Original Research

FACTORS AFFECTING SURGICAL SITE INFECTION IN GENERAL SURGERY: AN EVIDENCE-BASED META-ANALYTIC REVIEW AND CLINICAL RECOMMENDATIONS

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ABSTRACT

Background: Surgical site infections (SSIs) remain a leading cause of postoperative morbidity, cost and prolonged hospitalization. We synthesized contemporary evidence on patient, procedure and perioperative care factors associated with SSI in general surgery and summarized actionable prevention strategies.

Methods: We performed an umbrella meta-analytic review of systematic reviews, meta-analyses, randomized trials, guideline syntheses and high-quality cohort studies indexed through February 1st 2026 (PubMed, Medline, Embase, Cochrane, CENTRAL and guideline repositories) focusing on general surgical procedures (elective and emergency) and common risk factors in these interventions.

Results: Diabetes, obesity, smoking, malnutrition, hypoalbuminemia and Staphylococcus aureus carriage are consistently associated with increased SSI risk. Representative pooled effect sizes from meta-analyses: Diabetes OR ≈1.5–2.0; Obesity (BMI ≥30) OR ≈1.4–1.6; Smoking OR ≈1.4–1.8; Hypoalbuminemia OR >2.0 in many series. Operative duration and contaminated or dirty wound class strongly increase SSI risk. Emergency surgery confers higher risk than elective surgery. Observational synthesis associate transfusion and implants with moderate SSI risk increases. High-certainty RCT and guideline evidence support timely, guideline-concordant antibiotic prophylaxis, chlorhexidine–alcohol skin antisepsis, perioperative glycaemic control, avoidance of razor shaving and active warming to maintain normothermia. Evidence for perioperative hyperoxia is mixed. Multimodal bundles reduce SSI when implemented with high fidelity.

Conclusions: SSI risk in general surgery is multifactorial. High-yield preventive actions include timely antibiotic prophylaxis, chlorhexidine–alcohol skin antisepsis (where appropriate), perioperative glycaemic control, maintenance of normothermia, avoidance of razor shaving and multimodal prevention bundles. Preoperative optimization (smoking cessation, glycaemic and nutritional optimization, targeted S. aureus decolonization in selected populations) reduces risk where feasible. Further progress requires standardized SSI definitions, IPD meta-analyses to quantify interactions and pragmatic implementation research.

Keywords: Surgical site infection, SSI prevention, Antibiotic prophylaxis, Chlorhexidine–alcohol, Perioperative glycaemic control, Normothermia, active warming, Smoking cessation, Obesity (BMI), Hypoalbuminemia, malnutrition, Staphylococcus aureus decolonization, Wound contamination, wound class, Operative time, Surgical bundles, multimodal interventions, Perioperative oxygenation (FiO2), Transfusion-related infection risk.

INTRODUCTION

Surgical site infections (SSIs) contribute substantially to postoperative complications, increased hospital stays, readmissions and costs. [1] Although surveillance, prophylaxis and improved perioperative care have reduced SSI rates, SSIs remain a major quality and safety target in general surgery. [2, 3]

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Multiple patient-level risks (comorbidity, nutritional status), procedural factors (wound contamination, operative time) and perioperative care aspects (antibiotic timing, skin preparation, temperature management) influence SSI risk. [4,5,6] A contemporary synthesis integrating RCT evidence for interventions and observational evidence for patient and procedure factors can guide prioritized prevention in general surgery.

METHODS

Search Strategy and Eligibility

We conducted an umbrella-style review of systematic reviews, meta-analyses, randomized trials and major cohort studies indexed through

February 1st 2026 in PubMed/Medline, Embase, Cochrane CENTRAL and guideline repositories (WHO, CDC, ASHP/SIS). Search terms combined "surgical site infection" or "wound infection" with risk factors and interventions (e.g., diabetes, obesity, smoking, antibiotic prophylaxis, chlorhexidine) [1,2,3]. We prioritized high-quality systematic reviews and RCT evidence. Where multiple meta-analyses existed, we extracted the most recent high-quality pooled estimates and noted heterogeneity and limitations [4,5].

Scope and Definitions

Scope: General surgery (abdominal or general surgical procedures; elective and emergency). Primary outcome: SSI as defined by CDC/NHSN or clearly reported study definitions. [2] Included RCTs and observational cohort, case-control studies and meta-analyses synthesizing such studies. Timeframe: Studies published 2000–2026 were prioritized, though earlier landmark RCTs were included when relevant. [1,2,3,4,5,6]

Data extraction and synthesis

From each meta-analysis or major study we extracted pooled effect estimates (OR/RR/HR as reported), 95% CIs, heterogeneity metrics (I2), study counts and design (RCT vs observational). For interventions, RCT evidence and guideline recommendations were emphasized. We qualitatively synthesized factors without performing new pooled aggregate calculations. Where pooled estimates from recent meta-analyses were consistent we report representative effect magnitudes [4, 5, 6].

Assessment of evidence quality and bias

We considered study design (RCTs higher certainty), heterogeneity across specialties or procedures, potential confounding in observational studies, publication bias in original reviews and applicability to general surgery. Guideline syntheses (WHO, CDC, ASHP/SIS) were cross-referenced for interventions. [2, 3]

RESULTS

Overview of Evidence Base

The evidence base includes numerous observational studies linking patient comorbidities and procedural characteristics to SSI and multiple RCTs and meta-analyses addressing perioperative interventions. (Antibiotic timing, skin antisepsis, temperature, oxygen, glucose control) [1, 2, 3, 4, 5, 6] Heterogeneity in pooled analyses arises from variable surgery types, SSI definitions, follow-up duration, baseline SSI rates and adjustment for confounders [4, 5].

Patient Factors

Diabetes mellitus: Systematic reviews and pooled cohort analyses indicate diabetes increases SSI risk. Pooled ORs commonly range 1.5–2.0. Poor glycaemic control further elevates risk [7, 8, 9]. RCT and cohort evidence support perioperative glucose control reducing SSI [9, 10].

Obesity (BMI ≥30 kg/m2): Consistent association with increased SSI. (Pooled ORs ≈1.4–1.6 in general and colorectal case analyses) However the effect varies by threshold and procedure. [8, 10]

Smoking: Current smoking increases SSI and wound complications. (Pooled ORs ~1.4–1.8). Smoking cessation preoperatively lowers risk. [11]

Malnutrition or hypoalbuminemia: Low albumin and other malnutrition markers are linked to substantially higher SSI risk. (ORs often >2.0) [12]

Staphylococcus aureus colonization: Nasal or skin carriage increases S. aureus SSI risk. Screening and targeted decolonization (mupirocin ± chlorhexidine bathing) reduce S. aureus SSI in targeted populations. [13, 14]

Procedure Factors

Wound class, contamination and emergency vs elective: Contaminated or dirty wounds and emergency operations are consistently associated with higher SSI rates versus clean elective cases. [14,15]

Procedural Factors

Operative time: Longer procedures consistently correlate with increased SSI risk. Many studies report dose-response or threshold effects. [16]

Implants and prostheses: Presence of prosthetic material increases infection risk. (robust evidence in prosthetic joint literature) [17]

Blood transfusion: Observational studies associate allogeneic transfusion with higher SSI risk (ORs ~1.5–2.5), but confounding by severity exists. [16,18]

Perioperative Care and Interventions

Antibiotic prophylaxis (choice and timing): RCTs and systematic reviews demonstrate prophylactic antibiotics reduce SSI compared with no prophylaxis in clean–contaminated and many elective procedures. Observational data show higher SSI when antibiotics are given too early (>60–120 minutes) or after incision. Guidelines recommend administration within 60 minutes before incision for most agents (120 minutes for some agents). [2,5,19]

Skin antisepsis (chlorhexidine–alcohol vs povidone-iodine): Multiple RCTs and meta-analyses favour chlorhexidine–alcohol for many operations. Though procedure specific heterogeneity exists yet chlorhexidine–alcohol is generally recommended. [18,20,21]

Perioperative normothermia (active warming): RCTs and meta-analyses show preventing

hypothermia reduces SSI in some populations. Hence maintaining normothermia is strongly recommended. [20,22,23]
Perioperative oxygenation (high FiO2): Evidence is mixed though early trials showed benefit in colorectal surgery, but larger trials produced inconsistent results and safety concerns. Therefore, selective application is advisable. [24]
Glycaemic control: Perioperative hyperglycaemia increases SSI. Evidence supports glycaemic control in diabetic and selected non-diabetic patients to reduce SSI. [19,20]
Hair removal: Shaving with razors increases SSI risk. Therefore, clipping or no removal is preferred. [5]
Bundles and checklists: Multimodal SSI prevention bundles are associated with significant SSI reductions when fidelity is high. [25]

Heterogeneity and Limitations of the Evidence
Many pooled estimates combine diverse procedures. Risk magnitudes vary by specialty, wound class and baseline rates. Heterogeneity in meta-analyses frequently ranges from moderate to high.[12] A large portion of patient and procedural data is derived from observational studies at risk of residual confounding. SSI definitions and surveillance methods vary across studies. Publication bias and small-study effects have been reported in some syntheses [4, 5, 6].

DISCUSSION

Principal Findings
This umbrella meta-analytic review synthesizes contemporary randomized, observational and guideline evidence to characterize determinants of surgical site infection (SSI) risk in general surgery and to prioritize actionable prevention strategies. The evidence confirms that SSI risk is multifactorial driven by baseline patient vulnerabilities (diabetes, obesity, smoking, malnutrition, hypoalbuminemia and Staphylococcus aureus carriage) [10,11,12,13], procedural characteristics (wound contamination class, emergency status, operative duration, presence of implants) [14,15,16,17] and modifiable perioperative care practices (timing and choice of antibiotic prophylaxis, skin antisepsis, maintenance of normothermia, glycaemic control, hair removal practices) [2,5,18,19,20,21,22]. High-certainty RCT and guideline-concordant evidence supports a set of high-yield interventions (timely antibiotic prophylaxis, chlorhexidine–alcohol skin preparation for many procedures, avoidance of razor shaving, perioperative glycaemic control, active warming to maintain normothermia) while bundles and multimodal implementation strategies demonstrate the largest, reproducible reductions in SSI when fidelity is high [2,18,20,21,22,23,24,25]. Interventions with inconsistent or context-dependent evidence (notably perioperative hyperoxia) require selective application and further study. [24]

Interpretation in Context of Prior Literature
Our findings align with prior guideline syntheses and systematic reviews identifying similar patient and procedural risk factors. (CDC/WHO/ASHP/SIS) [2, 3, 4, 5, 15] Representative pooled effect sizes (e.g., diabetes OR ≈1.5–2.0; obesity OR ≈1.4–1.6; smoking OR ≈1.4–1.8; hypoalbuminemia OR >2.0) reflect recent meta-analyses and cohort studies. [10,11,12] The persistent association of wound contamination and operative time with SSI risk echoes NNIS/SIR models and earlier work on operative duration and complications. [14, 16] Randomized evidence favouring chlorhexidine–alcohol over povidone-iodine for skin antisepsis and the benefit of perioperative normothermia remain key pillars of prevention. [18, 20] The critical importance of administering prophylactic antibiotics within the recommended pre-incision window is supported by large observational cohorts showing time-sensitive SSI reduction. [5, 19]. Mixed results for perioperative hyperoxia (positive signals in some colorectal trials but inconsistent larger RCTs such as PROXI) illustrate the need for surgical-specialty nuance when applying interventions. [24] Observational associations between transfusion and SSI likely reflect immunomodulatory effects and confounding by severity. Therefore, conservative transfusion practices and blood-conservation strategies remain prudent. [16, 18]

Clinical Implications and Prioritization
The multifactorial nature of SSI supports a tiered approach. Immediate, high-impact measures supported by randomized evidence should be implemented universally. Guideline-concordant antibiotic prophylaxis timing, dosing, chlorhexidine–alcohol skin antisepsis where appropriate, perioperative normothermia via active warming, perioperative glucose management for diabetics and selected non-diabetics and hair-clip or no-shave policies [2, 18, 20, 22]. Multimodal bundles combining these elements with process measures (checklists, order sets) and post-discharge surveillance yield the most consistent reductions when fidelity is high [21, 25]. Preoperative optimization (smoking cessation, nutritional assessment and management, glycaemic control, selective S. aureus screening and targeted decolonization) confers additional benefit where timing permits [11, 12, 13].

Implementation and Measurement Considerations

Successful implementation requires local adaptation and multidisciplinary engagement (surgery, anaesthesia, nursing, infection prevention) with standardized order sets, intraoperative prompts for warming and antibiotic timing, clear insulin algorithms for glucose control and robust SSI surveillance using CDC/NHSN definitions including post-discharge monitoring [2,5,19,25]. Bundle adherence metrics and outcome feedback are essential to sustain improvements. High fidelity correlates strongly with SSI reductions in the literature [25,21].

Limitations and Evidence Gaps

Key limitations include reliance on observational data for many risk-factor estimates, heterogeneity across specialties and wound classes and variable SSI definitions and surveillance methods across studies [4,5,6,12]. The umbrella approach used existing meta-analyses and guideline syntheses rather than de novo IPD pooling, limiting granularity on interactions (e.g., diabetes vs obesity) and procedure-specific thresholds. Evidence for some interventions (perioperative hyperoxia, topical prophylaxis, transfusion causality) remains inconclusive or context-dependent and local pathogen prevalence, resource constraints, chlorhexidine contraindications and mupirocin resistance necessitate tailored approaches [13,16,24].

Research Priorities

Priorities include IPD meta-analyses to quantify interactions (e.g., diabetes vs obesity), pragmatic multicentre RCTs, implementation trials for contested interventions (e.g., FiO2 strategies), comparative evaluations of bundle components, trials on optimal nutritional and albumin-directed interventions, timing, duration of preoperative smoking cessation, cost-effectiveness and implementation science studies to identify scalable bundle deployment across resource settings. Standardization of SSI definitions and surveillance durations is essential to reduce heterogeneity and improve comparability [4,5,6].

Clinical Recommendations (Table1)

Implement a bundled approach: Guideline concordant antibiotic timing and dosing, standardized skin antisepsis (chlorhexidine–alcohol where appropriate), active warming, perioperative glucose protocols and hair-clipping with no-shaving policies [2,5,18,19,22,25].

Preoperative optimization: Integrate smoking cessation, nutritional assessment and treatment along with glycaemic optimization into preoperative pathways. [7,11,12]

Targeted infection control: Consider S. aureus screening and decolonization for high-risk procedures as per local epidemiology. [13]

Audit and feedback: Monitor bundle adherence and SSI rates via robust surveillance and quality improvement cycles. [25]

Research Recommendations

Conduct IPD meta-analyses to improve quantification of interactions (e.g., obesity vs diabetes) and clinically useful thresholds (BMI, glucose targets).

Standardize SSI definitions, surveillance durations and adjustment set across studies.

Pragmatic RCTs and implementation research for contested interventions (e.g., FiO2 strategies) and determine optimal bundle components and sustainment approaches.

CONCLUSIONS

SSIs in general surgery arise from interacting patient vulnerabilities, procedural exposures and perioperative care practices. High-certainty measures include timely guideline-concordant antibiotic prophylaxis, chlorhexidine–alcohol skin antisepsis where appropriate, perioperative glycaemic control, active warming to maintain normothermia, avoidance of razor shaving combined with multimodal bundles and preoperative optimization (smoking cessation, nutritional and glycaemic management, targeted S. aureus decolonization) offer the most effective strategy to reduce SSI burden. Continued progress requires IPD syntheses, standardized surveillance and pragmatic implementation research to translate evidence into sustained practice across diverse surgical settings.

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Table1. Clinical Recommendations

Factor	Effect (approx.)	Key recommendation
Diabetes	OR 1.5–2.0	Periop glycaemic control
Obesity (BMI ≥30)	OR 1.4–1.6	Risk stratify, optimize technique
Smoking	OR 1.4–1.8	Preop cessation where possible
Hypoalbuminemia/malnutrition	OR >2.0	Nutritional assessment and optimization
S. aureus carriage	↑ S. aureus SSI	Targeted screening/decolonization
Contaminated/dirty wounds; emergency	Substantially ↑ risk	Enhanced prophylaxis, surveillance
Long operative time	Dose-response ↑ risk	Minimize duration/stage procedures
Antibiotic prophylaxis (timing)	Timing critical	Give within 60 min preincision (per guidelines)
Skin antisepsis (CHG–alcohol)	Lower SSI vs povidone-iodine	Use CHG–alcohol if not contraindicated
Normothermia (active warming)	↓ SSI	Maintain periop normothermia
Hair removal (razor)	↑ SSI	Clip or avoid shaving
Periop high FiO2	Mixed evidence	Not routine; selective use
Multimodal bundles	Significant ↓ SSI with high fidelity	Implement bundles with audit and feedback