preventive measures assessed	Self-reported compliance survey
Baier et al. (2022)	Surgeons, anesthesiologists, surgical and anesthesia nurses	Hand hygiene (WHO "5 moments")	Direct observation validated by infection-control nurses
Schweizer et al. (2015)	Surgical teams, hospital infection preventionists, and project staff	S. aureus screening, targeted decolonization, and prophylaxis tailored to MRSA status	NHSN surveillance for complex S. aureus SSI and monitoring of bundle adherence
Pollmann et al. (2020)	Orthopedic hospital service and Norwegian Hip Fracture Register	Observational study of SSI risk factors and mortality	Local and registry data for early deep SSI, delayed hemiarthroplasty infection and mortality

Groups are listed only where documented in the source reports.

3.6 Risk of bias and certainty of evidence

Most nonrandomized intervention studies carried a serious risk of bias because of historical controls, co-interventions, and limited adherence data. The randomized trial raised some concerns. Table 4 summarizes the study-level assessments and outcome-level certainty ratings. Certainty was rated low for SSI incidence and process adherence, and very low for economic outcomes, downgraded for serious risk of bias and imprecision.

Table 4. Independent risk-of-bias and GRADE certainty of evidence assessments

Study	**Design**	**Tool**	**Overall Risk of Bias**
Dhawan et al. (2023)	RCT	RoB 2	Some concerns
Kawamura et al. (2016)	Cohort	ROBINS-I	Serious
Kritikou et al. (2019)	Cohort	ROBINS-I	Serious
Lustenberger et al. (2020)	Cohort	ROBINS-I	Serious
Ribed et al. (2020)	Cohort	ROBINS-I	Serious
Erichsen Andersson et al. (2022)	Cohort	ROBINS-I	Serious
Conaty et al. (2018)	Cohort / QI	ROBINS-I	Serious
Chow et al. (2020)	Case series	JBI	Moderate
Thakore et al. (2015)	Case-control	NOS	Moderate
Suranigi et al. (2021)	Case-control	NOS	Moderate
Tomsic et al. (2021)	Cross-sectional	AXIS	Moderate
Baier et al. (2022)	Cross-sectional	AXIS	Moderate
Schweizer et al. (2015)	Cohort	ROBINS-I	Serious
Pollmann et al. (2020)	Observational cohort	NOS	Moderate
GRADE Summary of Findings			
Outcome	Studies (n)	Certainty	Reasons for downgrading
SSI incidence (bundles)	3 pooled + 4 narrative	Low	Serious risk of bias (observational designs), imprecision

Study	Design	Tool	Overall Risk of Bias
Process adherence	2	Low	Serious risk of bias, indirectness
Economic outcomes	3	Very low	Serious risk of bias, imprecision, indirectness

RCT, randomized controlled trial; QI, quality improvement; JBI, Joanna Briggs Institute; NOS, Newcastle-Ottawa Scale; AXIS, Appraisal tool for Cross-Sectional Studies; SSI, surgical site infection. Chow's JBI rating applies to descriptive case-series findings. Its comparative before–after estimate had serious risk of bias under ROBINS-I because the historical comparison lacked a concurrent control or adjustment for temporal changes.

3.7 Discussion

Surgical site infection after orthopedic surgery is a preventable but persistent complication whose consequences are amplified by implants, frail patient populations, and the need for revision surgery (Pollmann et al., 2020; Adeyemi and Trueman, 2019). Prevention is therefore best understood as a system property rather than the product of any single practice: it emerges from the reliable delivery of many small actions by different professions, and from surveillance that tells teams whether those actions are working (WHO, 2018; Schreiber et al., 2018).

The exploratory pooled estimate from three nonrandomized comparisons favored bundles, with no heterogeneity detected across the three estimates. Schweizer et al. (2015) found a lower rate of complex S. aureus SSI in the hip or knee arthroplasty subgroup (rate ratio 0.48, 95% CI 0.29–0.80). The cardiac surgery estimate was 0.86 (95% CI 0.47–1.57). Studies evaluating prophylaxis prescribing or overall surgical complications addressed different outcomes. Regression to the mean after an infection cluster and secular changes may partly explain the reductions seen in historical-control studies.

Several mechanisms plausibly explain these effects. A large share of orthopedic SSIs arise from the patient's own flora, particularly Staphylococcus aureus carried in the anterior nares and on the skin, and molecular typing in the randomized trial traced the only breakthrough infection to an endogenous strain. Intranasal mupirocin combined with chlorhexidine washing lowers the bacterial burden near the incision and was shown, in the landmark trial of nasal carriers, to reduce hospital-associated S. aureus infection (Bode et al., 2010), which is the rationale for the recommendation of decolonization before orthopedic surgery in WHO guidance (WHO, 2018). Skin antisepsis with an alcohol-based chlorhexidine preparation provides rapid kill and residual activity that povidone-iodine alone lacks, which is consistent with the observation in a prospective case-control study that iodine-only preparation was more frequent among infected patients than controls. Iodophor-impregnated adhesive drapes and waterproof draping further limit recontamination of the wound edge by skin flora during long operations.

Optimizing antibiotic prophylaxis acts through a different pathway: giving an appropriate agent at the correct time and dose so that tissue concentrations exceed the minimum inhibitory concentration at incision, redosing during prolonged procedures, and stopping promptly. Embedding these rules in electronic order entry with renal-function and dose alerts, and pairing them with pharmacist bedside review, converts guideline knowledge into default behavior, which probably explains why adherence improved most for duration and dosing, the items most prone to human error. Prolonged or broad-spectrum prophylaxis, by contrast, selects for resistant organisms; the inverse relationship between cefazolin-based prophylaxis and methicillin-resistant S. aureus infection in the Japanese series suggests that stewardship and contact precautions act together by narrowing selective pressure and interrupting transmission from carriers (Kawamura et al., 2016). WHO likewise advises against continuing prophylaxis after the operation (WHO, 2018), a position the stewardship-oriented programs operationalized.

Operating-room discipline contributes through airborne and contact routes. Reducing door openings and staff traffic limits the shedding and resuspension of bacteria-carrying particles near the sterile field, which fits the improvement in the trauma center

that adopted such measures within a broader complication-avoidance bundle. Hand hygiene is the contact-transmission counterpart, yet the observational data suggest it is the least reliably performed element. Observed compliance was low overall, and surgeons performed worse than anesthesiologists, who carry out most aseptic tasks at the anesthesia workstation; this probably reflects a tendency among surgeons to equate hand hygiene with the preoperative scrub rather than with the many indications that arise during induction, positioning, and recovery.

The contrast between high self-reported and low observed compliance is instructive. Self-report overestimates behavior, as documented for hand hygiene by Jenner et al. (2006) and in work on overconfidence in infection-control proficiency by Bushuven et al. (2019), so process surveillance requires direct observation or electronic capture rather than questionnaires alone. The physician survey identified capability and planning, not motivation, as determinants of compliance, implying that education alone will not close the gap and that interventions tailored to skills and implementation planning are needed; psychologically tailored hand hygiene programs have been tested in cluster-randomized designs for this purpose (von Lengerke et al., 2019). This is consistent with reviews concluding that how a measure is implemented matters as much as which measure is chosen (Ariyo et al., 2019; Marche et al., 2021), and with evidence that compliance with guidelines and care bundles is frequently poor in routine practice (Leaper et al., 2015).

Surveillance functions as the feedback loop that makes these mechanisms visible. Programs that paired intervention with continuous case finding, audit, and structured case review, such as weekly morbidity conferences or infection-control nurse follow-up, were the ones able to demonstrate effects over several years, and the large hip fracture project suggested that infection rates continued to fall after the research team withdrew, pointing to cultural rather than purely procedural change. The case-control studies add the patient-level perspective: modifiable exposures such as smoking and prolonged preoperative hospitalization, and the predominance of multidrug-resistant Gram-negative organisms alongside staphylococci in one setting, argue for preoperative optimization pathways and antibiogram-informed prophylaxis. Infection also imposed a large economic penalty, in line with economic analyses after joint replacement (Adeyemi and Trueman, 2019) and cohort evidence linking SSI after hip fracture with excess mortality (Pollmann et al., 2020), which strengthens the case for multidisciplinary programs.

Several caveats temper these inferences. Most evidence is single-center, observational, and based on historical comparison; bundles combine many components, so the contribution of any one element cannot be isolated; adherence was seldom measured; surveillance definitions and post-discharge follow-up differed; and publication bias toward favorable quality-improvement reports is likely. Nevertheless, the convergence of process, outcome, and economic signals across designs and countries supports organizing SSI prevention in orthopedic surgery as a team-based, bundled, and continuously monitored program, with compliance measured by observation and tailored to the behavioral barriers of each professional group.

3.8 Strengths and limitations of this review

Strengths include the use of design-specific appraisal tools, the combination of intervention, surveillance, compliance, and risk-factor evidence, and transparent handling of discrepancies within source reports. Limitations include the small number of eligible studies, wide clinical and methodological heterogeneity, the restriction to English-language publications, reliance on aggregate data, and an exploratory pooled analysis of three nonrandomized comparisons.

4. CONCLUSIONS

Multidisciplinary, bundle-based prevention combined with continuous surveillance and feedback is consistently associated with fewer SSIs, better adherence to prophylaxis, and in some settings shorter stays and lower costs in orthopedic surgery. Observed compliance with basic practices such as hand hygiene remains well below self-reported levels, particularly among surgeons. The certainty of evidence is low because most studies are single-center, nonrandomized, and exposed to confounding. Future work should use controlled or stepped-wedge designs, report bundle adherence alongside outcomes, and adopt standardized surveillance definitions with post-discharge follow-up.

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AUTHOR CONTRIBUTIONS

All authors equally contributed to this work (Conceptualization, Methodology, Data Curation, Formal Analysis, Writing – Original Draft, Writing – Review & Editing, and Supervision).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

Ethics Statement

This study is a systematic review of previously published, de-identified data and did not involve new human or animal subjects; formal ethics approval was therefore not required.

Data Availability Statement

The data extraction tables supporting this review are available from the corresponding author upon reasonable request. All included studies are publicly available in the cited peer-reviewed sources.

REFERENCES

[1] Adeyemi, A., Trueman, P., 2019. Economic burden of surgical site infections within the episode of care following joint replacement. Journal of Orthopaedic Surgery and Research 14(1), 196. https://doi.org/10.1186/s13018-019-1224-8

[2] Ariyo, P., Zayed, B., Riese, V., Anton, B., Latif, A., Kilpatrick, C., Allegranzi, B., Berenholtz, S., 2019. Implementation strategies to reduce surgical site infections: a systematic review. Infection Control & Hospital Epidemiology 40(3), 287-300. https://doi.org/10.1017/ice.2018.355

[3] Baier, C., Tinne, M., von Lengerke, T., Gossé, F., Ebadi, E., 2022. Compliance with hand disinfection in the surgical area of an orthopedic university clinic: results of an observational study. Antimicrobial Resistance & Infection Control 11, 22. https://doi.org/10.1186/s13756-022-01058-2

[4] Bode, L.G., Kluytmans, J.A., Wertheim, H.F., Bogaers, D., Vandenbroucke-Grauls, C.M., Roosendaal, R., Troelstra, A., Box, A.T., Voss, A., van der Tweel, I., van Belkum, A., Verbrugh, H.A., Vos, M.C., 2010. Preventing surgical-site infections in nasal carriers of Staphylococcus aureus. The New England Journal of Medicine 362(1), 9-17. https://doi.org/10.1056/NEJMoa0808939

[5] Bushuven, S., Juenger, J., Moeltner, A., Dettenkofer, M., 2019. Overconfidence in infection control proficiency. American Journal of Infection Control 47(5), 545-550. https://doi.org/10.1016/j.ajic.2018.10.022

[6] Chow, C.L., Chan, P.H.A., Hung, Y.W., Fan, J.C.H., 2020. The application of evidence-based bundle approach to reduce surgical site infection in geriatric hip fracture patients: a single centre experience. Journal of Orthopaedics, Trauma and Rehabilitation 27(2), 133-141. https://doi.org/10.1177/2210491720928486

[7] Conaty, O., Gaughan, L., Downey, C., Carolan, N., Brophy, M.J., Kavanagh, R., McNamara, D.A.A., Smyth, E., Burns, K., Fitzpatrick, F., 2018. An interdisciplinary approach to improve surgical antimicrobial prophylaxis. International Journal of Health Care Quality Assurance 31(2), 162-172. https://doi.org/10.1108/IJHCQA-05-2017-0078

[8] DerSimonian, R., Laird, N., 1986. Meta-analysis in clinical trials. Controlled Clinical Trials 7(3), 177-188. https://doi.org/10.1016/0197-2456(86)90046-2

[9] Dhawan, B., Juyal, D., Rawre, J., Narayan, M., Velpandian, T., Sreenivas, V., Garg, B., Malhotra, R., 2023. Impact of bundled intervention on outcomes of patients undergoing clean orthopedic surgeries with hardware implants: small prospective randomized controlled trial. Surgical Infections 24(6), 566-574. https://doi.org/10.1089/sur.2023.119

[10] Downes, M.J., Brennan, M.L., Williams, H.C., Dean, R.S., 2016. Development of a critical appraisal tool to assess the quality of cross-sectional studies (AXIS). BMJ Open 6(12), e011458. https://doi.org/10.1136/bmjopen-2016-011458

[11] Erichsen Andersson, A., Gillespie, B.M., Karlsson, M., Malchau, H., Nellgård, B., Wikström, E., Rogmark, C., Tillander, J., 2022. Reduction of early surgical site and other care related infections in 3553 hip fracture patients: lessons learned

from the 5-year Safe Hands project. Antimicrobial Resistance & Infection Control 11, 113. https://doi.org/10.1186/s13756-022-01153-4

[12] Guyatt, G.H., Oxman, A.D., Vist, G.E., Kunz, R., Falck-Ytter, Y., Alonso-Coello, P., Schünemann, H.J., 2008. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 336(7650), 924-926. https://doi.org/10.1136/bmj.39489.470347.AD

[13] Higgins, J.P.T., Thompson, S.G., 2002. Quantifying heterogeneity in a meta-analysis. Statistics in Medicine 21(11), 1539-1558. https://doi.org/10.1002/sim.1186

[14] Jenner, E.A., Fletcher, B.C., Watson, P., Jones, F.A., Miller, L., Scott, G.M., 2006. Discrepancy between self-reported and observed hand hygiene behaviour in healthcare professionals. Journal of Hospital Infection 63(4), 418-422. https://doi.org/10.1016/j.jhin.2006.03.012

[15] Kawamura, H., Matsumoto, K., Shigemi, A., Orita, M., Nakagawa, A., Nozima, S., Tominaga, H., Setoguchi, T., Komiya, S., Tokuda, K., Nishi, J., 2016. 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. American Journal of Infection Control 44(2), 210-214. https://doi.org/10.1016/j.ajic.2015.09.014

[16] Kritikou, G., Avgerinos, K.I., Koutserimpas, C., Sourri, F., Hatzigeorgiou, D., Kottaridi, C., Bountouris, I., 2019. Effectiveness of a preventive bundle of measures for reducing surgical site infections in patients undergoing elective orthopedic procedures in a Hellenic Air Force Hospital. Il Giornale di Chirurgia 40(2), 120-126. https://pubmed.ncbi.nlm.nih.gov/31131811/

[17] Leaper, D.J., Tanner, J., Kiernan, M., Assadian, O., Edmiston, C.E. Jr., 2015. Surgical site infection: poor compliance with guidelines and care bundles. International Wound Journal 12(3), 357-362. https://doi.org/10.1111/iwj.12243

[18] Lustenberger, T., Meier, S.L., Verboket, R.D., Störmann, P., Janko, M., Frank, J., Marzi, I., 2020. The implementation of a complication avoidance care bundle significantly reduces adverse surgical outcomes in orthopedic trauma patients. Journal of Clinical Medicine 9(12), 4006. https://doi.org/10.3390/jcm9124006

[19] Ma, N., Cameron, A., Tivey, D., Grae, N., Roberts, S., Morris, A., 2017. Systematic review of a patient care bundle in reducing staphylococcal infections in cardiac and orthopaedic surgery. ANZ Journal of Surgery 87(4), 239-246. https://doi.org/10.1111/ans.13879

[20] Marche, B., Neuwirth, M., Kugler, C., Bouillon, B., Mattner, F., Otchwemah, R., 2021. Implementation methods of infection prevention measures in orthopedics and traumatology: a systematic review. European Journal of Trauma and Emergency Surgery 47(4), 1003-1013. https://doi.org/10.1007/s00068-020-01477-z

[21] Munn, Z., Barker, T.H., Moola, S., Tufanaru, C., Stern, C., McArthur, A., Stephenson, M., Aromataris, E., 2020. Methodological quality of case series studies: an introduction to the JBI critical appraisal tool. JBI Evidence Synthesis 18(10), 2127-2133. https://doi.org/10.11124/JBISRIR-D-19-00099

[22] Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372, n71. https://doi.org/10.1136/bmj.n71

[23] Pollmann, C.T., Dahl, F.A., Røtterud, J.H.M., Gjertsen, J.E., Årøen, A., 2020. Surgical site infection after hip fracture: mortality and risk factors: an observational cohort study of 1,709 patients. Acta Orthopaedica 91(3), 347-352. https://doi.org/10.1080/17453674.2020.1717841

[24] Ribed, A., Monje, B., García-González, X., Sanchez-Somolinos, M., Sanz-Ruiz, P., Rodríguez-González, C.G., Sanjurjo-Saez, M., 2020. Improving surgical antibiotic prophylaxis adherence and reducing hospital readmissions: a bundle of interventions including health information technologies. European Journal of Hospital Pharmacy 27(4), 237-242. https://doi.org/10.1136/ejhpharm-2018-001666

[25] Schreiber, P.W., Sax, H., Wolfensberger, A., Clack, L., Kuster, S.P., Swissnoso, 2018. The preventable proportion of healthcare-associated infections 2005–2016: systematic review and meta-analysis. Infection Control & Hospital Epidemiology 39(11), 1277-1295. https://doi.org/10.1017/ice.2018.183

[26] Schweizer, M.L., Chiang, H.Y., Septimus, E., Moody, J., Braun, B., Hafner, J., Ward, M.A., Hickok, J., Perencevich, E.N., Diekema, D.J., Richards, C.L., Cavanaugh, J.E., Perlin, J.B., Herwaldt, L.A., 2015. Association of a bundled intervention with surgical site infections among patients undergoing cardiac, hip, or knee surgery. JAMA 313(21), 2162-2171. https://doi.org/10.1001/jama.2015.5387

[27] Sterne, J.A.C., Savović, J., Page, M.J., Elbers, R.G., Blencowe, N.S., Boutron, I., Cates, C.J., Cheng, H.Y., Corbett, M.S., Eldridge, S.M., et al., 2019. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ 366, l4898. https://doi.org/10.1136/bmj.l4898

[28] Sterne, J.A., Hernán, M.A., Reeves, B.C., Savović, J., Berkman, N.D., Viswanathan, M., Henry, D., Altman, D.G., Ansari, M.T., Boutron, I., et al., 2016. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ 355, i4919. https://doi.org/10.1136/bmj.i4919

[29] Suranigi, S.M., Ramya, S.R., Devi, C.S., Kanungo, R., Najimudeen, S., 2021. Risk factors, bacteriological profile and outcome of surgical site infections following orthopaedic surgery. Iranian Journal of Microbiology 13(2), 171-177. https://doi.org/10.18502/ijm.v13i2.5976

[30] Thakore, R.V., Greenberg, S.E., Shi, H., Foxx, A.M., Francois, E.L., Prablek, M.A., Nwosu, S.K., Archer, K.R., Ehrenfeld, J.M., Obremskey, W.T., Sethi, M.K., 2015. Surgical site infection in orthopedic trauma: a case-control study evaluating risk factors and cost. Journal of Clinical Orthopaedics and Trauma 6(4), 220-226. https://doi.org/10.1016/j.jcot.2015.04.004

[31] Tomsic, I., Ebadi, E., Gossé, F., Hartlep, I., Schipper, P., Krauth, C., Schock, B., Chaberny, I.F., von Lengerke, T., 2021. Determinants of orthopedic physicians' self-reported compliance with surgical site infection prevention: results of the WACH-trial's pilot survey on COM-B factors in a German university hospital. Antimicrobial Resistance & Infection Control 10, 67. https://doi.org/10.1186/s13756-021-00932-9

[32] von Lengerke, T., Ebadi, E., Schock, B., Krauth, C., Lange, K., Stahmeyer, J.T., Chaberny, I.F., 2019. Impact of psychologically tailored hand hygiene interventions on nosocomial infections with multidrug-resistant organisms: results of the cluster-randomized controlled trial PSYGIENE. Antimicrobial Resistance & Infection Control 8, 56. https://doi.org/10.1186/s13756-019-0507-5

[33] Wells, G. A., Shea, B., O'Connell, D., Peterson, J., Welch, V., Losos, M., & Tugwell, P. (2000). The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Ottawa Hospital Research Institute. https://ohri.ca/en/who-we-are/core-facilities-and-platforms/ottawa-methods-centre/newcastle-ottawa-scale

[34] World Health Organization, 2018. Global guidelines for the prevention of surgical site infection, 2nd ed. WHO, Geneva, Switzerland. ISBN 978-92-4-155047-5.