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High incidence of multidrug-resistant organisms and modifiable risk factors associated with surgical site infections: a cohort study in a tertiary medical center in Kuala Lumpur, Malaysia from 2020 to 2023

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Abstract

Background Surgical site infections (SSIs) are a persistent challenge in healthcare, contributing significantly to patient morbidity, mortality, and healthcare costs. Despite advancements in preventive measures, SSIs remain prevalent, especially in countries like Malaysia where rates are higher than in high-income nations.

Methods A prospective, cohort study was conducted at the University Malaya Medical Center (UMMC), Malaysia, from November 2020 to May 2023. Clinical and microbiological data were collected, and logistic regression were performed to identify risk factors associated with SSIs.

Results A total of 1,815 patients undergoing orthopedic, neurosurgical, and general surgical procedures were monitored for SSIs. The incidence rate of SSIs was 3.23 per 100 procedures ($n=71$) with significant associations observed between SSI occurrence and prolonged surgical duration > 100 min, extended hospitalization > 5 days, trauma-to-surgery interval > 8 days, and presence of implants. Common pathogens isolated included *Staphylococcus aureus, Klebsiella pneumoniae*, and *Pseudomonas aeruginosa*. Multidrug-resistant organisms (MDROs) were identified in 42.1% of the total isolates.

Conclusions In this study, a high rate of MDRO and risk factors for SSI were identified. It emphasises the need for ongoing surveillance to guide infection prevention strategies and antimicrobial stewardship programs. Future

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research should prioritize evaluating the impact of targeted interventions tailored to identified risk factors to optimize surgical patient outcomes.

Keywords Antimicrobial resistance, Surgical site infection, Multidrug-resistant organisms

Introduction

Surgical site infections (SSIs) contribute to morbidity and mortality, especially in emergency and trauma situations, significantly burdening healthcare resources [1, 2]. An early study carried out in the same study settings estimated that SSIs contributed 25.4% of all hospital-acquired infections, emphasizing the need to further define the threat and create additional mitigation strategies [3]. SSIs have a substantial effect on patients, leading to higher chances of needing more surgeries, experiencing health complications, developing long-term consequences, having longer hospital admissions by 9.7 days, and incurring higher healthcare expenses at an estimated USD 20,000 per admission [4, 5].

Given these burdens, it is important to examine global and regional trends in SSI prevalence. SSIs are higher in low- and middle-income countries (LMICs) (11.8%) compared to high-income countries (1.2 to 5.2%) [6, 7]. A previous study from Malaysia has reported a higher rate of SSI (13%) compared to SSI rates recorded by studies from industrialized nations such as USA (1.08%) and England (0.4–2.5%) [8–10]. Similarly, a recent study showed that 13.8% of patients in Malaysia who underwent elective hepatobiliary, vascular, and colorectal surgeries acquired SSIs [11]. Similar SSI rates of 11.7–22% have been reported in a number of Malaysia state-level studies, reviewing procedures involving clean or clean-contaminated wounds such as caesarean section surgery, coronary artery bypass grafting (CABG) surgery, thyroid surgery, and laparoscopic surgery [11–14]. In the LMIC scenario, the risk of getting an SSI greatly increases the overall likelihood of financial catastrophe, with healthcare costs on the occasion exceeding 10% of annual household expenditure. Bearing this in mind, identification of appropriate solutions to combat SSI is a matter of global interest [15].

Even with improvements in preventive measures such as enhanced ventilation in operation theatre (OT), sterilizing techniques, advances in surgical technique, infection control practices, and antibiotic prophylaxis use, completely eliminating post-surgical infections is still difficult to achieve [16, 17]. While enhanced ventilation in operating theatres has been highlighted as an evidence-based strategy to reduce SSI, its implementation is resource-dependent and may not be feasible or widely practiced in all surgical settings, such as trauma or general surgery in low-resource environments. The Centers for Disease Control and Prevention (CDC) classify SSIs into two categories: incisional (superficial or deep) or affecting an organ or space [5, 18]. Insufficient resources, low public knowledge, and ineffective infection control policies influence the prevalence of SSIs as common healthcare-associated infections (HCAIs) in Malaysia [11, 14, 16].

In Malaysian hospitals, the Ministry of Health (MOH) reported that, in 2022, multidrug-resistant organisms (MDRO) were associated with 66.3% of hospital-acquired infections (HAIs), emphasizing the need for strengthened infection control efforts [19]. SSIs accounted for 16% of all HCAIs based on the MOH's point prevalence survey (PPS) conducted in 2022, with 10% of hospital-acquired MDRO infections attributed to SSIs, as reported in the national continuous surveillance data [19]. This highlights the significance of surveillance, identifying risk factors, and strengthening infection control measures. Thus, this study aims to determine the incidence and assess the microbiology of SSI associated with traumatic and non-traumatic injuries; describe associated risk factors; and determine what percentage are multidrug-resistant bacterial infections. Understanding these aspects is crucial for developing targeted infection control strategies, optimizing antibiotic use, and ultimately improving patient outcomes by reducing the incidence and severity of SSIs.

Methodology

Patient recruitment

This prospective, cohort study was conducted at the University Malaya Medical Center (UMMC), a tertiary teaching hospital in Kuala Lumpur, Malaysia, between November 2020 and May 2023. UMMC is a 1,600-bed tertiary teaching center that provides a comprehensive range of services, including consultation, diagnosis, treatment, counseling, prevention, and rehabilitation. UMMC is equipped to perform a variety of surgical procedures, such as colorectal, upper gastrointestinal, intracranial, spinal, neurovascular, trauma-related, and limb lengthening and reconstruction surgeries.

The study population included adult patients (≥18 years old) who underwent surgical procedures in the UMMC operation theater by the orthopaedic, neurosurgical and general surgery departments for either traumatic or non-traumatic injuries. Patients were excluded if they underwent surgeries where the wounds were classified as dirty-infected (e.g., peritonitis, perforated bowel, necrotizing fasciitis) [5, 18].

This study compares surgical patients who develop SSIs to those who do not. The non-SSI group consisted of patients from the same cohort who underwent similar

surgical procedures but did not develop SSIs, as identified through routine post-operative surveillance. Patients who did not develop SSIs were included as the comparison group, and their clinical outcomes were compared to those of the SSI group to identify risk factors associated with SSI development. This design allowed us to assess outcomes and ensure consistent application of SSI criteria.

Every surgical patient who met the inclusion criteria was prospectively followed by trained research staff and the treating surgeon as part of routine post-operative surveillance within the hospital's infection prevention and control program. Wounds were individually examined during the patient's hospital stay or during follow-up by the surgeons from the respective surgical team. All patients were followed up for 30 days (or day 90 for prosthetic surgeries) by a trained research officer and infection prevention team who reviewed medical record system (EMR) weekly to capture any readmissions or post-operative complications documented during follow-up visits. If an SSI was suspected based on the treating doctor's clinical assessment, the research staff obtained consent from the patient to participate in the study. SSIs were identified using NHS/CDC criteria, which align with both hospitals and national infection prevention guidelines in Malaysia. The criteria incorporate clinical findings, laboratory results, and the timing of infection onset relative to surgery [5, 18]. Once consent was obtained, the patient's medical records were reviewed, and relevant SSI and surgical procedure data were collected. Patients with SSIs were classified into three categories (superficial, deep, or organ/space) according to NHS/CDC criteria [5, 18]. This classification was determined in consultation with surgeons and infectious disease specialists. For non-SSI patients, the consent process as per protocol was not carried out but their de-identified data were included in the analysis. A total of 71 patients were approached to be recruited in this study.

All cultures collected post-operatively, ordered due to clinical suspicion of infection, were systematically recorded and analysed. This included both intraoperative cultures and those obtained at the bedside for suspected SSIs. Colonization and infection were distinguished based on clinical criteria outlined by the CDC/NHSN definitions for SSIs [5, 18]. Specifically, a diagnosis of infection required evidence of purulent discharge, abscess formation, or other systemic or local signs of infection. Positive cultures alone, without supporting clinical evidence, were classified as colonization.

Clinical data collection

Data for SSI subjects were systematically collected from patients' EMRs. This included patient demographics such as age, gender, smoking status, and underlying diseases (e.g., diabetes mellitus (DM), hypertension (HTN), cancer), as well as the date and type of injury. Non-trauma cases involved conditions such as cancer, epilepsy, or appendicitis, while trauma cases were categorized based on the nature of the injury, including motor-vehicle accidents, falls, assaults, fractures (e.g., hip, femur, tibia), dislocations, and polytrauma. The details of surgical procedures, such as open reduction and internal fixation (ORIF), debridement, external fixation, implant insertion, surgery duration, post-operative care, follow-up details, and the date of SSI onset and treatment, were also recorded. Additionally, patients' wounds were classified into three categories according to CDC guidelines: clean, clean-contaminated, and contaminated, based on the level and risk of contamination [5, 18].

On the other hand, for non-SSI patients, general information such as admission and discharge dates, type of injury (non-trauma or trauma), specific diagnoses, and dates of surgery were collected from ward and operation records. This limitation in data collection, especially the demographic data of non-SSI patients, was due to UMMC Medical Research Ethics Committee (UMMC-MREC) guidelines, which required informed and written consent from these patients, which was not obtained. Despite this limitation, the comparison group was carefully identified through routine surveillance, ensuring that non-SSI patients shared similar surgical and clinical contexts as those in the SSI group. All collected data were anonymized and stored securely to ensure patient confidentiality.

Local ethics approval was obtained from the UMMC-MREC (MREC ID: 2020616-8769) to conduct this study and to access patients' data.

Bacterial isolates identification and collections

Clinical samples obtained either in the ward or operation theater from suspected SSI sites were sent to the Medical Microbiology Diagnostic Laboratory (MMDL), Department of Medical Microbiology, UMMC, for routine microbiological investigation procedures. Microbiological identification was performed using the automated microbial identification VITEK® 2 MS system in MMDL, with additional molecular assays (polymerase chain reaction; PCR) conducted in the research laboratory to confirm the bacterial species of most isolates. Antimicrobial susceptibility tests were conducted using a combination of the VITEK® 2 system (bioMerieux, Marcy-l'Etoile, France), disc diffusion, and E-test methods. Specifically, for gram-negative rods (GNR), amikacin susceptibility was assessed using disc diffusion. Additionally, for *Corynebacterium striatum* and *Bacillus* species, susceptibility to penicillin and vancomycin was determined using E-test methods. For patients with multiple isolates of the same species, only the first isolate was included if

subsequent isolates shared identical antimicrobial susceptibility profiles. All results were interpreted according to the Clinical and Laboratory Standards Institute (CLSI) [20]. The bacterial isolates and their susceptibility data were then collected from the diagnostic laboratory for further analysis.

According to the Infectious Diseases Society of America (IDSA) 2023 guidance, MDROs refer to organisms that are non-susceptible to at least one antimicrobial agent across three or more antimicrobial classes [21].

Statistical analysis

Statistical analysis was performed using the collected data to identify the prevalence of SSI associated with traumatic and non-traumatic injuries; describe associated risk factors; and determine the percentage of multidrug-resistant bacterial infections. Data was entered using Microsoft Excel and transferred into STATA version 16 (StataCorp LLC). The Youden's Index was used to determine the best cut-off point which maximizes the sum of sensitivity and specificity-1 for the following numerical variables; (1) duration of surgery, (2) duration of hospitalization, and (3) duration from trauma to surgery.

Table 1 Baseline characteristics of patients with SSI ($n=60$)

	Frequency (%)
Age	Mean = 58.1, SD = 19.8
18–24 years old	6 (10.0)
25–54 years old	16 (26.7)
55–64 years old	13 (21.6)
≥ 65 years old	25 (41.7)
Gender	
Male	40 (66.7)
Female	20 (33.3)
Race	
Malay	26 (43.3)
Chinese	20 (33.3)
Indian	13 (21.7)
Bumiputra	1 (1.7)
Comorbidity	
Yes	46 (76.7)
Diabetes	23 (50.0)
Hypertension	29 (48.3)
Cancer	4 (6.7)
No	14 (23.3)
Smoking status	
Nonsmoker	49 (81.7)
Smoker	10 (16.7)
Ex-smoker	1 (1.60)
ASA Score	
I	7 (11.7)
II	36 (60.0)
III	16 (26.7)
IV	1 (1.6)

For descriptive statistics, numerical data were reported as the mean and standard deviation for variables with a normal distribution, and as the median and interquartile range (IQR) for variables that were not normally distributed. Categorical data were summarized using frequency and percentage. Simple logistic regression was conducted to ascertain the relationship between factors and SSI. A backward stepwise regression method was used to eliminate variables to identify factors independently associated with SSI. Variables with a P-value ≤ 0.10 in univariate analysis were eligible for inclusion in the model, and only variables with $P \leq 0.05$ were retained in the final model. Finally, multivariable logistic regression was performed to identify the independent factors associated with SSI. Findings were presented as a crude and adjusted odds ratio (OR) with a 95% confidence interval. The Hosmer-Lemeshow test was used to evaluate goodness of fit of the final model. A p-value of less than 0.05 was considered statistically significant for all analyses.

Results

SSI incidence and patient demographic

A total of 1,826 patients who underwent surgery with subsequent follow-up observation as part of the hospital's surveillance program were screened. The SSI rate among the observed patients was 3.89% ($n=71$). Among these 1,826 patients, a total of 2,200 surgical procedures were performed, resulting in an incidence rate of SSI 3.23 per 100 procedures ($n=71$). However, 11 identified SSI cases declined consent to participate in the study, resulting in the participation of 60 patients. The mean age of recruited patients who had SSI was 58.1 years (± 19.8) and the majority were males (66.7%) and of Malay ethnicity (43.3%) (Table 1). Approximately 76.7% ($n=46$) of patients had comorbidities and 60% ($n=36$) were classified as ASA Physical Status Classification System II. Out of the 60 SSI cases, 42 (70%) were associated with orthopedic trauma (Table 2). The trauma cases predominantly consisted of fractures of hip ($n=15$), femur ($n=12$), tibia ($n=8$), and others ($n=7$), which required surgeries like ORIF, external fixation, and debridement. Non-traumatic cases (26%) included procedures for degenerative joint diseases or tumor resections, such as total hip arthroplasty and tumor excisions. Of the SSI patients, 36 (%) and 24 (%) were diagnosed with superficial incisional and deep incisional SSI, respectively.

Three (5.0%) patients died because of septic shock secondary to SSI highlighting the severity of SSI-related complications despite intensive medical and surgical interventions. Patient 2, a 74-year-old Malay male with DM and HTN, succumbed to deep SSI and septic shock following cephalomedullary nailing for a femur fracture. Intraoperative cultures revealed multidrug-resistant organisms (*Pseudomonas aeruginosa*, MDR

Table 2 Clinical and procedural differences between SSI and non-SSI groups

Wound classification	SSI	Non-SSI
Clean	40 (66.7)	1289 (60.5)
Clean-contaminated	14 (23.3)	205 (9.6)
Contaminated	6 (10.0)	635 (29.8)
Type of surgery		
Trauma		
Orthopedic surgery	42 (70.0)	1804 (84.7)
Neurosurgery	2 (3.3)	59 (2.8)
General surgery	0 (0)	50 (2.3)
Non-trauma		
Orthopedic surgery	5 (8.3)	19 (0.9)
Neurosurgery	8 (13.3)	123 (5.8)
General surgery	3 (5.0)	74 (3.5)
Duration from trauma to surgery	Median = 11.5 days, IQR = 6-18.5	Median = 4 days, IQR = 1–8
Duration of hospitalization	Median = 9 days, IQR = 6- 21.5	Median = 6 days, IQR = 4–12
Duration of surgery	Median = 140min, IQR = 102.5–185	Median = 90 min, IQR = 55–135
Type of SSI		
Superficial incisional SSI	36 (60.0)	N/A
Deep incisional SSI	24 (40.0)	N/A
Organ-space SSI	0 (0)	N/A

Acinetobacter baumannii, Vancomycin-resistant *Enterococcus faecium* (VRE), *C. striatum*, and methicillin-resistant coagulase-negative *Staphylococci* (MRCoNS), and extensive antibiotic therapy and debridement failed to improve his condition. Patient 18, a 71-year-old Indian male with multiple comorbidities including DM, HTN, chronic kidney disease (CKD), and severe aortic stenosis (AS), developed a polymicrobial infection (*P. aeruginosa*, ESBL *Klebsiella pneumoniae*, *E. faecium*, and *E. faecalis*) following a right bipolar hemiarthroplasty for a neck of femur fracture. Despite debridement, wound washout, and targeted antibiotic therapy, he deteriorated and passed away less than two months after surgery. Patient 25, a 63-year-old Malay male with DM, CKD, and HTN, presented with septic shock and a poor prognosis after developing SSI following ORIF for a femur fracture. His condition worsened despite ICU care, antibiotics, and attempted interventions, leading to his death.

Factors associated with SSI

Through a simple logistic regression analysis (Table 3), it was determined that individuals who experienced a longer duration between trauma and surgery, extended hospital stay, and prolonged surgical procedures were significantly more prone to SSI. For this analysis, the "extended hospital stay" variable was defined as the number of days from patients' admission to the diagnosis of SSI, ensuring that this duration reflects a potential risk factor rather than a consequence of the infection. Patients undergoing trauma surgeries exhibited a 70% lower likelihood of experiencing SSI compared to those with non-trauma-related procedures (OR = 0.3, 95% Cl = 0.2, 0.6). Furthermore, individuals with implants and those classified as having contaminated wounds prior to surgery were also found to be at increased risk of SSIs.

Multivariable logistic regression analysis revealed significant associations between SSI with three variables: duration from trauma to surgery, duration of hospitalisation, and surgical duration (Table 3). Individuals with trauma-to-surgery intervals of 8 days or more exhibited a 5.5-fold increase in SSI risk (95% CI = 2.9, 10.3). Patients hospitalized for more than five days prior to SSI diagnosis were 2.7 times more likely to develop SSI compared to patients who stayed five days or less (OR = 2.7, 95% CI = 1.4, 5.5). Lastly, surgeries lasting more than 100 min were associated with a 2.8-fold higher risk of SSI compared to those completed below 100 min (95% CI = 1.4, 5.5).

We further investigated the role of hospitalization duration in SSI risk through a stratified analysis of SSI rates by wound class. The results demonstrate that hospitalization duration is a key factor influencing SSI risk. Patients with contaminated wounds were more likely to have shorter hospital stays (≤ 5 days), during which their risk of developing SSI was significantly lower (0.26%) (Table 4). In contrast, patients with clean wounds had longer hospital stays (> 5 days), contributing to a higher SSI rate of 3.60%.

The multivariable logistic regression model demonstrated a good fit, as indicated by the Hosmer-Lemeshow test ($X^2 = 8.88$, p-value = 0.064), with an area under the ROC curve of 0.7665.

Bacterial isolates and antimicrobial susceptibility profiles

Of the 60 recruited SSI patients, ten patients had negative cultures. From the 50 patients who had positive cultures, a total of 126 (60 Gram-positive and 66 Gram-negative) bacterial isolates were obtained including *Staphylococcus aureus*, *P. aeruginosa, K. pneumoniae*, *Escherichia coli*, *Acinetobacter* species, *E. faecalis, Proteus* species, and other species. Among these, 28 patients had a polymicrobial infection.

Of the 126 total isolates, 25 (19.8%) MDROs were found among the 60 Gram-positive isolates, and 28 (22.2%) MDROs were identified among the 66 Gram-negative isolates. Specifically, 12 (9.5%) were methicillin-resistant *S. aureus* (MRSA) and 12 (9.5%) were MRCoNS. Among the Gram-negative isolates, 6 (4.8%) were MDR *A. baumannii*, while 8 (6.4%) *E. coli* isolates were MDR, with 5 also producing extended-spectrum beta-lactamase (ESBL). Additionally, 11 (8.7%) *K. pneumoniae* isolates were MDR, including 9 ESBL producers

Table 3 Logistic regression analysis of factor associated with SSI

Simple regression analysis						Multivariable logistic regression analysis		
	Total	**SSI**	**Non-SSI**	**OR (95% CI)**	***p*-value**	**OR (95% CI)**	**Z**	***p*-value**
Duration from trauma to surgery								
≤ 8 days	1470 (75.1%)	15 (1.0%)	1455 (99.0%)					
> 8 days	487 (24.9%)	29 (6.0%)	458 (94.0%)	6.1 (3.3, 11.6)	< 0.001	5.5 (2.9, 10.3)	5.22	< 0.001
Total	1957 (100%)	44 (2.2%)	1913 (97.8%)					
Duration of hospitalisation								
≤ 5 days	903 (41.3%)	10 (1.1%)	893 (98.9%)					
> 5 days	1286 (58.7%)	50 (3.9%)	1236 (96.1%)	3.6 (1.8, 7.2)	< 0.001	2.7 (1.4, 5.5)	2.13	0.034
Total	2189 (100%)	60 (2.7%)	2129 (97.3%)					
Duration of surgery								
< 100 min	1218 (55.6%)	13 (1.0%)	1205 (99.0%)					
≥ 100 min	971 (44.4%)	47 (4.8%)	924 (95.2%)	4.7 (2.5, 8.8)	< 0.001	2.8 (1.4,5.5)	2.96	0.003
Total	2189 (100%)	60 (2.7%)	2129 (97.3%)					
Specialty								
General	127 (5.8%)	3 (2.4%)	124 (97.6%)					
Neuro	192 (8.8%)	10 (5.2%)	182 (94.8%)	2.3 (0.6, 8.1)	0.220			
Orthopaedic	1870 (85.4%)	47 (2.5%)	1823 (97.5%)	1.1 (0.3, 3.5)	0.916	-	-	-
Total	2189 (100%)	60 (2.7%)	2129 (97.3%)					
Type of injury								
Non-trauma	232 (10.6%)	16 (6.9%)	216 (93.1%)					
Trauma	1957 (89.4%)	44 (2.2%)	1913 (97.8%)	0.3 (0.2, 0.6)	< 0.001	-	-	-
Total	2189 (100%)	60 (2.7%)	2129 (97.3%)					
Presence of implant								
No	802 (36.6%)	14 (1.7%)	788 (98.3%)					
Yes	1387 (63.4%)	46 (3.3%)	1341 (96.7%)	1.9 (1.1, 3.5)	0.033			
Total	2189 (100%)	60 (2.7%)	2129 (97.3%)					
Wound class								
Clean wound	1329 (60.7%)	40 (3%)	1289 (97%)					
Clean-contaminated wound	219 (10%)	14 (6.4%)	205 (93.6%)	2.2 (1.2, 4.1)	0.014	-	-	-
Contaminated	641 (29.3%)	6 (0.9%)	635 (99.1%)	0.3 (0.1, 0.7)	0.007			
Total	2189 (100%)	60 (2.7%)	2129 (97.3%)					

Table 4 Stratified analysis of SSI rates by wound class and hospitalization duration

Wound Class	Hospitalization Duration	SSI Status = 0	SSI Status = 1	Total	SSI rate
Clean Wound	≤ 5 days	459	9	469	1.92
Clean Wound	> 5 days	830	31	861	3.60
Clean-contaminated	≤ 5 days	55	0	55	0.00
Clean-contaminated	> 5 days	150	14	164	8.54
Contaminated	≤ 5 days	379	1	380	0.26
Contaminated	> 5 days	256	5	261	1.92
Total		839	10	903	1.11

and 1 carbapenem-resistant *Enterobacterales* (CRE). Two (1.6%) *P. mirabilis* isolates were MDR with 1 being ESBL producers. Other notable findings included 1 (0.8%) isolate each of VRE, CRE *Enterobacter cloacae*, and MDR *P. aeruginosa*.

In this study, a significant proportion of the Gram-positive bacteria tested were resistant to penicillin (70.0%; 42/60), ciprofloxacin (39.6%; 21/53), erythromycin (39.6%; 21/53), and levofloxacin (35.8%; 19/53) (Table 5). The most common pathogen identified is *S. aureus*, among which 86.4% resistant to penicillin, 54.5% resistant to oxacillin and cefoxitin, and 50.0% resistant to ciprofloxacin, moxifloxacin, and levofloxacin. For *B. cereus*, only penicillin and vancomycin were tested against all isolates. Similarly, for *C. striatum*, all four isolates were tested against both penicillin and vancomycin, but only two were tested against ciprofloxacin, limiting the identification of MDRO in these two species.

A majority of Gram-negative isolates tested were resistant to ceftriaxone (53.8%; 28/52), cefuroxime (88.4%; 38/43), and co-trimoxazole (53.8%; 28/52) (Table 6). These rates included some *Enterobacterales* isolates with intrinsic resistance to certain antimicrobial agents. For example, in addition to exhibiting high resistance (100%; $n = 11$) to imipenem, *Proteus spp.* showed high resistance to cefuroxime and these included *P. penneri* and *P. vulgaris*, both of which are intrinsically resistant to

Table 5 Resistance profile of gram-positive bacteria

No	Antimicrobial agents tested	*Staphylococcus aureus* (*n* = 22, 36.7%)	CoNS (*n* = 15, 25.0%)	*Streptococcus* spp. (*n* = 4, 6.7%)	*Enterococcus* spp. (*n* = 12, 20.0%)	*Corynebacterium striatum* (*n* = 4, 6.7%)	*Bacillus cereus* (*n* = 3, 5.0%)	Total (*n* = 60)
		Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n* (%)
1	Penicillin	19 (86.4%)	12 (80.0%)	0	4 (33.3%)	4 (100%)	3 (100%)	42 (70.0%)
2	Oxacillin	12 (54.5%)	12 (80.0%)	-	-	-	-	24 (64.9%)
3	Cefoxitin	12 (54.5%)	12 (80.0%)	-	-	-	-	24 (64.9%)
4	Ampicillin	-	-	0	3 (25.0%)	-	-	3 (18.8%)
5	Vancomycin	0	0	0	1 (8.3%)	0	0	1 (1.67%)
6	Erythromycin	9 (40.9%)	6 (40.0%)	0	6 (50.0%)	-	-	21 (39.6%)
7	Tetracycline	1 (4.5%)	3 (20.0%)	1 (25.0%)	5 (41.7%)	-	-	10 (18.9%)
8	Co-trimoxazole	0	5 (33.3%)	0	-	-	-	5 (12.2%)
9	Rifampicin	0	0	-	-	-	-	0
10	Moxifloxacin	11 (50.0%)	7 (46.7%)	-	-	-	-	18 (48.6%)
11	Levofloxacin	11 (50.0%)	7 (46.7%)	0	1 (8.3%)	-	-	19 (35.8%)
12	Linezolid	0	0	-	-	-	-	0
13	Clindamycin	8 (36.4%)	4 (26.7%)	0	-	-	-	12 (29.3%)
14	Gentamicin	0	4 (26.7%)	-	-	-	-	4 (10.8%)
15	Ciprofloxacin	11 (50.0%)	7 (46.7%)	-	1 (8.3%)	2 (50.0%)	-	21 (39.6%)

-: Not tested; [a]*Streptococcus* spp. included *S. dysgalactiae* (*n* = 2) and *S. agalactiae* (*n* = 2)

cefuroxime. Additionally, *E. coli* and *K. pneumoniae* displayed high resistance rates against ampicillin-sulbactam, cefuroxime, ceftriaxone, ceftazidime, ciprofloxacin, and co-trimoxazole. More than half of the *A. baumannii* isolates were resistant to all antimicrobial agents tested.

Discussion

Out of 1,826 surgical patients and 2,200 surgical procedures analysed in this study from November 2020 to May 2023, 71 patients developed an SSI, resulting in an observed SSI incidence rate of 3.89% among patients and 3.23 per 100 procedures. This is comparable to SSI rates reported in various surgical procedures in developed countries. In one such study, from the United States, which included general, neuro, orthopaedic, cardiothoracic, and obstetrics-gynaecology surgeries, the reported SSI rate was 1.08 per 100 procedures [8]. The SSI rate observed in this study is lower than previously reported rates from Malaysian hospitals and other LMIC. The Malaysian national HCAI PPS report documented that 16% of HCAI were due to SSI rate in 2022 [19]. In 2018, Wong et al. reported an SSI incidence of 11.7% in the surgical department of a public general hospital [14]. The rate of SSI in Sierra Leone in 2021 was 11.5%, while a rate of 7.5% was reported in a 2019 study from China [22, 23]. The lower rate observed at UMMC is likely in part due to the implementation of a hospital-wide multimodal SSI prevention bundle since 2018. The bundle included standardized guidelines, an SSI prevention checklist, improved communication, and education and training [24]. A quality improvement study on caesarean sections at UMMC in 2020 also showed a significant reduction in the SSI rate by 50% following the implementation of the SSI care bundle [25]. Other countries such as Poland and several African countries, that adopted the strategies based on the guidelines by the World Health Organization (WHO), also reported improvements in infection prevention, with SSI rates dropping by 1.4% and 4.2%, respectively [26, 27].

Our study found a higher incidence of SSIs in elderly patients aged ≥ 65 years, all of whom had pre-existing conditions such as diabetes, hypertension, and cancer. This finding is consistent with prior research that identifies older age as a notable risk factor for SSI [28, 29]. The higher susceptibility of the elderly to SSIs can be linked to the higher rate of concurrent medical conditions and age-related changes in the immune system, such as reduced phagocytosis, cellular migration, and antibody generation [30, 31]. Furthermore, studies have frequently identified diabetes as a risk factor for the possibility of SSI [32, 33]. This is likely because diabetic individuals have a weakened immune system, and prone to slower wound healing rates.

Our analysis revealed significant associations between several variables and the risk of developing SSI. Patients who experienced longer periods of hospitalization (> 5 days) were found to have a 2.7 times higher risk of developing SSI compared to those who were hospitalized for 5 days or less (OR = 2.7, 95% CI: 1.4–5.5, p-value = 0.034). Prolonged hospitalization exposes patients to healthcare environments for extended durations, increasing the risk of exposure to nosocomial pathogens and potentially

Table 6 Resistance profile of gram-negative bacteria

No	Antimicrobial agents tested	Proteus spp.[b] (*n* = 11, 16.7%)	*Pseudomonas aeruginosa* (*n* = 14, 21.2%)	*Escherichia coli* (*n* = 9, 13.6%)	*Acinetobacter* spp. (*n* = 9, 13.6%)	*Enterobacter cloacae complex* (*n* = 8, 12.1%)	*Klebsiella pneumoniae* (*n* = 11, 16.7%)	*Morganella morganii* (*n* = 1, 1.5%)	*Citrobacter koseri* (*n* = 1, 1.5%)	*Serratia* spp.[c] (*n* = 2, 3.0%)	Total (*n* = 66)
		Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance; *n*, (%)	Resistance, *n* (%)
1	Ampicillin	11[a] (100%)	-	8 (88.9%)	-	-	11[a] (100%)	1[a] (100%)	-	2[a] (100%)	33 (97.1%)
2	Piperacillin-tazobactam	1 (9.1%)	2 (14.3%)	1 (11.1%)	-	3 (37.5%)	6 (54.5%)	0	0	0	13 (22.8%)
3	Ampicillin-sulbactam	6 (54.5%)	-	8 (88.9%)	6 (66.7%)	-	10 (90.9%)	1[a] (100%)	-	-	31 (75.6%)
4	Amoxicillin-clavulanate	5 (45.5%)	-	6 (66.7%)	-	8[a] (100%)	9 (81.8%)	1 (100%)	0	1[a] (50.0%)	30 (69.8%)
5	Amikacin	0	1 (7.1%)	0	6 (66.7%)	0	0	-	0	0	7 (10.8%)
6	Gentamicin	1 (9.1%)	1 (7.1%)	2 (22.2%)	6 (66.7%)	1 (12.5%)	3 (27.3%)	0	0	0	14 (21.2%)
7	Cefuroxime	10[a] (90.9%)	-	7 (77.8%)	-	8 (100%)	10 (90.9%)	1[a] (100%)	0	2[a] (100%)	38 (88.4%)
8	Ceftriaxone	1 (9.1%)	-	5 (55.6%)	9 (100%)	3 (37.5%)	10 (90.9%)	0	0	0	28 (53.8%)
9	Ceftazidime	0	3 (21.4%)	5 (55.6%)	7 (77.8%)	3 (37.5%)	10 (90.9%)	0	0	0	28 (42.4%)
10	Ciprofloxacin	2 (18.2%)	1 (7.1%)	6 (66.7%)	6 (66.7%)	1 (12.5%)	7 (63.6%)	0	0	0	23 (34.8%)
11	Imipenem	11 (100%)	1 (7.1%)	0	6 (66.7%)	1 (12.5%)	1 (9.1%)	1[a] (100%)	0	0	21 (31.8%)
12	Meropenem	0	1 (7.1%)	0	6 (66.7%)	0	1 (9.1%)	0	0	0	8 (12.1%)
13	Co-trimoxazole	5 (45.5%)	-	7 (77.8%)	6 (66.7%)	3 (37.5%)	7 (63.6%)	0	0	0	28 (53.8%)

-: Not tested; [a] includes isolates which were tested but intrinsically resistant; [b] *Proteus* spp. includes *Proteus mirabilis* (*n* = 5), *Proteus vulgaris* (*n* = 2), and *Proteus penneri* (*n* = 4). Both *P. vulgaris* and *P. penneri* intrinsically resistant to ampicillin and cefuroxime; [c] *Serratia* spp. included both *Serratia marcescens* (*n* = 1) and *Serratia rubidaea* (*n* = 1). According to CLSI, only *S. marcescens* is known to be intrinsically resistant to ampicillin, cefuroxime, and amoxicillin-clavulanate

compromising immune responses [34]. Additionally, we identified notable differences in SSI rates based on the classification of surgical wounds. The relatively low SSI rate of 3% for clean wounds was consistent with established reports [35, 36], which estimate SSI rates for this category to be between 1% and 5%. In contrast, clean-contaminated wounds exhibited a higher SSI rate of 6.4%, with an OR of 2.2 (95% CI: 1.2–4.1, p-value = 0.014). However, in this study, contaminated wounds had significantly lower SSI rates of 0.9% with an OR of 0.3 (95% CI: 0.1–0.7, $p = 0.007$). The National Nosocomial Infection Surveillance System (NNIS) highlights the increasing infection risk from clean to dirty wounds [37], with dirty wounds having the highest risk [38].

Interestingly, while contaminated wounds are generally associated with a higher risk of infection, our findings suggest that hospitalization duration plays a more critical role in influencing SSI rates. Patients with contaminated wounds often underwent surgery earlier and had shorter hospital stays (≤ 5 days), resulting in a significantly lower SSI rate (0.26%). Conversely, patients with clean wounds had longer hospital stays (> 5 days), contributing to an increased SSI rate of 3.60%. This suggests that differences in SSI rates were largely attributable to variations in hospitalization duration, rather than inherent differences in wound class. Prolonged hospitalization increases exposure to nosocomial pathogens, weakens immune responses, and facilitates microbial colonization, thereby elevating SSI risk [34]. Our findings highlight the need for optimizing preoperative hospitalization duration to mitigate SSI risk. In particular, ensuring timely surgical intervention for all patients, including those with clean wounds, may help in reducing prolonged hospital exposure and subsequent infections.

This study also found a significant association between a longer duration from trauma to surgery (> 8 days) and the risk of developing SSI. Though sparse, existing literature suggests that prolonged exposure of the wound to environmental contaminants may increase infection likelihood, and delayed surgical intervention can impair tissue viability and wound healing, increasing susceptibility to infection [39]. In addition, the study found a significant association between the length of the operation and the likelihood of SSI. Our statistical analysis provided strong evidence of this correlation, with a significant odds ratio for SSI in procedures lasting longer than 100 min. The findings correspond to other existing literature across various surgical disciplines. The risk of SSI increases gradually with each additional minute of surgical duration [34]. Surgeries that exceed 2 h are linked to a higher rate of SSI due to continuous exposure to and contamination by microorganisms in the operating room, jeopardizing the body's immune systems [40, 41]. To improve postoperative outcomes and lower the number of SSIs in clinical practice, it is important to use strategies to make surgeries more efficient and cut down on operating times.

Simple logistic regression analysis suggests that surgery involving the use of implants had a higher risk of developing SSI compared to those without implants in this study, as shown by the OR of 1.9 (95% CI: 1.1–3.5, p-value = 0.033). Past studies conducted in both experimental and clinical environments [42, 43] have consistently found a correlation between implants and the increased likelihood of SSI. Implants, including plates and clips, have been associated with an increased risk of infection as a result of their capacity to facilitate biofilm formation and bacterial colonization [44]. The adhesion of bacteria and the subsequent infection rates can be significantly influenced by the prosthesis's design and material composition [45]. Implants can cause disturbances in tissue perfusion and impair leukocytes' capacity to counter bacterial colonization, thereby increasing the likelihood of infection [45, 46]. Although the initial simple logistic regression analysis suggested that surgeries with implants had a higher risk of SSI compared to those without implants, after accounting for other factors in the multivariable logistic regression analysis, implants were no longer a significant predictor of SSI. This change suggests that the initial association between implant use and SSI may have been due to other factors not considered in the simple analysis. Surgeries with implants might be more complex and longer, which could increase the risk of SSI. When these other factors were accounted for, the apparent impact of implants on SSI risk became less significant, indicating that the initial finding may have been influenced by these other factors.

The majority (57.9%) of the isolates cultured in this study were non-MDROs, while 42.1% were identified as MDROs. This MDRO percentage is notably lower compared to healthcare institutions in other countries. For instance, a study from Ethiopia found that MDROs caused 79.2% of SSIs [47], and another study from Nepal reported an MDRO prevalence of 64.6% in SSIs [48]. Although healthcare infrastructure and resources differ significantly between Malaysia and these low-income countries, this comparison highlights the varying challenges in addressing MDROs globally. The lower percentage of MDROs in our institution may be attributed to the effective application of antibiotic guidelines by UMMC personnel [49].

This study identified *S. aureus* as the most prevalent causative agent, in line with previous research. According to a surveillance study conducted from 2015 to 2017 across various hospitals in the United States, *S. aureus* was reported as the most common pathogen found in SSI [50]. The overall rate of MRSA found in this study is 9.5% ($n = 12/126$), accounting for a major portion of *S. aureus*

isolates ($n = 12/22$). Although we did not collect specific data on colonization rates among our patients, the literature suggests that colonization rates among adults range from 9 to 33% [51], and several studies have reported that a significant proportion of colonized patients will eventually develop SSI MRSA infections [52, 53]. This colonization could contribute to the major portion of *S. aureus* observed in our study. Risk factors for colonization include chronic underlying illness, extended hospitalization, administration of broad-spectrum antibiotics, and frequent contact with healthcare facilities or healthcare workers (HCW) [52]. Hence, active screening and decolonization of high-risk patients are therefore recommended. Specifically, preoperative nares screening and targeted decolonization using chlorhexidine gluconate (CHG) and nasal mupirocin have been shown to reduce MRSA SSI in surgeries involving implants. Effective environmental cleaning and the use of contact precautions, such as gloves and gowns for HCW dealing with MRSA-colonized or infected patients, are critical in reducing MRSA transmission [52, 54, 55]. These measures highlight the importance of comprehensive infection control strategies to mitigate the risk of SSIs.

There was a notable prevalence of coagulase-negative staphylococci (CoNS), particularly MRCoNS in our study, highlighting the role of wound contamination by the patient's own pathogens (endogenous infection) as causative factors in SSI. This finding supports prior studies that have identified MRCoNS as a prevalent organisms in SSI cases [56, 57]. To address this, it is crucial to reduce the patient's microbial burden before surgery. This can be achieved through measures such as antiseptic washes with chlorhexidine gluconate (CHG) [58, 59].

In this study, ciprofloxacin resistance was observed in 39.6% of Gram-positive isolates, while levofloxacin resistance was slightly lower at 35.8%. The observed discrepancy in susceptibility between these two fluoroquinolones may reflect variations in bacterial resistance mechanisms and mutations, such as alterations in DNA gyrase or topoisomerase IV [60, 61]. Additionally, differences in prior antibiotic exposures among patients may have contributed to these variations. Ciprofloxacin is more commonly used in clinical practice, potentially leading to higher resistance rates compared to levofloxacin [62], which is less frequently prescribed. These findings highlight the importance of understanding local resistance patterns to guide effective antibiotic therapy and stewardship programs.

We also observed the presence of MDR and ESBL production among Gram-negative bacilli, including *P. aeruginosa, K. pneumoniae, E. coli*, *A. baumannii*, *P. mirabilis*, and *E. cloacae*. Various risk factors contribute to the presence of Gram-negative MDRO in SSIs, including prior antibiotic use, hospital environment contamination, prolonged hospital stays, and immunosuppression [63–65]. This study also found that the occurrence rate of Gram-negative MDRO was higher than that of Gram-positive MDRO, a trend that has been concerning in recent years in upper-middle-income countries like China and Mexico [66, 67]. This higher occurrence rate of Gram-negative bacteria can be attributed to its intrinsic resistance mechanisms such as their outer membrane and efflux pumps, their ability to acquire resistance genes, biofilm formation, and the selective pressure from the extensive use of broad-spectrum antibiotics in hospitals [68–70]. This emergence of resistance in Gram-negative bacteria, including CRE and ESBLs, presents considerable obstacles in the field of antimicrobial therapy and infection control. The diversity of MDROs in SSIs emphasizes the need for infection prevention and antimicrobial stewardship. Adherence to infection control practices, such as wound care, hand hygiene, and the implementation of SSI bundle checklist is crucial [58]. The rise of MDR pathogens, especially Gram-negative, highlights the importance of prudent antibiotic use and treatment strategies based on local resistance trends [67, 71]. Using WHO Access Group antibiotics and following duration guidelines can help reduce MDRO emergence [72]. Collaboration among healthcare professionals, infection control teams, and researchers is key to combating antibiotic resistance and improving SSI outcomes.

Ten recruited SSI patients showed no bacterial growth in cultures taken from their infection sites, despite displaying symptoms consistent with an SSI diagnosis. A study on SSIs in South Korea also found that 40.6% of patients were culture-negative. This could be partly due to the administration of antibiotics before the sample swab was taken [73]. Another contributing factor might be the presence of viable but non-culturable (VBNC) bacteria. In this state, bacteria enter a survival mode in response to harsh conditions such as extreme temperatures, nutrient deprivation, or the presence of antibiotics [74]. This state impedes detection and identification through standard culture methods and may consequently contribute to antibiotic resistance [75].

Limitations

This study has several limitations. First, it was conducted at a single tertiary teaching hospital in an urban setting, which may limit the generalizability of the findings to other settings, particularly in different regions or states with varying healthcare infrastructures and practices. The observational nature of the study precludes the establishment of causality between the identified risk factors and SSIs. Additionally, due to the lack of informed consent from non-SSI patients, we were unable to extract demographic data for this group. Consequently, common SSI risk factors such as comorbidities, older age,

and smoking status could not be used for comparative analysis between SSI and non-SSI groups. The study also faced recruitment challenges, as some SSI patients sought treatment at other hospitals or institutions or refused to consent to participate. Moreover, the NNIS risk index was not applied in this study due to limitations in available data for certain components required for its full implementation, such as the ASA score. Instead, we focused on the clinical factors available in the patient records and the surgical data for our analysis. The study did not assess the appropriateness of surgical antibiotic prophylaxis, a key factor in preventing SSIs due to incomplete data. Prior research highlights its significant association with reduced SSI incidence, representing an important area for future investigation. The study period coincided with the COVID-19 pandemic, which might have influenced hospital operations, infection control practices, and patient outcomes, potentially confounding the results. Future studies should adopt multicentre designs, evaluate antibiotic prophylaxis, and address confounding factors for more comprehensive insights into SSI prevention.

Conclusion

The incidence rate of SSI in this study is 2.74 per 100 procedures with a high prevalence of MDROs (42.1%). In this study, several preventable risk factors for SSI were identified which were extended hospital stays, a longer interval between time of trauma to surgery, prolonged surgery duration, and the presence of implants. This emphasises the need for ongoing surveillance to understand local epidemiology of SSI, to guide the development of infection prevention strategies and antimicrobial stewardship programs to tackle evolving resistance trends. Future efforts should focus on implementing and evaluating targeted interventions tailored to the identified risk factors to improve surgical outcomes and patient safety.

Abbreviations

ASA	American society of anaesthesiologists
CHG	Chlorhexidine gluconate
CRE	Carbapenem-resistant enterobacteriaceae
CoNS	Coagulase-negative staphylococci
ESBL	Extended-spectrum β-lactamases
GNR	Gram-negative rods
HAI	Hospital-acquired infection
HCAI	Healthcare-associated infections
HCW	Healthcare workers
LMIC	Low-middle income countries
MDRO	Multidrug-resistant organisms
MRCoNS	Methicillin-resistant coagulase negative staphylococci
MRSA	Methicillin-resistant staphylococcus aureus
OR	Odd ratio
PPS	Point prevalence survey
SSI	Surgical site infection
XDR	Extensively drug-resistant
VBNC	Viable but non-culturable
VRE	Vancomycin-resistant enterococci

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Author contributions

Conceptualization - CSJT, SSLSP, and MJG; Resources - CSJT, RDH, and SSLSP; Methodology - CSJT, SSLSP, AAA, MJG, and TLK; Investigation - ANM, SNT, RK, MRD, YKA, VN, and CYC; Validation - CSJT, SSLSP, VN, TLK, and AAA; Formal analysis - ANM, NAM, AK, and SZMR; Visualization - ANM, NAM; Supervision - CSJT, RDH, HCN, MJG, AS, AGL, and SSLSP; Writing–Original Draft - ANM, SSLSP, and CSJT; Writing– review & editing– all authors. All authors have read and agreed to the published version of the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the Medical Research Ethics Committee (MREC) of the University Malaya Medical Centre (UMMC) on 13 July 2020 (MREC-ID No.: 2020616-8769) in compliance with all applicable federal regulations governing the protection of human subjects. Extramural research review was conducted following the U.S. Navy Human Research Protection Program guidelines (HPRO.NAMRU2.2019.0009). All research activities conformed to the principles embodied in the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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