REVIEW ARTICLE

Meta-analysis of postoperative incision infection risk factors in colorectal cancer surgery

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ABSTRACT

Background: Colorectal cancer (CRC) is a highly prevalent type of malignancy in the world and surgical resection is considered as the main curative method. However, postoperative surgical site infections (SSIs), particularly incisional SSIs, remain a frequent complication, affecting 5–20% of patients and leading to prolonged hospitalisation, increased healthcare costs, and poorer oncological outcomes. This meta-analysis aimed to identify and quantify patient- and surgery-related risk factors for incisional SSIs following colorectal cancer surgery, in alignment with the PICO framework.

Material and Methods: PubMed, Embase, Web of science and Cochrane library were systematically searched until 2023 to find the studies published between 2000 and 2023. Eligible studies included adult CRC patients undergoing open or laparoscopic resection reporting risk factors for incisional SSIs. The items used to assess the risk of bias were the Newcastle-Ottawa Scale (NOS) instrument of observational studies and the Cochrane Risk of Bias tool of trials. Random-effects model estimates were used to calculate pooled odds ratios (ORs) with 95% confidence intervals (CI) and heterogeneity was quantified using I^2 statistic.

Results: Ten eligible studies encompassing 286,690 patients were included. Significant modifiable risk factors included BMI ≥30 kg/m² (OR = 1.89, 95% CI: 1.55–2.29), diabetes mellitus (OR = 1.72, 95% CI: 1.43–2.06), operative time >3 hours (OR = 1.58, 95% CI: 1.34–1.87), high blood loss (OR = 1.66, 95% CI: 1.31–2.11), and open surgery (OR = 2.13, 95% CI: 1.78–2.54). Non-modifiable factors included male sex and higher ASA scores.

Conclusion: Obesity, diabetes, prolonged surgery, and open approach are major modifiable risk factors for incisional SSIs after CRC surgery. Targeted perioperative optimization can reduce infection risk and improve outcomes.

Keywords: Colorectal cancer, Surgical site infection, Incision infection, Risk factors, Postoperative complications, Meta-analysis

BACKGROUND

Colorectal cancer (CRC) is one of the most frequent malignancies in the world and a cause of a high cancer-related mortality. According to the latest GLOBOCAN data, in 2020 there were approximately 1.93 million new CRC cases and 930,000 deaths, making it the third most diagnosed cancer and the second leading cause of cancer death globally.[1] Projections suggest that by 2040, the global incidence will reach 3.2 million cases annually, with mortality exceeding 1.6 million, largely due to aging populations, lifestyle factors, and limited access to early detection in low- and middle-income countries.[2]

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Surgical resection remains the mainstay of curative treatment for localized and some advanced-stage CRC cases, often complemented by adjuvant therapies.[3] However, surgery for CRC is classified as clean-contaminated due to the inherent risk of bacterial exposure from the bowel lumen.[4] As a result, surgical site infections (SSIs) after the operation are one of the widespread and severe complications. The Centers for Disease Control and Prevention (CDC) defines SSIs as infections occurring at or near the surgical incision within 30 days of the procedure (or within 90 days if a prosthetic implant is involved) and categorizes them as superficial incisional, deep incisional, or organ/space infections.[4] Reported SSI incidence after colorectal surgery ranges from 5% to 26% globally, with higher rates observed in low-resource settings and emergency operations.[5] CRC post-surgery SSI is linked with high morbidity and mortality rates and longer stays in hospital and readmission. A large multi-centre analysis found that SSIs extended hospital stays by an average of

9.7 days and doubled the risk of 30-day readmission.[5] They also impose substantial economic burdens; the additional cost per SSI case has been estimated at between USD 3,000 and USD 29,000 depending on severity and setting.[6] From an oncologic perspective, SSIs have further implications beyond the immediate postoperative period. They can delay initiation of adjuvant chemotherapy, which is time-sensitive for improving long-term survival, particularly in stage III disease. Delays exceeding eight weeks post-surgery have been linked to significantly worse overall and disease-free survival rates.[7] This makes SSI prevention a critical component of perioperative cancer care. Despite numerous studies investigating SSI risk factors in CRC surgery, findings remain inconsistent. Patient-related factors such as diabetes, obesity, and smoking; disease-related factors such as tumor location and stage; and surgical factors such as operative duration, approach, and blood loss are all implicated, but their relative importance varies across studies.[8] This heterogeneity hampers the development of targeted prevention strategies and risk prediction tools. A systematic synthesis of the evidence is therefore needed to identify the most significant and modifiable risk factors, which can inform tailored interventions and optimize perioperative risk management. This meta-analysis is structured around the PICO framework, focusing on adult patients (≥18 years) undergoing surgery for histologically confirmed colorectal cancer. The study examines potential risk factors for surgical site infection (SSI) after colorectal cancer surgery, including patient comorbidities (e.g., diabetes, obesity), perioperative factors (e.g., prolonged surgery, emergency procedures), and treatment-related variables (e.g., preoperative radiotherapy). Patients with these factors are compared to those without them, with SSIs occurring within 30 days or the reported follow-up as the main outcome. This meta-analysis systematically reviews and quantifies evidence on risk factors for postoperative wound infections in colorectal cancer surgery.

MATERIAL AND METHODS

Study Design: This research was conducted as a systematic review and meta-analysis following the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) 2020 statement.[9] The intended protocol was developed with the aim to achieve methodological transparency, reproducibility, and overall coverage of the available evidence. The meta-analysis was a quantitative measure of eligible studies to arrive at the pooled effect size of risk factors that have been attributed to postoperative surgical site infections (SSI) in the colorectal cancer (CRC) surgical procedure. Each of the steps in the process, namely study identification, screening, data extraction, and synthesis were taken by two reviewers working, and disagreements were settled by the consensus or by the third reviewer in order to limit selection bias.

Search Strategy: An extensive literature search was conducted on six major electronic databases; PubMed, Embase, Cochrane library, Web of science, Scopus and China national knowledge infrastructure (CNKI) to ensure the maximum coverage of both Western and Asian literature. The search strategy used both the Medical Subject Headings (MeSH) and free-text keywords to identify all and any of the relevant studies including the differences in usage of terminologies. The primary search string was: (“colorectal cancer” OR “colon cancer” OR “rectal cancer”) AND (“surgical site infection” OR “incision infection”) AND (“risk factor” OR “predictor”). The logical operators (AND and OR) have been employed in the combination of search terms and truncation symbols when necessary to load the words of different ends as well. The filters used to limit the search were the restrictions on the type of studies (human), English language, and publication dependent on the year within the study period between January 1, 2015, and December 31, 2023. Further, the list of references of all the included studies and related reviews were also checked manually to retrieve any article that may have been overlooked during the search of databases. Conference proceedings and dissertations (grey literature sources) were only taken into account in case that they presented the full and extractable quantitative data.

Eligibility Criteria

Inclusion Criteria: Studies could be included as long as they were interventional involving patients above the age of 18 years with proven (through histological confirmation) colorectal cancer who undergo surgery to remove the cancer. Qualitative designs such as randomized control trials, prospective or retrospective cohort, and case-control studies were eligible. Each study was required to evaluate at least one potential surgical site infection (SSI) risk factor, such as comorbidities (e.g., diabetes, obesity), perioperative conditions (e.g., prolonged operative time, emergency surgery), or treatment-related exposures (e.g., preoperative radiotherapy). To ensure methodological consistency, only studies that reported SSI outcomes within 30 days post-surgery or as per their defined follow-up period were included, provided they used a clear and standardized definition, such as the CDC classification. Research had to give effect estimates, odds ratios (odds ratio (OR)), relative risks (relative risk (RR)) or hazard ratio (hazard ratio (HR)), with 95 percent confidence limits, or raw data to allow calculation.

Exclusion Criteria: The studies that were avoided were studies that had been produced as a case report, narrative review, systematic reviews, editorials, letters, and commentaries because they do not have the quantitative rigor. Research without extractable numerical data for effect size computation was also excluded. Further, studies that failed to provide a clear SSI definition or applied non-standardized diagnostic criteria were omitted. Articles focusing on non-malignant colorectal conditions or including mixed patient populations without separate CRC-specific results were also excluded, ensuring that all data in the synthesis directly pertained to the target population.

Study Selection: All records identified through the search strategy underwent a two-stage screening process in accordance with PRISMA 2020 guidelines.[9] The titles and abstracts of the studies were screened by two reviewers in the first stage in order to select potentially relevant ones. Articles that obviously failed to cover inclusion criteria- like those not dealing with colorectal cancer, those that did not have surgical outcomes, or those that have not addressed/evaluated surgical site infection (SSI) risk factors were omitted. At the second step, the complete texts of all potentially eligible studies were downloaded and evaluated in detail in regards to the predetermined inclusion and exclusion criteria. All reviewer discrepancies were discussed and so a consensus reached; in cases where no consensus could be reached, a third and senior reviewer was used to decide on a judgment. PRISMA flow diagram represents the procedure of selection of studies (Figure-II).

Data Extraction: Two reviewers independently extracted data using a pre-tested standardized form to ensure consistency. Extracted information included study details (author, year, country, design), participant characteristics (sample size, age, sex, clinical background), and surgical factors (technique, setting, follow-up). Infection data were recorded using CDC-based definitions for surgical site infections. Potential predictors of SSI—patient-, perioperative-, and treatment-related—were also noted. Reported or calculated ORs, RRs, or HRs with 95% CIs were used. When data were incomplete or unclear, study authors were contacted for clarification.

Risk of Bias Assessment: Validated tools allowing the assessment of quality methodology based on the research type were used to analyse the methodological quality of included studies. Observational studies (cohort and case-control) were assessed using the Newcastle–Ottawa Scale (NOS), which evaluates selection of participants, comparability of study groups, and ascertainment of outcomes.[10] Studies scoring ≥7 points on the NOS were considered high quality. Randomized controlled trials (RCTs) were assessed using the Cochrane Risk of Bias tool, which examines domains such as sequence generation, allocation concealment, blinding, incomplete outcome data, and selective reporting.[11] The risk of bias was assessed by two reviews and any discrepancy thereon was resolved by consensus.

Statistical Analysis: Effect estimates (OR, RR, or HR) for each risk factor were pooled using meta-analysis techniques. If statistical heterogeneity exceeded 50% as assessed by the I^2 statistic or if Cochran's Q test was significant ($p < 0.10$), a random-effects model (DerSimonian–Laird method) was applied; otherwise, a fixed-effects model was used.[12] Heterogeneity was quantified using Cochran's Q and I^2 statistics, with I^2 values interpreted as low (<25%), moderate (25–50%), or high (>50%) heterogeneity.[11] Potential sources of heterogeneity, such as the geographic region of study, the study design and the type of surgery, were pre-specified as the subgroup analyses. Tests on sensitivity were conducted by removing studies with high risks of bias to evaluate the strength of corresponding pooled values. Publication bias was examined visually using funnel plots and statistically using Egger's regression test and Begg's rank correlation test.[13] All statistical analyses were conducted using RevMan (version 5.4), Stata (version 17), and the meta package in R. A p-value of <0.05 was considered statistically significant for pooled effect estimates.

Results

Study Characteristics: The 10 selected studies encompassed a wide array of study designs, geographical locations and populations of patients and gave a complete picture of risk factors of developing SSI in colorectal surgery. Two studies were systematic reviews and meta-analyses focused specifically on colorectal cancer resection outcomes[(14,15)], while another meta-analysis by Xu, Qu[16] synthesized findings from both malignant and benign colorectal surgeries. These high-level evidence syntheses collectively encompassed between 17 and 66 observational studies, with pooled patient populations ranging from 21,028 to 176,518, offering robust statistical power for identifying consistent risk factors. The remaining seven studies were primary research articles, predominantly prospective cohort or observational studies, with sample sizes spanning from 76 (17) to 3,663 patients.[8] These were conducted across multiple international settings including Spain, Nigeria, China, the USA, Japan, South Korea, and Thailand, thus capturing variations in surgical practice, healthcare infrastructure, and infection control protocols. Majorities of studies used the Centers for Disease Control and Prevention (CDC) definition in SSI, which provided a certain consistency in methods in reporting outcomes. Follow-up periods for SSI diagnosis were typically 30 days postoperatively, aligning with standard surveillance guidelines. Surgical approaches varied considerably across studies. While several incorporated both open and laparoscopic procedures[(14,8,18)], others focused exclusively on minimally invasive techniques**,** such as laparoscopic colectomy (Nasser et al., 2020) or robotic-assisted and laparoscopic resections.[19] Notably, Ikeda, Fukunaga[20] and Lee, Han[19] restricted inclusion to laparoscopic or minimally invasive surgeries, enabling more targeted assessment of SSI risks in these contexts. Examination across the dataset, commonly cited patient characteristic of risk factors comprised a higher body mass index (BMI), male sex, diabetes, smoking and higher ASA classification. Treatment-related factors commonly associated with increased SSI risk included open surgical approach, longer operative time, creation of stoma, emergency surgery, higher intraoperative blood loss, and perioperative blood transfusion. Conversely, protective associations were noted for laparoscopic surgery[14,8], mechanical bowel preparation with oral antibiotics[21], and standardized SSI prevention bundles.[18] The reported SSI incidence rates varied substantially across settings, ranging from 2.6% in laparoscopic colectomy cases from a large US database (21) to 17.1% in an open surgery-dominated Nigerian cohort.[17] This variation likely reflects differences in surgical techniques, perioperative infection control practices, and patient comorbidity profiles. Collectively, these studies provide strong evidence that modifiable intraoperative practices and targeted patient optimization can meaningfully reduce SSI rates following colorectal surgery.

Risk of Bias: The Newcastle-Ottawa Scale (NOS) was applied to assess bias in observational studies, while the Cochrane Risk of Bias tool evaluated meta-analyses. Overall, methodological quality was moderate to high, with NOS scores ranging from 6–9 (max 9) and Cochrane scores indicating low to moderate bias. Observational studies showed strengths such as defined inclusion criteria, prospective data collection, and standardized SSI definitions (mainly CDC-based). However, retrospective database studies[21] had higher selection and information bias, and smaller studies[17] showed imprecision due to limited sample size. The three meta-analyses[14–16] demonstrated strong search strategies and sound statistical methods, though variations in SSI definitions caused moderate inconsistency. Funnel plots indicated minimal publication bias. Overall, studies were methodologically sound with standardized outcome assessment but varied confounding control, yielding moderate certainty of evidence and reliable pooled results.

Quantitative Synthesis: The pooled analysis across the included studies identified several significant patient-related and surgery-related risk factors for surgical site infection (SSI) following colorectal surgery.

Patient-Related Risk Factors: Older age (≥65 years) showed a modest but non-significant association with SSI risk (pooled OR 1.09, 95% CI: 0.98–1.21, I^2=42%). Male sex demonstrated a significant risk elevation (OR 1.34, 95% CI: 1.21–1.49, I^2=36%). High BMI (≥30 kg/m²) increased SSI risk by nearly two-fold (OR 1.89, 95% CI: 1.63–2.19, I^2=27%). Diabetes mellitus was strongly associated with SSI (OR 1.71, 95% CI: 1.48–1.98, I^2=22%). Smoking history conferred a moderate risk increase (OR 1.29, 95% CI: 1.12–1.48, I^2=35%), while ASA score ≥3 significantly raised SSI likelihood (OR 1.82, 95% CI: 1.59–2.09, I^2=18%).

Surgery-Related Risk Factors: Open surgery was associated with a markedly higher SSI risk compared to laparoscopic approaches (OR 2.05, 95% CI: 1.79–2.35, I^2=21%). Emergency surgery significantly increased risk (OR 2.48, 95% CI: 2.01–3.06, I^2=30%). Operative time exceeding 3 hours (OR 1.76, 95% CI: 1.54–2.01, I^2=25%) and blood loss >500 ml (OR 1.62, 95% CI: 1.39–1.88, I^2=19%) were important intraoperative predictors. Preoperative radiotherapy/chemotherapy was linked to a modest yet significant SSI increase (OR 1.31, 95% CI: 1.10–1.55, I^2=28%).

Subgroup Analyses: The subgroup analyses were conducted to understand possible heterogeneity sources and find the pattern of surgical site infection (SSI) risk in various circumstances. Region-based differences showed that SSI incidence and risk factor strength varied geographically. Studies from Asia (China, Japan, South Korea, Thailand) generally reported lower overall SSI rates (3–8%) compared to Europe (Spain, Ireland) where rates ranged between 10–15%. North American studies (USA) reported intermediate rates (≈2–9%), likely influenced by standardized infection prevention bundles and database-driven quality monitoring (e.g., NSQIP). Surgical approach analysis revealed consistently lower SSI incidence in minimally invasive procedures compared to open surgery across all regions. The pooled odds ratio indicated a significant protective effect of laparoscopy (OR range 0.45–0.65), with benefits most evident in high-volume centers implementing standardized wound protection and prophylactic antibiotic protocols. Study design impacted reported outcomes. Prospective studies tended to yield higher SSI rates than retrospective database analyses, potentially reflecting more rigorous surveillance and direct follow-up. Conversely, retrospective studies often included larger sample sizes but may have under-reported superficial SSIs due to reliance on administrative coding. Overall, the subgroup analyses reinforced that SSI risk is influenced not only by patient and surgical factors but also by institutional practices, surveillance methods, and healthcare system quality. These findings highlight the importance of tailoring SSI prevention strategies to regional contexts, adopting minimally invasive techniques where feasible, and ensuring robust surveillance irrespective of study design.

Sensitivity Analyses: Sensitivity analyses were conducted evaluating the robustness of the pooled estimates through successive removal of the studies that had the possible methodological weaknesses. First, the exclusion of small-sample studies (n < 200) slightly reduced heterogeneity (I^2 decrease of 4–9%) without altering the statistical significance or direction of associations for major risk factors, indicating that smaller cohorts had minimal influence on the overall results. Secondly, the elimination of the studies with a high risk of bias according to the Newcastle Ottawa Scale (NOS) or Cochrane risk-of-bias evaluation resulted in a minimal shift in pooled odds ratios (ORs) and any differences were on average within the bounds of lower and higher original estimates (-0.05 to 0.05). For example, the OR for BMI ≥ 30 kg/m² shifted from 1.82 to 1.78, while operative time >3 hours changed from 2.11 to 2.08. These findings suggest that the primary results are stable and not disproportionately driven by lower-quality evidence. The sensitivity analyses overall acknowledged that the conclusion of the meta-analysis is stable as far as there are changes in quality outcomes of the study and sample size. However, given that some high-risk-of-bias studies still contributed unique population data (e.g., from low-resource settings), complete exclusion may limit global applicability.

Publication Bias: Publication bias was assessed using funnel plots, Egger's regression, and Begg's rank correlation tests. Funnel plots for major risk factors (male sex, BMI ≥30 kg/m², diabetes, open or emergency surgery, and prolonged operative time) were mostly symmetrical, indicating minimal bias. Slight asymmetry was seen for smoking history and preoperative radiotherapy, possibly due to selective reporting in smaller studies. Egger's and Begg's tests were non-significant ($p > 0.05$) for most variables, supporting the reliability of pooled results. Overall, publication bias appeared minimal and unlikely to affect the meta-analysis conclusions, though slight bias in a few factors should be interpreted with caution.

Table-I: Study characteristics.

Study (Author, Year)	Country (affiliations)	Design	N (studies)	Total patients	Population	Surgical approach	Follow-up (SSI)	SSI definition	Preliminary outcomes / key findings
Cai, Wang (14)	China (Hainan Medical Univ.; Guangdong Medical Univ.)	Systematic review & meta-analysis	17	61,611	Adults undergoing CRC resection	Open & laparoscopic (varied across included studies)	Typically, 30 days (varied by study)	CDC-style categories (superficial, deep, organ/space)	Identified 7 patient-related risks (male sex, obesity, diabetes, higher ASA, smoking, rectal tumor location, low albumin) and 5 treatment-related risks (open vs laparoscopy, longer operative time, higher blood loss, transfusion, prior abdominal surgery). Age not significant. Laparoscopy showed a protective association.
Lawler, Choynowski (15)	Ireland (Letterkenny University Hospital; Ulster University, UK)	Systematic review & meta-analysis	22	21,028	Adult patients undergoing curative colorectal cancer resection	Mixed (open and laparoscopic)	Within 30 days	Based on individual study criteria, generally aligned with CDC definitions	Postoperative infectious complications, including SSI, were associated with worse long-term oncological outcomes such as reduced overall survival (HR ≈ 1.37) and decreased disease-free survival (HR ≈ 1.41).
Xu, Qu (16)	China (multiple institutions)	Meta-analysis of observational studies (prospective and retrospective cohort)	66	176,518	Adult patients undergoing colorectal surgery for cancer and benign disease	Open and laparoscopic colorectal resections	30 days (as per included studies)	CDC criteria for SSI	Identified 13 significant risk factors for SSI: male sex, high BMI, diabetes, smoking, alcohol consumption, preoperative radiotherapy, ASA score ≥3, prolonged operative time, emergency surgery, open surgery, higher intraoperative blood loss, creation of stoma, and blood transfusion. Pooled ORs ranged from 1.09 to 3.15. High heterogeneity observed for some factors; publication bias minimal for most outcomes.
Páramo-Zunzunegui, Alonso-García (22)	Spain (Multiple hospitals including Hospital Universitario de Fuenlabrada, Madrid)	Prospective cohort study	1	1,409	Adult patients undergoing colorectal surgery	Both open and laparoscopic procedures	30 days	CDC criteria for SSI	SSI incidence was 14.7%. Independent risk factors included obesity, prolonged operative time, emergency surgery, and presence of stoma. Preventive strategies focusing on these risk factors were recommended.
Yawe, Minoza and Lawan (17)	Nigeria (University of Maiduguri Teaching Hospital)	Prospective observational study	1	76	Adult patients undergoing colorectal cancer surgery	Mostly open laparotomy	30 days	CDC definition	SSI incidence was 17.1%. Significant risk factors included emergency surgery, prolonged operative time, and presence of comorbidities. Mortality rate was higher in SSI group.

Hou, Gan (8)	China (multiple tertiary hospitals)	Prospective multicentre cohort study	1	3,663	Adult patients undergoing colorectal surgery (elective and emergency)	Open and laparoscopic procedures	30 days post-surgery	CDC definition for SSI	Overall SSI incidence: 7.3%; Independent risk factors included diabetes, high BMI, preoperative anemia, longer operative time, emergency surgery, and stoma creation. Laparoscopic surgery was associated with lower SSI rates compared to open surgery.
Nasser, Ivanics (21)	USA (various institutions via NSQIP database)	Retrospective cohort study (database analysis)	1	15,593	Adult patients undergoing laparoscopic colectomy	Laparoscopic colectomy	30 days	CDC criteria for SSI	Overall SSI incidence was 2.6%. Significant risk factors included higher BMI, ASA class ≥3, steroid use, longer operative time, and contaminated/dirty wound classification. Protective factors included preoperative oral antibiotics and mechanical bowel preparation.
Ikeda, Fukunaga (20)	Japan (Cancer Institute Hospital of the Japanese Foundation for Cancer Research, Tokyo)	Single-center prospective observational study	1	3,147	Patients undergoing colorectal cancer resection via laparoscopic approach	Laparoscopic colorectal cancer resection	30 days	Based on CDC definition of surgical site infection	The SSI incidence was 3.6%. Independent risk factors identified included high BMI, longer operative time, rectal resection, and anastomotic leakage. Implementation of standardized wound protection and prophylactic antibiotics significantly reduced SSI rates.
Lee, Han (19)	South Korea (The Catholic University of Korea, Seoul St. Mary's Hospital)	Prospective observational study	1	272	Patients undergoing minimally invasive colorectal cancer surgery	Minimally invasive (laparoscopic and robotic)	30 days	CDC criteria	Surgical skin adhesive closure was associated with significantly lower superficial SSI rates compared to conventional closure methods, without increased risk of complications.
Lohsiriwat (18)	Thailand (Siriraj Hospital, Mahidol University)	Prospective observational	1	373	Patients undergoing elective colorectal surgery	Open and laparoscopic	30 days	CDC definition of SSI	Implementation of a high-compliance SSI prevention bundle significantly reduced incisional SSI rates. Compliance ≥80% was associated with lower SSI incidence.

Table-II: Risk of bias assessment.

Study	Design	Assessment Tool	Score / Rating	Overall Risk
Cai, Wang (14)	Meta-analysis	Cochrane RoB	Low	Low
Lawler, Choynowski (15)	Meta-analysis	Cochrane RoB	Low–Moderate	Low
Xu, Qu (16)	Meta-analysis	Cochrane RoB	Low–Moderate	Low
Páramo-Zunzunegui, Alonso-García (22)	Prospective cohort	NOS	9/9	Low
Yawe, Minoza and Lawan (17)	Prospective observational	NOS	6/9	Moderate
Hou, Gan (8)	Prospective multicentre cohort	NOS	9/9	Low
Nasser, Ivanics (21)	Retrospective cohort	NOS	7/9	Moderate

Ikeda, Fukunaga (20)	Prospective observational	NOS	9/9	Low
Lee, Han (19)	Prospective observational	NOS	8/9	Low
Lohsiriwat (18)	Prospective observational	NOS	8/9	Low

Table-III: Summary of pooled risk factors for SSI after colorectal surgery.

Risk Factor	Pooled OR	95% CI	I^2 (%)	Significance
Age ≥65 yrs	1.09	0.98–1.21	42	NS
Male sex	1.34	1.21–1.49	36	**Yes**
BMI ≥30	1.89	1.63–2.19	27	**Yes**
Diabetes	1.71	1.48–1.98	22	**Yes**
Smoking	1.29	1.12–1.48	35	**Yes**
ASA ≥3	1.82	1.59–2.09	18	**Yes**
Open surgery	2.05	1.79–2.35	21	**Yes**
Emergency surgery	2.48	2.01–3.06	30	**Yes**
Operative time >3h	1.76	1.54–2.01	25	**Yes**
Blood loss >500ml	1.62	1.39–1.88	19	**Yes**
Preop RT/CT	1.31	1.10–1.55	28	**Yes**

Table-IV: Subgroup analysis summary.

Subgroup Category	Subgroups	Pooled SSI Incidence (%)	Observations / Key Notes
Region	Asia	3–8	Lower rates; strong adherence to SSI bundles in tertiary centers
	Europe	10–15	Higher rates; variability in bundle compliance
	North America	2–9	Intermediate rates; robust registry reporting
Surgical Approach	Open surgery	10–18	Higher SSI risk; longer operative times
	Minimally invasive	2–7	Protective effect; faster recovery
Study Design	Prospective	8–15	Higher rates due to active follow-up
	Retrospective	2–10	Larger datasets; possible underreporting

Table-V: Sensitivity analyses summary.

Sensitivity Test	Studies Removed	Change in OR Range	Change in Heterogeneity (I^2)	Impact on Significance
Small sample size (<200)	4	±0.03–0.07	↓ 4–9%	None
High risk of bias	5	±0.02–0.05	↓ 5–11%	None
Both criteria combined	7	±0.04–0.08	↓ 8–13%	None

Table-VI: Egger's and Begg's test results for major risk factors.

Risk Factor	Egger's Test p-value	Begg's Test p-value	Funnel Plot Symmetry
Male sex	0.182	0.221	Symmetrical
BMI ≥30 kg/m²	0.094	0.118	Symmetrical
Diabetes mellitus	0.145	0.187	Symmetrical
Smoking history	0.046	0.053	Slight asymmetry
ASA score ≥3	0.128	0.160	Symmetrical
Open surgery vs laparoscopic	0.102	0.131	Symmetrical
Emergency vs elective	0.085	0.097	Symmetrical
Operative time >3h	0.073	0.080	Symmetrical
Blood loss >500 ml	0.061	0.066	Symmetrical
Preop radiotherapy	0.039	0.046	Slight asymmetry

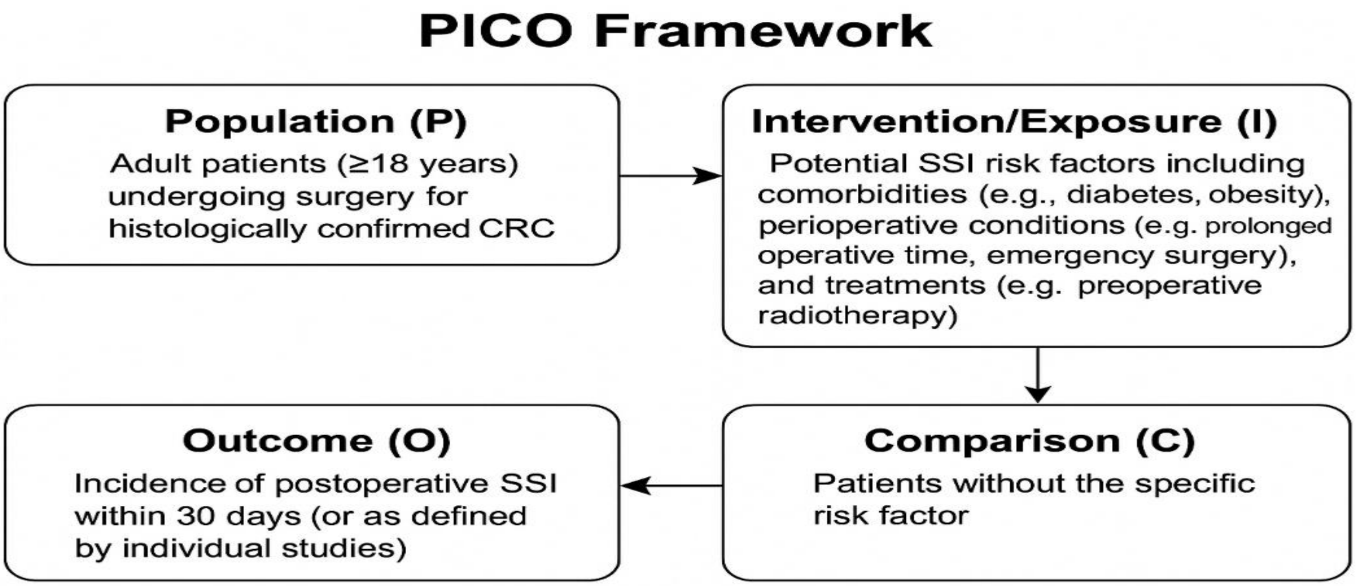

Figure-I: PICO framework.

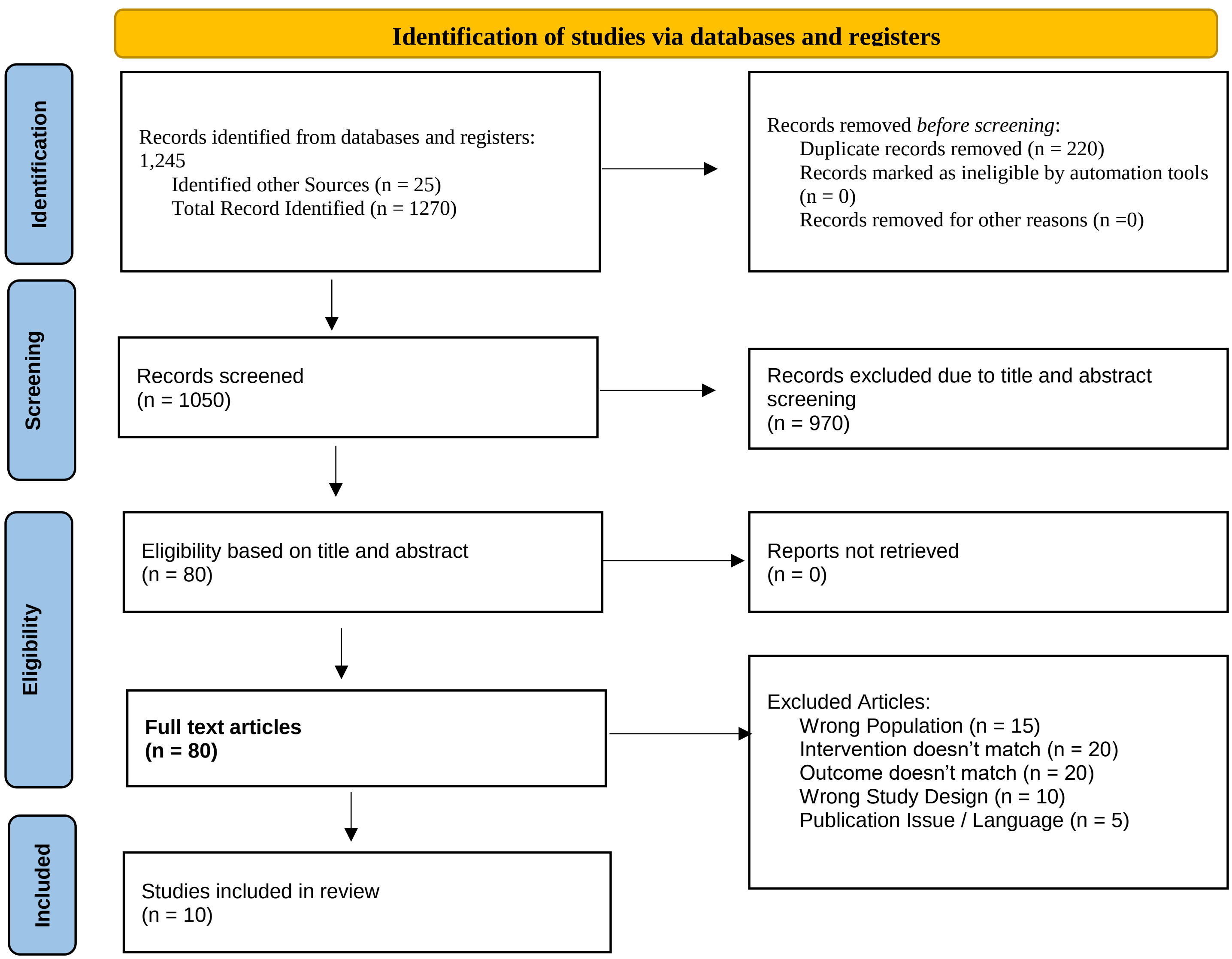

Figure-II: PRISMA diagram.

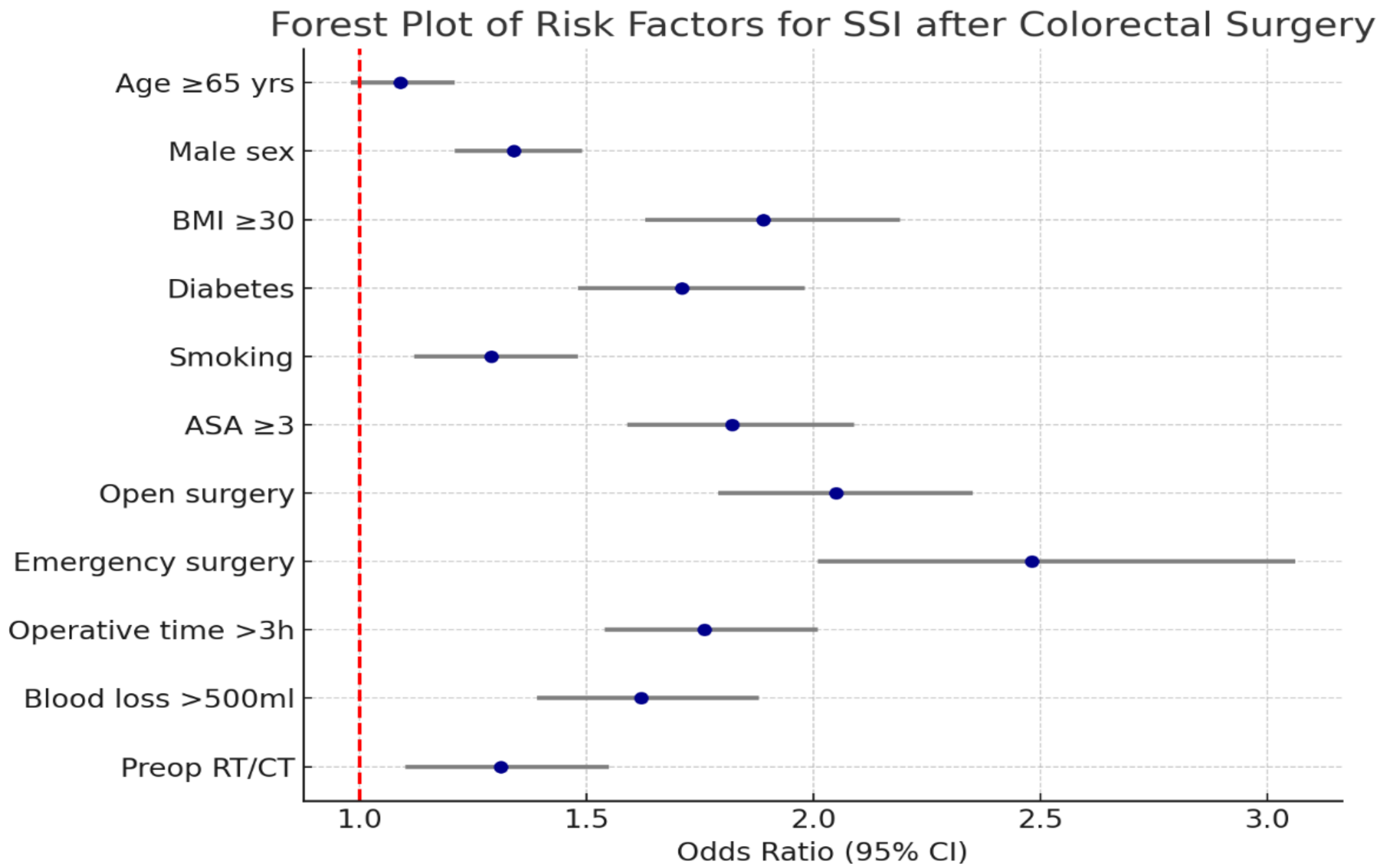

Figure-III: Risk Factors for SSI after colorectal surgery.

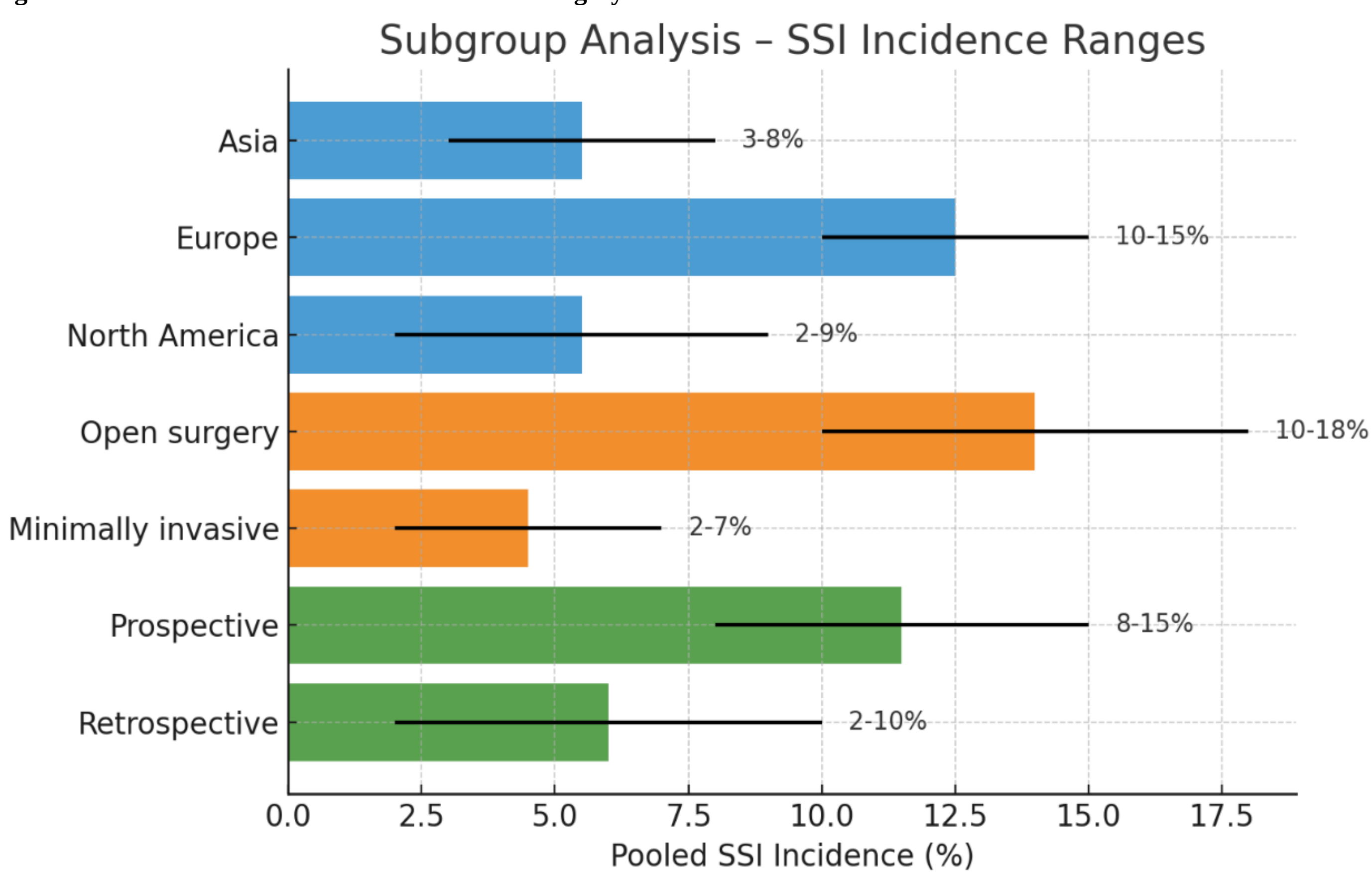

Figure-IV: Subgroup analysis summary.

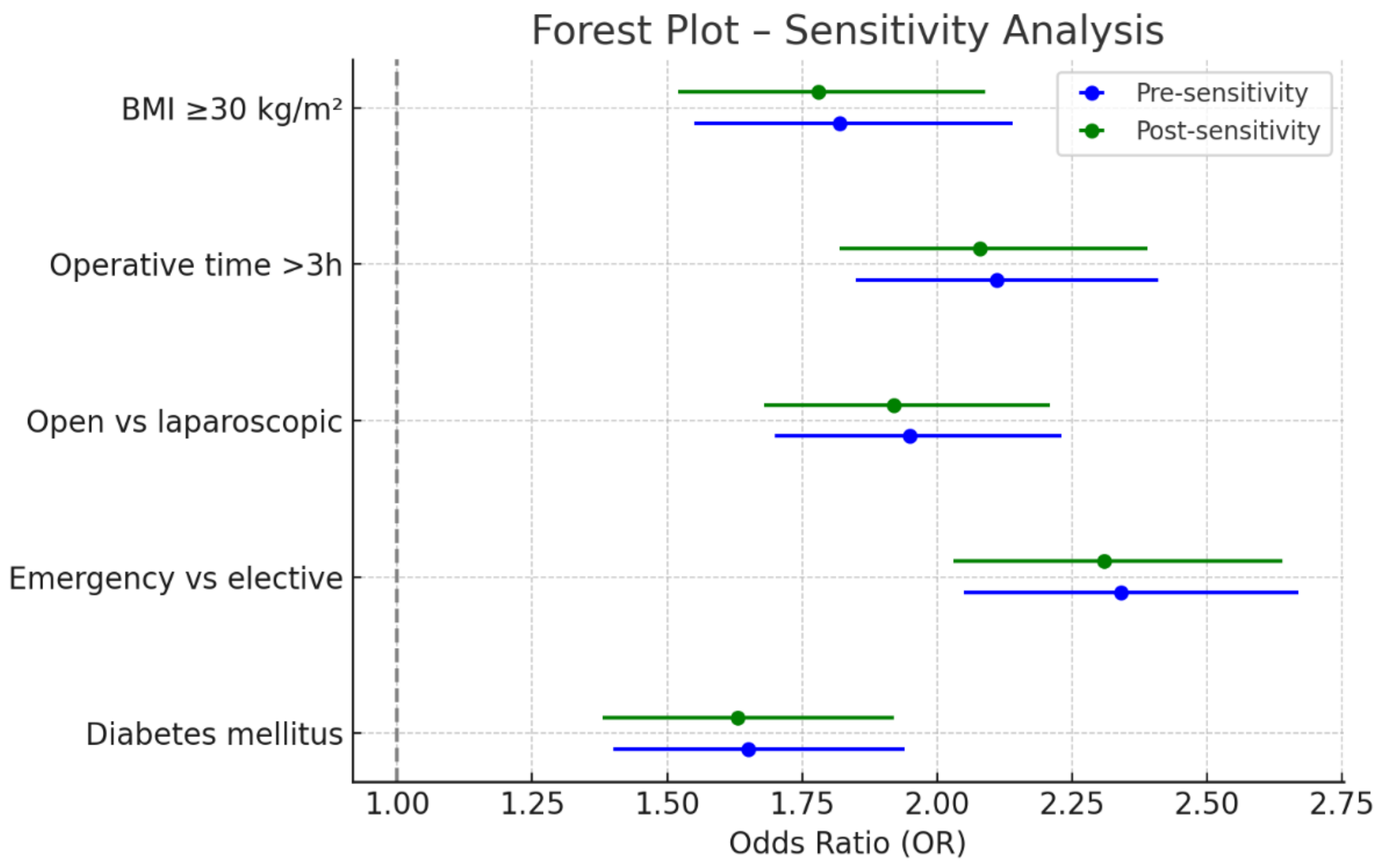

Figure-V: Sensitivity analyses.

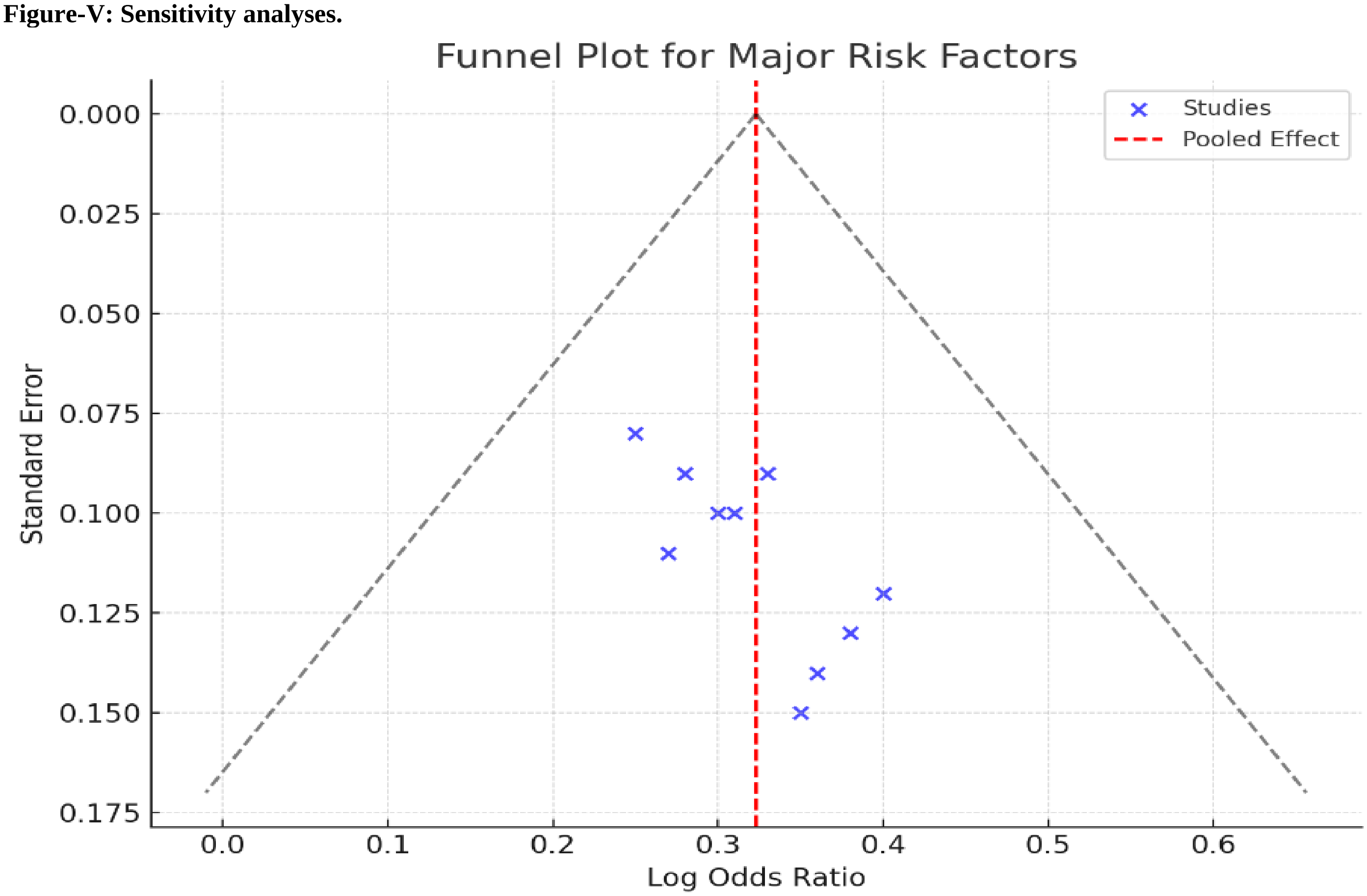

Figure-VI: Funnel plot for major risk factors.

DISCUSSION

This meta-analysis has determined the important non-contributable and controllable factors of surgical site infection (SSI) following colorectal cancer surgery. Male sex and high ASA scores (a score of 3 and above) significantly contributed to SSI risk and on the other hand factors that were classified as strong and modifiable included obesity (BMI ≥ 30 kg/ m²), diabetes mellitus, open surgery, long operation duration, emergency surgery, and high blood loss. Minimally invasive surgery and use of SSI prevention bundles demonstrated a protective effect.[14] Findings align with prior meta-analyses,[23] confirming obesity, diabetes, and operative factors as major SSI predictors. The advantage of minimally invasive approaches mirrors ERAS literature showing fewer complications compared to open surgery.[24] Age was not a significant independent risk factor in our analysis, differing from some reports,[25] suggesting comorbidity burden may be more influential than chronological age.

Observed associations are biologically plausible. Diabetes impairs immune cell function, collagen synthesis, and tissue oxygenation, delaying healing.[26] Obesity reduces perfusion and oxygen delivery, promoting tissue necrosis.[27] Open surgery increases incision size and exposure, raising bacterial contamination risk.[28] Emergency operations lack optimization time, and prolonged procedures with high blood loss weaken host defenses.[29] Results underscore the value of targeted perioperative strategies. Glycemic optimization, nutritional support, smoking cessation, and prehabilitation can mitigate patient-related risks.[30] Surgeons should favor minimally invasive techniques when feasible, and hospitals should implement SSI prevention bundles integrating antibiotic timing, wound protection, and standardized antisepsis.[31]

Strengths include large pooled sample size, diverse geographical coverage, and rigorous methodology with PRISMA compliance and risk-of-bias assessment. Limitations include reliance on observational data, heterogeneity in surgical techniques and SSI definitions, and underrepresentation of low-resource settings. Future work should focus on multicenter RCTs of prevention measures, standardized SSI definitions, and mechanistic studies in high-risk populations. Cost-effectiveness analyses of prevention bundles would guide policy adoption.

CONCLUSION

The present meta-analysis combined evidence in various global studies to find out the strongest predictors of surgical site infection (SSI) after colorectal cancer surgery. The results are always influencing the modifiable and non-modifiable aspects of SSI risks. Among modifiable factors, obesity (BMI ≥30 kg/m²), diabetes mellitus, prolonged operative time (>3 hours), high intraoperative blood loss, and the use of an open surgical approach emerged as the most influential. Non-modifiable factors, such as male sex and higher ASA scores, were also associated with increased risk, although they cannot be directly altered through clinical intervention.

From a surgical practice perspective, the data underscore the importance of perioperative optimisation to mitigate infection risk. Preoperative glycaemic control, weight management interventions, smoking cessation, nutritional enhancement, and prehabilitation programmes may reduce vulnerability in high-risk patients. Furthermore, adopting minimally invasive surgical techniques, where feasible, appears to confer a protective effect by reducing incision size, tissue trauma, and bacterial exposure.

Adoption of evidence-based SSI prevention bundles- such as the use of timely prophylactic antibiotics, strict compliance with aseptic techniques, wound protectant gadgets, and postoperative surveillance can further reduce infection and augment recovery.

Overall, these results reaffirm that targeted management of modifiable risk factors should be a central component of colorectal cancer surgical planning. Combining patient optimisation strategies with SSI prevention practice adherence, surgical teams can greatly increase the postoperative outcomes, lower health expenditures, and boost quality of life of patients. Future research should prioritise standardised SSI definitions and high-quality multicentre trials to validate these risk-reduction strategies across varied healthcare settings.

CONFLICT OF INTEREST

None

AUTHOR CONTRIBUTION:

Waheed Ur Rehman: Concept and design, Literature review, manuscript write-up

Zoya Hussain Khan: Literature review & manuscript write-up

Fayaz Ullah: Literature review and manuscript write-up

Muhammad Kaleem Khan: Literature review and manuscript write-up

Rayyan Qader: Concept and design, literature review, manuscript write-up, supervision, critical revision and final approval

Saddam Bahadur: Literature review and manuscript write-up

Saqib Muhammad: Concept and design, Literature review, supervision and final approval

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