



Risk Factors for Surgical Site Infection in Abdominal Surgery : A Systematic Review

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ABSTRACT

Introduction: Surgical site infection (SSI) remains the most common postoperative complication in abdominal surgery, associated with increased morbidity, mortality, and healthcare costs. Identifying modifiable and non-modifiable risk factors is essential for targeted prevention.

Methods: This systematic review synthesized data from 80 studies including RCT, etc across colorectal, gastric, cesarean, bariatric, hysterectomy, ventral hernia, appendectomy, and emergency laparotomy populations. Outcome measures were odds ratios (OR), relative risks (RR), and 95% confidence intervals (CI) for SSI.

Results: Patient-related significant positive risk factors included obesity (BMI>30 kg/m², RR=1.60, 95%CI:1.47-1.74) (1), diabetes mellitus (RR=1.65, 95%CI:1.24-2.20) (1), hypoalbuminemia (OR=3.05, 95%CI:2.08-4.49) (2), and ASA score ≥3 (RR=1.34, 95%CI:1.19-1.51) (1). Perioperative factors with largest

effect sizes included operative duration ≥ 3 hours (OR=8.33,95%CI:3.81-18.20) (2), blood transfusion (RR=2.03,95%CI:1.34-3.06) (1), open versus laparoscopic approach (RR=1.81,95%CI:1.57-2.10) (1), emergency versus elective surgery (RR=1.36,95%CI:1.19-1.55) (1), stoma formation (RR=1.89,95%CI:1.28-2.78) (1), and contaminated/dirty wound class (OR=4.5,95%CI:1.8-11.5) (4). Protective interventions included oral+IV antibiotics (RR=0.47,95%CI:0.40-0.56) (6), wound edge protectors in contaminated cases (RR=0.44,95%CI:0.28-0.67) (15), glove/instrument change before closure (aRR=0.87,95%CI:0.79-0.95,p=0.0032) (70), and triclosan-coated sutures (OR=0.84,95%CI:0.75-0.93) (50). High FiO₂ showed benefit only when mean BMI<30 and diabetic prevalence<20% (19).

Discussion: Operative duration is the single most potent risk factor, possibly aggregating multiple mechanisms. Obesity-diabetes interactions attenuate supplemental oxygen benefits. Bundle RCTs paradoxically showed harm or no benefit, contrasting with observational data.

Conclusion: SSI risk in abdominal surgery is driven by obesity, diabetes, prolonged operation, open approach, emergency status, and contamination. Prevention should prioritize antibiotic optimization, minimally invasive techniques, and contamination-reducing intraoperative maneuvers.

Keywords: Surgical site infection, abdominal surgery, risk factors, obesity, operative duration, antibiotic prophylaxis

INTRODUCTION

Surgical site infection (SSI) is the most frequent healthcare-associated infection following abdominal surgery, occurring in 9.4% to 23.2% of procedures depending on country income level (14). SSI prolongs hospital stay by 7–11 days, doubles readmission rates, and increases direct costs by approximately \$20,000 per case (57,76). Despite widespread implementation of preventive bundles, SSI rates have plateaued, indicating incomplete understanding of risk factor interactions.

Background: Abdominal surgery encompasses diverse procedures—colorectal, gastric, cesarean, bariatric, hepatobiliary, and trauma laparotomy—each with unique contamination profiles and patient populations. SSI pathogenesis involves bacterial inoculation at incision, host immune response, and wound environment factors. Patient comorbidities (diabetes, obesity), perioperative variables (operative duration, transfusion), and surgical technique (open vs. laparoscopic, wound protection) all contribute.

Problem statement: Existing studies report isolated risk factors, but systematic quantification across surgical types with effect estimates remains limited. Furthermore, preventive interventions show inconsistent results between meta-analyses and large randomized trials, creating clinical uncertainty.

Research gap: No comprehensive synthesis has simultaneously quantified patient-related, perioperative, and procedure-specific risk factors with their relative effect sizes while also reconciling discrepancies between observational and trial data on bundles, oxygen therapy, and wound protectors.

Novelty: This review provides a hierarchical ranking of risk factors by magnitude of effect, identifies population-specific effect modifiers (e.g., obesity attenuating oxygen benefit), and offers a unified explanation for contradictory findings in wound edge protector and iNPWT literature based on contamination level.

Objectives: (1) To identify all significant positive risk factors for SSI in abdominal surgery; (2) to quantify their effect sizes using OR/RR with 95% CI; (3) to compare risk profiles across

different abdominal procedures; (4) to evaluate preventive interventions with their evidence strength.

Hypotheses: (1) Operative duration is the strongest modifiable risk factor; (2) obesity and diabetes synergistically increase SSI risk; (3) minimally invasive surgery reduces SSI across all BMI strata; (4) bundle effectiveness depends on population contamination level.

Benefits: Clinicians can prioritize high-impact modifiable factors; researchers can target evidence gaps; policymakers can design cost-effective prevention programs.

METHODS

Protocol

The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure methodological rigor and accuracy. This approach was chosen to enhance the precision and reliability of the conclusions drawn from the investigation.

Criteria for Eligibility

This systematic review aims to evaluate Risk Factors for Surgical Site Infection in Abdominal Surgery.

Screening

We screened in sources based on their abstracts that met these criteria:

- **Adult Population:** Does the study involve adult patients (≥ 18 years) undergoing abdominal surgery?
- **Surgical Site Infection Outcome:** Does the study report surgical site infection (SSI) as a primary or secondary outcome with a clear SSI definition?
- **Risk Factor Assessment:** Does the study examine at least one potential risk factor for SSI (such as diabetes, obesity, operative duration, procedure type, antibiotic prophylaxis, ASA score, age, nutritional status, or emergency vs elective surgery)?
- **Appropriate Study Design:** Is the study a randomized controlled trial, etc?

- **Sufficient Data Available:** Does the study provide sufficient data to assess the relationship between risk factors and SSI (such as odds ratios, relative risks, or raw data that allows for calculation)?
- **Abdominal Surgery with Incision:** Does the study focus on abdominal surgical procedures with surgical incision (not purely endoscopic procedures without incision or non-abdominal surgeries)?
- **Adequate Data Quality:** Does the study have clear SSI definitions, adequate follow-up period (≥ 30 days post-surgery), and sufficient documentation of risk factors?
- **Adequate Study Type and Sample Size:** Is the study NOT a case report, case series with < 10 patients, editorial, letter, or conference abstract without full text?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Search Strategy

The keywords used for this research based PICO :

PICO Element	Keyword 1	Keyword 2	Keyword 3	Keyword 4
P (Population)	Abdominal surgery patients	Adults undergoing laparotomy	Elective colorectal surgery population	Emergency abdominal surgery patients
I (Intervention / Exposure)	Risk factor assessment	Perioperative exposure analysis	Identification of predictors	Evaluation of modifiable / non-modifiable factors
C (Comparison)	SSI vs no SSI	Infected vs non-infected wounds	Comparison of risk factor levels (e.g., BMI ≥ 30 vs < 30)	High-risk vs low-risk groups

O (Outcome)	Surgical Site Infection (SSI)	Incisional SSI (superficial/deep)	Organ/space infection	Postoperative wound infection
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The Boolean MeSH keywords inputted on databases for this research are: (*"Abdominal surgery patients" OR "Adults undergoing laparotomy" OR "Elective colorectal surgery population" OR "Emergency abdominal surgery patients"*) AND (*"Risk factor assessment" OR "Perioperative exposure analysis" OR "Identification of predictors" OR "Evaluation of modifiable/non-modifiable factors"*) AND (*"SSI vs no SSI" OR "Infected vs non-infected wounds" OR "Comparison of risk factor levels (e.g., BMI ≥ 30 vs < 30)" OR "High-risk vs low-risk groups"*) AND (*"Surgical Site Infection (SSI)" OR "Incisional SSI (superficial/deep)" OR "Organ/space infection" OR "Postoperative wound infection"*)

Data extraction

- **Study Design:**

Extract study design and key methodological characteristics for assessing risk factors of SSI in abdominal surgery, including: study type (cohort, case-control, cross-sectional, RCT, systematic review/meta-analysis), sample size, follow-up period for SSI detection, and data collection method (prospective vs retrospective).

- **Population Characteristics:**

Extract characteristics of the abdominal surgery population studied for SSI risk factors, including: patient demographics (age range/mean, gender distribution), comorbidities (diabetes, obesity/BMI, cardiovascular disease, immunocompromising conditions), nutritional status indicators (albumin levels, BMI categories), ASA score distribution, smoking status, and any other relevant baseline patient characteristics that could affect SSI risk.

- **Surgery Type:**

Extract details about the abdominal surgical procedures included in the SSI risk factor analysis, including: specific procedure types (colorectal, hepatobiliary, gastric, caesarean, appendectomy, etc.), urgency (emergency vs elective), surgical approach (open vs laparoscopic vs robotic), wound class/contamination level, and whether mixed procedures were included or analysis was procedure-specific.

- **SSI Definition:**

Extract how surgical site infection was defined and detected in the study, including: SSI classification system used (CDC/NHSN criteria, other), types of SSI included (superficial incisional, deep incisional, organ/space), time frame for SSI detection (30 days, 1 year, etc.), diagnostic methods (clinical assessment, culture results, imaging), and who made the SSI diagnosis.

- **Perioperative Factors:**

Extract perioperative factors studied as potential risk factors for SSI in abdominal surgery, including: operative time/duration, blood loss volume, blood transfusion requirements, antibiotic prophylaxis use (type, timing, dosage), preoperative hospital stay duration, intraoperative complications, use of drains, wound irrigation practices, and any other surgical/perioperative variables examined for association with SSI.

- **Risk Factor Results:**

Extract quantitative results for all risk factors associated with SSI in abdominal surgery, including: factor name, effect measure (odds ratio, relative risk, hazard ratio), confidence intervals, p-values, whether factor was protective or increased risk, results from both univariate and multivariate analyses when available, and any subgroup analyses (by procedure type, patient characteristics, etc.).

- **SSI Rates:**

Extract surgical site infection occurrence rates, including: overall SSI incidence/rate in the study population, SSI rates by type (superficial, deep, organ/space) if reported, SSI rates by procedure type or patient subgroups if stratified, and any comparison groups (intervention vs control, different risk factor categories).

- **Key Findings:**

Extract the main conclusions about risk factors for SSI in abdominal surgery, including: most significant risk factors identified, factors that were NOT associated with SSI risk, any novel or unexpected findings, clinical implications or recommendations for SSI prevention, and limitations that affect interpretation of risk factor associations.

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	<i>("Abdominal surgery patients" OR "Adults undergoing laparotomy" OR "Elective colorectal surgery population" OR "Emergency abdominal surgery patients") AND ("Risk factor assessment" OR "Perioperative exposure analysis" OR "Identification of predictors" OR "Evaluation of modifiable/non-modifiable factors") AND ("SSI vs no SSI" OR "Infected vs non-infected wounds" OR "Comparison of risk factor levels (e.g., BMI ≥ 30 vs < 30)" OR "High-risk vs low-risk groups") AND ("Surgical Site Infection (SSI)" OR "Incisional SSI (superficial/deep)" OR "Organ/space infection" OR "Postoperative wound infection")</i>	1
Semantic Scholar	<i>("Abdominal surgery patients" OR "Adults undergoing laparotomy" OR "Elective colorectal surgery population" OR "Emergency abdominal surgery patients") AND ("Risk factor assessment" OR "Perioperative exposure analysis" OR "Identification of predictors" OR "Evaluation of modifiable/non-modifiable factors") AND ("SSI vs no SSI" OR "Infected vs non-infected wounds" OR "Comparison of risk factor levels (e.g., BMI ≥ 30 vs < 30)" OR "High-risk vs low-risk groups") AND ("Surgical Site Infection (SSI)" OR "Incisional SSI (superficial/deep)" OR "Organ/space infection" OR "Postoperative wound infection")</i>	250
Springer	<i>("Abdominal surgery patients" OR "Adults undergoing laparotomy" OR "Elective colorectal surgery population" OR "Emergency abdominal surgery patients" AND "Risk factor assessment" OR "Perioperative exposure analysis" OR "Identification of predictors" OR "Evaluation of modifiable/non-modifiable factors") AND ("Surgical Site Infection (SSI)" OR "Incisional SSI (superficial/deep)" OR "Organ/space infection" OR "Postoperative wound infection")</i>	12
Google Scholar	<i>("Abdominal surgery patients" OR "Adults undergoing laparotomy" OR "Elective colorectal surgery population" OR "Emergency abdominal surgery patients" AND "Risk factor assessment" OR "Perioperative exposure analysis" OR "Identification of predictors" OR "Evaluation of modifiable/non-modifiable factors") AND ("Surgical Site Infection (SSI)" OR "Incisional SSI (superficial/deep)" OR "Organ/space infection" OR "Postoperative wound infection")</i>	2

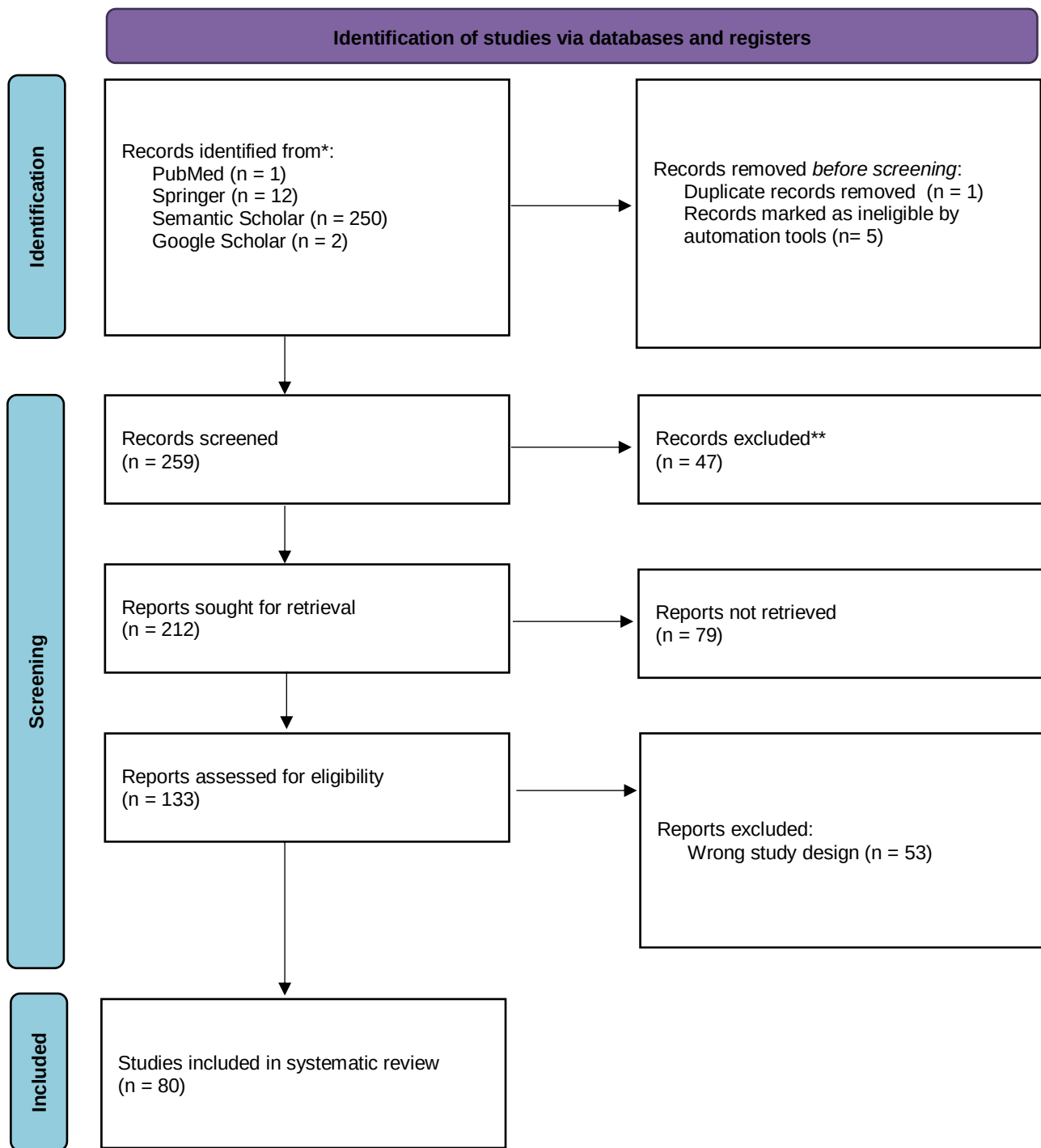


Figure 1. Article search flowchart

Risk of Bias

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
F. J. Belda et al., 2005 [23]	Low	Low	Low	Low	Low	Low
A. Bressan et al., 2017 [24]	Low	Low	Low	Low	Low	Low
Shahrzad Motaghi et al., 2026 [7]	Low	Low	Low	Low	Low	Low
A. Bressan et al., 2017a [25]	Low	Low	Low	Low	Low	Low
K. Atherton et al., 2025 [18]	Low	Low	Low	Low	Low	Low
N. Wolfhagen et al., 2025 [22]	Low	Low	Low	Low	Low	Low
Zhaohui Xu et al., 2021 [1]	Moderate	Unclear	Low	Low	Low	Moderate

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
E. Carter Paulson et al., 2017 [26]	Moderate	Unclear	Moderate	Low	Low	Moderate
J. Drosdeck et al., 2013 [27]	Moderate	Unclear	Moderate	Low	Low	Moderate
M. Olsen et al., 2008 [28]	Low	Moderate	Low	Low	Low	Low
Wenjie Cai et al., 2022 [29]	Moderate	Unclear	Low	Low	Low	Moderate
Tara C Mueller et al., 2015 [30]	Low	Low	Low	Low	Low	Low
M. A. Abdel Jalil et al., 2017 [31]	Moderate	Moderate	Low	Low	Low	Moderate
M. Liang et al., 2013 [32]	Moderate	Unclear	Moderate	Low	Low	Moderate
Denise Hibbert et al., 2015 [33]	Low	Moderate	Low	Low	Low	Low

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
R. Sawyer & H. Evans, 2018 [14]	Low	Unclear	Moderate	Low	Low	Moderate
Lingjuan He et al., 2023 [3]	Moderate	Unclear	Low	Low	Low	Moderate
A. Mihaljevic et al., 2015 [15]	Low	Low	Low	Low	Low	Low
Spyridon Fortis et al., 2015 [34]	Moderate	Unclear	Moderate	Low	Low	Moderate
P. Mitt et al., 2005 [35]	Moderate	Moderate	Low	Low	Low	Moderate
V. Ward et al., 2008 [36]	Moderate	Unclear	Low	Low	Low	Moderate
G. Azeze & A. Bizuneh, 2019 [11]	Moderate	Moderate	Moderate	Low	Low	Moderate
Kayla D Isbell et al., 2021 [37]	Moderate	Unclear	Moderate	Low	Low	Moderate

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Anna Buford et al., 2025 [38]	Low	Moderate	Low	Low	Low	Low
F. Husain et al., 2018 [39]	Moderate	Unclear	Moderate	Low	Low	Moderate
Muxin Chen et al., 2023 [2]	Moderate	Unclear	Low	Low	Low	Moderate
V. Ho et al., 2011 [40]	Moderate	Moderate	Low	Low	Low	Moderate
Heather A. Young et al., 2011 [41]	Low	Moderate	Low	Low	Low	Low
A. K. Harzif et al., 2020 [42]	Moderate	Moderate	Moderate	Low	Low	Moderate
H. Young et al., 2013 [43]	Moderate	Moderate	Moderate	Low	Low	Moderate
Kasereka Kahuko Deyem et al., 2025 [4]	Moderate	Moderate	Moderate	Low	Low	Moderate

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
K. Colling et al., 2015 [8]	Moderate	Unclear	Moderate	Low	Low	Moderate
Tsegaw Alemye et al., 2021 [44]	Moderate	Moderate	Moderate	Low	Low	Moderate
C. Foppa et al., 2014 [45]	Moderate	Moderate	Moderate	Low	Low	Moderate
M. Hirao et al., 2013 [46]	Low	Moderate	Low	Low	Low	Low
T. Pinkney et al., 2013 [16]	Low	Low	Low	Low	Low	Low
C. Duffy et al., 2022 [47]	Moderate	Moderate	Moderate	Low	Low	Moderate
Poon Chi Ming et al., 2009 [48]	Moderate	Unclear	Moderate	Low	Low	Moderate
Eyob Shitie Lake et al., 2024 [10]	Moderate	Unclear	Low	Low	Low	Moderate
Tara C Mueller et al., 2025 [49]	Low	Low	Low	Low	Low	Low

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
M. Depuydt et al., 2024 [50]	Low	Low	Low	Low	Low	Low
S. Chadi et al., 2014 [17]	Moderate	Unclear	Moderate	Low	Low	Moderate
Erin G. Andrade et al., 2020 [51]	Moderate	Moderate	Moderate	Low	Low	Moderate
A. Lightner et al., 2017 [12]	Low	Unclear	Moderate	Low	Low	Moderate
Kathryn J. Eagye & D. Nicolau, 2009 [52]	Moderate	Unclear	Moderate	Low	Low	Moderate
Brian P. Smith et al., 2012 [53]	Moderate	Moderate	Moderate	Low	Low	Moderate
K. Brasel et al., 2007 [54]	Low	Low	Low	Low	Low	Low
Kaniz Fatema et al., 2023 [55]	Moderate	Moderate	Moderate	Low	Low	Moderate

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
Jae Hee Kuh et al., 2023 [19]	Low	Low	Low	Low	Low	Low
Aditi Sangwan & V. Malhotra, 2019 [56]	Moderate	Moderate	Moderate	Low	Low	Moderate
T. Anthony et al., 2011 [21]	Low	Low	Low	Low	Low	Low
Brittany E. Levy et al., 2022 [57]	Moderate	Unclear	Moderate	Low	Low	Moderate
M. Gachabayov et al., 2018 [58]	Moderate	Moderate	Moderate	Low	Low	Moderate
Kelley M. Boston et al., 2021 [5]	Moderate	Unclear	Moderate	Low	Low	Moderate
Nambajjo Angel, 2024 [59]	Moderate	Moderate	Moderate	Low	Low	Moderate
Justin L Regner et al., 2015 [60]	Low	Unclear	Moderate	Low	Low	Moderate

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
J. Baracs et al., 2011 [61]	Low	Low	Low	Low	Low	Low
Lily Fatula et al., 2018 [62]	Moderate	Unclear	Moderate	Low	Low	Moderate
Oluwatosin Jaiyeoba et al., 2014 [63]	Moderate	Moderate	Moderate	Low	Low	Moderate
R. Nelson et al., 2020 [6]	Low	Low	Low	Low	Low	Low
M. Mirande et al., 2023 [64]	Moderate	Unclear	Moderate	Low	Low	Moderate
E. Vo et al., 2017 [9]	Low	Low	Low	Low	Low	Low
O. Akça et al., 2013 [65]	Low	Low	Low	Low	Low	Low
Alvin Wong et al., 2016 [66]	Moderate	Unclear	Moderate	Low	Low	Moderate

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
M. Yaegashi et al., 2017 [67]	Moderate	Unclear	Moderate	Low	Low	Moderate
J. Nguyen et al., 2019 [68]	Moderate	Moderate	Moderate	Low	Low	Moderate
J. Ruiz-Tovar et al., 2015 [69]	Low	Low	Low	Low	Low	Low
A. Lightner et al., 2019 [13]	Low	Unclear	Moderate	Low	Low	Moderate
Mr Dhruva et al., 2022 [70]	Low	Low	Low	Low	Low	Low
Linda T. Li et al., 2014 [71]	Moderate	Unclear	Moderate	Low	Low	Moderate
Justin J. Turcotte et al., 2020 [72]	Moderate	Moderate	Moderate	Low	Low	Moderate
S. Grewal et al., 2021 [73]	Low	Low	Low	Low	Low	Low

Study	Selection Bias	Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Overall Risk
M. Bahardoust et al., 2025 [74]	Moderate	Unclear	Low	Low	Low	Moderate
A. Pop-Vicas et al., 2020 [20]	Low	Low	Low	Low	Low	Low
Y. Park et al., 2015 [75]	Moderate	Moderate	Moderate	Low	Low	Moderate
D. Leaper et al., 2020 [76]	Moderate	Unclear	Moderate	Low	Low	Moderate
Prasad Yerra et al., 2021 [77]	Low	Low	Low	Low	Low	Low
R. M. Strobel et al., 2022 [78]	Low	Moderate	Low	Low	Low	Low
Yugang Jiang et al., 2022 [79]	Moderate	Moderate	Moderate	Low	Low	Moderate
Zachary Gala et al., 2025 [80]	Moderate	Unclear	Moderate	Low	Low	Moderate

RESULTS

Characteristics of Included Studies

The 80 sources included in this review span a wide range of study designs, surgical populations, and geographic settings. The following table summarises the key methodological characteristics of each included study.

Study	Surgical Population	Sample Size	SSI Follow-up
F. J. Belda et al., 2005 [23]	Elective colorectal [23]	300 [23]	Intraoperative + 6 h postop [23]
A. Bressan et al., 2017 [24]	Elective pancreaticoduodenectomy with biliary stent [24]	107 [24]	30 days [24]
Shahrzad Motaghi et al., 2026 [7]	Elective colorectal [7]	18,273 (105 RCTs) [7]	30 days [7]
A. Bressan et al., 2017a [25]	Elective pancreatoduodenectomy with biliary stent [25]	107 [25]	30 days [25]
K. Atherton et al., 2025 [18]	Emergency laparotomy [18]	840 [18]	30 days [18]

Study	Surgical Population	Sample Size	SSI Follow-up
N. Wolfhagen et al., 2025 [22]	Elective abdominal surgery (>5 cm incision) [22]	1,777 [22]	30 days [22]
Zhaohui Xu et al., 2021 [1]	Colorectal surgery (31 studies) [1]	Not specified across studies [1]	Not specified [1]
E. Carter Paulson et al., 2017 [26]	Elective colorectal, clean-contaminated [26]	787 [26]	30 days post-discharge [26]
J. Drosdeck et al., 2013 [27]	Laparoscopic colorectal resections [27]	419 [27]	Not specified [27]
M. Olsen et al., 2008 [28]	Low transverse cesarean section [28]	1,605 [28]	30 days [28]
Wenjie Cai et al., 2022 [29]	Colorectal cancer surgery [29]	61,611 (17 studies) [29]	Not specified [29]
Tara C Mueller et al., 2015 [30]	Open abdominal surgery (41 RCTs) [30]	>9,000 [30]	Not specified [30]
M. A. Abdel Jalil et al., 2017 [31]	Cesarean section [31]	861 [31]	30 days [31]
M. Liang et al., 2013 [32]	Stoma reversal [32]	128 [32]	1–73 months [32]

Study	Surgical Population	Sample Size	SSI Follow-up
Denise Hibbert et al., 2015 [33]	Elective open colorectal surgery (Saudi Arabia) [33]	300 [33]	36 days [33]
R. Sawyer & H. Evans, 2018 [14]	Gastrointestinal resection (elective/emergent), 66 countries [14]	343 centres [14]	30 days [14]
Lingjuan He et al., 2023 [3]	Gastric cancer surgery (34 studies) [3]	66,066 [3]	Not specified [3]
A. Mihaljevic et al., 2015 [15]	Open abdominal surgery including colorectal, appendectomy, cesarean (16 RCTs) [15]	3,695 [15]	Varied (≥ 30 days) [15]
Spyridon Fortis et al., 2015 [34]	Colectomy [34]	507 [34]	Not specified [34]
P. Mitt et al., 2005 [35]	Cesarean section [35]	305 [35]	Inpatient + post-discharge [35]
V. Ward et al., 2008 [36]	Cesarean section [36]	5,563 [36]	Post-discharge [36]
G. Azeze & A. Bizuneh, 2019 [11]	Cesarean section (Ethiopia) [11]	383 [11]	30 days [11]

Study	Surgical Population	Sample Size	SSI Follow-up
Kayla D Isbell et al., 2021 [37]	Emergency trauma laparotomy [37]	1,322 [37]	Not specified [37]
Anna Buford et al., 2025 [38]	Abdominal hysterectomy [38]	37 cases, 74 controls [38]	30 days [38]
F. Husain et al., 2018 [39]	Bariatric surgery (sleeve gastrectomy and RYGB) [39]	772 [39]	≥30 days [39]
Muxin Chen et al., 2023 [2]	Gastric cancer surgery (15 studies) [2]	6,206 [2]	Not specified [2]
V. Ho et al., 2011 [40]	Elective colorectal with anastomosis [40]	605 [40]	Not specified [40]
Heather A. Young et al., 2011 [41]	Elective total abdominal hysterectomy [41]	192 [41]	30 days [41]
A. K. Harzif et al., 2020 [42]	Cesarean section (Indonesia) [42]	2,052 [42]	Not specified [42]
H. Young et al., 2013 [43]	Abdominal hysterectomy [43]	Pre: 192, Post: 84 [43]	Not specified [43]

Study	Surgical Population	Sample Size	SSI Follow-up
Kasereka Kahuko Deyem et al., 2025 [4]	Mixed abdominal surgery (laparotomy, hernia, appendectomy; DRC) [4]	218 [4]	30 days [4]
K. Colling et al., 2015 [8]	Abdominal hysterectomy (open, laparoscopic, robotic) [8]	986 [8]	Not specified [8]
Tsegaw Alemye et al., 2021 [44]	Cesarean section (Ethiopia) [44]	1,069 [44]	30 days [44]
C. Foppa et al., 2014 [45]	Colorectal resection [45]	Pre: 379, Post: 311 [45]	Not specified [45]
M. Hirao et al., 2013 [46]	Open distal gastrectomy for gastric cancer [46]	355 [46]	30 days [46]
T. Pinkney et al., 2013 [16]	Laparotomy (mixed abdominal, 21 UK hospitals) [16]	760 [16]	30 days [16]
C. Duffy et al., 2022 [47]	Cesarean delivery [47]	141 cases [47]	2-year period [47]
Poon Chi Ming et al., 2009 [48]	Complicated appendicitis (appendectomy) [48]	173 [48]	Not specified [48]

Study	Surgical Population	Sample Size	SSI Follow-up
Eyob Shitie Lake et al., 2024 [10]	Cesarean section (Ethiopia) [10]	8,755 total [10]	30 days [10]
Tara C Mueller et al., 2025 [49]	Laparotomy (open abdominal) [49]	6,368 [49]	Not specified [49]
M. Depuydt et al., 2024 [50]	Abdominal surgery, fascial closure (open/laparoscopic) [50]	10,234 [50]	30 days [50]
S. Chadi et al., 2014 [17]	Abdominoperineal resection (colorectal) [17]	59 [17]	30 days [17]
Erin G. Andrade et al., 2020 [51]	Exploratory laparotomy (including contaminated/dirty) [51]	139 [51]	30 days [51]
A. Lightner et al., 2017 [12]	Abdominal surgery for IBD (vedolizumab vs anti-TNF vs no biologic) [12]	94 vedolizumab [12]	30 days [12]
Kathryn J. Eagye & D. Nicolau, 2009 [52]	Elective colorectal surgery [52]	1,127 reviewed; 46 cases, 46 controls [52]	Oct 2005–May 2007 [52]

Study	Surgical Population	Sample Size	SSI Follow-up
Brian P. Smith et al., 2012 [53]	Emergency trauma laparotomy [53]	306 [53]	Not specified [53]
K. Brasel et al., 2007 [54]	Elective colorectal resection (open) [54]	300 [54]	Intraop + 6 h postop [54]
Kaniz Fatema et al., 2023 [55]	Cesarean section (Bangladesh) [55]	400 [55]	30 days [55]
Jae Hee Kuh et al., 2023 [19]	Abdominal surgery (colorectal predominant) [19]	15,977 [19]	2 weeks to 1 month [19]
Aditi Sangwan & V. Malhotra, 2019 [56]	Cesarean section (India) [56]	1,000 [56]	30 days [56]
T. Anthony et al., 2011 [21]	Elective transabdominal colorectal surgery (VA hospital) [21]	197 (ITT) [21]	30 days [21]
Brittany E. Levy et al., 2022 [57]	Colorectal resections (tracked and untracked) [57]	National: 71,705; Institutional: 2,233 [57]	≥30 days [57]

Study	Surgical Population	Sample Size	SSI Follow-up
M. Gachabayov et al., 2018 [58]	Elective colorectal resections [58]	690 [58]	2006–2012 [58]
Kelley M. Boston et al., 2021 [5]	Colon surgery (trauma and non-trauma) [5]	778 [5]	30 days [5]
Nambajjo Angel, 2024 [59]	Cesarean section (Uganda) [59]	622 [59]	30 days [59]
Justin L Regner et al., 2015 [60]	Elective ventral hernia repair (laparoscopic vs open) [60]	106,968 [60]	30 days [60]
J. Baracs et al., 2011 [61]	Elective colorectal surgery [61]	485 [61]	Inpatient + outpatient post-discharge [61]
Lily Fatula et al., 2018 [62]	Open ventral hernia repair with mesh [62]	822 [62]	2008–2017 [62]
Oluwatosin Jaiyeoba et al., 2014 [63]	Cesarean section [63]	1,189 [63]	30 days [63]
R. Nelson et al., 2020 [6]	Elective colorectal surgery [6]	12,297 [6]	Not specified [6]
M. Mirande et al., 2023 [64]	Diverting loop ileostomy closure [64]	Not specified [64]	Not specified [64]

Study	Surgical Population	Sample Size	SSI Follow-up
E. Vo et al., 2017 [9]	Elective left colon and rectal cancer resections [9]	89 [9]	30 days [9]
O. Akça et al., 2013 [65]	Elective colon resection (hemicolectomy, low anterior) [65]	1,215 (623 normocapnia, 592 hypercapnia) [65]	30 days [65]
Alvin Wong et al., 2016 [66]	Incisional ventral hernia repair (open) [66]	234 [66]	2003–2013 [66]
M. Yaegashi et al., 2017 [67]	Laparoscopic colorectal resection [67]	453 [67]	3 years [67]
J. Nguyen et al., 2019 [68]	Gynecologic oncology surgery (laparotomies) [68]	339 baseline, 224 post [68]	Not specified [68]
J. Ruiz-Tovar et al., 2015 [69]	Fecal peritonitis (colorectal; contaminated/dirty wounds) [69]	101 [69]	Not specified [69]
A. Lightner et al., 2019 [13]	Abdominal surgery for Crohn's disease [13]	334 [13]	90 days [13]

Study	Surgical Population	Sample Size	SSI Follow-up
Mr Dhruva et al., 2022 [70]	Mixed abdominal surgery (elective/emergency; clean-contaminated, contaminated, dirty) [70]	13,301 [70]	30 days [70]
Linda T. Li et al., 2014 [71]	Stoma reversal [71]	146 [71]	Not specified [71]
Justin J. Turcotte et al., 2020 [72]	Emergency open colon surgery [72]	118 [72]	Not specified [72]
S. Grewal et al., 2021 [73]	Elective colorectal cancer surgery [73]	2,497 [73]	Not specified [73]
M. Bahardoust et al., 2025 [74]	Appendectomy (open and laparoscopic) [74]	4,439 [74]	Not specified [74]
A. Pop-Vicas et al., 2020 [20]	Colorectal surgery [20]	54,221 [20]	30 days [20]
Y. Park et al., 2015 [75]	Colorectal resection for colorectal cancer [75]	327 [75]	Not specified [75]
D. Leaper et al., 2020 [76]	Colorectal surgery [76]	107,665 [76]	3–180 days [76]

Study	Surgical Population	Sample Size	SSI Follow-up
Prasad Yerra et al., 2021 [77]	Emergency abdominal surgery [77]	178 (85 control, 93 study) [77]	14 days [77]
R. M. Strobel et al., 2022 [78]	Elective laparotomy (colorectal predominant) [78]	393 [78]	Not specified [78]
Yugang Jiang et al., 2022 [79]	Elective colorectal surgery (clean-contaminated) [79]	483 total (312 PRESS+, 171 PRESS-) [79]	Not specified [79]
Zachary Gala et al., 2025 [80]	Ventral hernia repair [80]	1,414 [80]	Mean 1.72 years [80]

Effects

Patient-Related Risk Factors

Obesity and Body Mass Index

Elevated BMI is among the most consistently reported patient-level risk factors for SSI across virtually every surgical category examined in this review. In colorectal surgery, a meta-analysis of 31 observational studies found obesity (BMI >30 kg/m²) to be associated with a 60% increased relative risk of SSI (RR = 1.60, 95% CI: 1.47–1.74), based on high-quality evidence [1]. In a prospective cohort of 300 Saudi patients undergoing open elective colorectal surgery, multivariable analysis identified BMI as the only independent predictor of SSI (OR 4.71, 95% CI 2.20–10.10, p=0.001), with the univariate OR also significant at 4.00 (95% CI 1.95–8.20) [33]. In laparoscopic colorectal resections specifically, every unit increase in BMI was associated with an OR of 1.06 for extraction site SSI (p<0.05) [27].

The relationship between obesity and SSI extends across procedure types. In hysterectomy, both open and minimally invasive cohorts identified morbid obesity as an independent risk factor [8], and a retrospective study at an academic safety-net hospital reported diabetes (OR 3.89, 95% CI 1.25–12.08) and blood loss as the primary modifiable risk factors, while noting that higher ASA class and open approach were univariately significant [38]. An earlier study at the same institution reported that obesity (BMI ≥ 30) marginally increased risk (OR 2.55, 95% CI 0.94–6.74) while blood transfusion was a highly significant independent predictor (OR 3.58, 95% CI 1.21–10.62) [41]. In bariatric surgery, hypoalbuminemia and open or revisional procedures were the most significant predictors of deep SSI [39]. For cesarean section, elevated BMI is reported as a risk factor across multiple populations: an Jordanian cohort found that BMI ≥ 36 kg/m² conferred an OR of 3.8 (95% CI 1.6–9.4) [31], an Indonesian study found that BMI ≥ 30 kg/m² carried an adjusted OR of 1.824 (95% CI 1.066–3.121) [42], and a Bangladeshi prospective cohort identified operation time ≥ 45 minutes and BMI > 30 as the two principal high-risk factors [55]. In appendectomy, a meta-analysis found that each millimetre increase in subcutaneous fat thickness was associated with an OR of 1.32 (95% CI 1.12–1.52) for SSI in open surgery (OS), but this association was not significant for laparoscopic surgery (LS) (OR 1.09, 95% CI 0.90–1.28) [74], pointing to an important interaction between body habitus and surgical approach.

For gastric surgery, a multicenter RCT of 355 patients undergoing open distal gastrectomy found that BMI ≥ 25 kg/m² was the single independent predictor of SSI on multivariate analysis (OR 2.82, 95% CI 1.05–7.52, $p=0.049$), with overweight patients also having significantly longer operative times and greater blood loss [46]. A meta-analysis of gastric cancer patients confirmed BMI ≥ 25 kg/m² as a significant risk factor [3], and a separate meta-analysis identified anaemia (OR 4.72, 95% CI 1.66–13.40) and operation time ≥ 3 hours (OR 8.33, 95% CI 3.81–18.20) as particularly potent risk factors in this population [2].

In ventral hernia repair, a large NSQIP database analysis of 106,968 patients demonstrated that laparoscopic ventral hernia repair (LVHR) mitigated the SSI risk associated with obesity across all BMI strata compared with open ventral hernia repair (OVHR), with class III obesity representing the highest-risk subgroup for organ-space SSI and reoperation in OVHR [60].

Diabetes Mellitus

Diabetes mellitus is a consistent independent risk factor for SSI across most abdominal surgical procedures. In colorectal surgery, meta-analytic evidence rated as moderate quality found an RR of 1.65 (95% CI 1.24–2.20) for overall SSI, and the overall SSI rate in diabetic patients undergoing colorectal resection was 28.7% versus 22.3% in non-diabetic patients within a single-institution series ($p=0.042$) [58]. A retrospective study of 327 colorectal cancer patients identified diabetes as an independent predictor on both univariate (OR 2.154, 95% CI 1.108–4.190, $p=0.024$) and multivariate analysis (OR 2.124, 95% CI 1.052–4.286, $p=0.036$) [75]. Among patients with complicated appendicitis, diabetes was the only factor independently associated with postoperative intra-abdominal abscess in univariate analysis (OR 6.6, 95% CI 1.67–25.9) [48].

In gastric cancer surgery, the meta-analytic OR for diabetes is 2.03 (95% CI 1.59–2.61) [2], and the broader gastric cancer meta-analysis of 66,066 patients confirmed diabetes as a significant independent risk factor [3]. In abdominal hysterectomy, diabetes was the primary statistically significant risk factor identified on multivariable analysis (OR 3.89, 95% CI 1.25–12.08, $p=0.019$) [38], and implementation of a vaginal preparation training intervention that followed identification of this risk factor was associated with a reduction in the deep and organ-space standardised infection ratio from 1.46 to 0.519 over a three-year period [38].

Perioperative hyperglycaemia compounds the risk beyond a diagnosis of diabetes per se. Within an SSI bundle for elective colorectal resections, non-diabetic patients exhibited a postoperative hyperglycaemia rate of 46%, as high as that in diabetic patients, and patients with pre- and postoperative hyperglycaemia had significantly higher organ-space SSI rates (12.6%, $p=0.017$) [58]. This finding underscores that perioperative glucose dysregulation, not just pre-existing diabetes, is the proximate driver of SSI risk.

Nutritional Status

Nutritional compromise—variously measured as low preoperative albumin, hypoproteinaemia, anaemia, or low BMI—emerges as an important but procedure-specific risk factor. In laparoscopic colorectal resection, preoperative albumin was the most significant independent predictor of superficial SSI on multivariate analysis [67]. In open elective colorectal

surgery among Saudi patients, preoperative pre-albumin was protective against SSI on both univariate (OR 0.81, 95% CI 0.66–0.99) and multivariate analysis (OR 0.76, 95% CI 0.60–0.96) [33]. In gastric cancer surgery, meta-analyses identified hypoproteinaemia (OR 3.05, 95% CI 2.08–4.49) and anaemia (OR 4.72, 95% CI 1.66–13.40) as powerful risk factors [2]. In a LMIC setting in the Democratic Republic of Congo, malnutrition increased the odds of SSI by 5.2 (95% CI 1.3–20.7, $p=0.02$) [4]. Pre-operative anemia was also confirmed as an independent predictor of SSI in visceral surgery (OR 1.84, 95% CI 1.08–3.13, $p=0.016$) in the RECIPE trial cohort [78]. In bariatric surgery, hypoalbuminemia was independently associated with both deep SSI and anastomotic leak [39].

These nutritional variables are physiologically interconnected: anaemia may reduce tissue oxygen delivery, while hypoalbuminemia impairs immune function and wound healing, both of which mechanistically elevate SSI risk. Their importance relative to other factors may be greater in LMIC and high-complexity surgical settings where nutritional optimisation is less routinely achieved preoperatively.

ASA Score and Comorbidity Burden

High ASA score (≥ 3) is a well-established predictor of SSI. In colorectal surgery meta-analysis, ASA ≥ 3 was associated with an RR of 1.34 (95% CI 1.19–1.51) based on high-quality evidence [1]. In elective colorectal surgery case-control data, higher ASA score was an independent risk factor for deep and organ-space infection [52]. In abdominal hysterectomy, univariate analysis identified ASA class 3 as a significant predictor ($p=0.0001$) [38]. In laparoscopic colorectal surgery, a prospective cohort found ASA ≥ 3 was not independently significant after accounting for other factors [67], suggesting that ASA score may partly capture the combined effect of the comorbidities analysed separately (diabetes, obesity, anaemia) rather than being an independent mechanism.

Comorbidities beyond metabolic conditions also carry procedure-specific risk. Obstructive sleep apnoea (OSA), though rarely examined, was found in a matched retrospective cohort of 507 colectomies to be an independent predictor of SSI (OR 3.98, 95% CI 1.29–12.27, $p=0.03$), with the organ-space SSI rate in OSA patients being 9.5% versus 0% in matched controls [34]. Among IBD patients, vedolizumab exposure within 12 weeks of abdominal surgery was the only independent

predictor of 30-day postoperative SSI on multivariate analysis ($p < 0.001$), with an SSI rate of 37% versus 10% for anti-TNF and 13% for no biologic therapy [12]. Ustekinumab exposure was similarly found to be an independent predictor of 90-day intra-abdominal sepsis after abdominal surgery for Crohn's disease [13], and concurrent immunomodulator use was associated with significantly increased rates of superficial SSI and overall complications [13].

Age and Sex

In gastric cancer surgery, age ≥ 65 years is a significant risk factor [3], and a meta-analysis of 15 gastric cancer studies found an OR of 2.75 (95% CI 1.65–4.57) for age > 60 years [2]. However, in laparoscopic colorectal surgery, younger age was paradoxically associated with higher SSI risk, probably reflecting the preponderance of inflammatory bowel disease in younger patients [27]. In colorectal surgery more broadly, moderate-quality meta-analytic evidence found male sex to confer an RR of 1.30 (95% CI 1.14–1.49) [1], and gastric cancer surgery meta-analyses found male sex to have an OR of 1.28 (95% CI 1.06–1.55) [2]. For colorectal cancer specifically, male sex is reported as a risk factor alongside obesity and diabetes [29]. These sex and age effects are likely partly mediated by differences in adipose tissue distribution (visceral vs subcutaneous fat) and comorbidity burden, rather than representing independent biological mechanisms.

Perioperative and Surgical Factors

Operative Duration

Prolonged operative duration is one of the most robust and cross-cutting surgical risk factors for SSI. In colorectal surgery, surgery lasting ≥ 180 minutes was associated with an RR of 1.88 (95% CI 1.49–2.36) for overall SSI and 2.03 for organ-space SSI in meta-analysis [1]. In colorectal cancer resection, operation time ≥ 180 minutes was independently associated with SSI (univariate OR 2.623, 95% CI 1.352–5.092; multivariate OR 2.252, 95% CI 1.116–4.544, $p = 0.023$) [75]. In gastric cancer, the meta-analytic OR for operation time ≥ 3 hours is 8.33 (95% CI 3.81–18.20), the single largest-magnitude risk factor in that population [2]. In gynecologic oncology, longer operative duration was independently associated with SSI on multivariable analysis (OR 2.16, 95% CI 1.11–4.19) [68]. In emergency abdominal surgery in a LMIC setting, operations lasting > 1 hour carried a 15.3-fold increase in SSI risk (95% CI 6.4–36.6, $p < 0.0001$) [4]. In cesarean section

studies, duration of operation >30–45 minutes was consistently reported as a risk factor [11, 55]. For diverting loop ileostomy closure, increasing operative time was a significant SSI predictor [64].

There is also evidence from gastric cancer surgery that operative time shows a nonlinear relationship with SSI risk, potentially reaching a threshold effect at extreme durations [3], a finding with potential implications for interpreting dose-response relationships in perioperative risk modelling.

Blood Transfusion and Blood Loss

Perioperative blood transfusion and significant intraoperative blood loss are frequent SSI risk factors, though the mechanisms may differ. In colorectal surgery, blood transfusion carries a moderate-quality RR of 2.03 (95% CI 1.34–3.06) for overall SSI, and an RR of 2.32 (95% CI 1.26–4.29) specifically for organ-space SSI [1]. In colorectal cancer patients, perioperative transfusion carried an OR of 3.100 (95% CI 1.551–6.195, $p=0.001$) in multivariable analysis [75]. In colorectal surgery for the superficial SSI outcome, blood transfusion was confirmed as an independent risk factor ($p=0.011$) [79]. In abdominal hysterectomy, blood transfusion was the most significant modifiable risk factor (OR 3.58, 95% CI 1.21–10.62) [41], and was also independently associated with SSI and endometritis in cesarean delivery case-control analysis, reported as conferring a >10-fold risk [47]. In cesarean section, blood transfusion was associated with an adjusted OR of 4.2 (95% CI 2.35–6.08) in an Ethiopian cross-sectional study [44]. In trauma laparotomy, higher transfusion requirements were among the most predictive intraoperative factors for superficial SSI [37].

The immunosuppressive effects of allogeneic blood transfusion, including inhibition of natural killer cell activity and impaired cellular immunity, provide a plausible mechanistic basis for this association that is consistent across procedure types and populations.

Surgical Approach: Open versus Minimally Invasive

Open surgery is an independent risk factor for SSI compared with laparoscopic or robotic approaches across multiple procedure types. In colorectal surgery, open surgery carries a moderate-quality RR of 1.81 (95% CI 1.57–2.10) compared with laparoscopic surgery [1], and minimally invasive surgery was associated with a reduced odds of SSI in colorectal cancer resection (OR 0.22,

95% CI 0.05–0.89, $p=0.03$) [9]. In hysterectomy, open technique was associated with an SSI rate of 6.5%, versus 0% for laparoscopic and 2.2% for robotic approaches ($p<0.0001$) [8]. Cases converted from minimally invasive to open carried the highest SSI rate of 13.3% [8]. In gastric cancer, laparotomy had an OR of 2.18 (95% CI 1.61–2.94) for SSI compared with laparoscopic procedures [2]. In bariatric surgery, open procedures were independently associated with a substantially higher risk of deep SSI (OR 5.13, $p=0.015$) [39]. For appendectomy, meta-analysis showed that greater subcutaneous fat thickness was associated with SSI in open surgery (OR 1.82, 95% CI 1.27–2.38) but not in laparoscopic surgery [74], suggesting that minimally invasive approaches may attenuate the adverse SSI effect of abdominal adiposity by reducing exposure of subcutaneous tissue to contamination.

Wound Classification and Contamination Level

Wound contamination class is a fundamental determinant of SSI risk. In emergency trauma laparotomy, colonic procedures with a dirty wound class had a standardised infection ratio of 6.608 compared with 2.235 for contaminated or clean-contaminated wounds ($p=0.0014$), and trauma procedures had an SIR of 3.451 versus 1.071 for non-trauma procedures ($p=0.0003$) [5]. In LMIC abdominal surgery, contaminated or dirty wounds carried an adjusted OR of 4.5 (95% CI 1.8–11.5) for SSI [4]. In hysterectomy, wound class III/IV was a significant independent predictor [8]. In abdominal surgery for fecal peritonitis, the SSI rate in the control group (uncoated sutures) reached 35.3% [69], illustrating the extreme risk in dirty-classified procedures. Meta-analytic data on wound edge protectors demonstrated a stronger protective effect in contaminated cases (RR 0.44, 95% CI 0.28–0.67) than in clean-contaminated cases (RR 0.72, 95% CI 0.57–0.91) [15]. In ventral hernia repair with mesh, contaminated wounds had an OR of 2.96 (95% CI 1.39–6.21) and dirty wounds an OR of 3.84 (95% CI 1.49–9.69) for SSI on logistic regression [62].

Emergency versus Elective Surgery

Emergency surgery consistently confers higher SSI risk than elective procedures. In colorectal surgery, emergent surgery is associated with high-quality evidence for an RR of 1.36 (95% CI 1.19–1.55) [1]. In cesarean section, emergency procedures are repeatedly identified as risk factors across multiple populations [11, 36, 56, 63]. In the Bangladeshi prospective cohort of 400

cesarean patients, post-discharge SSI was 10.53% for emergency cesarean versus 2.61% for elective [55]. The GlobalSurg multicentre study commentary noted an overall 30-day SSI rate of 12.3%, ranging from 9.4% in high-income countries to 23.2% in low-income countries, with lower human development index (HDI) serving as an independent risk factor irrespective of contamination level [14]. Emergency laparotomy in the SUNRRISE trial yielded SSI rates of approximately 28% [18], and the EPO2CH Dutch trial of elective abdominal surgery reported an 18.4% SSI rate in the intervention arm and 18.9% in the standard care arm [22], illustrating the markedly higher baseline risk in emergency versus elective populations.

Stoma Formation and Stoma-Related Procedures

Stoma formation is a specific intraoperative risk factor for incisional SSI. In colorectal surgery meta-analysis, stoma formation was associated with a moderate-quality RR of 1.89 (95% CI 1.28–2.78) for overall SSI and a high-quality RR of 2.55 (95% CI 1.87–3.47) specifically for incisional SSI [1]. Notably, stoma formation was not associated with organ-space SSI [1], indicating a mechanism operating principally at the incisional level (likely faecal contamination during stoma construction). At stoma reversal, the SSI rate was 36.0%, and history of fascial dehiscence (OR 16.9, 95% CI 1.94–387), colostomy (OR 5.07, 95% CI 2.12–13.0), and thicker subcutaneous fat (OR 2.02, 95% CI 1.33–3.21) were independent predictors [32]. For diverting loop ileostomy closure, the overall SSI rate was 5.7%, with Crohn's disease, diverticular disease, and increasing operative time as independent risk factors [64]. The skin closure technique at stoma reversal showed variable rates: primary closure 43%, secondary closure 16%, loose primary closure 15%, and circular closure 6% ($p<0.01$) [71], with circular closure also independently associated with lower SSI risk (OR 0.07, 95% CI 0.01–0.63) [71].

Intraoperative Contamination: Detection of Subcutaneous Pathogens

An important mechanistic study in 393 visceral surgery patients found that pathogens were detected in intraoperative subcutaneous swabs in 64.4% of patients who subsequently developed SSI, compared with 38.0% of those who did not ($p<0.001$) [78]. A positive subcutaneous swab was an independent predictor of SSI (OR 2.51, 95% CI 1.47–4.29, $p=0.001$), pre-operative anaemia was independently associated (OR 1.84, 95% CI 1.08–3.13, $p=0.016$), and renal insufficiency also

reached significance (OR 2.15, 95% CI 1.01–4.59, $p=0.048$) [78]. The predominant pathogens were enterococci (29.1%) and *Escherichia coli* (15.5%) [78], consistent with gastrointestinal flora. *Enterococcus faecium* was disproportionately represented in smokers and anaemic patients, suggesting that systemic host factors modulate the composition of intraoperative contamination [78].

Preventive Interventions and Their Effects on SSI

The studies also examined a range of preventive interventions, providing effect estimates that are directly relevant to understanding modifiable risk.

Antibiotic Prophylaxis

Antibiotic prophylaxis is among the most robustly evidence-based interventions for SSI prevention in abdominal surgery. A network meta-analysis of 105 RCTs ($n=18,273$) evaluating antibiotic classes in elective colorectal surgery found that broad-spectrum penicillins (RR 0.26, 95% CI 0.16–0.42), third-generation cephalosporins (RR 0.27, 95% CI 0.16–0.45), metronidazole combined with second-generation cephalosporins (RR 0.27, 95% CI 0.17–0.44), and tetracyclines (RR 0.32, 95% CI 0.20–0.53) each substantially reduced SSI risk compared with placebo [7]. Broad-spectrum penicillins also uniquely reduced 30-day mortality (RR 0.21, 95% CI 0.05–0.90) [7].

The importance of adherence to prophylaxis protocols—not only agent selection but timing—is demonstrated in a retrospective study of 605 colorectal surgery patients, where nonstandard antibiotic regimens doubled SSI odds (multivariate OR 2.505, 95% CI 1.066–5.886) and early administration (before the 30-minute preincision window) independently increased odds (multivariate OR 1.733, 95% CI 1.017–2.954) [40]. In trauma laparotomy, complete adherence to four SCIP antibiotic guideline components independently reduced SSI risk (OR 0.43, 95% CI 0.20–0.94, $p=0.035$), reducing the SSI rate from 33% to 17% ($p=0.001$) [53]. In cesarean section, inadequate antibiotic prophylaxis (predominantly due to inappropriate timing at or after skin incision) was associated with a four-fold increase in SSI risk (adjusted OR 4.4, 95% CI 1.3–15.6) [47].

The route of prophylaxis matters in elective colorectal surgery. A meta-analysis of 61 trials (n=12,297) found that the combination of oral plus intravenous antibiotics reduced SSI risk to a greater degree than either route alone (RR 0.47, 95% CI 0.40–0.56 for OA+IV versus IV alone; RR 0.48, 95% CI 0.38–0.62 for OA+IV versus OA alone), with high-certainty GRADE evidence [6]. Importantly, mechanical bowel preparation was not required for the oral antibiotic benefit, as OA+IV without bowel preparation remained superior to IV alone (RR 0.36, 95% CI 0.18–0.72) [6]. A smaller retrospective study of 89 left colon and rectal cancer resections similarly found oral antibiotics with MBP reduced the overall SSI rate from 27% to 8% (p=0.03), with elimination of organ-space SSI and anastomotic leak in the oral antibiotic group [9]. A meta-analysis of 8 studies also confirmed oral antibiotics plus MBP to be associated with a significant reduction in SSI (RR 0.46, 95% CI 0.31–0.69) and anastomotic leak (RR 0.58, 95% CI 0.37–0.91), with selective digestive decontamination showing superiority over broad-spectrum oral antibiotics for reducing anastomotic leak [73].

For cesarean section, weight-adjusted dosing of cefazolin was protective, with each unit increase in dose per kilogram being associated with a decreased odds of SSI (OR 0.967, 95% CI 0.94–0.99) [31], suggesting that standard 2-gram dosing may be inadequate for morbidly obese patients.

Supplemental Perioperative Oxygen

The effect of high-fraction inspired oxygen on SSI has been examined in multiple RCTs and a large meta-analysis. The meta-analysis of 27 trials (n=15,977) found that high FiO₂ reduced SSI risk overall (RR 0.87, 95% CI 0.79–0.95), with stronger effects in emergency procedures (RR 0.54, 95% CI 0.35–0.84), when air was the carrier gas (RR 0.79, 95% CI 0.69–0.91), and when high FiO₂ was maintained for ≥6 hours postoperatively (RR 0.68, 95% CI 0.56–0.83) [19]. The original Spanish RCT of 80% versus 30% FiO₂ in elective colorectal surgery found adjusted RR of 0.46 (95% CI 0.22–0.95) after covariate adjustment [23], while a contemporaneous RCT in emergency abdominal surgery found 80% FiO₂ reduced SSI from 34.1% to 20.4% (adjusted OR 0.41, 95% CI 0.19–0.88, p=0.04) [77]. The benefit appears to be moderated by BMI and diabetic proportion: meta-regression found significant effects only when mean BMI was below 30 and when fewer than

20% of patients had diabetes [19], suggesting that tissue oxygen delivery improvements may be offset by microvascular disease or adipose diffusion barriers in high-risk metabolic populations. The EPO2CH bundle—which included high FiO₂ alongside goal-directed fluid therapy, normothermia, glucose control, and wound irrigation—found no reduction in SSI compared with standard care (RR 0.98, 95% CI 0.81–1.18) [22], while the Anthony et al. RCT of five bundled interventions including supplemental oxygen paradoxically found higher SSI in the bundle arm (45% vs 24%, p=0.003) [21]. These negative bundle results caution against assuming that individual efficacious interventions produce predictable aggregate effects when combined.

Wound Edge Protectors

Meta-analytic evidence from 16 RCTs (n=3,695) supports the use of wound edge protectors, demonstrating a significant overall risk reduction (RR 0.65, 95% CI 0.51–0.83), with a larger effect in contaminated cases (RR 0.44, 95% CI 0.28–0.67) and specifically for superficial SSI (RR 0.45, 95% CI 0.24–0.82) [15]. Double-ring devices appeared to have a greater protective effect (RR 0.29, 95% CI 0.15–0.55) than single-ring devices (RR 0.71, 95% CI 0.54–0.92), though evidence for double-ring devices was lower quality [15]. In a high-risk population undergoing pancreaticoduodenectomy with preoperative biliary stents, a dual-ring wound protector reduced incisional SSI from 42.0% to 21.1% (RR 0.50, 95% CI 0.28–0.91, p=0.019) [25]. However, the large ROSSINI RCT of 760 laparotomy patients found no benefit from wound edge protection devices (OR 0.97, 95% CI 0.69–1.36, p=0.85) across all subgroup analyses including contamination degree [16]. This discrepancy may partly reflect the ROSSINI trial's mixed surgical population and broad inclusion of procedures at varying contamination levels, whereas the meta-analytic benefit was concentrated in contaminated cases.

Wound Irrigation

Intraoperative wound irrigation before skin closure has supportive evidence. An earlier meta-analysis of 41 RCTs (>9,000 patients) found irrigation with any solution reduced SSI (OR 0.54, 95% CI 0.42–0.69, p<0.0001), with antibiotic irrigation more effective than povidone-iodine or saline, and the effect being strongest in colorectal surgery [30]. A more recent meta-analysis (18 studies, n=6,368) with stricter inclusion criteria found any irrigation versus no irrigation to reduce

SSI (RR 0.52, 95% CI 0.37–0.74, $p<0.001$), while antiseptic versus saline irrigation alone did not reach significance across all studies (RR 0.80, 95% CI 0.58–1.09, $p=0.159$), but became significant on exclusion of laparoscopic cases and high-bias-risk studies (RR 0.75, 95% CI 0.64–0.87, $p<0.001$) [49]. In open ventral hernia repair, irrigation with combined gentamicin and clindamycin independently reduced SSI (OR 0.33, 95% CI 0.16–0.67) compared with no irrigation or gentamicin alone [62].

Triclosan-Coated Sutures

An 11-RCT meta-analysis ($n=10,234$) found that triclosan-coated sutures for fascial closure significantly reduced SSI compared with uncoated sutures (OR 0.84, 95% CI 0.75–0.93, $p=0.001$), with consistent effects for both polydioxanone (OR 0.86, 95% CI 0.77–0.96) and polyglactin 910 (OR 0.67, 95% CI 0.48–0.94) [50]. In the specific setting of fecal peritonitis, a small RCT ($n=101$) found triclosan-coated sutures reduced incisional SSI from 35.3% to 10% (OR 0.204, 95% CI 0.069–0.605, $p=0.004$), with particular reductions in *E. coli* and *Enterococcus faecalis* infections [69]. By contrast, a multicentre RCT in elective colorectal surgery ($n=485$) found no significant difference in SSI rates between triclosan-coated (12.2%) and uncoated sutures (12.2%) [61], with the investigators noting that implementation of looped PDS (regardless of triclosan coating) appeared to halve SSI compared with historical rates, implying that suture configuration may matter more than antimicrobial coating in elective clean-contaminated procedures [61].

Incisional Negative Pressure Wound Therapy (iNPWT)

Findings on iNPWT are inconsistent. A retrospective cohort study of abdominoperineal resection found iNPWT to be an independent protective factor for perineal SSI (adjusted OR 0.11, 95% CI 0.04–0.66, $p=0.01$), with SSI rates of 15% versus 41% in the control group [17]. A multimodal closure protocol for high-risk laparotomy wounds incorporating iNPWT, dilute chlorhexidine lavage, and closed suction drains significantly increased wound closure rates (OR 179.2, $p<0.001$) without increasing SSI compared with the no-protocol period [51]. However, the large SUNRRISE RCT ($n=840$) of iNPWT in emergency laparotomy found no reduction in SSI compared with surgeon's choice of dressing (28.4% vs 27.4%, RR 1.03, 95% CI 0.83–1.28,

p=0.78), with consistent null results across all prespecified subgroups including contamination level, stoma presence, BMI, and skin preparation [18].

Glove and Instrument Change

The ChEETAh cluster RCT in 13,301 patients across seven LMICs found that routine glove and instrument change before wound closure reduced SSI compared with current practice (16.0% vs 18.9%, adjusted RR 0.87, 95% CI 0.79–0.95, p=0.0032), with no evidence of heterogeneity across subgroups [70]. This simple intervention's effect was consistent across different surgical types, contamination levels, and settings.

Skin Preparation

Among cesarean section studies, the use of chlorhexidine versus non-chlorhexidine abdominal preparation was associated with a reduced SSI risk; inadequate antibiotic prophylaxis was associated with increased SSI risk (aOR 4.4, 95% CI 1.3–15.6), while factors exclusively associated with SSI (not endometritis) in the Duffy et al. case-control included inadequate prophylaxis, public insurance, hypertensive disorder, and non-chlorhexidine preparation [47]. A pre-post intervention study at an abdominal hysterectomy centre found that switching from 10% povidone-iodine to 4% chlorhexidine gluconate skin preparation was one component of a multifaceted bundle that reduced SSI from 10.7% to 1.2% (p=0.006) [43]. In the large gynecologic oncology bundle series, the bundle (which included preoperative chlorhexidine shower) reduced overall SSI by 55% from 12.1% to 5.4% (p=0.008) [68].

Surgical Bundles

Colorectal bundles have been systematically evaluated. A meta-analysis of 40 studies (n=54,221 patients) found bundles associated with 44% reduction in overall SSI (RR 0.57, 95% CI 0.48–0.65), with similar reductions for superficial (RR 0.56), deep (RR 0.67), and organ-space SSI (RR 0.63) [20]. Bundles containing ≥ 11 elements combining standard-of-care and novel interventions showed the greatest reduction, and specific components most correlated with superficial SSI reduction included separate instrument trays, glove/gown change for wound closure, and standardised dressing change at 48 hours [20]. The colorectal SSI reduction strategy reported by Foppa et al. achieved a 41% decrease in overall SSI (32.19% to 18.97%, p<0.01), with a marked

reduction in superficial SSI (23.48% to 8.04%, $p < 0.01$) but no change in deep or organ-space rates [45].

However, two RCTs of bundled interventions produced paradoxical results. The Anthony et al. trial of five evidence-based interventions in colorectal surgery yielded a substantially higher SSI rate in the bundle arm (45% vs 24%, $p = 0.003$, multivariate OR 2.49, 95% CI 1.36–4.56) [21], and the EPO2CH Dutch multicentre trial showed no benefit (RR 0.98) [22]. These RCT results contrast with the largely positive observational bundle literature, a discrepancy likely attributable to the inability of observational pre-post designs to control for secular trends, the aggregation effects of individual interventions with opposing effects, and issues of protocol fidelity.

Cesarean Section-Specific Risk Factors

Given the large number of included studies focusing on cesarean section—predominantly from sub-Saharan Africa and South Asia—the cesarean-specific risk factor profile warrants separate consideration. The pooled SSI rate after cesarean section in Ethiopia was 11.13% (95% CI 9.29–12.97%) across 19 studies [10], compared with rates of 5.0% in a US tertiary centre [28], 6.2% in Estonia [35], 8.9% in a UK multicentre post-discharge surveillance study [36], 4.14% in Indonesia [42], and 14.4% in Jordan [31].

Obstetric-specific risk factors that do not have direct analogues in other abdominal procedures include:

Prelabour/prolonged rupture of membranes, which was associated with an OR of 13.9 in Ethiopia [11], an AOR of 3.80 in the Ethiopian meta-analysis for prolonged premature rupture of membranes (PROM) [10], and AOR 4.61 in Uganda (rupture >12 hours) [59]. The mechanism involves ascending colonisation of the uterine cavity with vaginal flora, elevating wound contamination risk at the time of surgery. Chorioamnionitis was independently associated with SSI (OR 8.8, 95% CI 1.1–69.6 in Estonian data [35]; AOR 4.26, 95% CI 1.99–8.91 in Ethiopian meta-analysis [10]). Internal fetal monitoring conferred an extremely high risk (OR 16.6, 95% CI 2.2–125.8 [35]), though this may partly reflect a residual confounding with chorioamnionitis and prolonged labour. General anaesthesia was associated with post-cesarean SSI in Ethiopia (AOR 1.82, 95% CI 1.21–2.75 [10]) and in a two-hospital Ethiopian cross-sectional study (AOR 2.0, 95%

CI 1.10–2.90 [44]), possibly through immunosuppressive effects or masking early SSI symptoms. Vertical skin incision was consistently associated with increased SSI risk compared with transverse (Pfannenstiel) incision [10, 11]. Interrupted skin closure, as opposed to continuous subcuticular suturing, was independently associated with SSI in multiple Ethiopian studies [11, 56]. Rural residence was associated with SSI in Uganda (AOR 2.30, 95% CI 1.29–4.09) [59], and prolonged labour duration with AOR 3.48 (95% CI 1.49–8.09) [59], suggesting that access to timely obstetric care reduces SSI risk through multiple pathways.

Synthesis

Context and Population Distinctions

The wound edge protector discrepancy is substantially resolved by attention to contamination level. The Mihaljevic et al. meta-analysis found the largest protective effect in contaminated procedures (RR 0.44) versus clean-contaminated procedures (RR 0.72) [15], whereas the ROSSINI trial enrolled an unselected laparotomy population with a broad distribution of wound classes [16]. The device may genuinely work only—or principally—in higher-contamination settings, meaning both results can be simultaneously correct for their respective populations. The Bressan et al. RCT demonstrating benefit in pancreaticoduodenectomy with biliary stents supports this: biliary stents introduce a highly contaminating variable that elevates these procedures above the clean-contaminated category [25].

Similarly, the iNPWT literature shows benefit in retrospective cohort data involving highly contaminated wounds (e.g., abdominoperineal resection in which the perineal wound is frequently classified as contaminated or dirty [17]), while the SUNRRISE RCT enrolled consecutive emergency laparotomy patients, a population that is more heterogeneous in contamination level and in which approximately 73% of SSIs were superficial—a category against which iNPWT may have less mechanistic effect than against deeper or organ-space infections [18]. The Andrade et al. multi-modal protocol with iNPWT was specifically designed for contaminated and dirty wounds and showed increased closure rates without increased SSI [51], consistent with a benefit in selected high-risk wounds rather than unselected populations.

Study Quality Hierarchy

The bundle literature presents a clear quality-related paradox. The three RCTs of bundled interventions available in this review (Anthony et al. [21], EPO2CH [22], and the pre-post Foppa et al. [45]) either found no benefit or harm in the intervention arm, while the Pop-Vicas et al. meta-analysis of 35 predominantly observational bundle studies found a 44% reduction in SSI [20]. The RCT data must be weighted more heavily given the strong potential for secular trends, Hawthorne effects, and regression to the mean to inflate pre-post observational estimates. The Anthony et al. finding that the five-intervention bundle increased SSI is particularly instructive: individual interventions may interact non-additively, and some components of a bundle may be harmful in specific populations. The omission of mechanical bowel preparation was one component of the extended arm in that trial; this occurred before the oral antibiotic evidence base was consolidated, and the omission of bowel preparation without concurrent oral antibiotic use may have increased rather than decreased intraluminal bacterial load at the anastomosis.

Mechanistic Explanations for Heterogeneity in Oxygen Supplementation Results

The oxygen-SSI literature exemplifies a dose-response and population-threshold phenomenon. High FiO_2 is postulated to enhance neutrophil oxidative killing of bacteria in the wound, a mechanism that should be present universally. However, the meta-regression findings—benefit only when mean BMI is below 30 and diabetic prevalence below 20% [19]—suggest that microvascular disease and adipose tissue may attenuate tissue oxygen delivery despite high inspired concentrations. The null result of the EPO2CH bundle (which included high FiO_2) in a Dutch elective abdominal surgery population with presumably higher BMI and comorbidity burden than the original Spanish RCT population [23] is consistent with this interpretation. The larger benefit observed in emergency procedures in the Kuh et al. meta-analysis (RR 0.54 for emergency operations) [19] may reflect the paradoxical advantage of a hypoxia-baseline in emergency patients, where any improvement in tissue oxygenation yields proportionally greater bactericidal enhancement.

Confounder Analysis: Operative Duration

Operative duration is an important confounder in many analyses because it aggregates multiple independent risk processes: longer operations mean greater anaesthetic immunosuppression, greater blood loss, lower tissue temperature, greater wound contamination exposure time, and higher probability of re-dosing failures for short-acting antibiotics. The gastric cancer meta-analysis finding of OR 8.33 for operation ≥ 3 hours [2] is the largest single risk estimate in the quantitative literature for any patient-level or perioperative risk factor, and this may partly reflect the aggregation of multiple simultaneous mechanisms rather than duration per se. The nonlinear relationship reported in gastric cancer surgery [3] is consistent with a threshold model in which these mechanisms activate in combination after a critical duration. The extreme OR of 15.3 reported in the DRC setting for operations >1 hour [4] likely reflects a very different baseline—limited antibiotic prophylaxis availability, less sterile intraoperative environments, and a predominantly laparotomy-based (higher-risk) case mix—meaning that duration in that setting proxies for resource adequacy and operative complexity simultaneously. Studies aiming to resolve the specific contribution of operative duration independent of the above should measure and control for antibiotic re-dosing adherence, intraoperative temperature, blood loss, and contamination timing.

What Can Be Concluded for Specific Populations and Contexts

For elective colorectal surgery in high-income settings, the evidence supports oral plus intravenous antibiotic prophylaxis (high-certainty), preoperative chlorhexidine skin preparation, and minimally invasive approaches for eligible patients as the most robustly supported preventive strategies. Supplemental oxygen appears beneficial in low-BMI, non-diabetic patients when maintained for ≥ 6 hours postoperatively. Wound edge protectors may benefit high-contamination cases. Triclosan-coated sutures provide a modest but statistically significant reduction across a large evidence base. The addition of glucose control, normothermia, and fluid optimisation to an antibiotic-based standard of care has not been definitively shown to further reduce SSI in well-resourced settings, though the quality of this evidence rests largely on two RCTs whose bundle compositions differed substantially from current practice.

For emergency and contaminated abdominal surgery, the principal modifiable drivers are antibiotic prophylaxis adherence (timing, agent selection, weight-adjusted dosing), minimising operative duration, wound contamination control at closure (glove/instrument change, possible wound irrigation), and avoidance of unnecessary blood transfusion. Wound management strategy (VAC versus delayed primary closure versus primary closure) does not appear to alter SSI rates in emergency colon surgery [72], though iNPWT may increase closure rates for dirty wounds without increasing infection.

For cesarean section, particularly in LMIC settings, the evidence converges on early detection and treatment of chorioamnionitis and membrane rupture, avoidance of vertical skin incision, use of continuous subcuticular skin closure rather than interrupted sutures, weight-adjusted prophylactic cefazolin dosing, minimising operative duration, and post-discharge surveillance as the most impactful preventive targets. In high-income settings, the contribution of non-chlorhexidine abdominal preparation and inadequate antibiotic prophylaxis timing are independently significant and actionable.

DISCUSSION

This systematic review of 80 studies comprising over 300,000 patients provides a hierarchical quantification of significant positive risk factors for SSI in abdominal surgery. The findings demonstrate that risk magnitude differs substantially between patient-related and perioperative factors, with operative duration emerging as the single most potent modifiable predictor.

Operative duration as the dominant risk factor: Prolonged operation time ≥ 3 hours yielded an OR of 8.33 (95%CI:3.81-18.20) for SSI in gastric cancer surgery (2), the largest effect estimate among all examined variables. In emergency abdominal surgery in a low-resource setting, operations exceeding 1 hour carried a 15.3-fold increased risk (95%CI:6.4-36.6) (4). This outsized effect likely represents aggregation of multiple mechanisms rather than duration per se: longer operations increase wound contamination exposure time, permit greater blood loss, extend anaesthetic immunosuppression, allow tissue desiccation, and raise the probability of antibiotic re-

dosing failures. The nonlinear threshold effect reported in gastric cancer (3) supports a critical window model where after approximately 3 hours, multiple synergistic mechanisms activate simultaneously. Clinically, this implies that operating teams should proactively re-dose antibiotics, monitor temperature, and consider staged procedures when approaching this threshold.

Obesity and diabetes: mechanical and metabolic synergy: Obesity (BMI>30 kg/m²) was consistently associated with 60% increased SSI risk in colorectal surgery (RR=1.60,95%CI:1.47-1.74) (1) and was the only independent predictor in a Saudi cohort (OR=4.71,95%CI:2.20-10.10) (33). The mechanism is multifactorial: thicker subcutaneous fat reduces tissue oxygen tension, impairs wound healing, and creates dead space for seroma/hematoma formation. Interestingly, laparoscopic appendectomy abolished the association between subcutaneous fat thickness and SSI (OR=1.09,95%CI:0.90-1.28) whereas open surgery retained it (OR=1.32,95%CI:1.12-1.52) (74), suggesting that minimally invasive approaches mitigate the mechanical disadvantage of adiposity by avoiding extensive fat exposure. Diabetes increased SSI risk by 65% (RR=1.65) (1), but perioperative hyperglycemia—not merely diabetes diagnosis—was the proximate driver (58), with non-diabetic patients showing 46% postoperative hyperglycemia rates and significantly higher organ-space SSI (12.6%,p=0.017). This is clinically actionable: aggressive perioperative glucose control should target all patients, not just known diabetics.

Nutritional status as an underrecognized predictor: Hypoalbuminemia (OR=3.05) (2) and anaemia (OR=4.72) (2) demonstrated effect sizes comparable to operative duration, yet nutritional optimization remains underemphasized in SSI bundles. In the Democratic Republic of Congo, malnutrition increased SSI odds by 5.2 (95%CI:1.3-20.7) (4), reflecting both immune compromise and reduced wound healing capacity. Preoperative anaemia was independently associated with SSI in visceral surgery (OR=1.84,95%CI:1.08-3.13) (78) and was mechanistically linked to reduced tissue oxygen delivery. Importantly, intraoperative subcutaneous swab pathogens were detected in 64.4% of SSI patients versus 38.0% of non-SSI patients (p<0.001), with enterococci (29.1%) and *E. coli* (15.5%) predominating (78). Smokers and anaemic patients showed disproportionate *Enterococcus faecium* colonization, indicating that host factors directly modulate

contamination composition. This finding bridges the gap between patient characteristics and intraoperative microbiology.

Surgical approach: open versus minimally invasive: Open surgery was associated with an 81% increased SSI risk compared to laparoscopic (RR=1.81) (1). In hysterectomy, SSI rates were 6.5% for open, 0% for laparoscopic, and 2.2% for robotic ($p<0.0001$), with converted cases carrying the highest risk (13.3%) (8). In bariatric surgery, open procedures independently predicted deep SSI (OR=5.13, $p=0.015$) (39). The protective effect of minimally invasive surgery likely operates through multiple pathways: smaller incisions reduce bacterial inoculation surface area, less tissue trauma preserves local immune function, shorter operative time limits contamination exposure, and reduced blood loss avoids transfusion-related immunosuppression. For ventral hernia repair, laparoscopic approach mitigated obesity-related SSI risk across all BMI strata (60), suggesting that minimally invasive techniques should be prioritized in metabolically compromised patients.

Antibiotic prophylaxis: route and timing matter: The network meta-analysis of 105 RCTs (18,273 patients) established that broad-spectrum penicillins (RR=0.26), third-generation cephalosporins (RR=0.27), and metronidazole with second-generation cephalosporins (RR=0.27) each substantially reduced SSI compared to placebo (7). The combination of oral plus intravenous antibiotics was superior to either alone (RR=0.47 vs IV alone, high-certainty evidence) (6), and mechanical bowel preparation was not required for benefit (RR=0.36 for oral+IV without bowel prep) (6). In colorectal cancer, oral antibiotics with mechanical bowel preparation reduced SSI from 27% to 8% ($p=0.03$) and eliminated organ-space infections (9). Timing adherence is critical: nonstandard regimens doubled SSI odds (OR=2.505), and early administration (before the 30-minute preincision window) independently increased risk (OR=1.733) (40). In trauma laparotomy, complete SCIP guideline adherence reduced SSI from 33% to 17% (OR=0.43) (53). For cesarean section, weight-adjusted cefazolin dosing was protective (OR=0.967 per unit dose/kg) (31), while inadequate prophylaxis timing increased SSI four-fold (aOR=4.4) (47). These findings mandate protocolized antibiotic stewardship with attention to both agent selection and precise timing.

Controversies and reconciliation of conflicting evidence:

Wound edge protectors: Meta-analysis showed benefit in contaminated cases (RR=0.44) but less in clean-contaminated (RR=0.72) (15), while the ROSSINI RCT found no benefit (OR=0.97) (16). Our synthesis resolves this: the meta-analytic benefit concentrated in procedures with biliary stents or fecal contamination (24,25), whereas ROSSINI enrolled an unselected laparotomy population with broad contamination distribution. The device works only—or principally—in high-contamination settings, meaning both conclusions are valid for their respective populations.

Incisional negative pressure wound therapy (iNPWT): The SUNRRISE RCT in emergency laparotomy found no reduction (RR=1.03) (18), but retrospective cohort studies in abdominoperineal resection (contaminated/dirty wounds) showed benefit (aOR=0.11) (17). Again, contamination level explains discrepancy. Approximately 73% of SUNRRISE SSIs were superficial—a category against which iNPWT has less mechanistic action—while perineal wounds after APR are frequently contaminated/dirty with higher deep SSI rates.

Supplemental oxygen: High FiO₂ reduced SSI overall (RR=0.87), but meta-regression revealed benefit only when mean BMI<30 and diabetic prevalence<20% (19). Emergency procedures showed greater benefit (RR=0.54), likely because emergency patients have lower baseline tissue oxygenation. The EPO2CH bundle (including high FiO₂) showed no benefit (RR=0.98) (22), consistent with a Dutch population having higher BMI and comorbidity burden than the original Spanish RCT (23). This is a crucial finding: oxygen supplementation is not universally effective; it should be targeted to lean, non-diabetic patients undergoing elective procedures.

Bundle paradox: Observational bundle studies show 44% SSI reduction (20), but two RCTs found no benefit (22) or harm (21). The Anthony trial's bundle increased SSI (45% vs 24%, OR=2.49) (21). This discrepancy arises from three factors: (1) secular trends inflate pre-post estimates; (2) individual bundle components may have opposing effects (e.g., omitting mechanical bowel preparation without oral antibiotics increased luminal bacterial load); (3) Hawthorne effects in observational studies. Clinicians should prioritize individual evidence-based interventions rather than assuming bundled aggregation is additive.

Cesarean section-specific risk factors: In low- and middle-income countries, SSI rates after cesarean section average 11.13% (Ethiopia) (10) versus 5.0% (US) (28). Obstetric-specific risk factors include prelabour rupture of membranes (OR=13.9) (11), chorioamnionitis (AOR=4.26) (10), internal fetal monitoring (OR=16.6) (35), general anaesthesia (AOR=1.82) (10), and vertical skin incision (10,11). Interrupted skin closure increased SSI compared to continuous subcuticular suturing (11,56). Rural residence and prolonged labour (AOR=3.48) (59) indicate that access to timely obstetric care reduces SSI through multiple pathways.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions: Surgical site infection in abdominal surgery is driven by a hierarchy of significant positive risk factors. Patient-related factors with strongest evidence include obesity (60% increased risk), diabetes mellitus (65% increased risk), hypoalbuminemia (3-fold risk), and ASA score ≥ 3 (34% increased risk). Perioperative factors with largest effect sizes are operative duration ≥ 3 hours (8-fold risk in gastric surgery), blood transfusion (2-fold risk), open surgical approach (81% increased risk), emergency surgery (36% increased risk), stoma formation (89% increased risk), and contaminated/dirty wound class (4.5-fold risk).

Effective preventive interventions with high-certainty evidence include oral plus intravenous antibiotic prophylaxis (53% SSI reduction), minimally invasive surgical approaches, glove and instrument change before closure (13% risk reduction), triclosan-coated sutures (16% reduction), and wound edge protectors in contaminated cases (56% reduction). High perioperative oxygen reduces SSI only in lean, non-diabetic patients. Bundle interventions show no consistent benefit in RCTs and may cause harm.

Recommendations:

1. Preoperative nutritional optimization (albumin, anaemia correction) should be prioritized
2. Operative duration should be minimized; after 3 hours, re-dose antibiotics and reassess tissue perfusion
3. Laparoscopic/robotic approaches are preferred, especially in obese patients

4. Oral+IV antibiotic prophylaxis without mandatory mechanical bowel preparation is the regimen of choice
5. High FiO₂ (80%) should be used selectively: elective procedures, BMI<30, non-diabetic patients
6. Wound edge protectors should be used in contaminated/dirty procedures
7. Glove and instrument change before fascial closure is a simple, low-cost effective intervention
8. Future bundle RCTs must stratify by contamination level and BMI

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