Received: 26 October 2021 | Revised: 21 April 2022 | Accepted: 11 May 2022

DOI: 10.1111/zph.12979

ORIGINAL ARTICLE

WILEY

A quarterly survey of antibiotic prescribing in small animal and equine practices—Minnesota and North Dakota, 2020

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Funding information
University of Minnesota College of Veterinary Medicine Emerging, Zoonotic, and Infectious Disease Signature Program

Abstract

Antimicrobials are critical for medicine, but the problem of antimicrobial resistance (AMR) threatens the effectiveness of these valuable drugs. In USA, there are no national- or state-level programs or policies in place to track antibiotic use (AU) in dogs, cats, and horses, despite acknowledgement of this sector's importance to both the AMR problem and its solution. AU measurement is a key part of antibiotic stewardship and AMR prevention. This study aimed to fill existing gaps in the veterinary professions' knowledge of antibiotic prescribing in small animals and horses. To address this aim, medical record data were collected on a single day per quarter for 1 year from 19 Minnesota and North Dakota small animal and equine practices, totaling 1,899 veterinarian consults of dogs, cats, and horses. Overall, 25.8% of all canine, feline, and equine consults involved an antibiotic prescription. Third-generation cephalosporins were the most commonly prescribed systemic antibiotic drug class, and the long-acting injectable drug, cefovecin, was the most commonly prescribed antibiotic for cats (34.5%). Topical antibiotic preparations were prescribed frequently, especially in dogs (42.5% of canine prescriptions), though systemic antibiotics were often prescribed concurrently. Common general indications, based on problem or diagnosis recorded in the medical record, for antibiotics in all species combined were skin conditions (24.4%), otitis (22.1%), ophthalmic (9.4%), gastrointestinal (8.3%), respiratory (8.3%), and urinary tract (7.6%) diseases. While 44.2% of patients for which antibiotics were prescribed had cytology performed, only 3.9% had bacterial culture and susceptibility performed. In a pre-study survey, veterinarians' recommendations for AU differed from actual prescribing, suggesting collection of AU data provides more accurate assessments of veterinary prescribing behaviour than surveys. This study shows feasibility of AU measurement in small animals and horses. The data collection tool and standard operating procedures described prove suitable for national AU data collection.

KEYWORDS
anti-bacterial agents, antibiotic prophylaxis, antimicrobial stewardship, drug resistance, microbial, public health

1 | INTRODUCTION

Antimicrobial resistance (AMR) is one of the greatest public health challenges of our time, and antibiotic use (AU) is an important modifiable risk factor. Antibiotic stewardship, defined as the coordinated efforts to improve AU while effectively treating infections, is critical to combating AMR in any sector where antibiotics are prescribed. In USA, there are over 76 million pet dogs, 58 million pet cats, and 7 million horses (American Horse Council Foundation, 2018; American Veterinary Medical Association, 2018). Antibiotics are often prescribed for the treatment of infections in these animals. In 2018, the USA Food and Drug Administration (FDA) published a 5-year action plan to support antibiotic stewardship in veterinary medicine, including in companion animals (FDA, 2018).

Minimal data on the volume of and indications for AU in small animal and equine medicine are available to veterinary prescribers, clinics, researchers, or to public health professionals at the state and national levels. Despite identification of AU tracking as an essential part of antibiotic stewardship in veterinary medicine, hurdles exist at the prescriber level (e.g. insufficient time and awareness to measure AU), clinic or hospital level (e.g. lack of human and material resources, inability of electronic practice management systems to produce AU metrics), and at the level of the veterinary profession (e.g. lack of established AU measurement protocols, no regulatory responsibility to track AU). The International Society for Companion Animal Infectious Diseases (ISCAID) has published guidelines for diagnosis and treatment of canine superficial bacterial folliculitis and canine and feline urinary tract and respiratory tract diseases (Hillier et al., 2014; Lappin et al., 2017; Weese et al., 2019). Similarly, other organizations have created general antimicrobial prescribing guidance, such as the British Small Animal Veterinary Association's (BSAVA) PROTECT ME campaign and the Federation of European Companion Animal Veterinary Associations' (FECAVA) Recommendations for Appropriate Antimicrobial Therapy (BSAVA, 2018; FECAVA, 2018). However, without prescribing data, neither adherence to these guidelines nor improvement over time can be assessed at the practitioner, state, or national level.

The main objective of this study was to summarize antibiotic prescribing for dogs, cats, and horses in Minnesota and North Dakota small animal and equine practices by aggregating single day cross-sectional survey data collected quarterly for 1 year across multiple clinics. A secondary objective was to pilot a data collection tool and standard operating procedures for use in conducting a national survey to estimate AU across general and referral small animal practices.

Impacts

- Cats, dogs, and horses frequently receive antibiotic classes deemed critically important for human healthcare.
- While antibiotic-prescribing guidelines exist for canine skin infections, canine and feline urinary tract and respiratory tract infections, and equine strangles and foal pneumonia, additional evidence-based and peer-reviewed guidelines are needed to aid veterinarians in making antibiotic choices.
- Bacterial culture and susceptibility testing to guide antibiotic use is infrequently performed for dogs, cats, and horses. Microscopic evaluation (e.g. cytology) is inexpensive and can be performed with basic equipment present in most veterinary settings. While cytology was utilized more frequently than bacterial culture and susceptibility, expanded use could help guide antibiotic decision-making by small animal and equine veterinarians.

2 | MATERIALS & METHODS

2.1 | Ethics statement

This study was not determined to be human research by the University of Minnesota (UMN) Institutional Review Board and was exempt from review by the UMN Institutional Animal Care and Use Committee.

2.2 | Data collection

The study was designed to collect a single day of antibiotic prescribing data from small animal and equine veterinary practices each quarter for 1 year.

Veterinarians who had an email address associated with an active veterinary license under Minnesota Board of Veterinary Medicine (BVM) were sent an email invitation to participate in the survey with one reminder email. Announcements advertising the study were placed in the Minnesota Veterinary Medical Association newsletter, on social media, and shared by coauthors directly with veterinary colleagues. Nineteen small animal and equine practices in Minnesota and eastern North Dakota agreed to participate.

All veterinarians, veterinary technicians, and veterinary assistants at participating clinics were asked to complete an anonymous pre-study electronic survey consisting of multiple-choice questions designed to understand perceptions of AU and AMR and evaluate antibiotic recommendations for hypothetical prescribing scenarios (Appendix S1). For the study, each participating clinic contributed medical record data from all canine, feline, and equine patients seen by a veterinarian on four dates, one in each quarter of 2020. Visits that did not include consultation with a licensed veterinarian (e.g. veterinary technician visits) were excluded from data collection. This study was informed by the single-day point-prevalence survey approach used by the Centres for Disease Control and Prevention (CDC) to estimate AU in human hospitals and nursing homes (Magill et al., 2014). Given the regional nature of this study, and the intention to pilot the data collection approach for a national single-day survey of small animal prescribing, data were collected on a single day each quarter for 1 year. Clinics were asked to select one survey date each quarter that represented a standard day of practice (i.e. clinic open to their typical patient population), with no scheduled or unexpected abnormalities (e.g. staff meeting, snowstorm, COVID-19 closure). Survey dates were selected from prespecified 2-week ranges in 2020: quarter 1, January 6–19; quarter 2, April 6–19; quarter 3, July 6–19; and quarter 4, October 5–18. Data collection was conducted after the survey date to ensure medical records were complete. In each clinic, a veterinary technician, veterinarian, or other staff with working knowledge of the medical record system served as clinic study coordinator. Each quarter, clinic coordinators generated lists of canine, feline, and equine patients seen on the selected survey date and met with the research team to complete data entry. During data-collection meetings, the clinic study coordinator navigated patient medical records while a member of the research team entered data (data elements listed below) directly into a Research Electronic Data Capture (REDCap) database (Harris et al., 2009). Only the research team had access to the database. Quarter 1 data entry meetings occurred onsite at each participating clinic, and meetings for quarters 2–4 were conducted by web-based conferencing (Zoom Video Communications Inc). All 19 participating clinics completed four quarters of data collection.

Data collected for each patient included: signalment, hospitalization status (inpatient, outpatient), and reason for visit as listed in the appointment schedule (sick visit, wellness visit, surgery/procedure, recheck, euthanasia). All emergency visits were classified as sick visits and any visit that resulted in a euthanasia was classified as a euthanasia visit, regardless of whether it was scheduled as such. If a cat, dog, or horse was prescribed, administered, or currently receiving an antibiotic on the survey date or the calendar day prior, the name of antibiotic(s), route, and date initiated were recorded, as well as the indication for treatment and diagnostics performed. Indications for antibiotic prescriptions were based on the problems or diagnoses recorded in the medical record. Dose, duration, and frequency of antibiotic administration were recorded but are not described here. Ophthalmic antibiotic treatments were recorded as a general category without specification of the antibiotic drug components. Non-antibiotic treatments (e.g. antifungals, medicated shampoos) were not recorded.

2.3 | Data management

Antibiotic drugs were considered unique based upon chemical substance, in keeping with similar AU collection methodology in humans (Magill et al., 2014). Patients receiving two chemically distinct drugs (e.g. transition from intravenous ampicillin-sulbactam to oral amoxicillin-clavulanic acid) on the survey date were considered to have received two antibiotic drugs. Systemic antibiotics were defined as an antibiotic administered intramuscularly, intravenously, orally, subcutaneously, or via local infusion (e.g. intraarticularly). Topical antibiotics were defined as an antibiotic administered by ophthalmic, otic, or other topical application. If a patient received both a systemic and a topical antibiotic, the patient was included in the systemic antibiotic group when assessing diagnostic tests associated with antibiotic prescriptions.

2.4 | Data analysis

Data analyses, including 95% confidence intervals for results with 10 or more observations, were performed using SAS (Release 9.4. SAS Institute, 1997). Descriptive data are presented as frequencies (*n*) and percentages (%).

3 | RESULTS

3.1 | Demographics

Of 19 participating small animal and equine practices, 16 (84.2%) were in Minnesota and 3 (15.8%) in eastern North Dakota. These included 13 (68.4%) small animal exclusive practices, 3 (15.8%) equine exclusive practices, and 3 (15.8%) practices caring for small animal and equine patients. Most practices (7, 36.8%) were in large central metropolitan counties, 2 (10.5%) in large fringe metropolitan counties, 2 (10.5%) in medium metropolitan counties, 5 (26.3%) in small metropolitan counties, 2 (10.5%) in micropolitan counties, and 1 (5.3%) in a non-core county (Table S1; CDC, 2014). The median time for data entry each quarter was 60 min (range 20–360 min), averaging 2.64 min per patient.

There were 1,899 veterinarian consults included in the analysis from the 19 participating clinics across four collection dates. This included 1,868 (98.4%) outpatients and 31 (1.6%) inpatients, who had an overnight stay in the hospital the night before the survey day and/or stayed overnight in the hospital the same day as survey day. The analysis dataset consisted of 1,872 unique animals; 12 animals had two visits and one had three visits during the study period. Most consults were for dogs (1,277, 67.2%), followed by cats (422, 22.1%), and horses (202, 10.6%). The proportion of consults occurring in quarters 1–4 of 2020 was 24.8%, 19.1%, 29.4%, and 26.7%, respectively. During the second quarter (April 2020), there were fewer canine and feline consults and more equine consults than in other quarters, consistent with seasonal patterns in equine practice but also coinciding with the first spike in pandemic COVID-19 cases in the US Midwest. Across patients of all species, wellness visits (839, 44.2%) and sick visits (601, 31.7%) were the most common reasons for veterinary consultation. Surgeries and other procedures occurred in 25.7% of visits for horses (52/202,), 11.0% for dogs (140/1,277), and 10.0% for cats (42/420).

3.2 | Antibiotic drugs and indications

Over a quarter of all consults involved an antibiotic prescription (489/1,899, 25.8%, 95% CI: 23.8%–27.7%, Table 1). This accounted for 566 total prescriptions, of which 352 (62.2%, 95% CI: 58.2%–66.2%) were systemic antibiotics and 214 (37.8%, 95% CI: 33.8%–41.8%) were topical antibiotics (Table 2). Of all canine prescriptions, 42.5% (180/424, 95% CI: 37.8%–47.2%) were of topical formulation, as were 22.9% (25/109, 95% CI: 15.0%–30.8%) of feline

TABLE 1 Number of veterinary consults involving at least one antibiotic prescription

	≥1 antibiotic, any route		≥1 systemic antibiotic		≥1 topical antibiotic	
	No. consults	Percentage (95% CI)	No. consults	Percentage (95% CI)	No. consults	Percentage (95% CI)
All Consults (*n* = 1,899)	489	25.8 (23.8–27.7)	322	17.0 (15.3–18.6)	205	10.8 (9.4–12.2)
Canine (*n* = 1,277)	364	28.5 (26.0–31.0)	224	17.5 (15.5–19.6)	172	13.5 (11.6–15.3)
Inpatient (*n* = 6)	3	50.0 (10.0–90.0)	2	33.3 (0–71.1)	1	16.7 (0–46.5)
Outpatient (*n* = 1,271)	361	28.4 (25.9–30.9%)	222	17.5 (15.4–19.6)	171	13.5 (11.6–15.3)
Feline (*n* = 420)	100	23.8 (19.7–27.9)	79	18.8 (15.1–22.6)	25	6.0 (3.7–8.2)
Inpatient (*n* = 6)	2	33.3 (0–71.1)	2	33.3 (0–71.1)	0	0
Outpatient (*n* = 414)	98	23.7 (19.6–27.8)	77	18.6 (14.9–22.4)	25	6.0 (3.7–8.3)
Equine (*n* = 202)	25	12.4 (7.8–16.9)	19	9.4 (5.4–13.4)	8	4.0 (1.3–6.7)
Inpatient (*n* = 19)	11	57.9 (35.7–80.1)	11	57.9 (35.7–80.1)	1	5.3 (0–15.3)
Outpatient (*n* = 183)	14	7.7 (3.8–11.5)	8	4.4 (1.4–7.3)	7	3.8 (1.1–6.6)

TABLE 2 Antibiotic preparations and classes prescribed to canine, feline, and equine patients

	Number of prescriptions (*n*, %)		
	Canine (*n* = 424)	Feline (*n* = 109)	Equine (*n* = 33)
Topical preparation	**180, 42.5%**	**25, 22.9%**	**9, 27.3%**
Systemic preparation, all[a]	**244, 57.6%**	**84, 77.1%**	**24, 72.7%**
Aminoglycosides	0	0	6, 18.2%
Cephalosporins, first-generation	46, 10.9%	1, 0.9%	4, 12.1%
Cephalosporins, third-generation	45, 10.6%	31, 28.4%	7, 21.2%
Fluoroquinolones	15, 3.5%	8, 7.3%	0
Imidazoles	40, 9.4%	5, 4.6%	0
Lincosamides	8, 1.9%	5, 4.6%	0
Macrolides	1, 0.2%	6, 5.5%	0
Penicillin-beta lactamase inhibitors combinations	45, 10.6%	16, 14.7%	0
Penicillins	22, 5.2%	10, 9.2%	1, 3.0%
Sulfonamides	1, 0.2%	1, 0.9%	0
Tetracyclines	21, 5.0%	1, 0.9%	1, 3.0%
Trimethoprim sulfonamide combinations	0	0	5, 15.2%

Note: Third-generation cephalosporins: cefotaxime, cefovecin, cefpodoxime proxetil, ceftiofur crystalline free acid (long-acting formulation), and ceftiofur sodium. Aminoglycosides: amikacin and gentamicin. Beta lactamase inhibitors (potentiated penicillins): amoxicillin-clavulanic acid and ampicillin-sulbactam. Fluoroquinolones: ciprofloxacin, enrofloxacin, marbofloxacin, and orbifloxacin. Imidazoles: metronidazole. Lincosamides: clindamycin. Macrolides: azithromycin and tylosin. Penicillins: ampicillin and penicillin G. Sulfonamides: sulfadimethoxine. Tetracyclines: doxycycline and oxytetracycline. Topical/otic/ophthalmic: ciprofloxacin/ketoconazole/triamcinolone, mupirocin, ophthalmic antibiotic, otic enrofloxacin, otic florfenicol, otic gentamicin, otic neomycin, otic orbifloxacin, otic polymyxin B, silver sulfadiazine, and triple antibiotic. Trimethoprim sulfonamides combinations: sulfadiazine-trimethoprim and sulfamethoxazole-trimethoprim.

[a]Drugs were grouped by class as follows: First-generation cephalosporins: cefazolin and cephalexin.

prescriptions, and 27.3% (9/33) of equine prescriptions. Systemic antibiotic classes prescribed are shown in Table 2.

For canine systemic antibiotic prescriptions (*n* = 244), the three most common systemic antibiotic classes prescribed were first-generation cephalosporins (*n* = 46, 18.9%, 95% CI: 13.9%–23.8%), third-generation cephalosporins (*n* = 45, 18.4%, 95% CI: 13.6%–23.3%), and potentiated penicillins (*n* = 45, 18.4%, 95% CI: 13.6%–23.3%). The three most common systemic antibiotic classes for cats (*n* = 84) were third-generation cephalosporins (*n* = 31, 36.9%, 95% CI: 26.6%–47.2%), potentiated penicillins (*n* = 16, 19.0%, 95% CI:

10.7%–27.4%), and penicillins (*n* = 10, 11.9%, 95% CI: 5.0%–18.8%). Third-generation cephalosporins (*n* = 7, 29.2%), aminoglycosides (*n* = 6, 25.0%), and trimethoprim sulfonamide combinations (*n* = 5, 20.8%) were the most common systemic antibiotic classes prescribed to equine patients (*n* = 24). Of the five trimethoprim sulfonamide combination prescriptions for horses, four were sulfamethoxazole-trimethoprim and one was sulfadiazine-trimethoprim (Table 3). Specific systemic and topical antimicrobial drugs and frequency of prescription for each species are listed in Tables 3 and 4, respectively.

Third-generation cephalosporins were the most prescribed systemic antibiotic drug class (83/352, 23.6%, 95% CI: 19.2%–28.0%). Of the 83 patients receiving these drugs, 31 (37.3%, 95% CI: 26.9%–47.8%) had diagnostics (e.g., cytology, PCR, histopathology, serology, culture, and susceptibility) performed. Cefovecin, a one-dose long-acting injectable antibiotic, accounted for 44.6% (37/83, 95% CI: 33.9%–55.3%) of third-generation cephalosporin drugs prescribed. Third-generation cephalosporins were prescribed primarily for skin (*n* = 39, 47.0%, 95% CI: 36.3%–57.7%), orodental (*n* = 10, 12.0%, 95% CI: 5.1%–19.1%), urinary tract (*n* = 9, 10.8%), and respiratory tract (*n* = 8, 9.6%) indications. Fluoroquinolones made up 6.5% of all systemic antibiotics prescribed (23/352, 95% CI: 3.95%–9.12%), used commonly for urinary tract (*n* = 7, 30.4%%) and respiratory tract (*n* = 5, 21.7%) indications.

The most common general indications for antibiotic prescribing were skin conditions (138/566, 24.4%, 95% CI: 20.8%–27.9%), otitis (*n* = 125, 22.1%, 95% CI: 18.7%–25.5%), ophthalmic disease (*n* = 53, 9.4%, 95% CI: 7.0%–11.8%), gastrointestinal disease (*n* = 47, 8.3%, 95% CI: 6.0%–10.6%), respiratory tract disease (*n* = 47, 8.3%, 95% CI: 6.0%–10.6%), and urinary tract disease (*n* = 43, 7.6%, 95% CI: 5.4%–9.8%), with some variation across species (Figure 1). In dogs, cats, and horses, 29.7% of skin indications were treated with topical preparations (41/138, 95% CI: 22.1%–37.3%). The most common antibiotics prescribed to treat skin infections were cefpodoxime (26/138, 18.8%, 95% CI: 12.3%–25.4%), cephalexin (*n* = 26, 18.8%, 95% CI: 12.3%–25.4%), and otic neomycin (*n* = 23, 16.7%, 95% CI: 10.5%–22.9%). The most common antibiotic drugs prescribed to treat lower urinary tract infections were amoxicillin-clavulanic acid (18/43, 41.9%, 95% CI: 27.1%–56.6%), amoxicillin (*n* = 8, 18.6%), and cefovecin (*n* = 6, 14.0%). The most common antibiotic drugs prescribed to treat respiratory tract infections were doxycycline (16/47, 34.0%, 95% CI: 20.5%–47.6%), amoxicillin-clavulanic acid (*n* = 7, 14.9%), azithromycin (*n* = 6, 12.8%), and cefovecin (*n* = 6, 12.8%). The most common antibiotic drug prescribed to treat gastrointestinal infections was metronidazole (40/47, 85.1%, 95% CI: 74.9%–95.3%). Most otic and ophthalmic conditions were treated with topical antibiotics (122/125, 97.6%, 95% CI: 94.9%–100% and 48/53, 90.6%, 95% CI: 82.7%–98.4%, respectively).

3.3 | Diagnostic testing associated with antibiotic prescriptions

At least one type of diagnostic test (cytology, histopathologic evaluation, culture and susceptibility, PCR, serology) was performed for 49.5% (242/489, 95% CI: 45.1%–53.9%) of all dogs, cats, and horses who received an antibiotic, 38.8% (125/322, 95% CI: 33.5%–44.1%) of those who received at least one systemic antibiotic, and 70.1% (117/167, 95% CI: 63.1%–77.0%) of those who received only topical antibiotic(s). Of 489 patients prescribed an antibiotic, 216 (44.2%) had cytology or histopathology testing performed, while only 19 (3.9%) had bacterial culture and susceptibility testing performed.

3.4 | Survey of participant perceptions of AMR and antibiotic recommendations for hypothetical prescribing scenarios

The pre-study survey was completed by 177 employees from the 19 study clinics; this included 70 (54 small animal) veterinarians (39.6%), 93 veterinary technicians (52.5%), 10 veterinary assistants (5.6%), 2 receptionists (1.1%), 1 hospital manager (0.6%), and 1 patient coordinator (0.6%). Most (150/177, 84.8%) participants agreed that AMR presents clinical challenges in small animal and equine medicine. While 92.1% (163/177) of respondents believe that AU in human medicine contributes to the burden of AMR in people, only 42.9% (76/177) and 28.8% (51/177) felt that AU in small animals and horses, respectively, contributes to AMR in humans. Of the 70 veterinarians that completed the survey, 54.3% (*n* = 38) reported awareness of small animal AU guidelines published for specific conditions (e.g., respiratory tract infections). When veterinarians who treat small animals were asked how often these guidelines are used when deciding to prescribe antibiotics, 37.0% (20/54) reported never or rarely, 37.0% (20/54) sometimes, 25.9% (14/54) often, and none always. Veterinarians were asked to report their antibiotic of choice for common clinical conditions in dogs, cats, and horses. A comparison of these responses to the prescribing data for these conditions collected in this study is presented in Table 5. Client education on appropriate AU and administration (161/177, 91.0%), continuing education for veterinarians on judicious AU (*n* = 138, 78.0%), and AU guidelines (*n* = 131, 74.0%) were identified by respondents as approaches that could improve AU in veterinary medicine.

4 | DISCUSSION

Antibiotics were most commonly prescribed for dermatologic, otic, ophthalmic, gastrointestinal, respiratory, urinary, and orodental disease. Peer-reviewed antibiotic prescribing guidelines exist for canine and feline urinary tract and respiratory tract disease and for canine superficial bacterial folliculitis but are not available for other canine and feline syndromes, including non-specific acute diarrhea (Hillier et al., 2014; Lappin et al., 2017; Weese et al., 2019). Several entities have developed recommendations for antibiotic treatment of equine conditions, but peer-reviewed guidelines are few (Giguere et al., 2011; Sweeney et al., 2005).

TABLE 3 Systemic antibiotic drugs prescribed to each patient species, in order of frequency

Number of prescriptions (n, %)		
For canine patients (n = 244)	For feline patients (n = 84)	For equine patients (n = 24)
Amoxicillin-clavulanic acid (44, 18.0)	Cefovecin (29, 34.5)	Ceftiofur[a] (7, 29.2)
Cephalexin (40, 16.4)	Amoxicillin-clavulanic acid (15, 17.9)	Gentamicin (5, 20.8)
Metronidazole (40, 16.4)	Amoxicillin (6, 7.1)	Cefazolin (4, 16.7)
Cefpodoxime (36, 14.8)	Azithromycin (6, 7.1)	Sulfamethoxazole-trimethoprim (4, 16.7)
Doxycycline (21, 8.6)	Metronidazole (5, 6.0)	Penicillin G (1, 4.2)
Amoxicillin (12, 4.9)	Clindamycin (5, 6.0)	Amikacin (1, 4.2)
Cefovecin (8, 3.3)	Marbofloxacin (4, 4.8)	Oxytetracycline (1, 4.2)
Clindamycin (8, 3.3)	Ampicillin (3, 3.6)	Sulfadiazine-trimethoprim (1, 4.2)
Enrofloxacin (7, 2.9)	Orbifloxacin (3, 3.6)	
Ampicillin (6, 2.5)	Cefpodoxime (2, 2.4)	
Cefazolin (6, 2.5)	Doxycycline (1, 1.2)	
Marbofloxacin (5, 2.1)	Enrofloxacin (1, 1.2)	
Penicillin G (4, 1.6)	Cefazolin (1, 1.2)	
Ciprofloxacin (3, 1.2)	Penicillin G (1, 1.2)	
Ampicillin-sulbactam 1, 0.4)	Ampicillin-sulbactam (1, 1.2)	
Cefotaxime (1, 0.4)	Sulfadimethoxine (1, 1.2)	
Sulfadimethoxine (1, 0.4)		
Tylosin (1, 0.4)		

[a]n = 4 ceftiofur sodium, n = 3 ceftiofur crystalline free acid.

TABLE 4 Topical antibiotic drugs prescribed to each patient species, in order of frequency

Number of prescriptions (n, %)		
For canine patients (n = 180)	For feline patients (n = 25)	For equine patients (n = 9)
Otic (140, 77.8)	Otic (16, 64.0)	Ophthalmic antibiotic (7, 77.8)
Otic gentamicin (54, 30.0)	Otic neomycin (7, 28.0)	Otic neomycin (1, 11.1)
Otic florfenicol (37, 20.6)	Otic gentamicin (6, 24.0)	Silver sulfadiazine (1, 11.1)
Otic neomycin (35, 19.4)	Otic florfenicol (3, 12.0)	
Otic enrofloxacin (6, 3.3)	Ophthalmic antibiotic (8, 32.0)	
Otic polymyxin B (6, 3.3)	Mupirocin (1, 4.0)	
Otic orbifloxacin (2, 1.1)		
Ophthalmic antibiotic (37, 20.6)		
Mupirocin (1, 0.6)		
Ciprofloxacin/ketoconazole/triamcinolone (1, 0.6)		
Triple antibiotic (1, 0.6)		

Third-generation cephalosporins were the most prescribed drug class, with cefovecin the most common drug selected for treatment of cats. Feline patients received a third-generation cephalosporin over twice as frequently as canine patients. These findings are consistent with a study evaluating medical records for over 200,000 cats in the United Kingdom in which cefovecin was the most prescribed systemic antibiotic (Singleton et al., 2017). While veterinarians reported the preferential use of amoxicillin-clavulanic acid for the treatment of feline upper respiratory infections in the pre-study survey (51.0%), only 17.6% of cats with upper respiratory infections in this study were treated with amoxicillin-clavulanic acid, while 35.3% were treated with cefovecin. Cefovecin is an injectable, long-acting broad-spectrum drug, providing a treatment option for some clinical indications when compliance with oral dosing is a concern. In one UK study, 88% of medical records included no documented justification for selecting cefovecin over first-line choices for cats, and the authors underscored the importance of educating owners about orally medicating their cats (Burke et al., 2017). The most frequently prescribed antibiotic for horses in this study was ceftiofur, also a third-generation cephalosporin. Ceftiofur's broad-spectrum activity and safety profile make it a versatile agent for the treatment of equine patients, including the treatment of respiratory infections, skin infections, abscesses, urinary tract infections, and sepsis (Hardefeldt et al., 2020). Based on the pharmacologic preparation, ceftiofur provides long-acting intramuscular (ceftiofur crystalline free acid), intravenous (ceftiofur sodium, extra-label), and subcutaneous (ceftiofur sodium, extra-label) treatment options, which are advantageous in horses intolerant of repeated intramuscular injections with other antibiotics. The therapeutic duration of both cefovecin (14 days) and ceftiofur crystalline free acid (4 days following a single dose; 10 days with administration on Days 0 and 4) improves ease of administration and patient compliance, both of which are important treatment considerations in veterinary medicine, and likely play a significant role in the high prevalence of use observed in this study. These findings raise a public health concern, given the importance of this broad-spectrum drug class to human health and high-level

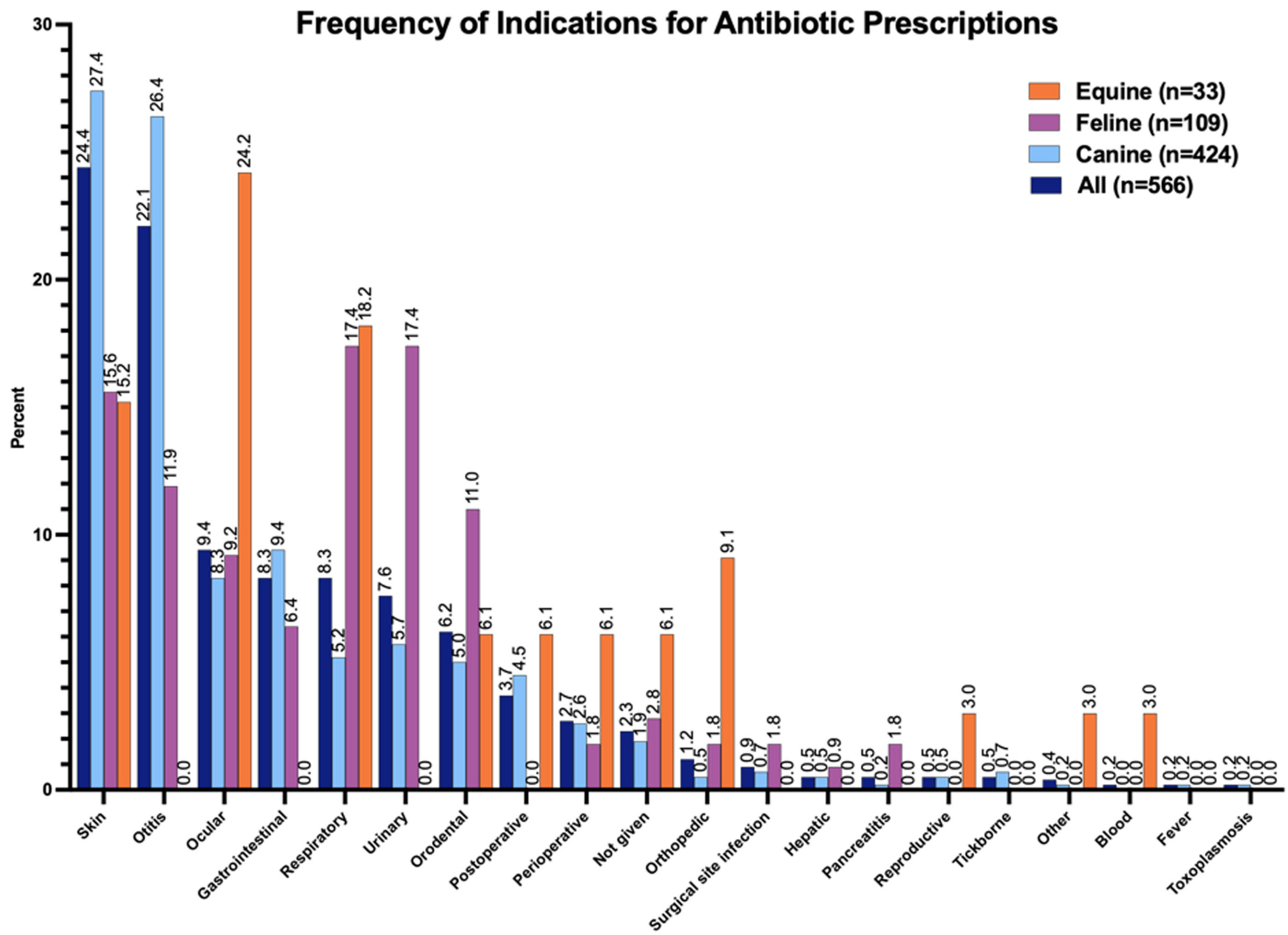

FIGURE 1 Frequency of indications for antibiotic prescriptions. The graph depicts the spread of indications for antibiotic prescriptions for dogs, cats, and horses

recommendations to avoid empiric use (OIE, 2015; World Health Organization, 2018).

In contrast to data from the UK in which potentiated penicillins were the most commonly prescribed systemic antibiotics in dogs (Singleton et al., 2017), we found that third-generation cephalosporins were prescribed as frequently as first-generation cephalosporins and potentiated penicillins. In the pre-study survey, 78.4% of responding veterinarians reported that they would choose cephalexin to treat canine superficial bacterial folliculitis. However, first- and third-generation cephalosporins were both commonly prescribed (46.2% and 35.9%, respectively) for canine skin infections. Ease of administration may play a role in this prescribing pattern. Cefpodoxime, a third-generation cephalosporin commonly used in small animal practice in the US, but not available for veterinary use in Europe, is smaller in pill size and is dosed once daily compared to twice-daily dosing required by cephalexin. Resistance associated with extended-spectrum β-lactamases remains a serious and continually emerging threat to health, and use of narrow-spectrum β-lactams over broad-spectrum drugs has been used as an antibiotic stewardship target to address this challenge (Bush & Bradford, 2020; CDC, 2019; Mölstad et al., 2017). Though both cefpodoxime and cefovecin are labelled for the treatment of skin infections in dogs and cats, ideally culture and susceptibility should guide administration of third-generation cephalosporins in veterinary medicine, which are included in the 'watch' group of the World Health Organization's AWaRe classification of antibiotics for evaluation and monitoring of use (World Health Organization, 2019). Of note, even first-generation cephalosporin use can result in selection of broad-spectrum cephalosporin resistant organisms (Kimura et al., 2017), thus steps beyond narrow-spectrum prescribing, such as use of topical formulations when applicable, should also be considered for antibiotic stewardship targets.

The most frequent indication for metronidazole in this study was gastrointestinal disease. In a large retrospective study of electronic health records, nearly 50% of dogs with acute diarrhea were prescribed a systemic antibiotic, and this was usually metronidazole (Singleton et al., 2019). Guidelines exist for enteropathogenic bacterial infections in dogs and cats (Marks et al., 2011). No peer-reviewed guidelines exist for antibiotic prescribing for non-infectious acute gastrointestinal diseases, though non-specific diarrhea is a common clinical complaint during veterinary consultations. Recent literature suggests that the use of metronidazole may not

TABLE 5 Pre-study Survey with hypothetical prescribing question and actual prescribing data (systemic antibiotics only)

Condition	Pre-study Survey	Prescribing results
Bacterial upper respiratory infection in horses	**19 veterinarians**	**3 prescriptions**
Sulfamethoxazole-trimethoprim	12 (63.2%)	2 (66.7%)
Ceftiofur sodium	3 (15.8%)	1 (33.3%)
Penicillin	4 (21.1%)	0 (0%)
Canine superficial bacterial folliculitis	**51 veterinarians**	**39 prescriptions**
Cephalexin	40 (78.4%)	18 (46.2%)
Third-generation cephalosporins	8 (15.7%)	14 (35.9%)
Amoxicillin/clavulanic acid	3 (5.9%)	3 (7.7%)
Amoxicillin	0 (0%)	1 (2.6%)
Doxycycline	0 (0%)	1 (2.6%)
Enrofloxacin	0 (0%)	1 (2.6%)
Marbofloxacin	0 (0%)	1 (2.6%)
Feline bacterial upper respiratory tract infection	**51 veterinarians**	**17 prescriptions**
Cefovecin	5 (9.8%)	6 (35.3%)
Azithromycin	0 (0%)	4 (23.5%)
Amoxicillin/clavulanic acid	26 (51.0%)	3 (17.65%)
Doxycycline	13 (25.5%)	1 (5.9%)
Amoxicillin	6 (11.8%)	0 (0%)
Fluoroquinolone	1 (2.0%)	3 (17.6%)
Canine and feline sporadic bacterial cystitis	**53 veterinarians**	**43 prescriptions**
Amoxicillin/clavulanic acid	19 (35.8%)	18 (41.9%)
Amoxicillin	24 (45.3%)	8 (18.6%)
Ampicillin/sulbactam	0 (0%)	1 (2.3%)
Third-generation cephalosporin	4 (7.5%)	9 (20.9%)
Fluoroquinolones	2 (3.8%)	7 (16.3%)
Sulfamethoxazole/trimethoprim	2 (3.8%)	0 (0%)
Varies based on symptoms and urinalysis results	1 (1.9%)	0 (0%)
Selection based upon susceptibility testing	1 (1.9%)	0 (0%)

hasten improvement of acute diarrhea and might result in gastrointestinal dysbiosis (Langlois et al., 2020; Pilla et al., 2020; Shmalberg et al., 2019). In the absence of a degenerative left shift, antibiotics are likely not indicated for acute hemorrhagic diarrheal syndrome (Unterer et al., 2011). Although antibiotics are indicated for the treatment of some diarrhea (e.g. histiocytic ulcerative colitis), our study highlights an opportunity to decrease inappropriate prescribing of antibiotics for the treatment of non-infectious diarrheal conditions. Diet change, prebiotics, and probiotics can be used to support dogs and cats with diarrhea when antibiotics are not indicated (Nixon et al., 2019; Shmalberg et al., 2019).

Peer-reviewed ISCAID guidelines suggest that amoxicillin and trimethoprim-sulfadiazine should be considered first-line therapy for lower urinary tract infections, and amoxicillin, amoxicillin-clavulanic acid, and doxycycline for upper respiratory tract bacterial infections in cats and dogs (Lappin et al., 2017; Weese et al., 2019). In our study, the first-line antibiotic doxycycline was prescribed most frequently for canine upper respiratory infections, consistent with ISCAID guideline recommendations (Lappin et al., 2017). While nearly half of veterinarians reported that they would use amoxicillin for the treatment of canine and feline lower urinary tract infections in the pre-study survey, amoxicillin-clavulanic acid and third-generation cephalosporins were prescribed more often than amoxicillin. Topical preparations accounted for over one-third of all antibiotic prescriptions counted in this study and were prescribed to treat superficial pyoderma, otitis externa, conjunctivitis, and corneal ulcers. A greater proportion of antibiotics prescribed to dogs were topical, as compared to cats and horses. However, nearly one-third of dogs given a topical antibiotic also received a systemic antibiotic. Otitis was the second most common indication for an antibiotic prescription, and nearly 98% of patients with otitis were prescribed topical therapy. Gentamicin was the most prescribed topical antibiotic in dogs, largely intended for treatment of otitis externa. Fluoroquinolones were also prescribed for topical otitis treatment, including a depot formulation that provides 28 days of antibiotic therapy in a single dose. No peer-reviewed guidelines exist for otitis externa treatment, but topical gentamicin and polymyxin B have been suggested as first-line and fluoroquinolones as third-line agents (Koch, 2017). Guidance is needed on this topic, including recommendations for non-antibiotic therapies, empiric antibiotic selection, and duration of antibiotic treatment. Such guidance is available for management of canine superficial bacterial folliculitis and includes alternatives to systemic antibiotics (Hillier et al., 2014). Dogs with methicillin-resistant *Staphylococcus pseudintermedius* pyoderma that failed systemic therapy with two different antibiotics have been shown to benefit from bathing three times a week with shampoo containing sodium hypochlorite and salicylic acid (Fadok & Irwin, 2019). Updated evidence-based guidelines would be welcome for multiple species and additional skin conditions.

Study clinics used bacterial culture and susceptibility testing infrequently (i.e., for less than 4% of animals prescribed an antibiotic), which is consistent with previous reports (American Veterinary Medical Association Task Force for Antimicrobial Stewardship in Companion Animal Practice, 2015; Murphy et al., 2012). Veterinarians have identified cost as a primary barrier to its use, although it is unclear whether the cost of diagnostic testing is a perceived or real obstacle (Fowler et al., 2016). In a small study in which clients were interviewed regarding their perceptions on antimicrobial therapies, 20% of pet owners said they would decline additional diagnostic tests, like culture and susceptibility, for financial reasons (Redding & Cole, 2019). Despite the challenges regarding culture and susceptibility testing, the use of less expensive in-house cytology is also an important part of clinical diagnosis and opportunities should be identified to improve use of cytologic evaluation as a part of antibiotic stewardship. In this study, cytology was performed more often than culture and susceptibility. Veterinarians are trained in basic cytologic evaluation and slide review, and most clinic-based practices have all the materials needed for in-house cytology. Cytologic sampling of easily accessible sites, such as ear and skin, can provide valuable diagnostic information, including the morphology and relative abundance of bacteria present, whether bacteria are intracellular, the presence of white blood cells, and even findings that provide a non-bacterial alternative diagnosis. Cytology can also aid in the interpretation of bacterial culture and susceptibility testing results.

The secondary objective of this study was to develop a data collection tool and standard operating procedures that can be scaled for use in a national single-day AU survey of small animal general practice and referral hospitals. Most reports of AU data are from academic institutions or are surveys of veterinarians' self-reported prescribing practices. In this study, veterinarians' recommendations for antibiotic prescribing for common conditions in the pre-study survey differed from actual prescribing for patients seen on the study dates with the same conditions. This suggests that collecting actual prescribing data provides a more accurate assessment of veterinary prescribing behaviour than surveying veterinarians' responses to hypothetical clinical scenarios, though the small sample size precludes us from making broad generalizations. Despite awareness of prescribing guidelines, clinical decision-making and antibiotic selection is likely influenced by additional variables, including practice norms, patient factors, and client pressures, which are not routinely accounted for in surveys. The study methodology described here provides a feasible approach when there is no universal data collection system and/or low bandwidth; it allows investigators to identify areas for antibiotic stewardship interventions, highlight conditions in which more prescribing guidance is needed for dogs, cats, and horses, and provides a practical way to monitor changes in prescribing over time. A national survey will be an important first step in establishing a baseline estimate of the prevalence of AU in small animal and equine veterinary practice, from which opportunities for AU improvement can be identified and progress towards that goal tracked.

4.1 | Limitations

Practices participating in this study were self-selected, and thus might not represent the broader veterinary community. This study was designed to measure antibiotic prescribing, not to determine whether prescribed antibiotics were indicated. Although we discuss broad trends, this presents some limitations on how definitively conclusions can be made regarding specific drug-indication findings. For example, we found that first-line antibiotics were often selected for upper respiratory tract infections but were unable to evaluate whether AU was aligned with prescribing guidelines (e.g., clinical signs of upper respiratory tract infection present for greater than 10 days in a feline patient). The study also did not differentiate between sporadic and recurrent conditions (e.g., cystitis), which might influence antibiotic selection. Given study design, patient outcomes could not be determined and, because diagnosis was not recorded for patients who did not receive an antibiotic prescription, we are unable to calculate rates of antibiotic prescribing for specific conditions. Additionally, the COVID-19 pandemic, which began to affect veterinary practice function in late March 2020, may have impacted the percentage of consults that resulted in an antibiotic prescription. The veterinary–client–patient relationship (VCPR) is defined by the American Veterinary Medical Association as the basis for interaction between clients, veterinarians, and the patients they treat (American Veterinary Medical Association, 2022). A valid VCPR is required for veterinarians to prescribe medications to a patient. As a result of the COVID-19 pandemic, the Minnesota BVM extended the time period within which a veterinarian must have examined a patient to maintain a valid VCPR from 12 to 18 months (Minnesota Board of Veterinary Medicine, 2021). The extension of the VCPR, as well as staffing and personal protective equipment shortages, may have delayed routine visits as well as planned surgeries, and increased the proportion of sick visits. Finally, the results of this study, conducted in a two-state region, likely cannot be extrapolated to broader populations because of differences in training and local practice.

5 | CONCLUSIONS

Overall, this study highlights trends in antibiotic prescribing in cats, dogs, and horses. This includes the frequent use of third-generation cephalosporins and the infrequent use of bacterial culture and susceptibility testing in small animal and equine practice. It also emphasizes the need for guidance in the utilization of topical antibiotic therapy for skin infections, as well as treatment guidance for non-specific acute diarrhoea in cats and dogs. The methodology used here can be applied to a national-level survey, performed on a single day, to collect AU data in veterinary practices. This is a feasible way to collect a large, uniform dataset of AU from multiple sites, with minimal effort from individual practices.

ACKNOWLEDGEMENTS

The authors sincerely thank the participants for their time and dedication to this research. The authors thank the University of Minnesota College of Veterinary Medicine Emerging, Zoonotic, and Infectious Disease Signature Program for funding this research.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

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How to cite this article: Bollig, E. R., Granick, J. L., Webb, T. L., Ward, C., & Beaudoin, A. L. (2022). A quarterly survey of antibiotic prescribing in small animal and equine practices—Minnesota and North Dakota, 2020. *Zoonoses and Public Health*, *69*, 864–874. https://doi.org/10.1111/zph.12979