Paper

Prevalence and antimicrobial resistance of canine urinary tract pathogens

J. L. Hall, M. A. Holmes, S. J. Baines

This study aims to describe the incidence and risk factors for positive urinary tract culture, the prevalence of urinary tract pathogens in single organism and mixed cultures and changes in their antimicrobial resistance over 10 years. A retrospective review of computer records detailing canine urine samples submitted between August 1999 and September 2009 for culture and sensitivity in a UK tertiary referral hospital is described. 17.5 per cent of 5923 samples (670 of 4530 dogs) were positive cultures. 85.3 per cent of cultures yielded a single isolate. The prevalence of bacterial species differed between mixed and single isolate cultures. Entire and neutered female dogs were more likely to return positive cultures than male dogs (OR=2.5 and 1.5, respectively). *Escherichia coli* was most commonly isolated (53.9 per cent) and affected female dogs, older dogs and neutered dogs more. There was an increase in the antimicrobial resistance of *Enterococcus faecalis* and *Pseudomonas Aeruginosa*, and a decrease in the effectiveness of enrofloxacin, cephalexin and oxytetracycline. The prevalence of urinary bacterial isolates is described for a large group of dogs. Monitoring changes in antimicrobial efficacy and microbial resistance guides the empirical use of antimicrobials for the treatment of urinary tract infection and helps formulate strategic plans to limit drug resistance.

Introduction

Bacterial urinary tract infection (UTI) is a common condition affecting dogs presenting to first opinion and specialist practice. Hospital proportional morbidity rates for UTI range from 10 per cent to 14 per cent (Kivisto and others 1977, Ling 1984) and have been reported as 0.3 per cent for persistent or recurrent UTIs (Norris and others 2000). UTI may occur as a primary disease, secondary to other conditions (eg, metabolic disease, immunocompromise, urinary retention) or iatrogenically (eg, immunosuppressive drug therapy, transurethral catheterisation and nosocomial infection during hospitalisation). The presence of highly pathogenic bacteria increases the risk of persistent UTI, although anatomical and metabolic diseases affecting host defences against bacterial colonisation are a more important cause (Oxenford and others 1984, Seguin and others 2003, Drazenovich and others 2004, Lulich and Osborne 2004).

Antimicrobial treatment is often administered on the basis of consistent clinical signs and urinary dipstick findings prior to, or in the absence of, urine culture and sensitivity results (Blondeau and Tillotson 1999, Black and others 2009). Factors affecting the choice of antimicrobial agent include the likely causative pathogens, the individual patient's history, expected urinary concentrations of the antimicrobial agent, route of administration (eg, intravenous, subcutaneous, oral), cost, availability and possibly local microbial resistance and susceptibility patterns (eg, hospital, region or country). As such, the empirical selection of antimicrobial drugs requires accurate up-to-date information describing the prevalence of bacterial pathogens within a group, and their antimicrobial resistance and sensitivity patterns.

Several studies demonstrate variation in the prevalence of canine urinary tract pathogens and their antimicrobial resistance patterns in first opinion (Ball and others 2008) and referral practice groups (Kivisto and others 1977, Weaver and Pillinger 1977, Ling 1984, Féria and others 2000, Norris and others 2000, Seguin and others 2003, Black and others 2009). The prevalence of human urinary tract pathogens and their antimicrobial resistance patterns have been shown to vary geographically (Blondeau and others, 1997). There is a single report describing the prevalence of canine urinary tract pathogens and their resistance and sensitivity in a small UK group (Weaver and Pillinger 1977).

In human medicine, UTIs are becoming more difficult to treat, and symptoms caused by antimicrobial-resistant bacteria take longer to resolve (Butler and others 2006). The use of antimicrobial agents leads to bacterial resistance in first-opinion human patients (Costelloe and others 2010) and developing resistance patterns have been described in hospitalised dogs (Prescott and others 2002). Multiple drug resistance in canine UTIs has been associated with the use of antimicrobials (Cooke and others 2002, Cohn and others 2003). Although guidelines for the empirical use of antimicrobial agents cannot replace culture and sensitivity as a gold standard for choosing drug therapy (Lulich and Osborne 2004), they may help to reduce the development of antimicrobial resistance, reduce the overall cost of treatment and, most importantly, reduce patient morbidity by improving the chance of selecting the most appropriate medication initially. In vitro antimicrobial susceptibility testing provides information to guide selection of appropriate empirical therapy, and also demonstrates trends in antimicrobial resistance within a population (Blondeau and Tillotson 1999, Seguin and others 2003).

The aims of this study were (1) to accurately describe the recent prevalence and antimicrobial resistance of bacterial species isolated from urine samples submitted for culture from a large group of dogs

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in the UK; (2) to describe changes in the prevalence of the bacterial species and their antimicrobial resistance over a 10-year period; (3) to analyse this data to provide information regarding the efficacy of antimicrobial drugs and how it altered with time which may help guide the empirical choice of antimicrobials. This large group of dogs was expected to provide accurate and reliable data to the investigation of risk factors leading to a positive urinary culture and development of recurrent UTIs.

Methods and materials

Data collection

Data for urine samples submitted for culture and sensitivity testing from dogs seen by the Royal Veterinary College (UK), between August 1999 and September 2009, were collected from a computer database (LIMS; Labvantage Solutions, Version LVL5.4). These included signalment (breed, age and sex), urine dipstick analysis, microscopic sediment analysis, bacterial species identification and antimicrobial resistance and sensitivity analysis. All information was collated into a spreadsheet (Microsoft Excel 2010). Recurrent isolates were defined as one or more growths of the same bacterial species in the same individual on one or more subsequent urinary samples.

Culture and antimicrobial sensitivity data

All urine samples were submitted to the same laboratory the Royal Veterinary College (UK). Urine samples were streaked using an inoculation loop onto Columbia agar supplemented with 5 per cent sheep blood and on MacConkey agar (Scientific Laboratory Supplies UK). Each plate was divided in half, such that each sample could be applied twice (1 ul and 10 ul) for quantitative analysis. Blood agar plates were incubated overnight in 5 per cent CO_2, while MacConkey agar plates were incubated aerobically, until adequate growth was present. Identification was based on colony type and morphology, Gram staining characteristics and standard biochemical tests. Antimicrobial susceptibility was assessed using the Kirby-Bauer disc diffusion method and interpreting the zones of growth inhibition according to the contemporary Clinical and Laboratory Standards Institute (CLSI) and British Society of Antimicrobial Chemotherapy (BSAC) guidelines. Disc antimicrobial concentrations were selected according to the contemporary BSAC guidelines. A standard panel of antimicrobials was tested against all positive cultures, including ampicillin, amoxicillin clavulanate, cefovecin, cefuroxime, cephalexin, enrofloxacin, oxytetracycline and trimethoprim/sulphonamide. An extended antimicrobial panel was performed if a bacterial isolate was resistant to six or more antimicrobials on the standard panel, if pseudomonas was cultured, or if the laboratory staff had an increased suspicion that resistance to six or more antimicrobials would be demonstrated, for example, a mucoid *Escherichia coli* colony was identified. Extended panel antimicrobials included amikacin, gentamicin, imipenem, marbofloxacin, neomycin, nitrofurantoin, norfloxacin 2 mg and 10 mg, ofloxacin, polymyxin B and ticarcillin, in addition to the standard panel.

The impact factor (likelihood that a urinary tract pathogen in a confirmed UTI would be sensitive to an antimicrobial drug based on in vitro culture and sensitivity testing) for individual antimicrobial agents was calculated using the formula to help select rational antimicrobial therapy (FRAT, equation 1, Blondeau and Tillotson 1999) for *E coli*, Proteus, *Klebsiella*, *Staphylococcus intermedius*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, coagulase negative staphylococci, *Enterococcus faecalis* and *Streptococcus canis*.

$$F_S = \sum_{i=1}^{n} P_{pathogen}(i) \times S_{antimicrobial} \times 100 \qquad (1)$$

The total impact factor (Fs) is the sum of the individual impact factors for each pathogen, where $P_{pathogen\,(i)}$ is the prevalence of pathogen i (as a percentage of the total number of bacterial species cultured), and $S_{antimicrobial}$ is the proportion of pathogen i susceptible to the antimicrobial in question (as a percentage of the total number of that bacterial species cultured). Bacterial isolates of species accounting for prevalence of <2 per cent were excluded (Blondeau and Tillotson 1999), as antimicrobial susceptibility data was limited.

Statistical analysis

Statistical analyses were performed using a computer software statistical package (IBM SPSS Statistics V.20.0; IBM). Normality of the age of the group was investigated using a Shapiro-Wilk test. Associations between age and sex were investigated using ANOVA. Logistic regression was used to examine the predictive value of breed, age, sex and neutering status on the likelihood of a positive urinary culture. χ^2 Analysis was performed to investigate whether recurrent infection was more likely for *E coli* infections, whether there was an association between sex and age with mixed or single isolate cultures, and whether recurrent *E coli* isolates were resistant to more antimicrobial agents than non-recurrent *E coli* isolates.

Analyses of the number of antimicrobials to which isolates were resistant included ampicillin, amoxicillin clavulanate, cefuroxime, cephalexin, enrofloxacin, oxytetracycline and sulphonamide/trimethoprim, which account for seven of the eight antimicrobials forming the standard susceptibility panel. Changes in the number of antimicrobials that bacteria were resistant to, and impact factors for individual antimicrobial drugs, were examined using simple linear regression. Cefovecin was excluded from all analysis as it had been included for only 3 of the 10 years. The extended panel antimicrobials were excluded because they were only performed when multiple resistance had been confirmed or suspected, and therefore, a bias towards more resistant bacteria would have been seen in samples tested for these antimicrobials.

Recurrent isolates were excluded from all analyses of the total group and examined separately. Bacterial species prevalence between the first and subsequent samples for recurrent isolates was compared using χ^2 analysis. Logistic regression was used to examine the predictive value of breed, age, sex and neutering status on the likelihood of recurrent infection.

For all statistical analyses, the threshold for significance was set at $P<0.05$ with no adjustment made for multiple testing.

Results

Animals and samples

Five thousand nine hundred and twenty-three urine samples were submitted from 4530 dogs during the period of study with a median of one sample per dog (range 1–10). The median age of the dogs was 6.3 years (range 0.2–17 years; 109 unspecified). The ages of the study group were skewed towards younger animals ($P<0.01$). The mean age of female dogs was 0.4 years younger than male dogs ($P=0.002$). There were 1131 intact males (25.0 per cent), 1179 castrated males (26.0 per cent), 602 entire females (13.3 per cent), and 1452 spayed females (32.1 per cent), with 166 (3.7 per cent) being of unknown gender. Females were more likely to be neutered ($P<0.0001$). Entire females were younger than all other groups of dogs ($P<0.01$, mean 4.2 years). For both sexes, entire animals were younger than neutered animals ($P<0.0001$). The most common breeds of dogs affected are listed in Table 1.

Microbial isolates

A positive culture was obtained from 1037 samples (17.5 per cent) from 670 dogs (14.8 per cent). A single bacterial species was isolated

TABLE 1: Frequency of dog breeds with a positive urine culture

Breed	Number (%)
Cross breed	387 (8.5)
Labrador	380 (8.4)
German shepherd dog	257 (5.7)
Boxer	217 (4.8)
Cocker spaniel	179 (4.0)
West Highland white terrier	136 (3.0)
Golden retriever	128 (2.8)
Staffordshire bull terrier	119 (2.6)
Dachshund	110 (2.4)
Jack Russell terrier	107 (2.3)
Cavalier King Charles spaniel	105 (2.3)
Springer spaniel	102 (2.2)
Yorkshire terrier	97 (2.1)

All breeds representing more than 2 per cent of the group are included

TABLE 2: The prevalence of bacterial species isolated from urine samples submitted for culture

Organism	Percentage of positive cultures (overall)	Percentage of positive cultures (single isolate)	Percentage of positive cultures (mixed isolates)
Coliforms	54.8	61.8	36.2
Escherichia coli	53.9	61.4	34.1
Non-specified	0.8	0.3	2.1
Staphylococcus	14.7	13.7	17.4
intermedius	8.3	8.8	6.9
coagulase-negative	3.7	2.8	6.0
aureus	2.0	1.7	2.7
Other	0.7	0.3	1.8
Enterococcus faecalis	11.2	7.6	20.7
Proteus	7.2	6.9	8.1
Pseudomonas aeruginosa	4.0	3.7	4.8
Streptococcus	3.5	2.0	7.2
canis	2.6	1.5	5.7
Other	0.8	0.6	1.5
Klebsiella	2.2	1.8	3.3
Other	2.5	2.5	2.4

in 884 samples (85.3 per cent). The number of isolates in mixed samples was two (128 samples; 12.4 per cent), three (22 samples; 2.1 per cent) and four (3 samples; 0.3 per cent). There were 1218 bacterial isolates in total.

The most common bacterial isolates were *E coli* (53.9 per cent), *E faecalis* (11.3 per cent), *S intermedius* (8.2 per cent), Proteus (7.2 per cent), coagulase-negative staphylococci (3.8 per cent), *P aeruginosa* (4.0 per cent), *S canis* (2.6 per cent), *Klebsiella* (2.2 per cent) and *S aureus* (2.0 per cent), with other isolates accounting for the remaining 4.8 per cent. The prevalence of bacterial species differed between mixed cultures and those where only a single species was isolated (Table 2).

Eight hundred and forty-five dogs (18.7 per cent of the group) had more than one urine sample submitted (median 2, range 2–10) representing 2238 samples. Of these samples, 604 (27.0 per cent) yielded a positive culture; 138 of the dogs (16.3 per cent) demonstrated more than one positive culture, of which 105 dogs (12.4 per cent) demonstrated 122 growths of the same pathogens (recurrent pathogens). Recurrent pathogens were cultured on one (86; 70.5 per cent) two (28; 23.0 per cent), three (7; 5.7 per cent) and four (1; 0.8 per cent) subsequent samples from the same animal. These isolates were *E coli* (65.6 per cent), *E faecalis* (10.7 per cent), Proteus (7.4 per cent), *S intermedius* (6.6 per cent), *S aureus* (4.1 per cent), *P aeruginosa* (4.1 per cent), coagulase-negative staphylococci (0.8 per cent) and *Salmonella* group G (0.8 per cent). *E coli* was associated with serial repeat positive urinary cultures (P=0.012).

Breed

Breeds with an increased risk of a positive urinary culture relative to Jack Russell terriers are shown in Table 3 (n=100). This breed was chosen because it demonstrated the lowest incidence of positive urinary culture for this group. Lhasa apso and Siberian husky breeds were more likely to have a recurrent positive urinary culture submitted (Lhasa apso n=4, P=0.04, OR 38.84, 95% CI 1.2 to 1262.44 and Siberian husky n=4, P=0.03, OR=36.5, 95% CI 1.3 to 992.1).

Age

Older age was associated with a positive urine culture (P=0.001, OR=1.043 per year of age). Infection with *E coli* was associated with older age (P=0.016). There was no effect of age on the incidence of recurrent infection (P=0.389).

Sex

Entire females (P<0.0001, OR=2.99) and neutered females (P<0.0001, OR=1.56) were more likely to have a positive urine culture compared with males. There was no difference between neutered and entire males. There was no effect of sex on the prevalence of bacterial isolates in mixed and single isolate cultures. Of the animals yielding a positive culture, neutered animal samples grew more *E coli* (63.2 per cent) than entire animals (34.8 per cent; P=0.03). Entire dogs had a lower risk of positive urine culture compared with neutered males (entire males P=0.03, OR=0.4, and entire females P=0.006, OR=0.31).

Antimicrobial resistance

There was no change in the number of antimicrobials to which *E coli*, *Proteus*, *S intermedius*, *Klebsiella* and *S canis* were resistant over the period of study. Coagulase-negative staphylococcus species showed a decrease (R^2=0.75, P=0.005) in the number of antimicrobials to which they were resistant. *E faecalis* and *P aeruginosa* showed a significant increase in the number of antimicrobials to which they were resistant (R^2=0.49, P=0.02 and R^2=0.49, P=0.02, respectively). Recurrent *E coli* infections were resistant to more antimicrobials than non-recurrent *E coli* isolates (P<0.0001).

The overall impact factors for all antimicrobials are shown in Table 4. There was a decrease in the impact factors for enrofloxacin

TABLE 3: The effect of breed on the likelihood of a positive urine culture relative to Jack Russell terriers

Breed	Number	P value	OR	95% CI for OR	
				Lower value	Upper value
Bichon Frise	57	0.014	7.501	1.493	37.68
Border collie	127	0.001	11.905	2.721	52.078
Boxer	210	0	15.011	3.537	63.707
Bulldog	45	0.004	10.685	2.097	54.438
Cavalier King Charles spaniel	102	0	14.462	3.264	64.075
Cocker spaniel	172	0.01	7.076	1.605	31.185
Cross breed	382	0.005	7.696	1.831	32.345
Dachshund	102	0.001	11.552	2.58	51.732
Dalmatian	50	0	19.139	4.064	90.132
Doberman	73	0.001	14.204	3.097	65.133
Greyhound	68	0.003	10.426	2.194	49.534
Golden retriever	174	0	15.642	3.673	66.605
German shepherd dog	236	0	13.266	3.133	56.167
Irish setter	46	0.001	13.646	2.795	66.636
Labrador	359	0	16.031	3.853	66.7
Min schnauzer	50	0.003	11.753	2.377	58.106
Rottweiler	63	0.001	14.375	3.095	66.769
Staffordshire bull terrier	110	0.001	11.686	2.612	52.28
Springer spaniel	188	0.007	7.653	1.758	33.32
Weimaraner	78	0	16.552	3.67	74.649
West Highland white terrier	130	0.013	6.764	1.493	30.637
Yorkshire terrier	92	0.024	5.99	1.27	28.255
Jack Russell terrier	100	Reference group			

Included breeds account for ≥1 per cent of the total number of dogs with a submitted urinary sample

TABLE 4: A summary of the average antimicrobial impact factors (IF) over the 10-year study period (where more than 100 colonies were tested)

Antimicrobial	Amoxiclav	Ampicillin	Carbenicillin	Cefovecin	Cefsulodin	Ceftazidime	Cefuroxime	Cephalexin	Chloramphenicol
Total IFs	46.86	22.39	37.05	64.37	9.23	57.66	47.22	53.61	47.97
Total colonies tested	931	932	234	218	230	230	930	931	237
Percentage of total bacterial colonies	76.44	76.52	19.21	17.9	18.88	18.88	76.35	76.44	19.46
Antimicrobial	Ciprofloxacin	Enrofloxacin	Gentamicin	Marbofloxacin	Oxytetracycline	Penicillin G	Polymixin B	TMS	
Total IFs	58.67	78.78	67.03	47.6	59.2	12.14	39.58	66.22	
Total colonies tested	236	946	244	140	932	831	181	932	
Percentage of total bacterial colonies	19.38	77.67	20.03	11.49	76.52	68.23	14.86	76.52	

(R^2=0.54, P=0.02), cephalexin (R^2=0.79, P=0.001) and oxytetracycline (R^2=0.61, P=0.01) over the study period. There was an increase in the impact factor for amoxicillin c(R^2=0.49, P=0.035) over 10 years. The disc concentration of amoxicillin clavulanate was altered in 2006; if the time period was divided into 1998–2006 and 2006–2009, then there was no significant change in the impact factor of amoxicillin clavulanate during either period.

Discussion

This study examines a large number of dogs (4530) and samples (5923) submitted for hospital patients over a 10 year period. Any clinically relevant associations are likely to have been discovered through examining such a large group, thus allowing us to accurately describe the prevalence of bacterial species within urine samples submitted from this group of dogs, the changes in antimicrobial resistance over a substantial time period and to investigate the risk factors for positive urinary culture with a high level of confidence.

The prevalence of lower urinary tract pathogens has only been investigated once in a UK group of 96 dogs in 1977 (Weaver and Pillinger 1977). There has been considerable change in the commonly used antimicrobials in the intervening years and that study did not investigate changing patterns of resistance with time. The relative prevalence of the bacterial species described in our paper is similar to recent large cohort studies (Ling and others 2001, Ball and others 2008, Black and others 2009). Positive cultures, 85.3 per cent, isolated a single bacterial species compared with, for example, 79 per cent, 90.9 per cent and 68 per cent of samples in other studies (Ling and others 2001, Ball and others 2008, Black and others 2009, respectively).

In this study, we cannot be certain as to the number of positive urine cultures that were caused by a genuine UTI or resulted from sample contamination. The concept of significant bacteriuria is to apply a threshold minimum bacterial growth above which a culture is considered representative, and below which it would be considered a contaminant or insignificant finding (Wooley and Blue 1976, Bush 1978, Ling and others 2001). This was not done (the relevant data was unavailable) and may lead to an over-representation of the number of positive bacterial cultures which correlate with a true UTI. Although this may affect the relative prevalence of the bacterial species cultured, there is no published data reporting this to be the case. Positive cultures were obtained from a relatively low proportion of urine samples (17.5 per cent) suggesting that contamination is not a major problem. It is our opinion that the similar prevalence of common bacterial isolates and incidence of positive urine cultures with previous detailed reports suggests that the majority of positive urinary cultures reported were linked to a UTI.

The breed and sex distribution of the group is similar to previous UTI studies (Ling and others 2001, Ball and others 2008, Black and others 2009). The ages of the dogs reflects a normal insured UK group (Dobson and others 2002) with younger animals being over-represented compared to a normal UK group (Thrusfield 1989). The finding that entire animals are significantly younger than neutered dogs is similar to findings in other UK groups (Guthrie and others 2012).

Our findings are consistent with previous studies demonstrating that positive urine cultures are more common in older dogs (Kivisto and others 1977, Ling and others 2001). The low OR of this finding (OR=1.045) suggests that this may not be useful when making clinical decisions regarding the likelihood of UTI in a patient manifesting consistent clinical signs, and the statistical significance demonstrated (P<0.0001) is a result of the large group size.

Compared with neutered male dogs, we found that entire and neutered female dogs are, respectively, 2.5 times and 1.5 times more likely to have a positive urinary culture. The finding that females are more likely to develop UTI is consistent with previous reports. However, our study suggests entire females are at increased risk compared with neutered females, which differs from other studies that report the opposite (Ling and others 1998, 2001, Seguin and others 2003) or no relationship (Freshman and others 1989). Conversely, neutered dogs demonstrated a higher risk of developing a recurrent infection compared with entire dogs. This finding is different from a paper describing no effect of sex on recurrent UTI (Norris and others 2000).

It is interesting to find that some breeds have a higher prevalence of positive urine cultures, and that certain breeds may have a higher risk of developing recurrent UTI. This may be associated with breed variation in biology, anatomy or susceptibility to diseases which may predispose to UTI (eg, hyperadrenocorticism, hypothyroidism). Additionally, higher-risk breeds may require medical or surgical interventions predisposing them to UTI or recurrent bacterial infections (possibly involving multiresistant bacterial species).

Ball and others (2008) investigated developing antimicrobial resistance by examining the mean number of antimicrobials to which bacterial isolates were resistant (1557 samples from 1149 dogs over a five-year period). To allow comparison with this recent large study, we also employed this method and demonstrated increasing multiple antimicrobial resistance for *P aeruginosa* and *E faecalis*, possibly as a result of increased antimicrobial usage (Costelloe and others 2010). Ball and others (2008) demonstrated increased antimicrobial resistance for only recurrent *E coli* isolates, and recurrent bacteria may be expected to show a higher degree of drug resistance. Therefore, our study more convincingly describes developing antimicrobial resistance. However, the assessment of the mean number of antimicrobials to which a bacteria is resistant does not account for changing patterns in antimicrobial resistance. For example, a species may be resistant to antimicrobials A–D out of a panel of eight for five years, and then E–H for five years resulting in no change in the mean. We suggest that assessment of the change in impact factors over the study period is a more accurate indicator of microbial effectiveness because changes in the prevalence of bacterial species as well as the patterns of drug sensitivity are accounted for. Reduced effectiveness of enrofloxacin, cephalexin and oxytetracycline was noted. These drugs may be being used as first-line antimicrobials with increasing frequency in cases of suspected urinary infection leading to the development of resistance. The apparent increase in amoxicillin clavulanate sensitivity over the 10 years is an artefact of the change in antimicrobial disc concentrations implemented in 2006 (according to the BSAC recommendations). There was no significant change in the impact factor of potentiated amoxicillin when the periods before and after this adjustment were considered independently. Ball and others (2008) describe generally higher impact factors for antimicrobials compared with this study. Impact factors were shown to decrease for most antimicrobials, although this was not investigated statistically. It is possible that our study describes a more resistant bacterial group. Implementation of guidelines on antimicrobial usage may limit the development of resistance and have been shown to reduce antimicrobial use in a veterinary hospital environment (Weese 2006).

The prevalence of bacterial species in cultured samples may not represent the actual prevalence in the group of animals, for example, if the organism can multiply in epithelial cells, or if an organism is difficult to culture. It is vital to consider collection method and quantitative bacterial growth data when deciding whether a true UTI is present. The collection method of the samples was unknown in many of the cases, leading to a possible over representation of contaminants since cystocentesis was not used exclusively. The disc diffusion method is insensitive for detecting subtle changes in antimicrobial resistance. If a change in the size of the zone of inhibition does not cross the break-point between resistance and sensitivity, then no change will be recorded. Future studies should focus on detailed bacteriological analysis to determine the minimum inhibitory concentration of antimicrobials for urinary bacterial species and molecular analysis of common resistance mechanisms. In vitro overestimation of urinary pathogen antimicrobial resistance is likely for commonly prescribed drugs (eg, trimethoprim sulphonamide, amoxicillin, amoxicillin clavulanate, cephalexin, oxytetracycline) because urinary concentration may exceed serum concentrations for these medications (Seguin and others 2003). There is an inherent bias towards a positive urine culture result, since clinicians will take samples when they have a clinical suspicion of UTI (based on clinical signs and urinary dipstick/sediment analysis) and for cases with clinical signs that are refractory to empirical treatment. When considering recurrent infections, it is difficult to determine whether a repeat culture of the same organism from the same individual is due to relapse of disease, or reinfection with the same bacterial species. Complex genetic identification of the isolate would be required to identify these cases with confidence.

This is a very complete description of group of dogs in a tertiary referral hospital, but some caution should be exercised when extrapolating these results to the population as a whole. There was no differentiation between hospital-acquired and community-acquired infections (already present when patients were hospitalised), and a primary care population may differ from a referral population due to a lower incidence of prior antimicrobial treatment and fewer complicating factors, for example, urinary catheterisation, urinary incontinence/retention, surgical intervention (Black and others 2009, Costelloe and others 2010). Nonetheless, a proportion of these cases would have been under primary clinical management with the UTI diagnosed prior to referral and similar cases treated in general practice are often not referred. Changes in resistance to antimicrobials may reflect antimicrobial use within the wider veterinary community, within the hospital or both. The data from this study may be most accurately applied to cases of seemingly intractable urinary infection, as these are the cases that are more likely to present to a referral hospital.

Culture and sensitivity is the gold standard when choosing appropriate antimicrobial therapy. The choice of antimicrobial is obviously dependent on more than in vitro resistance and sensitivity data, but this represents valuable information to inform rational selection of appropriate agents, and provides data on changing drug resistance in a known population. The impact factors presented (Table 4) demonstrate the likelihood that an antimicrobial will successfully treat a pathogen whil culture results are pending, for this and similar groups of dogs. Impact factors should not be considered in isolation, and a clinician must balance the decision to choose a particular drug with a thorough knowledge of an antimicrobial's pharmacokinetic data (eg, concentration in urine), safety profile, cost, ease of administration, legislation regarding prescription to domestic animals and adherence to recommended antimicrobial use strategies designed to reduce the development of resistance in urinary pathogens. The introduction of new antimicrobials to the veterinary market and continuing education of veterinary practitioners to improve the selection and administration of appropriate antimicrobial agents will undoubtedly affect the contemporary prevalence and resistance of urinary tract pathogens, and ongoing monitoring of urinary tract cultures is essential.

Conclusion

Overall, impact factors decreased for enrofloxacin, cephalexin and oxytetracycline, which is consistent with increasing resistance to these agents given that the prevalence to the bacterial species did not change during the study period. This information is useful when developing guidelines for the use of antimicrobials for the treatment of UTI. Veterinary surgeons have an obligation to minimise the development of resistant bacteria which can affect companion animal and human populations.

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