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STANDARD ARTICLE

Prevalence of antibiotic use for dogs and cats in United States veterinary teaching hospitals, August 2020

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Abstract

Background: Awareness of prescribing practices helps identify opportunities to improve antibiotic use (AU).

Objectives: To estimate AU prevalence in dogs and cats in U.S. veterinary teaching hospitals (VTHs) and identify antibiotic drugs commonly prescribed, indications for use, and evidence of bacterial infection.

Animals: Medical record data were collected from dogs and cats examined at 14 VTHs.

Abbreviations: AS, antimicrobial stewardship; AST, antimicrobial susceptibility testing; AU, antibiotic use; AVMA, American Veterinary Medical Association; FDA, U.S. Food and Drug Administration; IACUC, Institutional Animal Care and Use Committee; IRB, Institutional Review Board; PPS, point-prevalence survey; VTH, veterinary teaching hospital.

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Methods: Data were collected from VTH medical records of dogs and cats examined by primary care, urgent care, emergency and critical care, internal medicine, and surgery services on a single day during August 13-September 3, 2020. Data included signalment; clinical service; inpatient or outpatient status; clinical conditions; diagnostic tests; evidence of bacterial infection; intended reason for AU; name and route of antibiotics prescribed.

Results: Of 883 dogs and cats, 322 (36.5%) were prescribed at least 1 antibiotic. Among 285 antibiotics administered systemically intended for treatment of infection, 10.9% were prescribed without evidence of infection. The most common class of antibiotics presribed for systemic administration was potentiated penicillin for dogs (115/346, 33.3%) and cats (27/80, 33.8%). For dogs and cats, first-generation cephalosporins (93/346, 26.9% and 11/80, 13.8%, respectively) and fluoroquinolones (51/346, 14.7% and 19/80, 23.8%, respectively) was second or third most-prescribed. Common AU indications included skin, respiratory, and urinary conditions, and perioperative use.

Conclusions and Clinical Importance: Collaborative data collection provides a sustainable methodology to generate national AU prevalence estimates and bring attention to areas requiring additional research and detailed data collection. These efforts can also identify practice improvement opportunities in settings where future veterinarians are trained.

KEYWORDS
antibiotic indication, antibiotic measurement, antibiotic prophylaxis, antibiotic resistance, antibiotic stewardship, cats, dogs

1 | INTRODUCTION

The alignment of antibiotic drug selection with clinical rationale for therapy and diagnostic information is essential to optimize veterinary care and slow the development of antibiotic resistance. Measurement and evaluation of prescribing practices is essential to drive practice improvement for individual prescribers, hospitals, and the veterinary profession at large. The American Veterinary Medical Association (AVMA) has identified the concept of antibiotic use (AU) prescribing practice evaluation as 1 of the 5 core principles of antimicrobial stewardship (AS). AS is characterized by AVMA as the actions veterinarians take to preserve the effectiveness of antimicrobial drugs, including antibiotics, through oversight and medical decision-making.[1] Veterinary engagement has been identified as essential in the United States (U.S.) National Strategy and Action Plan for Combating Antibiotic-Resistant Bacteria.[2,3] In the U.S., processes exist for the routine measurement of the prevalence and appropriateness of AU in human inpatients and outpatients.[4-6] Similar processes are lacking for companion animal veterinary practice in the U.S., and there are a limited number of consensus documents that guide assessment of appropriateness of antibiotic prescribing.[7-9]

Outside of food-animal drug sales data collected by the U.S. Food and Drug Administration (FDA) and other special studies, there are few sources of data that track AU for animals within the U.S.[10-14] In 2020, there were 83.7 million dogs and 60.2 million cats in the U.S., with 45% and 26% of households owning dogs and cats, respectively.[15] This amounts to more dogs and cats than the combined human population in the United Kingdom and Australia. Despite this, antibiotic prescribing practices by veterinarians for dogs and cats remain poorly described.

In this study, antibiotic prescribing data were gathered from veterinary teaching hospitals (VTHs) in the U.S. Primary objectives were to measure the prevalence of AU in inpatient and outpatient dogs and cats and to identify the most common antibiotic drugs prescribed, indications for use, and associated evidence of bacterial infection.

2 | MATERIALS AND METHODS

2.1 | Ethics statement and recruitment

Data were collected by using a point-prevalence survey (PPS) methodology, which involved collection of uniform data from multiple study sites for a single time point (1 day). With a scope limited to collection of veterinary medical data, the study was determined exempt from review by the University of Minnesota Institutional Animal Care and Use Committee (IACUC). This study was categorized as "not human research" by the University of Minnesota Institutional Review Board (IRB).

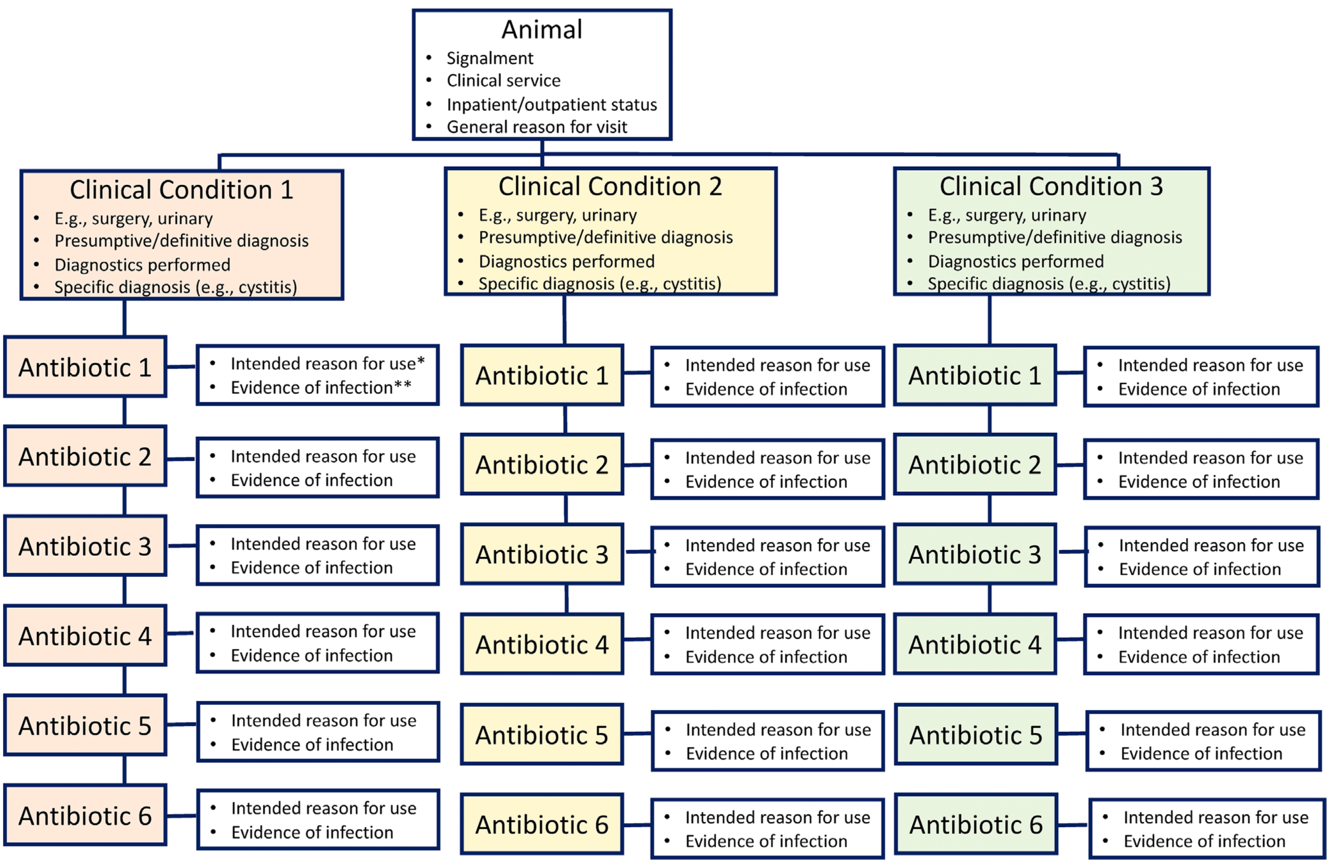
All small animal VTHs in the U.S. were invited to participate in the study. Recruitment occurred during June-August 2020 and was promoted through the American Association of Veterinary Medical Colleges, veterinary professional email listservs, social media, specialty board communication, including the American College of Veterinary Internal Medicine and the American College of Veterinary Preventive Medicine, and through professional networks of the co-authors. Fourteen VTHs agreed to participate and received IRB and IACUC exemption or approval from their individual institutions.

2.2 | Data collection

Participating VTHs identified facility coordinators who were responsible for obtaining local ethics approval (if required by institution), attending an online training session before data collection, adhering to standard operating procedures, utilizing training materials made available by the University of Minnesota researchers, completing a stewardship survey (see supplemental materials) with questions related to institutional AS efforts, entering medical record data into an electronic database, and contributing to the data validation process.

Each facility coordinator selected a single day representing normal operations from a prespecified 2-week range (August 17-30, 2020) as the "study day." Two VTHs selected a study day outside of this range because construction and extreme weather impacted hospital operations.

Clinical services included in the study were primary care, internal medicine, surgery, emergency and critical care, and urgent care. Urgent care services see outpatient cases outside of normal business hours that do not require hospitalization or other specialty care. Half of participating VTHs in this study have an urgent care service that operates separately from the emergency and critical care service. Dogs and cats seen by other specialty services (eg, dermatology, oncology, dentistry) in the VTHs were not included in the study. Medical records were reviewed for all dog and cat inpatients present between midnight and 11:59 PM local time on the study day and all dog and cat outpatients that had a consult with a veterinarian on the study day. Figure 1 shows the data collection structure. Collected data included signalment; clinical service; hospitalization status (inpatient or outpatient); reason for visit (wellness, sick, surgery/procedure, recheck, or euthanasia); up to 3 broad clinical conditions (eg, surgery, urinary condition); specific diagnosis for select clinical conditions (eg, pneumonia, lower urinary tract infection); diagnostic tests conducted on or before the study day and related to the clinical condition(s) (ie, antigen or PCR testing, complete blood count, culture and antimicrobial susceptibility testing [AST], cytology, fecal float, fluorescein stain, histopathology, serology/titers, or urinalysis); whether or not imaging was performed; and the name and route of antibiotics prescribed.



* Treatment of infection, prophylaxis, properties unrelated to the drug's antibacterial effects

** Confirmed infection, suspected infection, no evidence of infection

FIGURE 1 Data-collection structure in the 2020 veterinary teaching hospital point-prevalence survey.

TABLE 1 Criteria used to assign category for evidence of bacterial infection.

Evidence of bacterial infection category	Criteria
Confirmed bacterial infection	Documentation of (1) positive culture; (2) cytology/fluid analysis with presence of organisms with clinical signs of infection at the site of collection; (3) positive PCR with clinical signs of disease; (4) 4-fold rise in serologic titer.
Suspected bacterial infection	Documentation of (1) wound (surgical or open) with fever or redness or tenderness or warmth or swelling or bite history; (2) neutrophilic fluid/cytology with no organisms seen; (3) single positive serology with clinical signs of disease; (4) radiographs identifying pneumonia but without positive airway wash and/or culture and AST; (5) purulent skin disease without cytology or culture and AST; (6) purulent discharge from an orifice without cytology or culture and AST; (7) visualization of gastrointestinal perforation in the absence of "confirmed infection"; (8) fever of unknown origin; (9) fever with indwelling device (eg, urinary catheter, central line, implant with evidence of infection at the implant site); (10) lytic bony lesion; (11) echocardiographic evidence of vegetative lesion on heart valve.
No evidence of bacterial infection	No documentation of confirmed/suspected infection or if an alternative reason for antibiotic. Includes documented negative titers or cultures, no titers or cultures submitted, "preventative" uses, as written in medical record, or systemic antibiotic use after clean surgery. Alternative noninfectious diagnosis that explains clinical signs.

Results from diagnostic and imaging tests were used by facility coordinators to assign a level of evidence of bacterial infection (see below), but these test results were not recorded in the study database. Only diagnostic and imaging test results available on or before the study day were used to assign a level of evidence of bacterial infection, reflecting what was known to the clinician on the day of the prescription.

The generic antibiotic drug name was recorded for antibiotics in the medical record prescribed or administered to cats and dogs on the study day or the calendar day that preceded the study day, except for ophthalmic antibiotic preparations and "triple antibiotic" topical preparations (eg, Neomycin/Polymyxin B/Bacitracin, Neomycin/Polymyxin B/Gramicidin). Antibiotics initiated by referring veterinarians were recorded if the consulting VTH veterinarian made the decision to continue the antibiotic. If a dog or cat was prescribed multiple antibiotics, details of each were recorded. If an antibiotic drug was intended for use for more than 1 clinical condition in a single patient, it was affiliated with each condition in the study database.

In addition to antibiotic details described above, facility coordinators recorded the intended reason for AU (treatment of infection, prophylaxis, use for properties unrelated to the drug's antimicrobial effects [eg, prokinetic, anti-inflammatory]) or noted that the reason for AU could not be determined from information in the medical record. Because multiple conditions could be recorded for each animal, AU for a single animal could be associated with more than 1 intended reason for AU. After reviewing each medical record, facility coordinators used criteria in the study standard operating procedures to assign a level of evidence of bacterial infection (ie, confirmed infection, suspected infection, no evidence of infection) to each case where antibiotics were prescribed. Only information available on or before the study day was used to determine evidence of infection. Infection criteria (Table 1) were adapted from a previous study.[14]

2.3 | Data management and analysis

Data were entered and managed in a secure Research Electronic Data Capture (REDCap) database.[16] Data from each VTH could only be viewed by that submitting institution and by the University of Minnesota researchers. No identifiable client, pet, or prescriber data were collected.

Analyses and calculation of 95% confidence intervals (CI) were performed using SAS (Release 9.4. Cary, NC: SAS Institute, 1997). Data are summarized as frequencies (n) and percentages (%), with missing data excluded. The chi-square test was used to evaluate association between categorical variables. A *t*-test was used to assess a difference in means. For patient-level analysis, antibiotics were considered unique based upon generic name. For example, dogs and cats that were prescribed 2 systemic formulations of the same drug on the study day (eg, intravenous enrofloxacin with transition to oral enrofloxacin), were considered to have received a single antibiotic drug, and those that were prescribed 2 chemically distinct drugs (eg, transition from intravenous ampicillin-sulbactam to oral amoxicillin-clavulanate) on the study day were considered to have been prescribed 2 antibiotic drugs. Combination drugs, such as amoxicillin-clavulanic acid or triple antibiotic, were counted as 1 drug. The grouping of "antibiotics given systemically" includes intramuscular, intravenous, oral, subcutaneous, and local-infusion routes, and "antibiotics applied topically" includes those administered by ophthalmic, otic, or dermatologic routes. AU for broad clinical conditions, classified by general type (eg, surgery) or body system (eg, urinary), was summarized. Because dogs and cats could have more than 1 clinical condition recorded in the medical record, the number of conditions analyzed was greater than the number of animals (Figure 1).

3 | RESULTS

3.1 | Veterinary teaching hospitals and their AS practices

In 2020, there were 28 academic VTHs in the U.S., of which 14 (50%) participated in this study and completed the stewardship survey. Participating VTHs were located in 4 geographic regions, aligned with those regions used to describe AU in humans, including the Northeast (3), Midwest (5), South (4), and West (2).[4]

Most study VTHs (8/14, 57%) did not have an AS committee. Interest in establishing a committee was noted by 6 of 8 of those hospitals. Major barriers to establishing an AS committee included lack of staff time (7/8) and resources (5/8) dedicated to AS activities. Some VTHs reported lack of commitment or interest from hospital leadership (2/8) and staff (2/8) as major barriers. Most VTHs actively incorporate AS concepts into courses (13/14, 93%) and specifically include AS-focused lectures in the professional veterinary curriculum (11/14, 79%).

3.2 | Animals included

A total of 883 animals were included in the study, of which 80.5% were dogs and 19.5% were cats. The median number of cats and dogs included per hospital was 62.5 (interquartile range, 51-75). Additional demographic characteristics for dogs and cats, including hospitalization status, sex, age, attending clinical service, and primary visit reason, are presented in Table 2.

3.3 | Antibiotic drugs prescribed

Of the 883 dogs and cats included in the study, 322 were prescribed at least 1 antibiotic drug on the study day or day before, yielding an estimated AU prevalence of 36.5% (95% CI: 33.3%-39.6%) among primary care, urgent care, emergency and critical care, internal medicine, and surgery services. Study dogs and cats were prescribed a total of 452 antibiotic drugs, most of which were for systemic use

TABLE 2 Characteristics of dogs and cats in the 2020 VTH point-prevalence survey.

	Dogs, n = 711 (%)	Cats, n = 172 (%)	Total, n = 883 (%)
Species			
Dog	-	-	711 (80.5%)
Cat	-	-	172 (19.5%)
Sex			
Male neutered	270 (38.0%)	80 (46.5%)	350 (39.6%)
Male intact	98 (13.8%)	8 (4.7%)	106 (12.0%)
Female spayed	296 (41.6%)	70 (40.7%)	366 (41.4%)
Female intact	47 (6.6%)	14 (8.1%)	51 (6.9%)
Hospitalization status			
Inpatient	322 (45.3%)	85 (49.4%)	407 (46.1%)
Outpatient	389 (54.7%)	87 (50.6%)	476 (53.9%)
Age			
Median (years)	7.1	5.0	6.7
<4 months	22 (3.1%)	11 (6.5%)	33 (3.8%)
>4-12 months	59 (8.4%)	9 (5.3%)	68 (7.8%)
>1-3 years	99 (14.0%)	34 (20.0%)	133 (15.2%)
>3-7 years	169 (23.9%)	46 (27.1%)	215 (24.5%)
>7-10 years	143 (20.2%)	22 (12.9%)	165 (18.8%)
>10-15 years	198 (28.0%)	30 (17.7%)	228 (26.0%)
>15-20 years	17 (2.4%)	18 (10.6%)	35 (4.0%)
Missing	4 (0.6%)	2 (1.1%)	6 (0.7%)
Service			
Emergency and critical care	226 (31.8%)	80 (46.5%)	306 (34.7%)
Surgery	201 (28.3%)	19 (11.0%)	220 (24.9%)
Internal medicine	155 (21.8%)	41 (23.8%)	196 (22.2%)
Primary care	104 (14.6%)	24 (14.0%)	128 (14.5%)
Urgent care	25 (3.5%)	8 (4.7%)	33 (3.7%)
Visit reason			
Sick	419 (58.9%)	111 (64.53%)	530 (60.0%)
Recheck	112 (15.8%)	22 (12.8%)	134 (15.2%)
Surgery/Procedure	106 (14.9%)	15 (8.7%)	121 (13.7%)
Wellness	54 (7.6%)	8 (4.7%)	62 (7.0%)
Euthanasia	20 (2.8%)	16 (9.3%)	36 (4.1%)

TABLE 3 Antibiotic drug classes prescribed to dogs and cats on the study day.

	Number of drugs (n, %)		
	For dogs (n = 365)	For cats (n = 87)	Total (n = 452)
Topical preparation[a]	19, 5.2%	7, 8.0%	26, 5.8%
Systemic preparation, all[b]	346, 94.8%	80, 92.0%	426, 94.3%
Aminoglycosides	2, 0.6%	0, 0%	2, 0.5%
Amphenicols (chloramphenicol)	3, 0.9%	0, 0%	3, 0.7%
Cephalosporins, first generation	93, 26.9%	11, 13.8%	104, 24.4%
Cephalosporins, second generation	5, 1.4%	1, 1.3%	6, 1.4%
Cephalosporins, third generation	12, 3.5%	5, 6.3%	17, 4.0%
Fluoroquinolones	51, 14.7%	19, 23.8%	70, 16.4%
Imidazoles (metronidazole)	19, 5.5%	5, 6.3%	24, 5.6%
Lincosamides (clindamycin)	10, 2.9%	6, 7.5%	16, 3.8%
Macrolides	11, 3.2%	2, 2.5%	13, 3.1%
Penicillins	11, 3.2%	4, 5.0%	15, 3.5%
Potentiated penicillins	115, 33.2%	27, 33.8%	142, 33.3%
Tetracyclines (doxycycline)	14, 4.0%	0, 0%	14, 3.3%

[a]Topical antibiotic drug preparations include ophthalmic, dermatologic, and otic.
[b]Systemic antibiotic drugs in each drug class: Aminoglycosides: amikacin and neomycin; Amphenicols: chloramphenicol; Cephalosporins, first-generation: cefazolin and cephalexin; Cephalosporins, second-generation: cefoxitin; Cephalosporins, third-generation: cefovecin, cefpodoxime proxetil, and ceftazidime; Fluoroquinolones: enrofloxacin, marbofloxacin, orbifloxacin, and pradofloxacin; Imidazoles: metronidazole; Lincosamides: clindamycin; Macrolides: azithromycin and tylosin; Penicillins: amoxicillin and ampicillin; Potentiated penicillins: amoxicillin-clavulanic acid, ampicillin-sulbactam, and piperacillin-tazobactam; Tetracyclines: doxycycline.

(Table 3). Prevalence estimates by species and hospitalization status are displayed in Table 4. Animals prescribed an antibiotic were more likely to be inpatient (235/322, 72.9%) than outpatient (87/322, 27.0%; $P < .01$). Animals prescribed and not prescribed an antibiotic did not differ by age or species. Nearly a third of dogs and cats (31.7%, 102/322) were prescribed 2 or more antibiotic drugs, including 39.6% (93/235) of inpatients (Table 4).

Three hundred eight animals were prescribed 426 antibiotic drugs for systemic administration. The most common class of antibiotics for systemic administration in both dogs and cats were potentiated penicillins (Table 3), with amoxicillin-clavulanic acid and ampicillin-sulbactam most selected in that class (Table 5). First-generation cephalosporins and fluoroquinolones were the second or third most-prescribed class for dogs and cats (Tables 3 and 5). Carbapenems and glycopeptides (eg, vancomycin) were not prescribed to dogs and cats in this study.

Twenty-six animals each were prescribed 1 antibiotic drug for topical application. Of these 26 antibiotics, 13 (50%) were ophthalmic preparations, 7 (27%) dermatologic preparations, and 6 (23%) otic preparations. Dermatologic preparations included gentamicin (2), erythromycin (1), triple antibiotic (1), amikacin (1), metronidazole (1), and mupirocin (1). Antibiotics in otic preparations included florfenicol (3), gentamicin (1), neomycin (1), and enrofloxacin (1). Twelve (46%) dogs and cats that were prescribed an antibiotic for topical application were also prescribed a systemically administered antibiotic; this included all 8 inpatients that were prescribed an antibiotic for topical application (Table 4).

3.4 | Intended use for antibiotic drugs prescribed

The 426 antibiotic drugs prescribed for systemic use were associated with the following intended uses: treatment of infection (278, 63.9%), prophylaxis (112, 25.7%), and non-antimicrobial effects (19, 4.4%). An intended reason for AU could not be determined from the medical record for 26 (6.0%) prescriptions. The 3 most common antibiotics prescribed for systemic administration for the treatment of infection in inpatients were ampicillin-sulbactam (64/222, 28.8%), enrofloxacin (48/222, 21.6%), and amoxicillin-clavulanic acid (30/222, 13.5%). For outpatients, the 3 most common antibiotics prescribed for systemic administration for treatment of infection were amoxicillin-clavulanic acid (23/56, 41%), cephalexin (10/56, 18%), and enrofloxacin (7/56, 13%).

In some instances, the same antibiotic had more than 1 intended reason for AU or level of evidence of infection for a single patient. Of the 64.5% (285/442) of antibiotics prescribed for systemic administration intended for infection treatment, 28.1% (80/285) were prescribed for confirmed infections, 61.1% (174/285) for suspected infections, and 10.9% (31/285) when no evidence of infection was recorded in the medical record. Antibiotics prescribed for systemic administration intended for infection treatment without documented evidence of infection included ampicillin-sulbactam (9), enrofloxacin (7), amoxicillin-clavulanic acid (4), metronidazole (3), pradofloxacin (2), amoxicillin (1), cefazolin (1), chloramphenicol (1), clindamycin (1), piperacillin-tazobactam (1), and tylosin (1). Of the 77% (20/26) of antibiotics prescribed for topical application intended for infection

TABLE 4 Dogs and cats for which antibiotics were prescribed.

	Inpatient dogs, n = 322	Inpatient cats, n = 85	Inpatient total, n = 407
≥1 Antibiotic drug by any route	201 (62.4, 57.1-67.7)	34 (40.0, 29.6-50.4)	235 (57.7, 52.9-62.5)
≥1 Administered systemically	201 (62.4, 57.1-67.7)	34 (40.0, 29.6-50.4)	235 (57.7, 52.9-62.5)
≥1 Administered topically	7 (2.2, 0.6-3.8)	1 (1.2, 0-3.5)	8 (2.0, 0.06-3.3)
Number of antibiotic drugs			
1 Antibiotic drug	125 (38.8, 33.5-44.1)	17 (20.0, 11.5-28.5)	142 (34.9, 30.3-39.5)
2 Antibiotic drugs	63 (19.6, 15.2-23.9)	10 (11.8, 4.9-18.6)	73 (17.9, 14.2-21.7)
3 Antibiotic drugs	12 (3.7, 1.7-5.8)	1 (1.2, 0-3.5)	13 (3.2, 1.5-4.9)
≥4 Antibiotic drugs	1 (0.3, 0-0.9)	6 (7.1, 1.6-12.5)	7 (1.7, 0.5-3.0)
	Outpatient dogs, n = 389	**Outpatient cats, n = 87**	**Outpatient total, n = 476**
≥1 Antibiotic by any route	65 (16.7, 13.0-20.4)	22 (25.3, 16.2-34.4)	87 (18.3%, 14.8-21.8)
≥1 Administered systemically	57 (14.7, 11.1-18.2)	16 (18.4, 10.3-26.5)	73 (15.3, 12.1-18.6)
≥1 Administered topically	12 (3.1, 1.4-4.8)	6 (6.9, 1.6-12.2)	18 (3.8, 2.1-5.5)
Number of antibiotic drugs			
1 Antibiotic drug	56 (14.4, 10.9-17.9)	22 (25.3, 16.2-34.4)	78 (16.4, 13.1-19.7)
2 Antibiotic drugs	9 (2.3, 0.8-3.8)	0 (0)	9 (1.9, 0.7-3.1)
3 Antibiotic drugs	0 (0)	0 (0)	0 (0)
≥4 Antibiotic drugs	0 (0)	0 (0)	0 (0)
	All dogs, n = 711	**All cats, n = 172**	**Total inpatient and outpatient, n = 883**
≥1 Antibiotic by any route	266 (37.4, 33.9-41.0)	56 (32.6, 25.6-39.6)	322 (36.5%, 33.3-39.6)
≥1 Administered systemically	258 (36.3, 32.8-39.8)	50 (29.1, 22.3-35.9)	308 (34.9, 31.7-38.0)
≥1 Administered topically	19 (36.3, 32.8-39.8)	7 (4.1, 1.1-7.0)	26 (2.9, 1.8-4.1)
Number of antibiotic drugs			
1 Antibiotic drug	181 (25.5, 22.3-28.7)	39 (22.7, 16.4-28.9)	220 (24.9, 22.1-27.8)
2 Antibiotic drugs	72 (10.1, 7.9-12.3)	10 (5.8, 2.3-9.3)	82 (9.3, 7.4-11.2)
3 Antibiotic drugs	12 (1.7, 0.7-2.6)	1 (0.6, 0-1.7)	13 (1.5, 0.7-2.3)
≥4 Antibiotic drugs	1 (0.1, 0-0.4)	6 (3.5, 0.8-6.2)	7 (0.8, 0.2-1.4)

Note: Table includes count of animals prescribed antibiotic drugs on the study day, proportion, and 95% CI of the proportion.

treatment, 50% (10/20) were prescribed for confirmed infections and 50% (10/20) for suspected infections; none were prescribed when there was no evidence of infection recorded in the medical record.

3.5 | Clinical conditions for which antibiotics were prescribed

Of the 883 dogs and cats in the study, 844 animals had 1 (617, 70.1%), 2 (170, 19.1%), or 3 (57, 6.5%) conditions recorded that could be classified by type or body system. Thirty-seven (4.2%) had no clinical condition identified (ie, were healthy) and 2 (0.2%) had a single clinical condition for which the type or body system could not be determined. Common clinical conditions of dogs and cats associated with an antibiotic prescription are listed in Table 6.

Animals in the study had 299 clinical conditions for which systemic antibiotics were prescribed for treatment of infection. The most common indications included respiratory (19.4%, 58/299), hepatobiliary (12.0%, 36/299), surgical (11.7%, 35/299), urinary (11.7%, 35/299), and skin (11.7%, 35/299) infections. Ampicillin-sulbactam was the systemic antibiotic most used for treatment of infection (72/299, 24.1%), followed by enrofloxacin (59/299, 19.7%) and amoxicillin-clavulanic acid (56/299, 18.7%).

Animals in the study had 114 clinical conditions for which systemic antibiotics were prescribed for prophylaxis. Of these, 82.5% (94/114) were surgical and 17.5% (20/114) were nonsurgical conditions (6 trauma, 2 gastrointestinal, 2 urinary, 2 neoplasia, 2 cardiac, 1 skin, 1 hepatobiliary, 1 dental/oral, 1 ocular, 1 multisystemic, 1 cytopenia). Cefazolin was the systemic antibiotic most used for prophylaxis both overall (73/114, 64.0%) and for surgical prophylaxis (67/94, 71%). Other systemic antibiotics used for surgical prophylaxis included amoxicillin-clavulanic acid, ampicillin-sulbactam, cefoxitin, ceftazidime, and cephalexin. Antibiotics used for nonsurgical prophylaxis included amoxicillin-clavulanic acid, ampicillin, ampicillin-sulbactam, cefazolin, cefovecin, cephalexin, and piperacillin-tazobactam.

Antibiotics for systemic use were prescribed for non-antimicrobial effects for 19 clinical conditions. Of these, 11 were gastrointestinal, 4 surgical, 2 hepatobiliary, 1 endocrine, and 1 multisystemic

TABLE 5 Systemic antibiotic drugs prescribed for dogs and cats, in order of frequency.

Number of systemic antibiotic prescriptions (n, %)	
For dogs (n = 346)	**For cats (n = 80)**
Cefazolin (65, 18.8)	Amoxicillin-clavulanic acid (16, 20.0)
Ampicillin-sulbactam (63, 18.2)	Cefazolin (10, 12.5)
Amoxicillin-clavulanic acid (49, 14.2)	Ampicillin-sulbactam (9, 11.3)
Enrofloxacin (47, 13.6)	Enrofloxacin (9, 11.3)
Cephalexin (28, 8.1)	Pradofloxacin (7, 8.8)
Metronidazole (19, 5.5)	Clindamycin (6, 7.5)
Doxycycline (14, 4.0)	Metronidazole (5, 6.3)
Clindamycin (10, 2.9)	Cefovecin (4, 5.0)
Azithromycin (8, 2.3)	Amoxicillin (3, 3.8)
Cefpodoxime proxetil (8, 2.3)	Azithromycin (2, 2.5)
Ampicillin (7, 2.0)	Marbofloxacin (2, 2.5)
Cefoxitin (5, 1.4)	Piperacillin-tazobactam (2, 2.5)
Amoxicillin (4, 1.2)	Ampicillin (1, 1.3)
Ceftazidime (4, 1.2)	Cefoxitin (1, 1.3)
Marbofloxacin (4, 1.2)	Ceftazidime (1, 1.3)
Piperacillin-tazobactam (3, 0.9)	Cephalexin (1, 1.3)
Chloramphenicol (3, 0.9)	Orbifloxacin (1, 1.3)
Tylosin (3, 0.8)	
Amikacin (1, 0.3)	
Neomycin (1, 0.3)	

conditions. Metronidazole was the systemic antibiotic most used for non-antimicrobial effects (12/19, 63%) and often selected for gastrointestinal conditions (9/11, 81%). Other antibiotics used in this way included azithromycin (3/19, 16%), amoxicillin-clavulanic acid (2/19, 11%), neomycin (1/19, 5%), and tylosin (1/19, 5%).

3.6 | Use of diagnostic testing

At least 1 type of diagnostic test was performed for 59.1% (522/883) of all dogs and cats in the study, including 77.0% (246/322) of dogs and cats that were prescribed at least 1 antibiotic and 48.8% (274/561) of dogs and cats that were not prescribed an antibiotic. Of the 205 dogs and cats prescribed at least 1 antibiotic for treatment of infection, 79 (38.5%) had bacterial culture and AST, 67 (32.7%) had a urinalysis, and 52 (25.4%) had cytology conducted for the condition for which the antibiotic was prescribed.

3.7 | Diagnostics and AU for select clinical conditions with available prescribing guidelines

All 15 cases of lower urinary tract infection reviewed in the study had a urinalysis or culture and AST; 10 dogs and cats had both culture and AST and urinalysis, 3 had urinalysis only, and 2 had culture and AST only performed. Six of 10 cases of upper urinary tract infection had both urinalysis and culture and AST, 1 with urinalysis only, and 1 with culture and AST only; 2 had no urinalysis or culture and AST performed. Eleven of 15 (73%) dogs and cats with lower urinary tract infection and 7 of 10 with upper urinary tract infection had at least 1 prescription of an antibiotic drug. Three of 14 (21%) antibiotics prescribed for lower urinary tract infection and 3 of 9 antibiotics for upper urinary tract infection were recommended first-line drugs for these conditions.[9]

Fourteen dogs in the study were diagnosed with superficial focal pyoderma, of which 1 had both cytology and culture and AST, 5 had cytology only, and 1 had culture and AST only performed; 7 had no cytology or culture and AST performed. Six of 14 (43%) dogs with superficial focal pyoderma were prescribed an antibiotic (5 systemic, 2 topical), and all prescriptions were in accordance with published guidelines.[7]

There were 25 cases of pneumonia (23 in dogs, 2 in cats). Twenty-four (96%) had imaging, with 4 of those patients having both cytology and culture and AST performed and 2 culture and AST only. Twenty-three dogs and cats (92%) had 34 antibiotic prescriptions; 17/23 (74%) were treated with antibiotics in accordance with antibiotics recommended as first-line agents.[8] Upper respiratory tract disease was uncommon in this study, with 2 cases reported for each species. Of these, diagnostic testing consisted of complete blood count and urinalysis for 1 cat and imaging for both dogs. Only 1 dog was treated with an antibiotic; this antibiotic was not a recommended first-line agent.[8]

DISCUSSION

In the U.S., barriers to collecting AU data for dogs and cats include logistical challenges of accessing prescribing data within and across diverse veterinary electronic health record systems and a lack of standard diagnostic coding. PPS methodology used in this study overcomes these obstacles and provides a feasible way to estimate AU prevalence in dogs and cats. Of the 883 dogs and cats reviewed, 58% of inpatient animals and 18% of outpatient animals were prescribed antibiotics on the study day or day before. Outpatient AU prevalence is likely underrepresented because of the exclusion of some specialty services, including dermatology and oncology. Using similar methodology, CDC reports approximately 50% AU prevalence for hospitalized human patients.[5] The 4 most commonly prescribed antibiotic drug classes in this study were potentiated penicillins, first-generation cephalosporins, fluoroquinolones, and imidazoles, which mirrors findings from a longitudinal study in 3 VTHs.[12]

Of the 278 antibiotic prescriptions used for infection treatment, 3 (ampicillin-sulbactam, amoxicillin-clavulanic acid, and enrofloxacin) made up 62% of use. Gastrointestinal, skin, and urinary conditions accounted for 41% of all outpatient AU; surgery, gastrointestinal, and respiratory conditions accounted for 54% of inpatient AU. This study did not include all specialty services and thus prescribing for some

TABLE 6 Clinical conditions documented overall and in association with prescription of ≥1 antibiotic for dogs and cats.

Condition	Dogs		Cats		Total	
	Number of conditions	Conditions with ≥1 antibiotic, % (95% CI)[a]	Number of conditions	Conditions with ≥1 antibiotic, % (95% CI)[a]	Number of conditions	Conditions with ≥1 antibiotic, % (95% CI)[a]
Surgical	122	74.6 (66.9-82.3)	23	47.8	145	70.3 (62.9-77.8)
Gastrointestinal	106	17.0	21	19.1	127	17.3
Respiratory	77	49.4 (38.2-60.5)	18	11.1	95	42.1 (32.2-52.0)
Urinary	59	39.0	27	33.3	86	37.2 (27.0-47.4)
Orthopedic, nonsurgical	74	5.4	5	0	79	5.1
Skin	64	43.8 (31.6-55.9)	12	41.7	76	43.4 (32.3-54.6)
Neurologic	59	6.8	10	30.0	69	10.1
Neoplasia	48	8.3	13	15.4	61	9.8
Endocrine	42	4.8	12	0	54	3.7
Cardiac	37	5.4	4	0	41	4.9
Hepatobiliary	31	51.6	8	87.5	39	59.0
Trauma	26	50.0	8	25.0	34	44.1
Toxicity	21	0	5	0	26	0
Dental/oral	21	9.5	4	50.0	25	16.0
Ocular	19	47.4	5	100	24	58.3
Immune-mediated	20	15.0	3	0	23	13.0
Otic	10	70.0	6	66.7	16	68.8
Pancreatic	10	50.0	4	0	14	35.7
Multisystemic	4	75.0	5	80.0	9	77.8
Reproductive	8	62.5	1	100	9	66.7
Peritonitis	7	100	1	100	8	100
Fever of unknown origin	3	66.7	4	75.0	7	71.4
Blood infection	4	75.0	2	50.0	6	66.7
Overweight	4	0	2	0	6	0
Behavioral	5	0	0	-	5	0
Cytopenia	4	50.0	1	0	5	40.0
Anemia	2	0	2	0	4	0
Lyme disease	1	100	0	-	1	100
Other	8	12.5	6	0	14	7.1
Open diagnosis	15	20.0	5	0	20	15.0
Total	911	32.5 (29.5-35.5)	217	30.4 (24.3-36.5)	1128	32.1 (29.4-34.8)
No condition identified	29	0	8	0	37	0
Type not recorded in record	1	100	2	0	3	33.3

Note: Listed in order of frequency.
[a]95% CI calculated for conditions where ≥30 consults were associated with antibiotics.

conditions (eg, dermatologic) is likely underrepresented. Review of facility protocols for the most used drug classes and most common clinical conditions for which antibiotics are prescribed would allow VTH AS committees to ensure best practices are established for these prescribing events. Because approximately 40% of hospitalized animals prescribed an antibiotic were prescribed 2 or more antibiotic drugs, AS leaders could also place emphasis on reviewing treatment plans for overlapping antibiotic coverage.

AU for prophylactic indications accounted for 26% of prescriptions, highlighting an opportunity for AS teams to review facility protocols and monitor prophylactic prescribing. More detailed assessment to understand perioperative AU, including situations where it is not usually indicated (eg, spay, neuter, other clean surgeries), would be beneficial to guide veterinary AS practice. Data are needed to understand current uses of antibiotics for post-surgical patients and to inform best practice recommendations for specific conditions.

The prevalence for use of antibiotics for nonantimicrobial effects was 4.4% in this study, and metronidazole was the drug most used in this category. Consensus from the American College of Veterinary Internal Medicine does not support the use of antibiotics for nonantimicrobial activities.[17] Though metronidazole use for gastrointestinal illness was less common in this VTH study than in other studies in companion animals, it does appear to be an area for practice improvement in veterinary teaching settings.[11,18] Given the availability of recent literature suggesting that metronidazole does not speed the resolution of acute diarrhea and can lead to gastrointestinal dysbiosis, clinical guidelines and education for acute diarrhea would be an impactful contribution to AS.[19-21]

Concordance with published peer-reviewed antibiotic prescribing guidelines in this study was variable. AU for urinary tract diseases did not consistently align with empiric prescribing guidance,[9] though the high prevalence of culture and AST for these urinary infections may have influenced the selection of antibiotics that are not considered first-line agents. The populations of animals seen at VTHs often receive antibiotic therapy before referral. Less than half of dogs with superficial pyoderma were prescribed an antibiotic, and all prescriptions were in accordance with published guidelines.[7] However, because specialty dermatology services were not included, this study might represent prescribing for less complicated dermatologic conditions. Nearly three-quarters of dogs and cats with pneumonia were prescribed recommended antibiotic drugs.[8] Where animals did not receive first-line treatment for pneumonia, culture and AST and cytology findings do not appear to have supported antibiotic selection since these tests were infrequently performed. It will be important to understand whether VTH deviations from published prescribing recommendations are related to lack of guideline uptake or factors specific to clinical infections seen in academic centers. This study has identified potential areas for immediate AS intervention, but more targeted data collection is necessary to quantify rates of AU appropriateness and targets for prescribing behavior change. Although a majority (13/14) of veterinary colleges in this study reported teaching AS concepts in the veterinary curriculum, less than half (6/14) had an active AS committee in the VTH. In settings where future veterinarians are trained, clinicians should reflect on differences between what students are taught in didactic courses and the real-world AU decision-making to which they are exposed in the clinical year.

Targets for AS and improved prescribing may be different for VTHs and primary care practices. In contrast to reports of AU in small animal primary care, use of third-generation cephalosporins was uncommon in the VTH cohort.[11,22] Cefovecin has been reported elsewhere as commonly used for diverse indications, especially for feline patients.[11,22-25] In this VTH study, cefovecin was selected for 5% of cats prescribed an antibiotic as compared to 35% of cats in a recent study of AU in Midwest companion animal primary care practices utilizing a PPS methodology.[11] Similarly, cefpodoxime proxetil was selected for 2% of dogs prescribed an antibiotic in this VTH study, compared to 15% of dogs prescribed an antibiotic in the same primary care practice study.[11] The comparatively low rates of third-generation cephalosporin use in this and a previously published VTH study highlights the need to understand drivers for prescribing this drug class in other companion animal veterinary settings.[12]

Overall use of culture and AST testing was low and was performed in 39% of all cats and dogs that were prescribed an antibiotic for infection treatment. This is consistent with other AU and prescriber behavior studies.[14,26-29] Only 28% of dogs and cats prescribed an antibiotic for the purpose of treating an infection had a confirmed infection and 11% had no evidence of infection. VTHs often have microbiology laboratories on-site. In addition, dogs and cats presenting to academic institutions may be more likely to have received previous antibiotic courses, putting them at higher risk of multidrug-resistant infections. Veterinarians have cited cost as an obstacle to performing culture and AST.[27] Additional work is needed to identify opportunities to increase access to and use of culture and AST as an essential diagnostic and AS tool.

PPS methodology allows distribution of effort across participating institutions to estimate a population-level AU prevalence with data from a single time point. Common drug use patterns for cats and dogs described in this 14-institution single-day study are similar to those identified through a comprehensive 5-year review of antibiotics used in 3 VTHs.[12] However, there are limitations to the PPS study design, which only describes a snapshot in time and thus cannot record delayed prescribing or duration of injectable antibiotics. Uncommon conditions (eg, infective endocarditis) and use of antibiotics (eg, carbapenems, vancomycin) that are of high importance but used infrequently might not be captured. Although common outpatient conditions are captured with this methodology, metrics regarding appropriateness of prescribing behaviors can be difficult to calculate given the small sample size and lack of supporting information, like duration of clinical signs and disease recurrence. Another potential limitation is variability in the quality and completeness of the medical records used to extract study data. VTH participation was voluntary, and the study was conducted during the first year of the COVID-19 pandemic, thus these self-selected organizations might not represent all VTHs in the U.S. Additionally, the COVID-19 pandemic may have affected volume and acuity of cases.

As the profession continues to engage veterinary partners in evidence-based approaches to AS, routine measurement of AU will be essential. Data collection must continue at the national level to monitor trends in AU and to identify needs for in-depth AU surveys, prescribing guidelines for common or high-priority clinical conditions, continuing education content, and information technology solutions to support AU and AS programs in clinical settings.[30] Reducing inappropriate and unnecessary AU is a benefit to individual animals and contributes to the overall prevention of antimicrobial resistance in clinical settings, regionally, and nationally. Collaborative initiatives will inform sustainable solutions to track AU nationally, identify common metrics for use in companion animal AS, and inform approaches to use those data for action.

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CONFLICT OF INTEREST DECLARATION

JL Granick and JE Sykes were invited members for Zoetis' Companion Animal Antimicrobial Stewardship Advisory Board during a 2 day virtual meeting in 2021. JL Granick has received a gift through the University of Minnesota Foundation from Merck Animal Health to support a graduate student for 1 year to work on an unrelated project. Neither of these relationships impacted the design, execution, analysis or interpretation of the data presented in this study. No other authors declare a conflict of interest.

OFF-LABEL ANTIMICROBIAL DECLARATION

This study collected data on antimicrobial use in cats and dogs, though evaluation of extra-label use was not assessed in this study. Because they are not labeled for use in dogs and cats, all use of ampicillin-sulbactam, azithromycin, ceftazidime, cefoxitin, metronidazole, piperacillin-tazobactam was extra-label. Additionally, intravenously administered injectable enrofloxacin is also extra-label.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Authors declare no IACUC or other approval was needed.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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