

Rectal Colonization with Carbapenemase-Producing *Enterobacteriaceae* in Pre-Operative Patients: Prevalence, Risk Factors, and Surgical Outcomes

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Received July 7, 2025; Accepted August 16, 2025; Online Published September 20, 2025

Abstract

Background: Emergence and dissemination of resistance to carbapenems among carbapenemase-producing *Enterobacteriaceae* (CPE) has led to limited therapeutic options for patients infected with CPE.

Objectives: This study aimed to determine the prevalence of CPE colonization among newly admitted patients scheduled for surgery, identify the risk factors for acquiring CPE, and assess post-surgical outcomes among CPE carriers.

Methods: A total of 152 patients scheduled for various types of planned surgery were included in the study. Two rectal swabs were collected from each patient and processed following the CDC-recommended method for screening Carbapenem-resistant *Enterobacteriaceae* (CRE). Probable CRE colonies were then tested using the mCIM for carbapenemase production according to CLSI guidelines. Patients were followed up after two months to monitor for any post-surgical infections. Surveillance swab sampling was conducted to detect the spread of CPE in the hospital environment by CPE carriers.

Results: A high occurrence (15.13%) of CPE colonization was recorded in patients admitted for different planned surgeries. A history of antibiotic therapy was significantly associated with CPE acquisition ($P < 0.001$). A significantly higher proportion of CPE carriers developed post-surgical infections compared to non-carriers (87% vs. 13.1%; $P < 0.0001$). All the patients who developed post-surgical infections with CRE were already harboring CPE in their intestines. On environmental sampling, 15 (65.2%) of the 23 CPE-colonized patients were found to be positive for CPE.

Conclusion: High rates of intestinal carriage of CPE among freshly admitted patients, as detected in our study, pose a risk to individuals for CPE infection, leading to antibiotic therapy, long-term hospital stays, and loss of daily wages. Therefore, infection control policies should be formulated by hospitals to screen for CPE carriage during hospital admission, followed by containment of CPE to prevent transmission.

Keywords: Carbapenem-Resistant *Enterobacteriaceae* (CRE), Carbapenemase-Producing *Enterobacteriaceae* (CPE), Surveillance, CRE Screening, Post-Operative Infection

1. Background

Carbapenems are considered the cornerstone for treating severe and life-threatening infections caused by Extended-spectrum beta-lactamase (ESBL) producing *Enterobacteriaceae*. However, the emergence and rapid spread of carbapenem resistance have significantly limited treatment options for patients infected with carbapenemase-producing *Enterobacteriaceae* (CPE), as these organisms are often resistant to all β -lactam antibiotics and many other antimicrobial classes. The frequent co-existence of additional resistance genes further complicates therapeutic management and is associated with poorer clinical outcomes.¹⁻³ In recent times, it has become a serious threat to public health due to the high mortality, increased length of hospital stay,

and increased cost of health care associated with these organisms.¹ Intestinal colonization by CPE can serve as a reservoir for the transmission of these pathogens, particularly in enclosed environments such as hospitals. The prevalence of gastrointestinal carriage of CPE has been reported to range from 0.3% to 18.3% globally, based on data from single-center studies.⁴ The environment and colonized patients are continuous exogenous sources from which other patients can be colonized via the transiently colonized hands of healthcare workers.³ Surveillance for multidrug-resistant organisms in stool or rectal swab samples is not routinely performed in most hospitals because of cost and technical difficulties. CPE screening to identify asymptomatic carriers and formulating infection control measures for

CPE containment is of utmost importance in preventing transmission of carbapenem-resistant pathogens and improving patient outcomes. There are different methods of CPE screening and detection recommended by the Clinical and Laboratory Standards Institute (CLSI) guidelines. According to the CLSI 2022 guidelines,⁵ testing of *Enterobacterales* for carbapenemase production by the CarbaNP test, the modified carbapenem inactivation method (mCIM), EDTA-modified carbapenem inactivation method (eCIM), and molecular tests should be done only for epidemiological or infection prevention purposes. The Centers for Disease Control and Prevention (CDC) has formulated guidelines for screening and controlling the transmission of Carbapenem-resistant *Enterobacteriaceae* (CRE).³ However, infection prevention strategies should be structured based on the local epidemiology of CRE carriage, at-risk patient populations, and available resources.

The majority of studies have identified prolonged hospital stays, treatment with broad-spectrum antibiotics, indwelling devices, and stays in intensive care units (ICUs) as high-risk factors for CPE colonization.^{2,4} However, there is very limited data available regarding community-acquired CPE in India, which could enter hospitals and pose a threat to admitted patients.

2. Objectives

This study was designed to screen newly hospitalized pre-operative patients for colonization with CPE by rectal swab culture in a tertiary center in eastern India. We also tried to point out the risk factors associated with the acquisition of CPE and post-operative outcomes among CPE carriers.

3. Methods

A longitudinal study was conducted over three months from August to September 2022, involving newly admitted patients scheduled for various elective surgeries

in the Departments of General Surgery, Orthopaedics, and Gynaecology & Obstetrics. Patients were enrolled in the study after obtaining informed consent. Patients undergoing emergency procedures, ophthalmic or ENT surgeries, critically ill patients, and patients on ventilators were excluded. The study was approved by the Institutional Ethics Committee under letter no. 20/IEC/2018-2019.

After patient allocation, two rectal swabs were collected from each study subject pre-operatively and promptly transported to the microbiology laboratory. The rectal swabs were processed following the CDC-recommended culture method for CRE screening.⁶ Briefly, a 10- μ g meropenem disc was aseptically placed in 5 ml of trypticase soy broth (TSB). The broth was then inoculated with the rectal culture swab and incubated overnight at 35 ± 2 °C. The next day, subculture was performed with 100 μ l of the broth onto a MacConkey agar plate and incubated overnight at 35 ± 2 °C. The MacConkey agar plate was then examined for lactose-fermenting (pink-red) colonies. Lactose-fermenting colonies were marked as "probable CRE" colonies and stocked in glycerol saline broth. Speciation of these isolates was done using Vitek® 2 Compact (BioMerieux, France). The modified carbapenem inactivation method (mCIM) was performed (Figure 1) and interpreted for phenotypic confirmation of carbapenemase production according to the CLSI guidelines.⁵ The study population was designated as "Patients colonized with CPE" and "Patients negative for CPE" according to the mCIM positive and negative results of the isolates, respectively. A repeat mCIM test was done in case of an indeterminate result. Targeted environmental sampling was conducted for CPE-colonized patients to detect CRE. Surface swab samples were collected from patients' beds, bed linens, bedside tables, cardiac tables, bed railings, etc. The samples were processed similarly to rectal swabs.

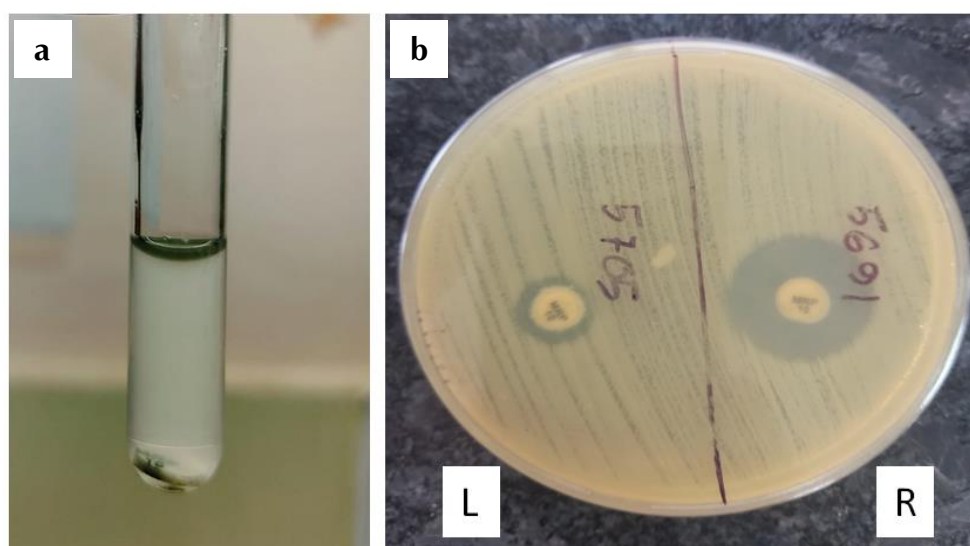


Figure 1. (a) 10 μ g Meropenem Disc in Bacterial Suspension Tube; (b) mCIM result: L) Carbapenemase Positive, R) Carbapenemase Negative.

All patients were followed up at the end of two months to document post-operative outcomes. In case of post-surgical infection, appropriate samples were collected and sent to the microbiology department for culture. The samples were processed according to standard microbiology techniques. The identification and antibiotic susceptibility testing were done using Vitek® 2 Compact (BioMerieux, France).

Normally distributed data were presented as mean with standard deviation (SD), and skewed distributed data were presented as median with interquartile range (IQR). Group differences were assessed using a Chi-square test or Fisher's exact test for categorical variables. For non-normally distributed continuous variables, the Mann–

Whitney U test was applied. In all statistical tests, the *P*-value was considered less than 0.05.

4. Results

A total of 304 rectal swabs were collected from 152 patients who met the inclusion criteria, with two swabs collected from each patient. The age of the patients ranged from 15 to 76 years, with a median age of 40. No pediatric surgical cases were present in our study. The majority (42%) of the patients belonged to the age group of 40-60 years. 80.3% of the study population were female. The majority of the patients (28.3%) were admitted for minor surgical procedures such as abscess drainage, diagnostic laparoscopy, and medical termination of pregnancy (Table 1).

Table 1. Demographic Distribution of Study Population (n = 152)

Distribution according to age group and sex			
Age (Years)	Male	Female	Total n = 152 (%)
<20	1	5	6 (3.94)
20-40	10	53	63 (41.4)
40-60	13	51	64 (42.1)
>60	6	13	19 (12.5)
Total	30 (19.7)	122 (80.3)	152
Patients undergone different types of surgery			
1. Minor surgical procedure			43 (28.3)
2. Cholecystectomy			39 (25.6)
3. Hysterectomy			21 (13.8)
4. Orthopaedic operations			15 (9.8)
5. Hernioplasty			7 (4.6)
6. Laprotomy			6 (3.9)
7. Mastectomy and drainage of breast abscess			5 (3.2)
8. Anal fistulotomy			4 (2.6)
9. Appendectomy			1 (0.6)
10. Others			11 (7.2)

Out of 152 patients, 54 (35.52%) patients tested positive for "probable CRE" in the screening test, and a total of 82 *Enterobacteriaceae* isolates were identified, consisting of *Escherichia coli* (50, 61%) and *Klebsiella pneumoniae* (32, 39%). Carbapenemase producers identified by mCIM were detected in 23 patients who were classified as "CPE carriers," while the remaining 129 patients who did not harbor CPE were classified as "CPE non-carriers" (Figure 2).

We also determined the risk factors associated with CPE colonization and compared them with the patients without CPE colonization (Table 2). A history of antibiotic intake within the previous thirty days was significantly associated with CRE colonization ($P < 0.001$). Other factors such as previous hospital admission, previous surgery, previous GI surgery, and diabetes were more common in CPE carriers but statistically insignificant. The incidence of post-surgical infection among the study population was found to be 146 per 100 patients per year.

On analysis of post-surgical outcomes (Table 3), a significantly higher proportion of CPE carriers developed post-surgical infections compared to non-carriers (87% vs. 13.1%; $P < 0.0001$), with an odds ratio (OR) of 43.92 (95% CI: 11.78–163.82). Urinary tract infections (UTIs) and surgical site infections were significantly more common in CPE carriers than in non-carriers. Notably, pathogens were isolated from the site of infection in 82.6% of CPE carriers, whereas only 8.5% of non-carriers had positive cultures ($P < 0.0001$). CRE organisms were exclusively isolated from CPE carriers (30.4%), and none from non-carriers. CPE carriers were also more likely to experience prolonged hospital stays exceeding 3 days ($P < 0.0001$) and required more frequent repeat hospital visits ($P < 0.0001$). Furthermore, 91.3% of CPE carriers required antibiotic therapy, compared to only 14.7% of non-carriers ($P < 0.0001$). On environmental sampling, CPE was isolated from the environmental surfaces of 15 (65.2%) CPE-colonized patients.

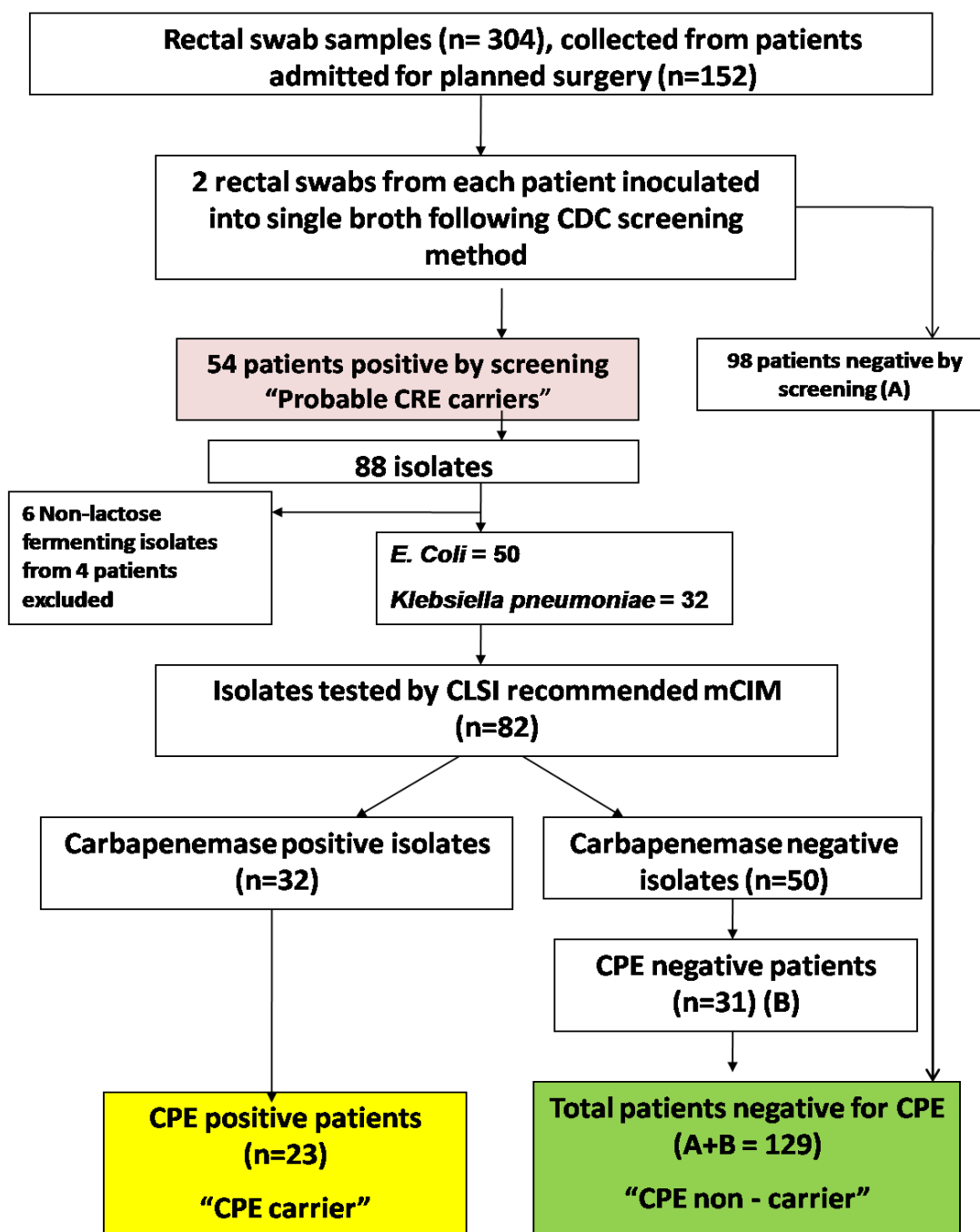


Figure 2. Schematic Presentation of CPE Screening Results.

Table 2. Comparison of Risk Factors Associated with Patient Colonized with CPE and Patient Negative for CPE (n = 152)

Variable	CPE carrier n = 23	CPE non-carrier n = 129	P	Odds Ratio (OR)	CI of OR
1. Sex					
Male	6 (26.09)	24 (18.60)	0.4	1.54	0.55-4.32
Female	17 (73.91)	105 (81.40)			
2. Previous hospital admission	15 (65.21)	66 (51.16)	0.21	1.78	0.71-4.51
3. Previous surgery	8 (34.78)	37 (28.68)	0.55	1.32	0.51-3.39
4. Previous GI surgery	3 (13.04)	9 (6.98)	0.32	2.0	0.49-8.02
5. Previous antibiotic intake within last 30 days	17 (73.91)	32 (24.80)	<0.001*	8.58	3.11-23.64
6. Previous chronic disease	7 (30.43)	52 (40.31)	0.37	0.64	0.24-1.68
7. Diabetes	3(13.04)	12 (9.30)	0.57	1.46	0.37-5.64

GI: Gastrointestinal

Table 3. Post Surgical Outcome Analysis among CPE Carriers and Non-carriers

Risk factors	Total	CPE carrier n = 23 (%)	CPE non-carrier n = 129 (%)	P	Odds Ratio (OR)	CI of OR
Post surgical Infection	37	20 (87)	17 (13.1)	<0.0001	43.92	11.78 – 163.82
UTI	26	13 (56.5)	13 (10.0)	<0.0001	11.60	4.25 – 31.66
SSI	6	4 (17.4)	2 (1.5)	0.0003	13.37	2.29 – 78.06
Fever	7	2 (8.7)	5 (3.9)	0.30	2.36	0.43 – 12.98
Pathogen isolated from site of infection	30	19 (82.6)	11 (8.5)	<0.0001	50.95	14.70 – 176.56
<i>E. coli</i> and <i>K. pneumoniae</i> isolated from infection	19	13 (56.5)	6 (4.7)	<0.0001	26.65	8.33 – 85.21
CRE isolated	7	7 (30.4)	0 (0)	NA	NA	NA
Extended hospital stay > 3 days	69	20 (87)	49 (38)	<0.0001	10.88	3.07 – 38.54
Require repeat hospital visit	41	18 (78.2)	23 (17.8)	<0.0001	16.59	5.58 – 49.28
Require antibiotic therapy	40	21 (91.3)	19 (14.7)	<0.0001	60.80	13.16 – 280.73

UTI: Urinary tract infection; SSI: Surgical; NA: Not applicable.

5. Discussion

Gram-negative bacteria, specifically *Enterobacteriaceae*, are common causes of both community-acquired and hospital-acquired infections, including urinary tract, bloodstream, and lower respiratory tract infections.⁷ These bacteria can acquire genes encoding multiple antibiotic resistance mechanisms, including extended-spectrum β -lactamases (ESBLs), AmpCs, and carbapenemases.⁸ Carbapenems have been regarded as the antibiotic of choice to treat infections caused by extended-spectrum β -lactamase (ESBL)-producing strains. Increasing rates of carbapenem resistance, especially among members of the *Enterobacteriales* family, pose a serious regional and global challenge.⁹ CRE are at the top of the WHO Bacterial priority pathogen list for 2024, as they are often resistant to all β -lactam drugs and frequently carry mechanisms conferring resistance to other antimicrobial classes, further limiting treatment options.¹⁰ Carbapenem resistance arises through various mechanisms, including: (1) structural changes in penicillin-binding proteins (PBPs), (2) loss or reduction of outer membrane porins, (3) activation of efflux pumps, and (4) production of β -lactamases or carbapenemases that degrade β -lactam antibiotics.^{11,12} Resistance can also result from CTX-M and AmpC enzyme combinations, leading to low-level resistance, while co-expression of β -lactamases with porin mutations contributes to high-level resistance and reduced treatment efficacy.¹³

Overall, CRE can develop resistance either through chromosomal mutations in porin genes (non-carbapenemase-producing CRE) and/or by producing carbapenem-hydrolyzing enzymes (carbapenemase-producing CRE). The expression of carbapenemase genes alone typically accounts for resistance in about 30% of CRE cases.¹² Common types of carbapenemases present in *Enterobacteriaceae* are known as KPC (*Klebsiella pneumoniae* carbapenemase), NDM (New Delhi Metallo-beta-lactamase), and OXA (Oxacillin-hydrolyzing carbapenemase).¹⁴

The emergence and spread of CP-CRE are significant clinical and public health concerns because carbapenemase genes are carried on mobile genetic elements that can be spread horizontally to naive bacteria, thus contributing to the reservoir of resistance in both environmental and clinical *Enterobacteriaceae*.⁸ Many CRE-colonized individuals

do not develop infections; however, they can still spread the bacteria.³ With very limited therapeutic options, prevention of CRE infections through active surveillance, containment, and judicious use of antibiotics is of utmost importance.

The alarming increase in CRE prevalence worldwide is worrisome. In many endemic settings in the UAE and Iran, prevalence as high as 24.7% to 29.8% has been noted.^{15,16} Currently, there are no recommendations for routine surveillance of faecal carriage in India. Our study recorded a very high occurrence of 35.52% of CRE colonization in patients admitted for different planned surgeries. These patients are newly admitted to the hospital, not more than 24 hours ago. This result is in contrast to the report by Rai et al., which found a 9.9% faecal carriage rate in outpatients attending their hospital.¹⁷ However, a study from a tertiary care center showed an 18.1% CRE colonization rate among hospitalized patients.⁴ A study from South India reported a 3% estimated carbapenem resistance rate among clinical *Enterobacteriaceae* isolates, with a 4-fold higher resistance rate (~12%) for ertapenem.¹⁸ In this study, 23 patients (15.13%) were found to be colonized by CPE, which is comparable to the 16.14% found in a study by Fernandes-Pineda et al.¹⁹ A study from Kolkata showed that 16.9% of stool surveillance isolates and 23% of clinical isolates were carbapenem-resistant.²⁰

We also tried to analyze the risk factors that may play a role in CPE faecal colonization. The factors significantly present in CPE-colonized patients included previous hospitalization, previous surgical procedures, previous gastrointestinal surgery, previous antibiotic intake, presence of chronic disease, and diabetes. As our patients were hospitalized for a very short time, the length of hospital stay, presence of indwelling devices, and stay in the intensive care unit were not included in this study. A similar association has been reported previously during the study of risk factors for acquiring CRE infections.^{2,4} It is known that broad-spectrum antibiotics, such as carbapenems, can destroy the susceptible proportion of strains that are part of the normal flora, allowing infection to be caused by the resistant ones. It has been documented that other classes of antimicrobials, namely cephalosporins, fluoroquinolones, vancomycin,

metronidazole, and carbapenems, can also contribute to this issue. Exposure to multiple antibiotics leads to antibiotic selection pressure and, consequently, the emergence of resistant strains.²¹⁻²³

In this study, we assessed the clinical outcomes associated with colonization by carbapenemase-producing *Enterobacteriaceae* among hospitalized patients. Our findings indicate that CPE colonization is significantly associated with adverse clinical outcomes, including higher rates of post-surgical infections, urinary tract infections, surgical site infections, prolonged hospital stays, repeat hospital visits, and the need for antibiotic therapy. CPE carriers were nearly 44 times more likely to develop post-surgical infections compared to non-carriers. This strong association underscores the pathogenic potential of colonizing CPE strains and their likely role in transitioning from colonization to invasive infection under compromised host conditions, such as after surgery. Similarly, the markedly higher odds of urinary tract infections and surgical site infections among carriers (OR: 11.60 and 13.37, respectively) point to the clinical burden posed by CPE colonization, particularly in settings where mucosal or skin barrier integrity is compromised. In a study from Jodhpur,²⁴ a high proportion of CRE infections (89.2%) have been reported in previously colonized patients. Pneumonia (36.4%), surgical site infections (21.2%), blood-stream infections (3.0%), and urinary tract infections (12.1%) were reported in the study.

In other studies, the cumulative rate of infection has been found to be 16.5% in CRE-colonized patients. The most common site of infection was the lung, followed in decreasing frequency by the urinary tract, primary bloodstream, and skin and soft tissue, including surgical sites.²⁵ A higher mortality rate (56.7%) in patients infected with CPE than in patients infected with carbapenemase nonproducers (47.7%) was reported previously.² Previous studies have suggested that the removal of the focus of infection, such as a catheter, debridement, or drainage, is an effective way of improving survival among patients with carbapenem-resistant *Klebsiella pneumoniae* infections.²

Our study has certain limitations. First, the relatively small number of CPE carriers limits the generalizability of our findings. Second, we did not perform molecular typing to characterize the specific carbapenemase genes or their transmission dynamics.

6. Conclusion

CPE colonization is a significant predictor of poor clinical outcomes, including a higher risk of infection, increased antibiotic use, and a greater healthcare burden. Active surveillance, strict infection control practices, and antimicrobial stewardship are essential strategies to mitigate the risks associated with CPE colonization in hospital settings. Surveillance culture becomes an essential

tool in infection control programs, not only during outbreaks but also as a routine measure in settings endemic for CRE. Therefore, the target patient population and timing for CRE screening should be dependent on local epidemiological data for risk stratification, and policies should be formulated by hospital infection control authorities.

Research Highlights

What Is Already Known?

CPE infections pose a serious threat due to limited therapeutic options. Gastrointestinal colonization by CPE is considered a key source of transmission in healthcare settings. Surveillance cultures are increasingly recognized as important tools in infection control programs.

What Does This Study Add?

This study identifies a high rate of CPE colonization among patients admitted for planned surgeries. CPE carriers had a significantly higher risk of post-surgical infections. These findings highlight the need for pre-admission CPE screening and containment strategies to prevent hospital-acquired CPE infections.

Author Contributions

SD: Investigation, Writing - Original Draft, Data Curation; KV: Writing - Review & Editing, Data Curation, Formal Analysis; RG: Investigation, Writing - Original Draft, Writing - Review & Editing, Project Administration, Supervision, Resources; SB: Writing - Original Draft, Writing - Review & Editing, Project Administration, Supervision; NA: Writing - Original Draft, Writing - Review & Editing, Project Administration, Supervision.

Conflict of Interest Disclosures

All authors declared that they have no conflict of interest.

Funding/Support

This research received no external funding.

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