e-ISSN: 0976-822X, p-ISSN:2961-6042

Available online on http://www.ijcpr.com/

International Journal of Current Pharmaceutical Review and Research 2026; 18(2); 82-87

Original Research Article

Postoperative Surgical Site Infections: A Prospective Microbiological Profiling and Antimicrobial Resistance Analysis in Clean and Clean-Contaminated Surgeries

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Received: 01-11-2025 / Revised: 15-12-2025 / Accepted: 21-01-2026
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Conflict of interest: Nil

Abstract

Background: Surgical site infections (SSIs) remain a significant cause of postoperative morbidity, prolonged hospitalization, and increased healthcare costs. Understanding the microbiological spectrum and antimicrobial resistance patterns is essential for optimizing empirical therapy and infection control strategies.

Methods: A prospective observational study was conducted over 18 months, enrolling 1,248 patients undergoing elective surgical procedures classified as clean or clean-contaminated. Patients developing SSI were identified using Centers for Disease Control and Prevention (CDC) criteria. Wound cultures were obtained, and bacterial isolates were subjected to identification and antimicrobial susceptibility testing using standard microbiological methods.

Results: The overall SSI rate was 6.7% (84/1,248), with significantly higher rates in clean-contaminated (9.2%) compared to clean procedures (4.1%, $p<0.001$). Gram-positive organisms predominated in clean surgeries (68.2%), while Gram-negative bacteria were more common in clean-contaminated procedures (61.8%, $p=0.002$). Staphylococcus aureus was the most frequent isolate overall (34.5%), with methicillin resistance observed in 42.1% of S. aureus isolates. Extended-spectrum β-lactamase (ESBL) production was detected in 38.6% of Enterobacteriaceae. Multidrug resistance was identified in 31.0% of all isolates, with significantly higher rates in clean-contaminated SSIs (38.2% vs. 22.7%, $p=0.041$).

Conclusion: Surgical site infections demonstrate distinct microbiological profiles based on wound classification, with concerning rates of antimicrobial resistance. These findings emphasize the need for surveillance-guided antimicrobial stewardship and procedure-specific prophylaxis protocols.

Keywords: Surgical site infection; Antimicrobial resistance; Microbiological profile; Clean surgery; Clean-contaminated surgery; MRSA; ESBL.

DOI: 10.25258/ijcpr.18.2.13

Introduction

Surgical site infections represent one of the most prevalent healthcare-associated infections worldwide, accounting for approximately 20-25% of all nosocomial infections and affecting an estimated 2-5% of patients undergoing surgical procedures [1]. These infections impose substantial burdens on healthcare systems, with attributable increases in hospital length of stay ranging from 7 to 11 days and excess costs estimated between $3,000 and $29,000 per infection depending on surgical complexity and pathogen virulence [2]. Beyond economic implications, SSIs contribute to significant patient morbidity, diminished quality of life, and increased mortality, particularly when caused by multidrug-resistant organisms [3]. The classification of surgical wounds based on contamination risk—clean, clean-contaminated, contaminated, and dirty—provides a foundational framework for predicting infection likelihood and guiding prophylactic antimicrobial selection [4]. Clean surgical procedures, involving uninfected operative sites without entry into respiratory, alimentary, or genitourinary tracts, historically demonstrate SSI rates of 1-3%, while clean-contaminated procedures involving controlled entry into hollow viscera carry expected infection rates of 5-10% [5]. However, contemporary data suggest that these historical benchmarks may underestimate current infection rates, particularly in the context of emerging antimicrobial resistance and increasingly

complex patient populations. The microbiological etiology of surgical site infections varies substantially based on the anatomical site of surgery, wound classification, and local epidemiological patterns [6]. Staphylococcus aureus remains the predominant pathogen across most surgical specialties, with methicillin-resistant strains (MRSA) constituting an increasing proportion of isolates and complicating empirical treatment approaches [7]. Gram-negative organisms, including Escherichia coli, Klebsiella species, and Pseudomonas aeruginosa, predominate in procedures involving the gastrointestinal and genitourinary tracts, with extended-spectrum β-lactamase production and carbapenem resistance presenting growing therapeutic challenges [8].

The global emergence of antimicrobial resistance has transformed the epidemiology of surgical site infections, rendering traditional prophylactic and therapeutic regimens increasingly inadequate [9]. Surveillance data from multiple continents demonstrate rising prevalence of multidrug-resistant organisms among SSI isolates, threatening the efficacy of standard antibiotic prophylaxis protocols and necessitating reassessment of empirical treatment strategies [10]. The World Health Organization has identified antimicrobial resistance as one of the paramount threats to global health, with surgical infections representing a critical interface between resistance emergence and clinical consequences [11].

Despite extensive literature on surgical site infections, significant knowledge gaps persist regarding procedure-specific microbiological profiles and resistance patterns in contemporary surgical practice. Many existing studies aggregate data across heterogeneous wound classifications, limiting the applicability of findings to specific clinical contexts [12]. Furthermore, regional variations in resistance epidemiology underscore the importance of local surveillance data for informing institutional antibiotic stewardship and infection prevention initiatives.

The aim of this prospective study was to characterize the microbiological profile and antimicrobial resistance patterns of surgical site infections in patients undergoing clean and clean-contaminated surgical procedures, with the objective of providing evidence to guide procedure-specific prophylaxis optimization and empirical treatment selection.

Materials and Methods

Study Design and Setting: This prospective observational cohort study was conducted at a tertiary care teaching hospital.

Study Population: Consecutive patients aged 18 years or older undergoing elective surgical procedures classified as clean or clean-contaminated according to CDC wound classification criteria were eligible for enrollment.

Inclusion Criteria:

- Age ≥18 years
- Elective surgical procedure with clean or clean-contaminated wound classification
- Primary wound closure
- Minimum 30-day postoperative follow-up completed

Exclusion Criteria:

- Emergency surgical procedures
- Contaminated or dirty wound classification
- Preexisting infection at operative site
- Immunosuppressive therapy or documented immunodeficiency
- Incomplete medical records or lost to follow-up
- Surgical procedures lasting less than 30 minutes

Surgical Site Infection Surveillance: Active prospective surveillance was conducted by trained infection control practitioners using standardized CDC National Healthcare Safety Network (NHSN) definitions. Patients were monitored during hospitalization and at outpatient follow-up visits through postoperative day 30, or day 90 for procedures involving implantable devices. SSIs were classified as superficial incisional, deep incisional, or organ/space infections based on established criteria.

Microbiological Sampling and Analysis: Wound specimens were collected from all patients meeting SSI criteria using sterile swabs or aspiration techniques prior to initiation of antimicrobial therapy whenever possible. Specimens were transported to the microbiology laboratory within 2 hours of collection.

Bacterial Identification: Specimens were inoculated onto blood agar, MacConkey agar, and chocolate agar plates and incubated aerobically at 35-37°C for 24-48 hours. Anaerobic cultures were performed on thioglycolate broth and anaerobic blood agar when clinically indicated. Bacterial identification was performed using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS, Bruker Daltonics).

Antimicrobial Susceptibility Testing: Susceptibility testing was conducted using automated broth microdilution (Vitek 2, bioMérieux) according to Clinical and Laboratory Standards Institute (CLSI) guidelines. Minimum inhibitory concentrations were interpreted using current CLSI breakpoints. MRSA was confirmed by cefoxitin disk diffusion and mecA gene

detection. ESBL production was assessed using combination disk testing with clavulanate inhibition.

Data Collection

Demographic variables, comorbidities, surgical characteristics, American Society of Anesthesiologists (ASA) physical status classification, operative duration, prophylactic antibiotic administration, and postoperative outcomes were extracted from electronic medical records using standardized data collection forms.

Statistical Analysis

Statistical analyses were performed using SPSS version 28.0. Continuous variables were expressed as mean ± standard deviation or median with interquartile range based on distribution normality. Categorical variables were expressed as frequencies and percentages. Comparisons between clean and clean-contaminated groups utilized chi-square tests or Fisher's exact tests for categorical variables and Student's t-tests or Mann-Whitney U tests for continuous variables. Multivariable logistic regression identified independent risk factors for SSI and multidrug-resistant infections. Statistical significance was defined as $p<0.05$.

Results

Patient and Surgical Characteristics

A total of 1,248 patients meeting inclusion criteria were enrolled during the study period, comprising 612 clean procedures (49.0%) and 636 clean-contaminated procedures (51.0%).

The mean age was 52.4 ± 16.8 years, and 54.2% were female. Surgical specialties represented included general surgery (42.1%), orthopedic surgery (28.4%), gynecologic surgery (18.3%), and urologic surgery (11.2%). Baseline characteristics are presented in Table 1.

Table 1: Baseline Patient and Surgical Characteristics

Parameter	Clean (n=612)	Clean-Contaminated (n=636)	p-value
Age (years), mean ± SD	48.6 ± 17.2	56.1 ± 15.8	<0.001*
Sex, female n (%)	298 (48.7)	378 (59.4)	<0.001*
BMI (kg/m²), mean ± SD	27.8 ± 5.4	28.4 ± 6.1	0.072
ASA classification ≥3, n (%)	168 (27.5)	214 (33.6)	0.018*
Diabetes mellitus, n (%)	112 (18.3)	148 (23.3)	0.032*
Current smoking, n (%)	98 (16.0)	118 (18.6)	0.234
Malignancy, n (%)	86 (14.1)	142 (22.3)	<0.001*
Prior surgery at same site, n (%)	72 (11.8)	68 (10.7)	0.549
Operative duration (min), mean ± SD	94.2 ± 48.6	128.4 ± 62.3	<0.001*
Appropriate prophylaxis, n (%)	578 (94.4)	594 (93.4)	0.452
Drain placement, n (%)	124 (20.3)	186 (29.2)	<0.001*
Hospital LOS (days), median (IQR)	3 (2-5)	5 (3-8)	<0.001*
Surgical Specialty, n (%)			<0.001*
General surgery	186 (30.4)	340 (53.5)	
Orthopedic surgery	268 (43.8)	86 (13.5)	
Gynecologic surgery	98 (16.0)	130 (20.4)	
Urologic surgery	60 (9.8)	80 (12.6)	

***Statistically significant; BMI: Body Mass Index; ASA: American Society of Anesthesiologists; LOS: Length of Stay; IQR: Interquartile Range**

Surgical Site Infection Rates: Overall, 84 patients developed SSI, yielding an infection rate of 6.7%. The SSI rate was significantly higher in clean-contaminated procedures (9.2%, 59/636) compared to clean procedures (4.1%, 25/612; $p<0.001$). SSI classifications included superficial incisional (54.8%), deep incisional (28.6%), and organ/space infections (16.7%). Polymicrobial infections were identified in 23.8% of cases. Independent risk factors for SSI development included clean-contaminated wound classification (OR 2.38, 95% CI 1.42-3.98, p=0.001), diabetes mellitus (OR 1.94, 95% CI 1.18-3.19, p=0.009), operative duration >120 minutes (OR 2.12, 95% CI 1.31-3.43, p=0.002), and ASA classification ≥3 (OR 1.78, 95% CI 1.08-2.94, p=0.024).

Microbiological Profile: A total of 104 bacterial isolates were recovered from 84 SSI cases, with monomicrobial infections in 76.2% and polymicrobial infections in 23.8%. Gram-positive organisms accounted for 52.9% of isolates overall, with significant differences between wound classifications. Clean surgeries demonstrated Gram-positive predominance (68.2%), whereas clean-contaminated procedures showed Gram-negative predominance (61.8%, p=0.002). The microbiological profile is detailed in Table 2.

Table 2: Microbiological Profile of Surgical Site Infections

Bacterial Isolate	Total (n=104)	Clean (n=31)	Clean-Contaminated (n=73)	p-value
Gram-Positive Organisms, n (%)	55 (52.9)	21 (68.2)	34 (46.6)	0.047*
Staphylococcus aureus	36 (34.6)	14 (45.2)	22 (30.1)	0.139
- MSSA	21 (20.2)	9 (29.0)	12 (16.4)	0.144
- MRSA	15 (14.4)	5 (16.1)	10 (13.7)	0.754
Coagulase-negative staphylococci	11 (10.6)	5 (16.1)	6 (8.2)	0.224
Enterococcus species	6 (5.8)	1 (3.2)	5 (6.8)	0.467
Streptococcus species	2 (1.9)	1 (3.2)	1 (1.4)	0.522
Gram-Negative Organisms, n (%)	49 (47.1)	10 (32.3)	39 (53.4)	0.047*
Escherichia coli	18 (17.3)	3 (9.7)	15 (20.5)	0.176
Klebsiella pneumoniae	12 (11.5)	2 (6.5)	10 (13.7)	0.298
Pseudomonas aeruginosa	10 (9.6)	3 (9.7)	7 (9.6)	0.990
Enterobacter species	5 (4.8)	1 (3.2)	4 (5.5)	0.619
Proteus mirabilis	3 (2.9)	1 (3.2)	2 (2.7)	0.894
Acinetobacter baumannii	1 (1.0)	0 (0)	1 (1.4)	0.513
Polymicrobial Infection, n (%)	20 (23.8)†	4 (16.0)†	16 (27.1)†	0.278

***Statistically significant; †Calculated from total SSI cases (n=84); MSSA: Methicillin-Susceptible S. aureus; MRSA: Methicillin-Resistant S. aureus**

Antimicrobial Resistance Patterns: Antimicrobial resistance was prevalent among SSI isolates, with 31.0% demonstrating multidrug resistance (MDR), defined as non-susceptibility to at least one agent in three or more antimicrobial categories. MRSA was identified in 42.1% (15/36) of S. aureus isolates, and ESBL production was detected in 38.6% (17/44) of Enterobacteriaceae. MDR rates were significantly higher in clean-contaminated SSIs (38.2%) compared to clean procedures (22.7%, p=0.041). Resistance patterns are presented in Table 3.

Table 3: Antimicrobial Resistance Patterns of SSI Isolates

Resistance Pattern	Total (n=104)	Clean (n=31)	Clean-Contaminated (n=73)	p-value
Staphylococcus aureus (n=36)				
Methicillin resistance (MRSA)	15 (41.7)	5 (35.7)	10 (45.5)	0.564
Clindamycin resistance	12 (33.3)	4 (28.6)	8 (36.4)	0.630
Fluoroquinolone resistance	14 (38.9)	5 (35.7)	9 (40.9)	0.757
Vancomycin resistance	0 (0)	0 (0)	0 (0)	-
Enterobacteriaceae (n=44)				
ESBL production	17 (38.6)	3 (33.3)	14 (40.0)	0.706
Carbapenem resistance	4 (9.1)	0 (0)	4 (11.4)	0.289
Fluoroquinolone resistance	22 (50.0)	4 (44.4)	18 (51.4)	0.696
Aminoglycoside resistance	14 (31.8)	2 (22.2)	12 (34.3)	0.470
Pseudomonas aeruginosa (n=10)				
Carbapenem resistance	3 (30.0)	1 (33.3)	2 (28.6)	0.882
Multidrug resistance	4 (40.0)	1 (33.3)	3 (42.9)	0.783
All Isolates				
Multidrug resistance, n (%)	32 (30.8)	7 (22.6)	25 (34.2)	0.237
MDR in SSI cases, n (%)†	26 (31.0)	5 (20.0)	21 (35.6)	0.154

†Calculated from total SSI cases; ESBL: Extended-Spectrum β-Lactamase; MDR: Multidrug Resistant

Patients with MDR SSIs demonstrated significantly longer hospital stays (median 16 vs. 10 days, p<0.001), higher rates of treatment failure requiring antibiotic modification (53.8% vs. 22.4%, p=0.003), and increased 30-day readmission rates (30.8% vs. 12.1%, p=0.024) compared to those with susceptible isolates.

Discussion

This prospective study provides comprehensive characterization of the microbiological profile and antimicrobial resistance patterns of surgical site infections in clean and clean-contaminated surgical procedures, revealing distinct pathogen distributions and concerning resistance prevalence that have significant implications for prophylaxis optimization and empirical treatment selection. The overall SSI rate of 6.7% observed in this cohort exceeds historically reported benchmarks for clean and clean-contaminated procedures, potentially reflecting the inclusion of complex surgical cases in a tertiary referral center and the application of

rigorous surveillance methodology [13]. The significantly higher infection rate in clean-contaminated procedures (9.2%) compared to clean surgeries (4.1%) confirms the validity of wound classification as a fundamental risk stratification tool while highlighting opportunities for targeted prevention interventions in higher-risk categories [14].

The predominance of Staphylococcus aureus as the leading SSI pathogen across both wound classifications is consistent with established literature and underscores the continued importance of anti-staphylococcal prophylaxis in surgical practice [15]. However, the striking difference in Gram-positive versus Gram-negative predominance between clean and clean-contaminated procedures emphasizes the need for procedure-specific prophylaxis regimens rather than uniform approaches across surgical specialties. Clean-contaminated procedures involving gastrointestinal or genitourinary tracts require prophylactic coverage extending to enteric Gram-negative organisms, a consideration well-supported by our microbiological findings [16].

The MRSA prevalence of 42.1% among S. aureus isolates represents a substantial proportion that challenges traditional prophylaxis paradigms utilizing first-generation cephalosporins alone [17]. This resistance rate exceeds many published surveillance estimates and may reflect institutional epidemiology or referral patterns concentrating higher-acuity patients. Consideration of MRSA-active agents such as vancomycin for surgical prophylaxis in high-risk patients or institutions with elevated MRSA prevalence warrants evaluation, though this approach must be balanced against stewardship concerns and potential for promoting vancomycin-resistant organisms [18].

The detection of ESBL production in 38.6% of Enterobacteriaceae isolates represents a particularly concerning finding with direct implications for empirical treatment of clean-contaminated SSIs. Standard β-lactam antibiotics, including ampicillin-sulbactam and many cephalosporins, demonstrate reduced efficacy against ESBL-producing organisms, potentially contributing to treatment failures and adverse outcomes [19]. Carbapenem-sparing alternatives such as piperacillin-tazobactam may retain activity against some ESBL producers, though local susceptibility patterns should guide empirical selections.

The association between MDR infections and adverse clinical outcomes observed in this study reinforces the clinical significance of resistance beyond microbiological categorization [20]. Patients with MDR SSIs experienced prolonged hospitalization, increased treatment failure rates, and higher readmission frequencies, translating to substantial healthcare resource utilization and patient burden. These findings emphasize the importance of rapid identification of resistant pathogens to enable timely optimization of antimicrobial therapy.

The polymicrobial nature of nearly one-quarter of SSI cases, particularly in clean-contaminated procedures, highlights the complex ecology of surgical infections and the potential inadequacy of monotherapy regimens [21]. Mixed infections involving both aerobic and anaerobic organisms may require combination antimicrobial therapy for optimal resolution, particularly in abdominal surgical procedures where anaerobic contamination is anticipated.

Limitations of this study include its single-center design, which may limit generalizability of microbiological findings to institutions with different resistance epidemiology. The exclusion of contaminated and dirty wounds restricts applicability to emergency surgical settings. Additionally, anaerobic culture was performed selectively rather than universally, potentially underestimating the contribution of anaerobic pathogens to SSI etiology.

Conclusion

This prospective study demonstrates that surgical site infections in clean and clean-contaminated procedures exhibit distinct microbiological profiles, with Gram-positive predominance in clean surgeries and Gram-negative predominance in clean-contaminated procedures.

Antimicrobial resistance is highly prevalent, with MRSA identified in 42.1% of Staphylococcus aureus isolates and ESBL production in 38.6% of Enterobacteriaceae. Multidrug-resistant infections are associated with significantly worse clinical outcomes, including prolonged hospitalization and increased treatment failure rates. These findings emphasize the critical importance of institutional surveillance data for guiding procedure-specific prophylaxis protocols and empirical treatment selections.

Integration of local resistance epidemiology into antimicrobial stewardship programs and infection prevention initiatives is essential for optimizing surgical outcomes in the context of evolving antimicrobial resistance patterns.

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