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Patterns of bacterial culture and antimicrobial susceptibility test results for dogs with retrobulbar abscesses: 133 cases (2002–2019)

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OBJECTIVE
To evaluate patterns of bacterial culture and antimicrobial susceptibility test results for dogs with retrobulbar abscesses and generate recommendations for empirical antimicrobial selection.

ANIMALS
133 dogs examined between 2002 and 2019.

PROCEDURES
Records were retrospectively reviewed to determine type of bacterial culture, number and type of bacterial isolates, antimicrobial susceptibility test results, concurrent and recent antimicrobial exposure, effect of culture results on antimicrobial regimen, and outcome.

RESULTS
Aerobic culture alone was performed in 37 dogs, and aerobic and anaerobic culture was performed in 96 dogs. Isolates were recovered from 96 dogs, with multiple isolates recovered from 54 (56%) of those dogs. Of the 69 dogs for which both aerobic and anaerobic culture was performed and at least 1 isolate was obtained, 34 (49%) had purely aerobic infections, 15 (22%) had mixed aerobic and anaerobic infections, and 20 (29%) had purely anaerobic infections. *Pasteurella* spp (n = 26), *Streptococcus* spp (20), and *Escherichia coli* (12) were the most common aerobic isolates. *Bacteroides* spp (n = 22), *Actinomyces* spp (10), and *Fusobacterium* (10) spp were the most common anaerobic isolates. Susceptibility test results led to changes in the antimicrobial regimen in 37 of 80 (46%) dogs. Of the 76 dogs for which outcome information was available, 78 (97%) recovered.

CLINICAL RELEVANCE
Multipathogen and anaerobic infections were common in dogs with retrobulbar abscesses. Susceptibility data supported the use of amoxicillin-clavulanate or a combination of clindamycin and enrofloxacin as first-line treatments. Additional study is needed to characterize anaerobic antimicrobial susceptibilities and to compare results of susceptibility testing with in vivo responses to antimicrobial administration.

Retrobulbar abscesses are common, painful ophthalmic emergencies in dogs.[1] Affected dogs frequently have difficulty eating and sometimes require hospitalization for supportive care.[1] Most dogs recover with appropriate treatment, but corneal ulceration, keratoconjunctivitis sicca, prolapse of the gland of the third eyelid, vision loss, and other ocular complications are occasional sequelae.[2,3] Life-threatening complications such as intracranial empyema and sepsis have also been documented.[4,5] Thus, proper, prompt treatment of retrobulbar abscesses is essential.

In dogs, treatment of retrobulbar abscesses generally incorporates an extended course of systemic antimicrobial administration, with additional medical or surgical interventions included when needed. Although the initial response to appropriate antimicrobial treatment is usually rapid, most ophthalmologists recommend administration for several weeks at a minimum to ensure elimination of the infection in the relatively sequestered confines of the orbit.[1] However, costs associated with extended courses of antimicrobials can be substantial, particularly for large-breed dogs, and medication-induced adverse effects such as nausea or inappetence may occur. In addition, bacterial resistance to antimicrobials is increasingly documented in companion animals, and because of the impact of bacterial resistance on animal and human health, responsible use and stewardship of antimicrobials have become focuses of attention in veterinary medicine.[6–10]

Selection of antimicrobial treatment on the basis of bacterial culture and susceptibility test results is considered the standard of care for dogs with retrobulbar abscesses.[1] Sample collection frequently re-

quires image-based guidance, with ultrasonography or CT used to locate the abscess and allow insertion of a needle without causing damage to the globe or other orbital structures. Sampling may be precluded, however, by abscess location, owner finances, or limitations on availability of imaging equipment and trained personnel. Even when sampling is successfully performed, antimicrobial treatment must be instituted before culture and susceptibility test results are available. Therefore, culture and susceptibility test results from historical cases are often used as a guide for rational initial or empirical treatment.

The largest study[11] of dogs with retrobulbar abscesses to date evaluated culture and susceptibility data for 34 dogs. *Staphylococcus, Escherichia, Bacteroides, Clostridium,* and *Pasteurella* spp were the most common isolates, and cephalosporins, extended-spectrum penicillins, potentiated penicillins, and carbapenems were recommended as first-line treatments on the basis of antimicrobial susceptibility test data. As the authors of that study[11] noted, however, most dogs examined at their institution with signs suggestive of a retrobulbar abscess did not have sampling performed, suggesting that their study population may have represented dogs with refractory or otherwise complicated disease. Moreover, for 14 (41%) dogs in that study, bacterial culture yielded no growth, leaving only 20 dogs with positive culture results for analysis.

At our institution, imaging-guided sample collection for bacterial culture and antimicrobial susceptibility testing is recommended at the time of initial presentation for all dogs suspected to have retrobulbar abscesses. The objectives of the study reported here were to retrospectively evaluate patterns of bacterial culture and antimicrobial susceptibility test results for dogs with retrobulbar abscesses and generate recommendations for empirical antimicrobial selection.

Materials and Methods

A medical records search was performed to identify dogs treated for a retrobulbar abscess between 2002 and 2019 at the Foster Hospital at Cummings School of Veterinary Medicine at Tufts University or at the Tufts Veterinary Emergency Treatment and Specialties. Dogs were included if the diagnosis was confirmed by means of diagnostic imaging, cytologic examination, or both and if sampling was performed for bacterial culture and antimicrobial susceptibility testing. Bacterial culture and susceptibility testing was performed by a commercial laboratory (Idexx Laboratories Inc).

Medical records of dogs included in the study were reviewed, and information was collected regarding type of culture performed (aerobic, anaerobic, or both), number and type of bacterial isolates obtained from each sample, antimicrobial susceptibility test results (on both an isolate and patient basis), concurrent or recent antimicrobial exposure, effect of culture results on antimicrobial regimen (eg, whether culture results led to a change in antimicrobial treatment or a decrease in the number of antimicrobials administered), and patient outcome. In most cases, an inciting cause for the abscess could not be determined, and information on underlying causes is therefore not reported. In addition, information on patient weight, antimicrobial dosage, and duration of antimicrobial treatment was frequently not available in the medical record and is also not reported.

Antimicrobial susceptibility data were evaluated on a patient level for dogs for which both aerobic and anaerobic cultures were performed and at least 1 isolate was recovered. For these dogs, overall antimicrobial susceptibility was assessed on the basis of all culture and antimicrobial susceptibility data to determine which antimicrobial or combination of antimicrobials would have been predicted to treat all isolates recovered from that patient.

Laboratory procedures for antimicrobial susceptibility testing varied according to species and time period. Some isolates were tested with broth dilution methods (reported as minimum inhibitory concentrations with a designation of susceptible, intermediate, or resistant), whereas others were tested with disk diffusion methods (reported as susceptible, intermediate, or resistant without numerical data). For other isolates, antimicrobial recommendations were made on the basis of the bacterial species' typical responses to antimicrobials in lieu of testing. For the purposes of the present study, isolates were considered susceptible to an antimicrobial if susceptibility testing was confirmatory or if a specific recommendation had been made by the laboratory regarding predicted susceptibility to that antimicrobial. To maintain a conservative bias, if a particular isolate displayed intermediate susceptibility or was not tested for susceptibility to a particular antimicrobial, the isolate was assumed to be resistant to that antimicrobial. Multidrug resistance (MDR) and extensive drug resistance (XDR) were evaluated on the basis of previously published criteria, with MDR defined as resistance to at least 1 antimicrobial in each of 3 or more drug classes and XDR defined as resistance to at least 1 antimicrobial in all but 1 or 2 tested classes.[12]

For the patient-level analysis, culture and susceptibility test results were compared with recommendations made in previous publications for empirical treatment (cephalosporins and extended-spectrum or potentiated penicillins, with cephalexin, cefpodoxime, and amoxicillin-clavulanate selected as representative drugs because they are available in oral formulations and commonly used in clinical practice) and with the 2 most common empirical antimicrobial protocols currently used in the hospitals from which the patient population was drawn (combination treatment with clindamycin and enrofloxacin or with enrofloxacin and metronidazole).[1,11]

Although carbapenems were recommended as an empirical treatment in a previous publication,[11] this class of antimicrobial is generally not considered a first-line treatment and is reserved for specific nosocomial or resistant infections, with carbapenem resistance becoming an increasing issue.[13] As such, we did not feel that carbapenems represented an

appropriate drug choice for most dogs with retrobulbar abscesses regardless of an isolate's susceptibility profile and therefore did not elect to evaluate patient-level susceptibility to carbapenems, despite the previous recommendation.

Dogs were considered to have had a good outcome if the infection resolved and the patient was comfortable following initial medical and surgical treatment. Dogs that required additional courses of antimicrobials or additional surgical intervention or that developed complications such as sepsis, osteomyelitis, or an intracranial abscess were considered to have had a poor outcome.

Results

One hundred thirty-three dogs met the criteria for inclusion in the study. Aerobic culture alone was performed in 37 dogs; both aerobic and anaerobic culture was performed in the remaining 96 dogs. Fifty-two (39%) dogs had no concurrent or recent antimicrobial exposure. Nineteen (14%) dogs had received antimicrobials for the presumed abscess but were no longer receiving antimicrobials at the time of sampling. Information regarding antimicrobial type and duration of treatment was often unavailable for this subset of the population because treatment had generally been directed by the referring veterinarian and referral records were incomplete. The remaining 62 (47%) dogs were receiving antimicrobials systemically at the time of sampling. Thirty-seven of these 62 (60%) dogs had been receiving antimicrobials for ≤ 3 days, including 14 dogs that had received only a single dose of antimicrobials. Antimicrobials administered prior to sampling consisted of amoxicillin-clavulanate or ampicillin-sulbactam (37 dogs); a fluoroquinolone (18 dogs); cephalexin, cefpodoxime, or cefovecin (14 dogs); ampicillin or amoxicillin (8 dogs); clindamycin (8 dogs); metronidazole (7 dogs); and some other antimicrobial or an unknown antimicrobial (4 dogs).

Eighty-one of the 133 (61%) aerobic cultures yielded at least 1 bacterial isolate. One additional aerobic culture yielded bacteria on a Gram stain of the enrichment broth, but the bacteria could not be cultured or speciated. Thirty-two of the 96 (33%) anaerobic cultures yielded at least 1 isolate. Overall, at least 1 isolate was obtained from 96 of the 133 (72%) dogs, with a single isolate obtained from 42 (32%) dogs, 2 isolates obtained from 35 (26%) dogs, 3 isolates obtained from 13 (10%) dogs, and 4 isolates obtained from 6 (5%) dogs. Of the 69 dogs for which both aerobic and anaerobic culture was performed and at least 1 isolate was obtained, 34 (49%) had purely aerobic infections, 15 (22%) had mixed aerobic and anaerobic infections, and 20 (29%) had purely anaerobic infections.

Bacterial culture of samples from 37 dogs yielded no bacterial isolates. Twenty-nine (78%) of these dogs were receiving antimicrobials at the time of sampling. However, for the study population as a whole, at least 1 isolate was recovered from 33 of the 62 (53%) dogs receiving antimicrobials at the time of sampling and from 63 of the 71 (89%) dogs not receiving antimicrobials at the time of sampling. Dogs with negative culture results that were receiving antimicrobials at the time of sampling had been receiving antimicrobials for a median of 3 days (range, 1 to 21 days), whereas dogs with positive culture results that were receiving antimicrobials at the time of sampling had been receiving antimicrobials for a median of 2 days (range, 1 to 60 days). Antimicrobials administered were similar between these groups, with 9 of the 33 (27%) dogs with positive culture results while receiving antimicrobials and 11 of the 29 (38%) dogs with negative culture results while receiving antimicrobials being treated with amoxicillin-clavulanate or ampicillin-sulbactam monotherapy, and 10 of 33 (30%) dogs with positive culture results and 10 of 29 (34%) dogs with negative culture results being treated with a cephalosporin or fluoroquinolone alone. The remaining dogs were receiving another drug or a combination of drugs, but no other antimicrobials or antimicrobial combinations were represented by > 2 dogs in either group.

One hundred twenty aerobic isolates representing 31 species were documented **(Table 1)**. *Pasteurella* spp (n = 26), *Streptococcus* spp (20), and *Escherichia coli* (12) were the most common aerobic isolates. Fifty-five anaerobic isolates representing 6 species were recovered. *Actinomyces* spp were

Table 1—Bacterial isolates recovered from 133 dogs with retrobulbar abscesses.

Aerobic isolate (n = 120)

Identification	No. of isolates
Pasteurella spp	26
Streptococcus spp	20
Escherichia coli	12
Staphylococcus spp	11
Nonenteric gram-negative rods	11
Corynebacterium spp	10
Neisseria spp	4
Acetinobacter spp	3
Bacillus spp	3
Enterobacter cloacae	2
Enterococcus spp	2
Lactobacillus spp	2
Proteus mirabilis	2
Achromobacter sp	1
Aeromonas hydrophila	1
Bergeyella zoohelcum	1
Eikenella corrodens	1
Escherichia hermanii	1
Klebsiella sp	1
Micrococcus sp	1
Pseudomonas aerophila	1
Stenotrophomonas maltophila	1
Unspeciated "normal flora"	3

Anaerobic isolate (n = 55)

Identification	No. of isolates
Bacteroides spp	22
Actinomyces spp	10
Fusobacterium spp	10
Peptostreptococcus spp	9
Clostridium spp	2
Prevotella spp	2

recovered from aerobic cultures by the diagnostic laboratory but are considered anaerobes in terms of their behavior and antimicrobial susceptibilities and were categorized as anaerobes for the present study.

Susceptibility testing was not performed on all isolates, and in some instances, the laboratory substituted antimicrobial recommendations based on predicted behavior. Furthermore, some isolates were listed as "normal flora" for which neither susceptibility testing results nor recommendations were provided; this designation was sometimes given even for isolates with heavy growth from a documented abscess. Susceptibility testing was performed for 76 of the 120 (63%) aerobic isolates, and recommendations based on predicted behavior were made for 30 of the 120 (25%) aerobic isolates and all 55 (100%) of the anaerobic isolates. β-Lactamase testing was performed for *Bacteroides* isolates, with 7 of 22 (32%) *Bacteroides* isolates producing β-lactamases. A designation of "normal flora" was made for 14 of 120 (12%) aerobic isolates, including representatives of the genera *Corynebacterium*, *Lactobacillus*, α-*Streptococcus*, and *Aeromonas*.

Specific antimicrobials included in susceptibility testing panels varied according to time and species. Percentages of isolates resistant to antimicrobials commonly used in clinical practice were calculated, with results presented for antimicrobials tested against > 20% of the isolates that underwent susceptibility testing **(Figure 1)**.

Of the 175 total isolates, only 25 (14%) were classified as having MDR (18 isolates from 17 dogs) or XDR (7 isolates from 6 dogs; **Table 2**). Five XDR isolates were *E coli* (2 distinct *E coli* isolates were cultured from a single patient). Two other isolates (*Achromobacter* spp and *Stenotrophomonas maltophila*) were deemed inherently XDR prior to testing; further testing was performed on the *Achromobacter* isolate, which was found to be resistant to gentamicin and all fluoroquinolones assayed. Of the dogs with MDR isolates, 6 had received or were currently receiving antimicrobials (2 had received antimicrobials previously but were not receiving antimicrobials at the time of sampling; 4 had received antimicrobials for 1, 2, 3, and 9 days prior to sampling). Of the dogs with XDR isolates, 3 were receiving antimicrobials at the time of sampling (for 1, 7, and 60 days).

Patient-level antimicrobial susceptibility test results could be calculated for 69 dogs **(Figure 2)**. Amoxicillin-clavulanate was tested against 60 of 76 (79%) isolates for which susceptibility testing was performed, while cephalexin was tested against 64 of 76 (84%) isolates, cefpodoxime against 55 of 76 (72%) isolates, and enrofloxacin against 58 of 76 (76%) isolates. By contrast, only 16 of 76 (21%) aerobic isolates tested were assayed for susceptibility to clindamycin, although it is expected to have activity against gram-positive aerobic bacteria such as *Staphylococcus* and *Streptococcus* spp, which made up 26% of aerobic isolates in our patient population. Because metronidazole shows activity only in the anaerobic spectrum and because anaerobic susceptibility testing is not performed by most laboratories, no isolates were specifically tested against metronidazole, and assessment was made based on recommendations of predicted susceptibility.

Information regarding the effects of bacterial culture and susceptibility test results on antimicrobi-

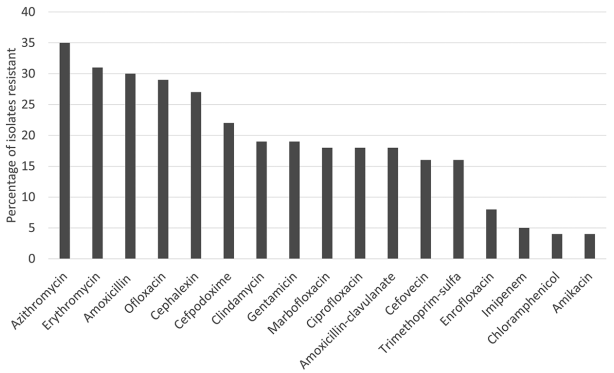

Figure 1—Antimicrobial resistance of bacterial isolates obtained from 133 dogs with retrobulbar abscesses. Only those antimicrobials for which testing was performed for > 20% of isolates are shown.

Table 2—Isolates from Table 1 classified as multidrug resistant (MDR) or extensively drug resistant (XDR).

MDR

Identification	No. of isolates
α-Hemolytic *Streptococcus* spp	7
Staphylococcus pseudintermedius	2
Staphylococcus hominis	2
Enterobacter cloacae	2
Staphylococcus epidermidis	1
Proteus mirabilis	1
Escherichia coli	1
Acetinobacter calcoaceticus-baumannii	1
Pseudomonas aeruginosa	1

XDR

Identification	No. of isolates
Escherichia coli	5
Stenotrophomonas maltophila	1
Achromobacter spp	1

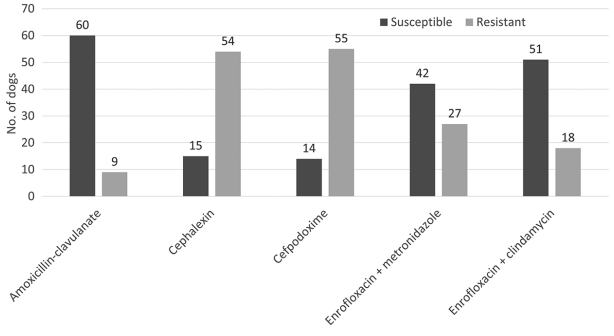

Figure 2—Patient-level antimicrobial susceptibility test results for 69 dogs with retrobulbar abscesses. Data are provided for antimicrobials recommended in past publications and for the 2 antimicrobial combinations currently preferred at our institution.

al selection was available for 80 of the 96 dogs from which at least 1 isolate was recovered. Antimicrobials were substituted or an additional antimicrobial was added to the treatment regimen for 11 dogs, drugs were removed from the treatment regimen for 26 dogs, and no changes were made for 43 dogs.

Information on outcome was available for 78 of the 96 dogs from which at least 1 isolate was recovered. Of those 78 dogs, 59 recovered fully with medical management directed by culture and susceptibility test results and were reported by their owners to have a comfortable, cosmetic eye (information regarding vision was not included in the medical record for most dogs). Surgical management beyond drainage with a needle and syringe at the time of sampling was elected as part of the initial treatment in 17 dogs. Seven dogs underwent surgical drainage and debridement of the abscess; 6, including 1 with a foreign body in the orbit, underwent enucleation; 3 underwent foreign body removal without enucleation; and 1 underwent removal of a bony sequestrum involving the zygomatic process of the frontal bone. All 17 of these dogs reportedly recovered.

The remaining 2 dogs had more complicated courses. One dog with a history of porcupine quills and an initial polymicrobial culture including an MDR *Streptococcus* isolate developed recurrent abscesses following initial treatment with amoxicillin-clavulanate and doxycycline and required additional exploratory surgery. No foreign material was found. No samples were obtained for bacterial culture at the time of surgery, but the dog appeared to recover following a second course of treatment with the same antimicrobials used initially. Subsequently, this dog developed entropion secondary to atrophy of orbital contents. Because the eye was nonvisual, enucleation was performed. Although no infection was apparent at the time of enucleation, a defect in the bony medial wall of the orbit was discovered that allowed communication between the orbit and nasal cavity. The other dog with a complicated course had experienced substantial head trauma with nasal bone and frontal sinus fractures and subsequently developed a retrobulbar abscess with an MDR *Acetinobacter* isolate. The dog was treated with enrofloxacin but was euthanized 2 months after the initial diagnosis owing to persistent infection and complications arising from the initial injury.

Outcome information was also available for 17 of the 37 dogs with negative culture results. All 17 of these dogs recovered with antimicrobial treatment. One dog from this group also underwent initial surgical debridement of the abscess, and another dog from this group underwent enucleation initially to allow removal of quills that had migrated behind the globe. Of those 17 dogs successfully treated without guidance from culture results, 8 were treated with amoxicillin-clavulanate in combination with metronidazole; 4 were treated with clindamycin and enrofloxacin; and 1 each was treated with metronidazole, enrofloxacin, amoxicillin-clavulanate with metronidazole and enrofloxacin, amoxicillin-clavulanate with clindamycin and enrofloxacin, and amoxicillin-clavulanate alone.

Discussion

Rational antimicrobial use and antimicrobial stewardship improve patient outcomes and preserve treatment options for resistant infections in people and veterinary patients.[14] With a rise in resistant infections in veterinary patients and the realization that resistant organisms can be passed between people and pets, interest in the development of antibiograms and other tools to improve prescribing practices is growing.[7–10,15,16] The standard of care in our hospital for dogs with retrobulbar abscesses has evolved with these priorities in mind. However, antimicrobial treatment for this condition typically must be instituted prior to availability of culture and susceptibility test results. As such, establishing a foundation for rational empirical antimicrobial choices for suspected retrobulbar abscesses is key. The present study presents bacterial culture and susceptibility test data for the largest population of dogs with retrobulbar abscesses evaluated to date, including 96 dogs for which both aerobic and anaerobic cultures were performed. This study was the first to evaluate antimicrobial susceptibility on a patient level and the first to document MDR and XDR bacterial isolates from dogs with retrobulbar abscesses.

Multipathogen infections were common in this patient population, with ≥ 2 isolates obtained from 54 of the 96 (56%) dogs with positive culture results and anaerobic pathogens identified in 36 of these 96 (37%) dogs. These findings highlight the importance of performing both aerobic and anaerobic culture and selecting antimicrobials with broad-spectrum coverage when choosing empirical treatment. At least 1 isolate was recovered from most dogs receiving antimicrobials at the time of sampling (33/62 [53%]), suggesting that imaging-guided sampling still has value in dogs that have already received antimicrobials and that instituting antimicrobial treatment when sampling is likely to be delayed may not prevent subsequent identification of etiologic agents.

Bacterial species recovered in the present study were similar to those documented in a previous study.[11] *Pasteurella* spp were the most commonly identified isolate in our patient population. Antimicrobial resistance of *Pasteurella* strains cultured from veterinary patients has varied substantially in past reports,[17–19] from < 6% to 17%, but is generally thought to be low, with the exception of a few antimicrobials such as erythromycin. One study[20] evaluating canine bite wounds, however, found concerning rates of resistance to enrofloxacin and aminoglycosides. For most of the dogs in the present study from which a *Pasteurella* sp was recovered, further speciation was not performed, and antimicrobial recommendations were substituted for susceptibility testing for 15 of 26 (58%) *Pasteurella* isolates. Antimicrobials recommended by the laboratory usually included ampicillin, amoxicillin-clavulanate, tetracycline, and enrofloxacin, with the occasional addition or substitution of cephalosporins, trimethoprim-sulfonamides, or erythromycin. More recent work shows that distinct strains, even within the same *Pasteurella* sp, seem to differ markedly in

their virulence and antimicrobial susceptibility.[21] Dogs in the present study with *Pasteurella* isolates were often treated on the basis of laboratory recommendations, rather than results of susceptibility testing, and outcomes were generally good. Nevertheless, there is some danger in relying on assumptions about antimicrobial susceptibility, and the lack of susceptibility testing for some isolates was a weakness of the present retrospective study. Commercial laboratories providing microbiological services should be encouraged to perform susceptibility testing rather than providing generalized recommendations.

Streptococcus spp, *Staphylococcus* spp, and *E coli* were the next most common aerobic isolates in the present study. Concerns about antimicrobial resistance associated with these species in people and in dogs are long-standing and have spawned numerous investigations, particularly in the past 2 years.[15,16,22–27] In particular, a recent study[8] identified substantial resistance to amoxicillin-clavulanate among *Staphylococcus* and *E coli* isolates from veterinary patients, with around half of *Staphylococcus pseudintermedius* and *E coli* isolates resistant to this drug. In the present study, 5 of 11 *Staphylococcus* isolates and 6 of 20 *Streptococcus* isolates met the criteria for classification as MDR, including 2 *Staphylococcus* isolates classified as methicillin resistant. Of the 12 *E coli* isolates, 5 were classified as XDR and 1 was classified as MDR. Most of the dogs with these resistant isolates had had brief recent exposure to antimicrobials, which aligns with previous reports[28] documenting the potential impact of short-term antimicrobial use on antimicrobial resistance. Recent work suggests improved antimicrobial prescribing practices including the use of culture and susceptibility testing may blunt trends toward increased antimicrobial resistance in these aerobic bacterial species.[29]

Anaerobic orbital infections in dogs have been documented previously,[5,11,30] and in the present study, at least 1 anaerobic isolate was obtained from 32 of the 96 (33%) dogs in which anaerobic culture was performed. Antimicrobial resistance in anaerobes has received less attention than resistance in aerobes, likely because antimicrobial susceptibility testing for anaerobes requires specialized handling and is not routinely performed in most laboratories.[31–34] Still, antimicrobial resistance in anaerobes is becoming a concern in people.[34–36] In dogs, most recent studies[37,38] have focused on *Clostridium difficile* because of its potential for morbidity in humans. However, clostridial species were recovered from only 2 dogs in the present study. *Bacteroides* spp were the most commonly cultured anaerobes and the second most commonly cultured genus overall. *Actinomyces*, *Fusobacterium*, and *Peptostreptococcus* spp were also recovered from substantial numbers of dogs.

Bacteroides spp, particularly *Bacteroides fragilis*, show the greatest recent increases in antimicrobial resistance among anaerobic isolates from people.[34] *Bacteroides* spp frequently possess a β-lactamase gene, and rates of resistance to nonpotentiated penicillins are high. Resistance to clindamycin among *Bacteroides* spp is variable and usually low but can range up to 69% for some strains.[34,36,39] Strains resistant to potentiated penicillins and metronidazole are now occasionally seen.[36] *Bacteroides* resistance patterns in dogs appear similar, and resistance also seems to be increasing over time.[31–33] *Fusobacterium* and *Peptostreptococcus* spp exhibit less resistance in both people and dogs, although *Fusobacterium* strains resistant to amoxicillin-clavulanate were reported in 1 study.[31,36]

Actinomyces spp have not previously been reported as common isolates from retrobulbar abscesses[11] but were common in the patient population in the present study. *Actinomyces* spp are generally considered to be inherently resistant to metronidazole and more reliably sensitive to penicillins and clindamycin, although clindamycin-resistant strains have now been documented in people.[34,40] The difficulty in empirically selecting an antimicrobial that would provide adequate coverage for the common anaerobic pathogens in our study population highlights the need for speciation and susceptibility testing for clinical patients. On the basis of currently available information, clindamycin or a potentiated penicillin such as amoxicillin-clavulanate would appear to be the best choice for coverage of the anaerobic portion of the spectrum owing to the substantial number of *Actinomyces* isolates from our patients. Patient-level analysis performed on the dogs in the present study supported this recommendation, but further studies are needed that incorporate susceptibility testing of anaerobic isolates.

Importantly, in vitro drug susceptibility test results do not always correlate with in vivo efficacy, even when susceptibility testing is universally performed. Drug penetration into the retrobulbar space and into infected tissues is a major factor modulating the patient response to antimicrobials. Antimicrobial delivery is dependent on a complex interplay of drug, tissue, and pathogen factors such as molecule size and lipophilicity, protein binding, route of administration, bioavailability, tissue pH and vascular supply, and ability of microbes to sequester in WBCs.[41] Retrobulbar abscesses can develop by extension of infection from numerous surrounding structures with widely varying tissue characteristics, including the maxillary teeth, nasal cavity and sinuses, and zygomatic salivary or lacrimal glands.[1] In addition, because the orbit is partially bounded by nondistensible tissues (ie, bone), space-occupying lesions such as abscesses have the potential to occlude blood flow to the area and impair drug delivery. All of these factors suggest that culture data alone may be insufficient to determine the optimal treatment for retrobulbar abscesses.

Particular concerns related to the treatment of retrobulbar abscesses of sinonasal or odontogenic origin include the relative inability of β-lactams and metronidazole to penetrate bone, which may render them less effective.[42] Furthermore, in some infected tissues, β-lactamase inhibitors may display poorer tissue penetration than the β-lactam antimicrobial they are meant to accompany,[43] possibly erasing the advantages of amoxicillin-clavulanate, which otherwise appears to be the most rational empirical antimicrobial choice on the basis of culture and susceptibility test results from the present study. Fluoro-

quinolones typically display good tissue penetration and can reach pathogens sequestered in leukocytes, although they may not be able to do so in areas of decreased perfusion.[44,45] Clindamycin similarly shows good in vivo ability to penetrate infected and inflamed tissue and bone.[42,46] First-generation cephalosporins like cephalexin, by contrast, penetrate infected tissues less effectively, although cefpodoxime may perform better in this regard.[47] Much additional work is needed to characterize drug penetration into infected orbital tissues.

The lack of standardization of antimicrobials selected for susceptibility testing and the common laboratory practice of substituting recommendations for susceptibility testing were further limitations of the present study. In particular, the failure to test most gram-positive aerobic pathogens identified in this study for susceptibility to clindamycin likely led to an underestimation of the performance of the enrofloxacin-clindamycin combination. As noted, veterinarians who use commercial laboratories for microbiological testing should state an expectation of susceptibility testing when submitting samples. The designation of certain isolates as "normal flora" is also problematic and points to another opportunity for better communication between clinicians and commercial laboratories. For some of these samples, the source was described on the submission form as "eye" or "head" or another nondescript term was used. Specifying that the submission was obtained from an abscess or requesting susceptibility testing even if isolates are classified as "normal flora" might improve the quality of information obtained from culture and susceptibility testing.

More generally, an awareness of the limitations of traditional bacterial culture methods should be cultivated. Polymerase chain reaction assays and other molecular methods may yield results more reflective of actual pathogen populations, particularly in patients with multipathogen infections and patients that have already received antimicrobials.[48,49] Molecular diagnostic testing may also aid in the identification of previously underreported bacterial species.[50] The availability of molecular diagnostic testing is limited in veterinary medicine at the present time. Cytology, however, is readily available and may be a useful complement to culture and susceptibility testing. Generation of a detailed morphological description of bacteria present in samples obtained from retrobulbar abscesses, including gram-staining characteristics, may, when used in conjunction with culture and susceptibility testing, help clinicians select the most appropriate long-term antimicrobial regimen.

Regardless, outcomes in our patient population suggested that culture and susceptibility testing still provide a useful guide to treatment for dogs with retrobulbar abscesses. Changes, including addition, substitution, or discontinuation of drugs, were made in antimicrobial regimens for 37 of 80 (46%) dogs with positive culture results for which follow-up information was available. Almost all dogs with positive culture results recovered without major complications; the 2 dogs that experienced complicated disease courses had other factors present that were likely the cause of their poorer outcomes. These findings emphasize the importance of sampling and microbiological testing in dogs with retrobulbar abscesses.

The present study demonstrated that multipathogen, mixed aerobic-anaerobic, and pure anaerobic infections are all common in dogs with retrobulbar abscesses. Empirical and initial antimicrobial choices should provide coverage against gram-positive, gram-negative, and anaerobic bacteria. Multidrug-resistant pathogens were relatively uncommon, although the common laboratory practice of substituting recommendations for susceptibility testing may have understated the degree of antimicrobial resistance in this patient population. Additional limitations included the lack of availability of anaerobic susceptibility testing data and the minimal information available regarding drug delivery to infected orbital tissues. Nevertheless, amoxicillin-clavulanate monotherapy and the combination of enrofloxacin and clindamycin appear to be rational first-line choices for dogs with retrobulbar abscesses, and results of the present study do not support the use of cephalosporins, which were recommended by previous authors.[11] Because common bacteria and their resistance patterns can vary with geography and over time, clinicians treating dogs with retrobulbar abscesses should use these findings in conjunction with local culture results to develop antibiograms to guide individual prescribing practices.[7–10]

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