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Original Research Article

Predictors of Postoperative Surgical Site Infections Following Major Elective General Surgical Procedures

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Abstract

Background: Surgical site infections (SSIs) represent a significant burden on healthcare systems worldwide, contributing to increased morbidity, mortality, prolonged hospitalization, and elevated healthcare costs. Identifying modifiable and non-modifiable risk factors for SSI development is essential for implementing targeted prevention strategies in surgical patients.

Methods: This prospective observational cohort study was conducted at a tertiary care teaching hospital. A total of 486 consecutive patients undergoing major elective general surgical procedures were enrolled. Demographic, clinical, operative, and postoperative variables were collected and analyzed. SSI was diagnosed according to Centers for Disease Control and Prevention criteria within 30 days postoperatively. Univariate and multivariate logistic regression analyses were performed to identify independent predictors of SSI.

Results: The overall SSI incidence was 12.8% (62/486). Superficial incisional SSI was most common (54.8%), followed by deep incisional (29.0%) and organ/space infections (16.1%). Multivariate analysis identified diabetes mellitus (OR=2.84, 95% CI: 1.52-5.31, p=0.001), obesity with BMI ≥30 kg/m² (OR=2.46, 95% CI: 1.28-4.72, p=0.007), prolonged operative time >180 minutes (OR=3.12, 95% CI: 1.68-5.79, p<0.001), contaminated/dirty wound classification (OR=4.28, 95% CI: 2.14-8.56, p<0.001), and ASA score ≥III (OR=2.18, 95% CI: 1.14-4.17, p=0.018) as independent predictors of SSI. Patients with SSI had significantly longer hospital stays (14.6±5.8 vs. 6.2±2.4 days, p<0.001).

Conclusion: Multiple patient-related and procedure-related factors significantly predict SSI following major elective general surgery. Targeted interventions addressing modifiable risk factors, particularly glycemic control and operative efficiency, may reduce SSI incidence and improve surgical outcomes.

Keywords: Surgical Site Infection, Risk Factors, General Surgery, Postoperative Complications, Wound Infection, Predictors.

Introduction

Surgical site infections remain among the most prevalent healthcare-associated infections worldwide, affecting approximately 2-5% of patients undergoing inpatient surgical procedures and up to 20% of patients undergoing abdominal surgery [1]. These infections impose a substantial burden on patients and healthcare systems, resulting in significant morbidity, increased mortality, prolonged hospitalization, hospital readmissions, and considerable financial costs [2].

In the United States alone, SSIs account for approximately 20% of all healthcare-associated infections and contribute to an estimated $3.3 billion in additional healthcare expenditures annually [3]. The pathogenesis of SSI involves complex interactions between microbial contamination, patient-related factors, and procedure-related variables [4].

The most common causative organisms include Staphylococcus aureus, coagulase-negative staphylococci, Enterococcus species, and Escherichia coli, with increasing prevalence of multidrug-resistant organisms presenting additional therapeutic challenges [5]. Understanding the epidemiology and risk factors for SSI is fundamental to developing effective prevention strategies. Numerous studies have investigated risk factors for SSI across various surgical specialties. The National Nosocomial Infections Surveillance (NNIS) risk index, incorporating wound classification, ASA score, and operative duration, has been widely utilized for risk stratification [6]. However, this index may not fully capture the complexity of SSI risk in contemporary surgical practice, particularly with advances in minimally invasive techniques, antimicrobial prophylaxis protocols, and perioperative care bundles [7].

Patient-related factors including diabetes mellitus, obesity, smoking, malnutrition, immunosuppression, and advanced age have been consistently associated with increased SSI risk [8]. Diabetes mellitus, affecting over 400 million individuals globally, impairs wound healing and immune function, rendering diabetic patients particularly susceptible to postoperative infections [9]. Obesity, another increasingly prevalent condition, is associated with technical surgical challenges, reduced tissue oxygenation, and altered pharmacokinetics of prophylactic antibiotics [10].

Procedure-related factors including operative duration, wound classification, emergency versus elective surgery, surgical technique, and perioperative antibiotic administration timing significantly influence SSI development [11]. Prolonged operative time increases the duration of tissue exposure, potential for contamination, and cumulative tissue trauma [12]. Additionally, intraoperative hypothermia, hyperglycemia, and hypoxia have been identified as modifiable risk factors amenable to targeted interventions [13].

Despite extensive research, significant variability exists in SSI rates across institutions, geographic regions, and surgical procedures, reflecting differences in patient populations, surveillance methodologies, and prevention practices [14]. Furthermore, many studies have focused on specific surgical procedures or patient populations, limiting the generalizability of findings to broader general surgical practice [15].

The implementation of evidence-based SSI prevention bundles, incorporating elements such as appropriate antibiotic prophylaxis, skin preparation, normothermia maintenance, and glycemic control, has demonstrated efficacy in reducing infection rates [16]. However, optimal risk stratification remains essential for targeting prevention efforts toward highest-risk patients and procedures.

A comprehensive understanding of SSI predictors specific to major elective general surgical procedures in contemporary practice is needed to inform institutional quality improvement initiatives and personalized prevention strategies. The aim of this study was to identify patient-related and procedure-related predictors of surgical site infections following major elective general surgical procedures and to quantify the impact of SSI on postoperative outcomes.

Materials and Methods

Study Design and Setting: This prospective observational cohort study was conducted at the Department of General Surgery of a tertiary care teaching hospital.

Study Population: Consecutive adult patients (≥18 years) undergoing major elective general surgical procedures were eligible for inclusion. Major surgical procedures were defined as operations requiring general or regional anesthesia with an anticipated duration exceeding 60 minutes and involving incision of skin and underlying tissues. Procedures included elective colorectal resections, hepatobiliary surgery, and gastric surgery, hernia repairs with mesh placement, small bowel resections, and major soft tissue procedures.

Exclusion criteria included: emergency surgical procedures, minimally invasive/laparoscopic procedures converted to open surgery, patients with active infection at the surgical site preoperatively, immunocompromised patients (HIV/AIDS with CD4 count <200 cells/μL, active chemotherapy within 30 days, chronic immunosuppressive therapy), patients with incomplete medical records or loss to follow-up within 30 days, and refusal to participate.

Sample Size Calculation: Based on an anticipated SSI rate of 12% and the desire to evaluate approximately 10 potential predictor variables in multivariate analysis, a minimum sample size of 420 patients was calculated using the rule of 10 events per variable. Accounting for a 15% dropout or incomplete data rate, a target enrollment of 490 patients was established.

Data Collection: A standardized data collection form was developed and piloted prior to study initiation. Data were collected prospectively by trained surgical residents and research coordinators. Variables were categorized into four domains:

Demographic Variables: Age, sex, body mass index (BMI), smoking status (current, former, never), and alcohol consumption.

Clinical Variables: Diabetes mellitus (defined as HbA1c ≥6.5% or use of antidiabetic medications), hypertension, chronic kidney disease, chronic liver disease, chronic obstructive pulmonary disease, coronary artery disease, malignancy, preoperative albumin level, preoperative hemoglobin level, and ASA physical status classification.

Operative Variables: Type of surgical procedure, wound classification (clean, clean-contaminated, contaminated, dirty), operative duration, estimated blood loss, blood transfusion requirement, prophylactic antibiotic administration (timing and appropriateness), skin preparation method, use of surgical drains, and surgeon experience level (attending versus resident as primary surgeon).

Postoperative Variables: SSI occurrence within 30 days, type of SSI (superficial incisional, deep incisional, organ/space), time to SSI diagnosis, causative organisms, length of hospital stay, intensive care unit admission, reoperation requirement, and 30-day mortality.

Definition of Surgical Site Infection: SSI was diagnosed according to the Centers for Disease Control and Prevention (CDC) National Healthcare Safety Network criteria. Superficial incisional SSI involved only skin or subcutaneous tissue within 30 days postoperatively with at least one of the following: purulent drainage, organisms isolated from culture, pain/tenderness/ swelling/redness, or deliberate opening of wound by surgeon. Deep incisional SSI involved deep soft tissues with purulent drainage, spontaneous dehiscence or deliberate opening with fever or localized pain, or abscess detected on imaging or direct examination. Organ/space SSI involved any anatomic site other than the incision that was opened or manipulated during the procedure.

Surveillance Methodology: All patients were examined daily during hospitalization for signs of wound infection. Wound assessments were performed using a standardized checklist evaluating erythema, warmth, drainage, dehiscence, and induration. Following discharge, patients were contacted by telephone at 15 and 30 days postoperatively using a structured questionnaire. Patients reporting symptoms suggestive of SSI were evaluated in the outpatient clinic. Medical records were reviewed to capture any emergency department visits or readmissions.

Statistical Analysis: Data were analyzed using IBM SPSS Statistics version 27.0 and R version 4.2.0. Continuous variables were expressed as mean ± standard deviation or median with interquartile range as appropriate based on distribution assessed by Shapiro-Wilk test. Categorical variables were expressed as frequencies and percentages.

Univariate analysis comparing patients with and without SSI was performed using independent samples t-test or Mann-Whitney U test for continuous variables and chi-square test or Fisher's exact test for categorical variables. Variables with $p<0.20$ in univariate analysis were entered into multivariate logistic regression analysis using backward stepwise selection. Results were expressed as odds ratios with 95% confidence intervals. Model performance was assessed using the Hosmer-Lemeshow goodness-of-fit test and area under the receiver operating characteristic curve (AUC-ROC). A two-tailed p-value <0.05 was considered statistically significant.

Results

Patient Enrollment and Baseline Characteristics: During the study period, 542 patients were assessed for eligibility. Fifty-six patients were excluded due to emergency surgery (n=18), conversion from laparoscopic approach (n=12), preoperative infection (n=8), immunocompromised status (n=7), loss to follow-up (n=6), and refusal to participate (n=5). The final analysis included 486 patients. The mean age was 56.8±14.2 years, and 278 (57.2%) were male. The mean BMI was 27.4±5.6 kg/m². The most common comorbidities were hypertension (42.4%), diabetes mellitus (28.6%), and current smoking (22.4%). Table 1 presents demographic and clinical characteristics stratified by SSI status.

Table 1: Demographic and Clinical Characteristics of Study Population

Variable	Total (n=486)	SSI (n=62)	No SSI (n=424)	p-value
Demographics				
Age (years), mean±SD	56.8±14.2	61.4±12.8	56.1±14.3	0.006*
Male sex, n (%)	278 (57.2)	38 (61.3)	240 (56.6)	0.484
BMI (kg/m²), mean±SD	27.4±5.6	30.2±6.4	27.0±5.4	<0.001*
BMI ≥30 kg/m², n (%)	142 (29.2)	32 (51.6)	110 (25.9)	<0.001*
Current smoker, n (%)	109 (22.4)	22 (35.5)	87 (20.5)	0.008*
Alcohol use, n (%)	98 (20.2)	16 (25.8)	82 (19.3)	0.233
Comorbidities				
Diabetes mellitus, n (%)	139 (28.6)	34 (54.8)	105 (24.8)	<0.001*
Hypertension, n (%)	206 (42.4)	32 (51.6)	174 (41.0)	0.116
Coronary artery disease, n (%)	68 (14.0)	12 (19.4)	56 (13.2)	0.194
COPD, n (%)	42 (8.6)	8 (12.9)	34 (8.0)	0.198
Chronic kidney disease, n (%)	34 (7.0)	8 (12.9)	26 (6.1)	0.054
Malignancy, n (%)	186 (38.3)	28 (45.2)	158 (37.3)	0.232
Laboratory Values				
Albumin (g/dL), mean±SD	3.8±0.6	3.4±0.7	3.9±0.5	<0.001*
Albumin <3.5 g/dL, n (%)	118 (24.3)	28 (45.2)	90 (21.2)	<0.001*
Hemoglobin (g/dL), mean±SD	12.6±2.1	11.8±2.3	12.7±2.0	0.002*
ASA Score ≥III, n (%)	156 (32.1)	34 (54.8)	122 (28.8)	<0.001*

BMI: body mass index; COPD: chronic obstructive pulmonary disease; ASA: American Society of Anesthesiologists; SD: standard deviation. *Statistically significant (p<0.05).

Operative Characteristics: The most common procedures were colorectal resections (34.6%), hepatobiliary surgery (22.0%), and hernia repairs with mesh (18.5%). Mean operative duration was 156.4±58.6 minutes. Wound classification distribution was: clean (21.8%), clean-contaminated (52.3%), contaminated (18.1%), and dirty (7.8%). Table 2 summarizes operative variables stratified by SSI status.

Table 2: Operative Characteristics Stratified by Surgical Site Infection Status

Variable	Total (n=486)	SSI (n=62)	No SSI (n=424)	p-value
Procedure Type, n (%)				0.024*
Colorectal resection	168 (34.6)	28 (45.2)	140 (33.0)	
Hepatobiliary surgery	107 (22.0)	14 (22.6)	93 (21.9)	
Hernia repair with mesh	90 (18.5)	6 (9.7)	84 (19.8)	
Gastric surgery	62 (12.8)	8 (12.9)	54 (12.7)	
Small bowel resection	38 (7.8)	4 (6.5)	34 (8.0)	
Other major procedures	21 (4.3)	2 (3.2)	19 (4.5)	
Wound Classification, n (%)				<0.001*
Clean	106 (21.8)	4 (6.5)	102 (24.1)	
Clean-contaminated	254 (52.3)	28 (45.2)	226 (53.3)	
Contaminated	88 (18.1)	18 (29.0)	70 (16.5)	
Dirty	38 (7.8)	12 (19.4)	26 (6.1)	
Operative Duration				
Duration (min), mean±SD	156.4±58.6	198.6±64.2	150.2±55.4	<0.001*
Duration >180 min, n (%)	148 (30.5)	36 (58.1)	112 (26.4)	<0.001*
Blood Loss and Transfusion				
EBL (mL), mean±SD	286.4±224.6	412.8±298.4	268.0±206.2	<0.001*
Blood transfusion, n (%)	64 (13.2)	18 (29.0)	46 (10.8)	<0.001*
Other Operative Factors				
Drain placement, n (%)	218 (44.9)	38 (61.3)	180 (42.5)	0.006*
Appropriate antibiotic timing, n (%)	452 (93.0)	54 (87.1)	398 (93.9)	0.058
Attending surgeon, n (%)	386 (79.4)	44 (71.0)	342 (80.7)	0.081

EBL: estimated blood loss; SD: standard deviation. *Statistically significant (p<0.05).

SSI Incidence and Characteristics: The overall SSI incidence was 12.8% (62/486). Superficial incisional SSI was most common (34/62, 54.8%), followed by deep incisional (18/62, 29.0%) and organ/space infections (10/62, 16.1%). The median time to SSI diagnosis was 7 days (IQR: 5-12 days). Microbiological cultures were positive in 52 cases (83.9%).

The most common organisms were Escherichia coli (26.9%), Staphylococcus aureus (23.1%), Klebsiella pneumoniae (15.4%), Enterococcus species (11.5%), and Pseudomonas aeruginosa (9.6%). Polymicrobial infections occurred in 19.2% of cases.

Multivariate Analysis: Variables with p<0.20 in univariate analysis were entered into multivariate logistic regression. Independent predictors of SSI are presented in Table 3. The model demonstrated good calibration (Hosmer-Lemeshow test p=0.684) and acceptable discrimination (AUC-ROC=0.812, 95% CI: 0.758-0.866).

Table 3: Multivariate Logistic Regression Analysis of SSI Predictors

Variable	Adjusted OR	95% CI	p-value
Diabetes mellitus	2.84	1.52-5.31	0.001*
BMI ≥30 kg/m²	2.46	1.28-4.72	0.007*
ASA Score ≥III	2.18	1.14-4.17	0.018*
Albumin <3.5 g/dL	1.92	1.02-3.62	0.044*
Operative duration >180 min	3.12	1.68-5.79	<0.001*
Contaminated/Dirty wound	4.28	2.14-8.56	<0.001*
Blood transfusion	1.86	0.92-3.78	0.086
Current smoking	1.64	0.86-3.14	0.134

OR: odds ratio; CI: confidence interval; BMI: body mass index; ASA: American Society of Anesthesiologists. *Statistically significant (p<0.05). Model fit: Hosmer-Lemeshow p=0.684; AUC-ROC=0.812.

Impact of SSI on Outcomes: Patients developing SSI had significantly prolonged hospital stays (14.6±5.8 vs. 6.2±2.4 days, $p<0.001$). ICU admission was required in 22.6% of SSI patients compared to 8.3% of non-SSI patients ($p=0.001$). Reoperation was necessary in 14.5% of SSI patients versus 2.4% of non-SSI patients ($p<0.001$). The 30-day mortality rate was 4.8% in the SSI group compared to 0.9% in the non-SSI group ($p=0.024$).

Discussion

This prospective cohort study comprehensively evaluated predictors of surgical site infections following major elective general surgical procedures, identifying diabetes mellitus, obesity, prolonged operative time, contaminated/dirty wound classification, elevated ASA score, and hypoalbuminemia as independent risk factors. The overall SSI incidence of 12.8% is consistent with published literature for major open abdominal procedures, reflecting the inherent complexity and contamination risk associated with these interventions [17].

Diabetes mellitus emerged as a significant predictor with nearly three-fold increased odds of SSI development. This finding corroborates extensive literature documenting the adverse effects of hyperglycemia on immune function, wound healing, and infection risk. Ata et al. demonstrated that both preoperative hyperglycemia and postoperative glucose variability independently predicted SSI in general surgical patients [18]. The mechanisms underlying this association include impaired neutrophil function, reduced chemotaxis, and compromised microvascular perfusion in diabetic patients [19]. Our results reinforce the importance of perioperative glycemic optimization as a modifiable intervention.

Obesity, defined as BMI ≥30 kg/m², was associated with 2.46-fold increased SSI risk. This relationship has been consistently observed across surgical specialties and may reflect multiple contributing factors. Thelwall et al. analyzed over 400,000 surgical procedures and identified obesity as a significant independent risk factor for SSI [20]. Adipose tissue is relatively hypovascular, potentially compromising antibiotic delivery to the surgical site and tissue oxygenation essential for oxidative killing of pathogens [21]. Furthermore, technical challenges associated with operating on obese patients may increase tissue trauma and operative duration.

Prolonged operative duration exceeding 180 minutes tripled the odds of SSI development, consistent with findings from large database analyses. Cheng et al. reported a linear relationship between operative duration and SSI risk across multiple procedure categories [22]. Extended procedures allow greater cumulative bacterial contamination, increased tissue desiccation and trauma, and potential reduction in prophylactic antibiotic serum concentrations below therapeutic levels [23]. This finding emphasizes the importance of surgical efficiency and the potential benefit of antibiotic redosing during prolonged procedures.

Wound classification remained a powerful predictor, with contaminated and dirty wounds demonstrating over four-fold increased SSI risk compared to clean and clean-contaminated wounds. This validation of established risk stratification frameworks supports continued utilization of wound classification in SSI surveillance and prevention protocols. The CDC wound classification system, despite limitations, remains a practical and relevant risk assessment tool [24].

Elevated ASA score (≥III) reflected the impact of overall health status on infection susceptibility. Patients with significant systemic disease have diminished physiological reserve and immune competence, rendering them more vulnerable to postoperative complications. Akinbami et al. identified ASA classification as an independent predictor of SSI in colorectal surgery [25]. This association underscores the importance of preoperative optimization of comorbid conditions when feasible. Hypoalbuminemia, a marker of malnutrition and catabolic state, was associated with nearly doubled SSI risk. Serum albumin reflects nutritional status and synthetic liver function, both relevant to wound healing and immune function. Hennessey et al. demonstrated that preoperative albumin levels below 3.5 g/dL significantly increased postoperative complications including SSI [26]. Nutritional optimization through oral supplementation or enteral feeding may represent a modifiable intervention in elective surgical patients.

The microbial profile observed in this study reflects typical flora associated with abdominal surgery SSI. The predominance of gram-negative organisms, particularly E. coli and Klebsiella species, is consistent with colorectal and gastrointestinal procedures comprising a significant proportion of the study population. The persistence of S. aureus as a major pathogen emphasizes the continued relevance of gram-positive coverage in prophylactic antibiotic regimens [27].

The substantial impact of SSI on clinical outcomes observed in this study is consistent with previous investigations. Ban et al. reported that SSI following colorectal surgery was associated with doubled length of stay and significantly increased healthcare costs [28]. The eight-day prolongation of hospitalization and increased reoperation and mortality rates observed underscore the clinical and economic importance of SSI prevention.

Several limitations warrant acknowledgment. The single-center design may limit generalizability to other settings with different patient populations or practices. Despite prospective data collection, unmeasured confounders may have influenced outcomes. The composite nature of major general surgery procedures introduces heterogeneity, though this reflects real-world practice. Follow-up was limited to 30 days, potentially missing some late-onset infections. Strengths include prospective design, standardized surveillance methodology, comprehensive data collection, and robust statistical analysis.

Future research should evaluate the implementation of targeted prevention bundles incorporating risk stratification based on identified predictors. The integration of machine learning algorithms may enhance predictive accuracy and enable real-time risk assessment. Additionally, investigation of novel preventive interventions such as antimicrobial sutures, negative pressure wound therapy, and enhanced perioperative glycemic control protocols in high-risk populations is warranted [29].

Conclusion

This prospective study identified multiple independent predictors of surgical site infection following major elective general surgical procedures. Diabetes mellitus, obesity, prolonged operative duration, contaminated or dirty wound classification, elevated ASA score, and hypoalbuminemia significantly increased SSI risk. The overall SSI incidence of 12.8% and its substantial impact on hospital length of stay, intensive care requirements, reoperation rates, and mortality underscore the clinical significance of this complication. These findings support the implementation of targeted prevention strategies focusing on modifiable risk factors, including rigorous perioperative glycemic control, weight optimization when feasible, surgical efficiency to minimize operative duration, and nutritional optimization in malnourished patients. Risk stratification based on identified predictors may enable personalized prevention approaches and resource allocation toward highest-risk patients. Continued surveillance and quality improvement initiatives are essential for reducing the burden of surgical site infections in surgical practice.

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