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Predictors of carbapenem-resistant Enterobacterales enteric colonization among patients admitted to a companion animal intensive care unit

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Objective
To estimate prevalence and identify factors associated with carbapenem-resistant Enterobacterales (CRE) enteric colonization in companion animals admitted to an ICU.

Methods
The study population included canine and feline patients admitted to The Ohio State University Veterinary Medical Center ICU between January 2024 and June 2025. In total, 5,552 rectal swabs were collected from 3,834 patients during routine screening. A retrospective case-control study included all CRE-positive patients (n = 61) and randomly selected CRE-negative controls (137). Cases were defined as ICU patients with at least 1 positive CRE fecal culture during hospitalization, whereas controls had no positive CRE fecal cultures during their hospitalization.

Results
Prevalence of CRE colonization was 1.59% (61 of 3,834 patients; 95% CI, 1.24% to 2.04%). *Escherichia coli* carrying bla_{NDM} was the most frequently identified isolate, accounting for 78.7% (48 of 61 patients; 95% CI, 66.9% to 87.1%). Predictors of CRE colonization included increased comorbidity burden (unit OR, 1.96; 95% CI, 1.43 to 2.75), intact reproductive status (OR, 4.39; CI, 1.47 to 11.03), longer hospitalization (unit OR, 1.31; CI, 1.14 to 1.53), recent surgery (OR, 2.72; CI, 1.29 to 5.87), and antimicrobial use within the previous 3 months (OR, 2.71; CI, 1.23 to 6.07).

Conclusions
These predictors suggest targets for infection prevention and control measures to protect patients and staff. The association between recent antimicrobial exposure and CRE colonization reinforces the importance of antimicrobial stewardship in veterinary medicine.

Clinical Relevance
Although uncommon, CRE-colonized patients can serve as reservoirs for transmission and are at risk of subsequent infection.

Keywords: carbapenem-resistant Enterobacterales, CRE, veterinary intensive care, surveillance, enteric colonization

β-Lactam antibiotics are among the most frequently prescribed drug classes, used across a wide range of clinical indications. Based on structural differences, they are classified into penicillins, cephalosporins, carbapenems, and monobactams, along with β-lactamase inhibitors that protect these agents from enzymatic degradation.[1]

Among the β-lactams, carbapenems have the broadest spectrum of activity and are the most potent against gram-positive and gram-negative bacteria. As a result, carbapenems are often reserved for the treatment of highly resistant and/or life-threatening invasive infections in humans and animals, yet bacterial acquired resistance to carbapenems has emerged as an important antimicrobial resistance threat. Of primary concern are the carbapenem-resistant Enterobacterales (CRE) harboring mobile genetic elements that encode for production of carbapenemase that can inactivate all β-lactam antimicrobials.[2] Carbapenem-resistant Enterobacterales also frequently acquire resistance to other classes of antimicrobial drugs, making them extremely difficult to treat.[3]

Carbapenem-resistant Enterobacterales pose a significant threat in human clinical settings, particularly among

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high-risk patient populations such as those housed in ICUs. They produce opportunistic healthcare-associated infections, including pneumonia, bloodstream infections, and urinary tract infections.[4] Infections that are caused by CRE in ICU patients have been linked to high mortality rates.[5] In 2011, the NIH Clinical Center in Bethesda, Maryland, experienced an outbreak of CRE resulting from a carbapenem-resistant *Klebsiella pneumoniae*. Despite the use of aggressive infection control measures, CRE ultimately colonized or infected 18 patients, resulting in 11 deaths.[6] The epidemiologic investigation indicated that patients who were asymptomatically colonized, together with environmental reservoirs in the facility, contributed to nosocomial transmission on shared medical equipment.[6]

Carbapenem-resistant Enterobacterales present a similar risk to patients in veterinary hospitals. In companion animal ICUs of large veterinary referral centers, the transmission of CRE occurs mainly because of the high density of susceptible patients, invasive interventions, and patients receiving antimicrobial treatments including the use of last-resort antimicrobials.[7,8] In 2020, a retrospective review[9] of a large university veterinary hospital's records identified 6 animals with carbapenem-resistant *Escherichia coli* isolated from clinical infections. All the animals were housed in the ICU for more than 24 hours, with each overlapping in time with more than 1 other affected animal. All samples were collected from respiratory specimens, except for 2 urine isolates from a single dog.

Companion animals may serve as potential reservoirs for antimicrobial-resistant bacteria that can colonize or infect humans. In addition, companion animals can acquire antimicrobial-resistant bacteria via multiple routes, including animal or human contact, raw pet food products, and environmental exposure during outdoor activities.[10,11] Until recently, animals were thought to play a minor role in the spread of CRE.[12] However, reports of sporadic infections in dogs caused by CRE in Germany,[13] Spain,[14,15] and the US[9,16–20] suggest that companion animals might be an overlooked reservoir of CRE. However, data on CRE fecal colonization in companion animals, particularly regarding prevalence and risk factors in ICU settings, remain limited. Understanding the epidemiology of CRE colonization in veterinary ICUs is essential for guiding infection prevention and control and antimicrobial stewardship strategies, as colonized patients may serve as reservoirs for disease transmission.

The purpose of this study was to identify predictors of CRE fecal colonization among canine and feline patients admitted to the ICU at The Ohio State University (OSU) Veterinary Medical Center (VMC). The process of identifying colonized patients and characterizing admission prevalence provides important context for interpreting identified predictors and helps inform infection prevention and control efforts by supporting early detection, reducing nosocomial transmission risk, and guiding rapid response strategies to prevent potential outbreaks within the ICU.

Based on previous literature and human studies, we hypothesized that both host-related and clinical factors, including recent antimicrobial exposure, increased comorbidity burden, prolonged hospitalization, recent surgical procedures, raw diet consumption, and other healthcare- or contact-associated exposures (eg, boarding or immunosuppressive therapies), were associated with increased odds of CRE colonization.

Materials and Methods

Setting and sample population

This retrospective case-control study used data from canine and feline patients admitted to the ICU at the OSU VMC, a tertiary referral hospital, between January 2024 and June 2025. The ICU can accommodate approximately 40 patients at full capacity, with a typical daily census of 20 to 25 patients. As part of routine medical examinations, fecal swabs for CRE screening were collected from all ICU patients upon admission and every 48 hours thereafter during hospitalization. Cases included all patients with enteric CRE colonization identified by fecal surveillance culture, defined as at least 1 CRE-positive culture detected at any time during their ICU stay. Controls were randomly selected from patients that remained CRE-negative on all fecal surveillance cultures collected throughout hospitalization. All eligible CRE-negative patients were assigned a unique numerical identifier. A random number generator (https://www.calculator.net/random-number-generator.html) was used to randomly select the control patients included in the study. Patients with a documented CRE-positive status were assigned a permanent label alert in the electronic medical record, prompting fecal screening at every future visit to the VMC.

Each patient's fecal swab was inoculated into MacConkey broth modified with meropenem (0.5 µg/mL) and zinc (70 µg/mL) for enrichment. Each tube was incubated during 18 to 24 hours at 37 °C. After incubation, the MacConkey broth was inoculated onto selective MacConkey agar containing 0.5 µg/mL of meropenem and 70 µg/mL of zinc sulfate and streaked for isolation. Colonies that were observed on the selective agar were subcultured onto Mueller-Hinton agar supplemented with meropenem (0.5 µg/mL) and zinc (70 µg/mL). Isolates were tested for carbapenemase production (Carba NP assay),[21] screened for CRE genotype with a rapid and visual immunochromatographic assay (NG-Test Carba-5; Hardy Diagnostics), and identified with matrix-assisted laser desorption ionization–time of flight following the manufacturer's protocol (Bruker Scientific). Antimicrobial susceptibility tests were performed via microbroth dilution to determine the minimum inhibitory concentrations of a panel of antimicrobials included in a commercial plate panel (Sensititre Companion Animal Gram Negative COMPGN1F Vet AST Plate; Thermo Fisher Scientific). Plate reading was performed with a commercial system (Biomic; Giles Scientific), and minimum inhibitory concentration interpretation was performed following Clinical and Laboratory Standards Institute recommendations.[22] Because meropenem was not included in the commercial plate panel, additional testing was performed on isolates categorized as susceptible or intermediate to imipenem in the commercial plate panel.

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Data extraction

Patient data were extracted from a cloud-based veterinary practice management software (EzyVet; Idexx) that includes all patient medical records. For this study, the following information was extracted for each patient: reproductive status, breed, weight, age, number of comorbidities, duration of hospitalization, history of boarding or daycare in the past 6 months, raw diet status, and whether the patient underwent surgery at the OSU VMC within the last 6 months.

Additionally, data were collected on whether the patient had any of the following procedures or received these treatments during hospitalization: ultrasound, MRI, CT, dialysis, chemotherapy, or corticosteroids. Antimicrobial use was also recorded and categorized into 3 time periods: during the 3 months prior to hospitalization, between 3 and 6 months prior to hospitalization, and during hospitalization. Antimicrobials were also categorized by their respective drug classes, and the number of different classes of antimicrobials administered was quantified.

Information regarding raw diet consumption and boarding/daycare attendance was unavailable for some patients because this information was not consistently documented in the medical record and was recorded as missing values for analysis. Patients with missing data were excluded only from analyses involving the corresponding variable. Additional details regarding the definition and determination of each study variable are provided in **Table 1**.

Statistical analysis

The outcome of interest was patient CRE colonization status during ICU hospitalization. All additional patient variables were investigated as possible predictors based on previously reported risk factors for CRE colonization and infection, primarily from the human medical literature and studies of other multidrug-resistant organisms in veterinary medicine.[23–27]

The Pearson χ^2 test or Fisher exact test, as appropriate, was used to assess the unadjusted association between each variable and the outcome of colonization with CRE. Variables that were associated with CRE colonization status on initial screening ($P < .05$) were included in a multivariable logistic regression analysis to assess their adjusted association with patient colonization status. Final models were developed via a backward stepwise selection process with $P < .05$ as criteria to remain in the model. All statistical analyses were performed with JMP Pro 18 (SAS Institute Inc) and Excel (Microsoft Corp). Model fit was assessed with the Hosmer-Lemeshow goodness-of-fit χ^2 test.[28] Potential collinearity among the independent variables was assessed via variance inflation factors with low values (range, 1.02 to 1.11) interpreted to indicate no evidence of problematic collinearity.[29]

This study was reviewed and approved by the OSU IACUC (protocol No. 2024A00000075). Informed owner consent was obtained as part of the hospital admission process.

Results

The study population consisted of 198 animals, including 61 cases and 137 controls. Most animals were canine (80.3% of cases, 72.3% of controls), and the sex distribution was similar between groups, with males representing 57.4% of cases and 51.8% of

Table 1—Definitions of the outcome and predictor variables evaluated for their association with carbapenem-resistant Enterobacterales (CRE) colonization among canine and feline patients admitted to the ICU at The Ohio State University Veterinary Medical Center (OSU VMC).

Variable	Definition
CRE colonization status	Cases included all patients with enteric CRE colonization identified by fecal surveillance culture, defined as at least 1 CRE-positive culture detected at any time during their ICU stay. Controls were randomly selected from patients that remained CRE negative on all fecal surveillance cultures collected throughout hospitalization.
Reproductive status	Classified as intact or neutered/spayed at the time of ICU admission.
Age	Age (y) at ICU admission.
Body weight	Body weight (kg) at ICU admission.
Comorbidity burden	Total No. of concurrent medical conditions documented at ICU admission. Individual diagnoses were reviewed and classified into predefined disease categories (cardiovascular, dermatological, endocrinologic, gastrointestinal, hepatobiliary, neurologic, ophthalmologic, orthopedic, reproductive, respiratory, urinary tract/renal, neoplastic, systemic infectious, and other). Patients with multiple concurrent conditions were assigned to all applicable categories, and the total No. of comorbidities was used in the analysis.
Hospitalization duration	Total duration of the hospitalization (d).
Boarding/daycare attendance	History of boarding or daycare attendance within the previous 6 months, recorded as yes, no, or unknown if not documented
Raw diet consumption	History of raw diet consumption, recorded as yes, no, or unknown if not documented.
Previous surgery	History of surgery performed at the OSU VMC within the previous 6 months.
Diagnostic imaging	Ultrasound, CT, or MRI performed during hospitalization.
Dialysis	Dialysis performed during hospitalization.
Chemotherapy	Administration of chemotherapy during hospitalization or within the previous 6 mo.
Corticosteroid administration	Administration of systemic corticosteroids during hospitalization or within the previous 6 mo.
Previous antimicrobial	Administration of 1 or more systemic antimicrobial agents during hospitalization, within the previous 3 mo, or between 3 and 6 mo before hospitalization.
Antimicrobial classes	Antimicrobials were classified by drug class, and the No. of different antimicrobial classes administered was recorded.

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controls. Most animals were neutered; however, nonsterilized animals were more common among cases (24.6%) compared with controls (10.2%).

A total of 5,552 fecal swab samples were collected from 3,834 OSU VMC ICU patients between January 2024 and June 2025. Of these, 61 patients (1.59%; 95% CI, 1.24% to 2.04%) were positive for CRE enteric colonization. Among the 61 colonized patients, *E coli* expressing bla_{NDM} was the most common genotype, recovered from 48 patients (78.69%; 95% CI, 1.24% to 2.04%). *Enterobacter hormaechei* was recovered from 12 patients (19.67%; 95% CI, 11.5% to 31.3%), of which 3 harbored bla_{NDM}, 2 carried both bla_{NDM} and bla_{KPC}, and 7 carried $bla_{OXA-48-like}$. *K pneumoniae* was identified from only 1 patient (1.64%; 95% CI, 0.3% to 8.7%), which carried bla_{NDM}. Colonization status at admission could not be distinguished from in-hospital acquisition of CRE. Given that detection relied on serial rectal swab sampling and CRE shedding may be intermittent, a negative result at admission was not considered sufficient to exclude preexisting colonization.[30]

Figure 1 shows the monthly isolation rates of the CRE strains from January 2024 to June 2025. *Escherichia coli* expressing bla_{NDM} was the most prevalent strain, with 2 major spikes observed in October 2024 and March 2025.

As shown in **Supplementary Table S1**, antimicrobial susceptibility testing of the isolates demonstrated high levels of multidrug resistance among CRE isolates. As expected, all isolates were resistant to β-lactams, including penicillins and cephalosporins, while susceptibility to imipenem varied. A total of 28 isolates were susceptible or intermediate to imipenem. Of these, 26 were resistant to meropenem by disk diffusion, while 2 isolates could not be tested for meropenem susceptibility due to lack of isolate availability.

All isolates remained susceptible to amikacin, whereas a high proportion of isolates were resistant to tetracyclines, gentamicin, fluoroquinolones, and trimethoprim-sulfamethoxazole. Chloramphenicol showed moderate activity, with 34.04% of isolates susceptible.

For *E hormaechei* isolates carrying bla_{NDM}, resistance was common for most other antimicrobial classes, including fluoroquinolones, tetracycline, and folate pathway antagonists (eg, trimethoprim sulfa). Susceptibility to imipenem and gentamicin was observed in approximately 75% of isolates. *Enterobacter hormaechei* isolates carrying $bla_{OXA-48-like}$ showed slightly higher susceptibility to imipenem (85.71% susceptible), but resistance remained common to multiple antimicrobial classes, including tetracyclines and fluoroquinolones. The 2 isolates of *E hormaechei* carrying both bla_{NDM} and bla_{KPC} exhibited the most extensive resistance phenotype, with resistance to nearly all antimicrobial classes evaluated, except for amikacin. The bla_{NDM} *K pneumoniae* isolate displayed extensive drug resistance, with resistance to most antimicrobial classes.

From January 2024 to June 2025, only 1 patient was identified with a clinical infection associated with CRE. The patient was a 4-year-old male pit bull-type dog that underwent gastrotomy and duodenal resection with anastomosis for foreign body removal. At the 2-week recheck, the abdominal incision showed cranial and caudal dehiscence with necrotic tissue. The wound was cultured, and a carbapenem-resistant *E coli* with bla_{NDM} was identified. Antimicrobial susceptibility testing showed resistance against all β-lactams (intermediate to imipenem), fluoroquinolones, aminoglycosides (except amikacin), and trimethoprim-sulfamethoxazole. Throughout the hospitalization of this patient, the first 2 screening fecal swab samples received were negative, while the third and fourth samples were positive for CRE enteric colonization.

The analysis of continuous independent variables revealed no significant differences in weight or age between colonized (cases) and noncolonized (control) patients. The mean weight of cases was 16.1 kg

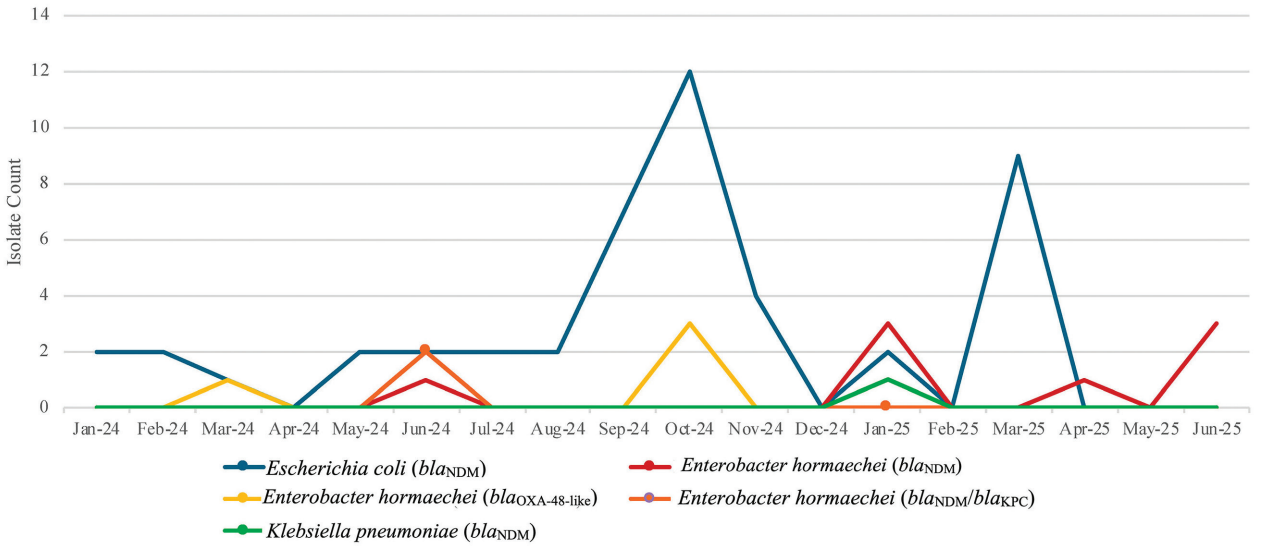


Figure 1—Monthly distribution of carbapenem-resistant Enterobacterales isolated from fecal swab samples of canine and feline patients hospitalized in the ICU at The Ohio State University Veterinary Medical Center between January 2024 and June 2025. Isolation rates (%) are shown by bacterial species and carbapenemase genotype.

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(SD, 14.55) compared to 17.43 kg (SD, 15.41) in controls (P = .57), while the mean age was 6.4 years (SD, 4.3) in cases and 6.74 years (SD, 4.18) in controls (P = .89). Hospitalization length was significantly different, with colonized patients experiencing longer hospital stays (mean, 5.59 days; SD, 3.37) than controls (mean, 3.66 days; SD, 1.94; P < .01).

The results of unadjusted associations found that the odds of colonization were nearly 3 times as high in nonsterile patients as in patients that were spayed or neutered. Patients with 3 or more comorbidities had over 4 times the odds of colonization compared to those with 2 or fewer comorbidities. Undergoing diagnostic imaging (CT, MRI, and/or ultrasound) was associated with lower odds of being colonized. Although only a small number of animals underwent dialysis, those that did have higher odds of being colonized. Patients that had undergone surgery within the past 6 months were twice as likely to be colonized with a CRE strain.

Other patient characteristics, including sex (male vs female), species (canine vs feline), corticosteroid use, chemotherapy, raw food consumption, and recent history of boarding, daycare, or grooming were not associated with CRE enteric colonization. Descriptive statistics and unadjusted associations are summarized in **Table 2**.

Patients exposed to antibiotics within the 3 months prior to hospitalization had higher odds of CRE colonization than those without recent antimicrobial exposure. The odds of CRE colonization in patients receiving antibiotic treatment during hospitalization were 5 times those of patients not receiving antibiotics. Patients exposed to 2 or more classes of antibiotics had higher odds of CRE colonization compared to those exposed to fewer classes. Exposure to β-lactams, fluoroquinolones, and tetracyclines was associated with increased odds of CRE colonization. Exposure to other antibiotic classes, including macrolides, lincosamides, sulfonamides, and nitroimidazoles, was not associated with CRE colonization status.

Descriptive statistics and unadjusted associations of antimicrobial exposure with CRE colonization status are summarized in **Table 3**.

Predictor variables that had unadjusted associations with CRE colonization status—including neuter/spay status, number of comorbidities, history of dialysis or surgery within the last 6 months, history of antibiotic use

Table 2—Comparison of demographic characteristics, clinical variables, and potential predictor variables between CRE-colonized (cases; n = 61) and noncolonized (controls; n = 137) canine and feline patients admitted to the ICU at the OSU VMC between January 2024 and June 2025.

Variable	Cases	Controls	OR	95% CI	*P* value
Sex					
Male	35 (57.37)	71 (51.82)	1.25	0.68–2.31	.47
Female	26 (42.62)	66 (48.18)			
Neuter status					
Nonsterile	15 (24.59)	14 (10.21)	2.865	1.28–6.4	< .01
Sterile	46 (75.41)	123 (89.78)			
Species					
Canine	49 (80.33)	99 (72.26)	1.57	0.75–3.26	.23
Feline	12 (19.67)	38 (27.74)			
Comorbidities					
≤ 2 comorbidities	27 (44.26)	106 (77.37)			
≥ 3 comorbidities	34 (55.74)	31 (22.63)	4.3	2.26–8.20	< .001
Boarding/daycare/grooming in the last 6 mo					
Yes	9 (16.67)	11 (10.78)	1.66	0.64–4.28	.3
No	45 (83.33)	91 (89.22)			
Missing/unknown	7	35			
Consumption of raw food					
Yes	2 (4)	1 (1.06)	3.88	0.34–43.82	.55
No	48 (96)	93 (98.94)			
Missing/unknown	11	43			
CT/MRI/ultrasound					
Yes	35 (57.38)	102 (74.45)	0.46	0.24–0.87	< .05
None	26 (42.62)	35 (25.55)			
Dialysis					
Yes	5 (8.19)	1 (0.73)	12.14	1.39–106.3	< .05
None	56 (91.80)	136 (99.27)			
Chemotherapy					
Yes	3 (4.92)	7 (5.11)	0.96	0.24–3.85	> .1
None	58 (95.08)	130 (94.89)			
Corticosteroids					
Yes	19 (31.15)	30 (21.9)	1.61	0.82–3.17	.16
None	42 (68.85)	107 (78.1)			
Surgery					
Yes	28 (45.9)	40 (29.2)	2.06	1.10–3.84	< .05
None	33 (54.1)	97 (70.8)			

Case and control values are given as number (percentage).

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Table 3—Descriptive analysis and univariable associations between antimicrobial exposure and CRE colonization among canine and feline patients admitted to the intensive care unit at the OSU VMC between January 2024 and June 2025.

Variable	Cases	Controls	OR	95% CI	*P* value
History of antibiotic use between 3 and 6 mo ago					
Yes	1 (1.64)	4 (3.01)	0.54	0.06–4.91	.87
No / not sure	60 (98.36)	129 (96.99)			
N/A	0	4			
History of antibiotic use in the last 3 mo					
Yes	20 (32.79)	25 (18.25)	2.19	1.1–4.35	< .05
No	41 (67.21)	112 (81.75)			
History of antibiotics used during hospitalization					
Yes	53 (86.89)	77 (54.16)	5.16	2.28–11.68	< .001
No	8 (13.11)	60 (42.21)			
No. of different classes of antibiotics to which the patient was exposed					
< 2 different classes of antibiotics	33 (54.1)	109 (79.56)			
≥ 2 different classes of antibiotics	28 (45.9)	28 (20.44)	3.3	1.72–6.34	< .001
β-Lactam exposure					
Yes	49 (80.33)	73 (53.28)	3.58	1.75–7.31	< .001
No	12	64			
Aminoglycoside exposure					
Yes	0	0	N/A	N/A	N/A
No	61	137			
Fluoroquinolone exposure					
Yes	21 (34.43)	18 (13.14)	3.471	1.68–7.16	< .001
No	40	119			
Macrolide exposure					
Yes	5 (8.2)	9 (6.57)	1.27	0.41–3.96	.88
No	56	128			
Lincosamides exposure					
Yes	8 (13.11)	6 (4.38)	3.3	1.09–9.96	.06
No	53	131			
Tetracycline exposure					
Yes	9 (14.76)	4 (2.92)	5.755	1.7–19.5	< .01
No	52	133			
Sulfonamides exposure					
Yes	1 (1.64)	2 (1.46)	1.13	0.1–12.65	> .1
No	60	135			
Nitroimidazoles exposure					
Yes	1 (1.64)	3 (2.19)	0.74	0.08–7.3	> .1
No	60	134			

Case and control values are given as number (percentage).
N/A = Not available.

in the last 3 months and during hospitalization, number of different classes of antibiotics to which the patient was exposed, and exposure to β-lactams, fluoroquinolones, and tetracyclines—were included in a multivariable logistic regression model to assess their adjusted associations with CRE colonization status. The independent variables included in the multivariable model were assessed for potential multicollinearity via variance inflation factor, which indicated no evidence of problematic collinearity. The following variables remained as predictors of CRE colonization status in the final model: number of comorbidities, reproductive status, number of hospitalization days, surgery in the last 6 months, and history of antibiotics in the last 3 months. The final multivariable logistic regression model demonstrated that the model fit the data well according to the Hosmer-Lemeshow goodness-of-fit test ($\chi^2 = 4.84$; $df = 8$; $P = .775$). The final multivariable logistic regression model is summarized in **Table 4**.

Table 4—Multivariable logistic regression analysis of factors associated with CRE colonization in canine and feline patients admitted to the ICU at the OSU VMC between January 2024 and June 2025.

Variable	OR[a]	95% CI	*P* value
No. of comorbidities	1.96	1.43–2.75	< .001
Intact status	4.39	1.47–11.03	< .05
No. of hospitalization days	1.31	1.14–1.53	< .001
Surgery in the last 6 mo (at the OSU VMC)	2.72	1.29–5.87	< .01
History of antibiotics in the last 3 mo	2.71	1.23–6.07	< .05

[a]Odds ratios for categorical variables are reported relative to the reference category (nonintact status, no surgery within the previous 6 months, and no antimicrobial use within the previous 3 months). Odds ratios for continuous variables represent the change in odds associated with a 1-unit increase in the variable.

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Discussion

Enteric colonization with CRE in companion animals has been increasingly recognized, but available information remains limited to a handful of surveillance studies and outbreak reports.[10,25,27,31–33] Recent surveillance data from the US indicate that the prevalence of CRE carriage in companion animals is low (0.21%) while demonstrating the circulation of diverse carbapenemase types, including NDM, KPC, and OXA-48-like enzymes, highlighting the zoonotic and public health relevance of these organisms.[34] Recent US nationwide data based on 4 years of antimicrobial susceptibility test results from a diagnostic laboratory reported a low CRE prevalence among companion animals (98.9% of Enterobacterales susceptible to imipenem), although findings are based on clinical submissions rather than active surveillance or colonization screening.[35]

In comparison, the prevalence observed in our ICU population (1.59%) is lower than the 11% admission and 25.6% acquisition reported in Italy[31] and far lower than rates documented during outbreak investigations.[25] Such variation likely reflects differences in study context (routine surveillance vs outbreak investigations) and regional epidemiology. In our setting, active surveillance includes both patient screening and environmental monitoring, enabling targeted cleaning that likely reduces transmission and colonization.

Regarding antimicrobial susceptibility testing, as expected, all isolates were resistant to β-lactams, including penicillins and cephalosporins. Despite this broad resistance, susceptibility to amikacin, was largely preserved, suggesting potential therapeutic relevance. However, the clinical use of aminoglycosides may be limited by their well-documented risk of nephrotoxicity, particularly in patients with preexisting kidney disease, critically ill patients, or those receiving prolonged therapy, thereby leaving clinicians with limited treatment options.[36]

Notably, variability in imipenem susceptibility was observed among NDM-producing isolates, with a proportion of isolates remaining susceptible or intermediate to this drug. This finding highlights the heterogeneous expression of carbapenem resistance and supports previous observations that carbapenemase-producing organisms may exhibit discordant susceptibility profiles across different carbapenems.[37–39] This has been well described and may reflect differences in antimicrobial activity, pharmacodynamic properties, and interpretive criteria.[37–39] In particular, meropenem has been shown to provide improved sensitivity for detecting carbapenem resistance compared to other carbapenems, including imipenem, which may result in isolates being classified as resistant to meropenem while remaining susceptible or intermediate to imipenem.[39]

Carbapenem resistance in Enterobacterales is primarily mediated by carbapenemase enzymes, including metallo-β-lactamases such as NDM, and is often influenced by additional mechanisms such as altered outer membrane permeability and efflux.[40] These factors, combined with differences in intrinsic antimicrobial activity between agents, such as the slightly greater activity of meropenem compared to imipenem, may differentially affect individual carbapenems, resulting in discordant susceptibility patterns between agents such as imipenem and meropenem. Clinically, these findings suggest that reliance on imipenem susceptibility alone may fail to identify some carbapenemase-producing Enterobacterales. Therefore, when carbapenem resistance is suspected, additional testing such as meropenem susceptibility testing or carbapenemase detection methods should be considered to improve detection.

Differences in susceptibility patterns between NDM-producing and OXA-48-like–producing isolates further emphasize the role of enzyme-specific hydrolytic activity, as OXA-48-like enzymes are known to confer lower levels of carbapenem resistance compared to metallo-β-lactamases.[41] Additionally, isolates coharboring multiple carbapenemase genes demonstrated more extensive resistance, suggesting additive or synergistic effects of resistance mechanisms.[40] Overall, these findings underscore the complexity of antimicrobial resistance phenotypes in CRE and the importance of drug-specific susceptibility testing.

Upon multivariable analysis, 5 variables remained associated with CRE colonization: (1) number of comorbidities, (2) neuter/spay status, (3) duration of hospitalization, (4) history of surgery within the past 6 months, and (5) antibiotic use in the last 3 months.

Our observed association of CRE colonization with higher comorbidity burden has been previously observed in human patients[42,43] and, to our knowledge, represents the first report identifying comorbidity burden as a predictor for CRE colonization in companion animals.

Nonsterile (intact) patients have almost 5 times the odds of colonization, suggesting possible behavioral influences on exposure. Intact animals may have behavioral patterns that increase contact with other animals or contaminated environments, such as roaming, more frequent social interactions, mounting behavior, or attendance in settings where close contact occurs.

Length of hospital stay is also associated with CRE enteric colonization status. Colonized patients have a notably longer hospitalized stay than noncolonized control patients. Prolonged hospitalization increases opportunities for exposure to contamination within the hospital environment, contact with healthcare workers, and transmission from colonized or infected patients. This finding is consistent with evidence from both companion animals[31] and human healthcare.[23,43–45]

Surgery within the previous 6 months was also identified as a relevant factor in the unadjusted analysis. Others have also reported surgical procedures associated with CRE acquisition in a US veterinary teaching hospital.[25]

Patients that were exposed to antibiotics within the previous 3 months had more than twice the odds of CRE colonization, while those receiving antibiotics during hospitalization had 5 times the odds of colonization. Also, patients that are exposed to 2 or more classes of antibiotics are significantly more likely to be colonized. This suggested that hospital-based antibiotic pressure is a major driver of colonization, possibly due to selective pressure followed by

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nosocomial transmission. This is consistent with evidence that broad-spectrum antibiotic use disrupts the gut microbiota, reducing protective commensals and facilitating CRE expansion by enriching nutrient availability and diminishing inhibitory microbial metabolites.[46]

Consistent with our results, there are reports that individuals colonized with CRE are more likely to have received prior antibiotic treatment than controls, with increased odds observed for exposure to fluoroquinolones (OR, 3.75; 95% CI, 1.35 to 10.38), cephalosporins (OR, 2.37; 95% CI, 1.17 to 4.80), carbapenems (OR, 5.41; 95% CI, 1.35 to 21.95), and aminoglycosides (OR, 5.44; 95% CI, 1.02 to 29.14).[47] Additional evidence has linked prior fluoroquinolone use to CRE colonization.[24,48] There are also reports that demonstrate that previous use of β-lactam/β-lactamase inhibitors or carbapenems within 3 months is more common among patients colonized with CRE on admission compared to noncolonized patients.[49]

In veterinary settings, studies[11,26,27] have reported that prior antibiotic use is associated with colonization by extended-spectrum β-lactamase-producing Enterobacterales in companion animals. However, evidence directly linking recent antibiotic exposure to CRE colonization in companion animals remains limited. A recent study[26] identified β-lactam and metronidazole administration as risk factors associated with in-hospital carbapenemase-producing CRE acquisition in dogs, and others[31] have similarly reported an association between piperacillin-tazobactam treatment and CRE acquisition during hospitalization.

These results highlight the multifactorial nature of CRE colonization risk, with both patient-related (comorbidities and neuter/spay status) and clinical/procedural factors (hospitalization, surgery, and antibiotic use within the last 3 months) contributing to colonization dynamics. The strong association with comorbidity burden and recent antimicrobial exposure supports existing evidence that host vulnerability and antimicrobial pressure are key drivers of colonization. Interestingly, the association with intact status may reflect underlying biological or behavioral differences that warrant further investigation.

In this study, variables that are no longer associated with CRE colonization following adjustment in the multivariable model likely reflect unexpected confounding or correlation with the retained predictors. Exposures such as corticosteroid therapy, chemotherapy, or boarding/grooming may initially appear associated with colonization because they predict other factors such as comorbidity burden, recent hospitalization, or antimicrobial exposure. Once these stronger predictors are accounted for in the multivariable model, the independent contribution of those variables diminishes. This suggests that their effect may be indirect, mediated through the primary predictor identified.

Dialysis showed a notably strong unadjusted association with colonization. In human medicine, dialysis has been associated with an increased risk of carriage of multidrug-resistant organisms, consistent with the higher odds observed in this study.[50] However, our results should be interpreted with caution due to the extremely wide CI (95% CI, 1.39 to 106.3), which indicates that the estimate is imprecise, likely due to the small number of patients that received dialysis. Several limitations should be considered when interpreting the findings of this study. First, colonization at admission versus in-hospital acquisition could not be distinguished. As a result, variables such as hospitalization duration may appear associated with colonization even if some patients were already colonized on admission. Accurately determining prior colonization was challenging, since CRE shedding can be intermittent and may not be detected at every sampling point, making it difficult to reliably classify colonization status at the time of hospital entry.[30] In addition, because this study was limited to ICU patients, the observed prevalence and associated outcomes likely reflected a critically ill population and may not be representative of the broader hospitalized companion animal population. Consequently, the prevalence estimates may not be generalizable to other hospital settings. Similarly, because the study was conducted at a tertiary referral center, the magnitude of the observed associations may differ in primary care or specialty practices with different patient populations and antimicrobial use patterns. Finally, high clinical workload and competing clinical priorities may have resulted in missed sampling time points or loss to follow-up, which could have influenced estimates of colonization duration and acquisition. This may have affected the estimated prevalence of CRE colonization, although this likely represents nondifferential misclassification.

These findings have important implications for infection prevention and antimicrobial stewardship in veterinary clinical settings, particularly in high-risk environments such as ICUs in tertiary referral and large veterinary hospitals. Patients with a higher comorbidity burden and recent antimicrobial exposure should be considered at increased risk for CRE colonization and may benefit from targeted screening and infection control measures.

Efforts to minimize unnecessary antimicrobial use remain key. Judicious antimicrobial prescribing, including adherence to stewardship principles and avoidance of broad-spectrum agents when not clinically indicated, reduces selective pressure that promotes CRE colonization.

Given the association with duration of hospitalization, strategies aimed at reducing length of stay, when clinically appropriate, may also decrease opportunities for CRE acquisition. Patients requiring prolonged hospitalization should be considered at increased risk of acquiring CRE and other multidrug-resistant organisms and therefore warrant heightened vigilance and reinforced infection control measures throughout their hospital stay. Strict adherence to infection control practices, including hand hygiene, environmental cleaning, and appropriate use of personal protective equipment, remains essential, particularly for patients identified as high risk.

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