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Vet. Res. 30 (1999) 285–298

Review article

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(Received 16 October 1998; accepted 17 December 1998)

Abstract – Certain strains of *Escherichia coli* behave as pathogens in dogs and cats causing gastro-intestinal and extra-intestinal diseases. Among the five known groups of diarrhoeagenic *E. coli*, namely enteropathogenic *E. coli* (EPEC), enterotoxigenic *E. coli* (ETEC), enteroinvasive *E. coli* (EIEC), shiga-toxin producing *E. coli* (STEC) and enteroaggregative *E. coli* (EAggEC), only EPEC and ETEC were clearly associated with enteric disease in young dogs. ETEC isolates from diarrhoeic dogs were found to be positive for the heat-stable enterotoxins STa and STb but negative for heat-labile enterotoxin (LT). Canine ETEC were found to be different from those of other animals and humans by their serotypes, production of alpha-haemolysin and adhesive factors and by the production of uncharacterized types of enterotoxins by some ETEC. Canine EPEC could be distinguished from EPEC of humans or other animals by their serotypes and by the *eae*-protein intimin which mediates intimate adherence of EPEC to intestinal mucosa cells. STEC were occasionally isolated from faeces of healthy and diarrhoeic dogs but their role in canine diarrhoea is not yet well known. EIEC and EAggEC were not reported to occur in dogs or cats. Very little is known on diarrhoegenic *E. coli* in cats and further epidemiological investigations on this subject are needed. Besides its role in gastro-intestinal infections, *E. coli* can cause infections of the urogenital tract and systemic disease in dogs and cats. Extra-intestinal pathogenic *E. coli* strains from dogs and cats belong to a limited number of serotypes and clonal groups and are frequently found as a part of the normal gut flora of these animals. Many of these *E. coli* strains carry P-fimbriae and produce alpha-haemolysin and a necrotizing cytotoxin (CNF1). Some of the frequently isolated types of extra-intestinal pathogenic *E. coli* from dogs, cats and humans were found to be highly genetically related but showed differences in their P-fimbrial adhesins which determine host specificity. Transmission of extra-intestinal and enteral pathogenic *E. coli* between dogs and humans was reported. Further research is needed, however, to determine the role of dogs and cats as transmission vectors of pathogenic *E. coli* strains to other animals and humans. © Inra/Elsevier, Paris.

***Escherichia coli* infections / dogs / cats / humans / diarrhoea / extra-intestinal diseases / virulence factors**

Résumé – ***Escherichia coli*, un agent pathogène du chien et du chat.** Certaines souches d'*Escherichia coli* sont pathogènes pour le chien et le chat, et provoquent des maladies gastro-intestinales et extra-intestinales. Parmi les cinq groupes d'*E. coli* responsables de diarrhée à savoir *E. coli* entéropathogène (EPEC), *E. coli* entérotoxinogène (ETEC), *E. coli* entéroinvasive (EIEC), *E. coli* produi-

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sant des toxines Shiga (STEC) et *E. coli* entéroaggrégatif (EAggEC), seules les EPEC et les ETEC ont été clairement associés à des maladies entériques chez les jeunes chiens. Des isolats d'ETEC issus de chiens diarrhéiques sont positifs en sonde nucléique pour des gènes d'entérotoxines thermostables Sta et Stb mais négatifs pour des gènes d'entérotoxines thermolabiles (LT). Les ETEC canins étaient différents des ETEC des autres animaux et des humains par leurs sérotypes, par la production de l'hémolysine alpha, de facteurs d'adhésions et par la production d'entérotoxines encore non-caractérisées. Les EPEC canins peuvent être distingués des EPEC des humains ou d'autres animaux par leurs sérotypes et par l'intimine (Eae) qui permet l'adhésion intime des EPEC sur les cellules de la muqueuse intestinale. Les STEC, en revanche, ont parfois été isolés des fèces de chiens en bonne santé ainsi que de fèces de chiens diarrhéiques, mais leur rôle dans la diarrhée canine n'est pas encore bien connu. Les EIEC et EAggEC n'ont pas été signalés chez les chiens et les chats. On a peu de renseignements concernant la diarrhée due à l'*E. coli* chez les chats et des études épidémiologiques complémentaires sont nécessaires. *E. coli* peut provoquer également des infections de la voie urogénitale et des affections systémiques chez le chien et le chat. Les souches pathogènes d'*E. coli* extra-intestinales de chiens et de chats appartiennent à un nombre limité de sérotypes et de clones et font fréquemment partie de la flore intestinale normale de ces animaux. Plusieurs de ces souches d'*E. coli* produisent des fimbriae de type P, une hémolysine alpha et une cytotoxine nécrosante (CNF1). Les souches d'*E. coli* isolées d'infections extra-intestinales chez le chien, le chat et l'homme sont génétiquement très similaires, néanmoins les séquences de leurs adhésines de type P sont différentes et pourraient déterminer la spécificité d'hôte. La transmission d'*E. coli* pathogène à localisation extra-intestinale et entérique pathogène entre les chiens et les humains a été signalée. Toutefois, d'autres études sont nécessaires pour déterminer le rôle des chiens et chats en tant que vecteurs dans la transmission des souches d'*E. coli* pathogènes de l'homme et d'autres animaux.

infections dues à *Escherichia coli* / chiens / chats / humains / diarrhée / maladies extra-intestinales / facteurs de virulence

Plan

1. INTRODUCTION

Dogs and cats belong to those species of animals which have been living in a close community with man for many thousands of years. Large populations of these domestic animals are present in industrialized countries. For example, the number of dogs and cats living in Germany is estimated to be 5 million and 6 million, respectively (pers. comm.). As a consequence, contacts between humans, dogs and cats are numer-

ous and the possibility of transmission of micro-organisms between these different host species is extremely high.

The enterobacterium *Escherichia coli* is a normal commensal inhabitant of the gut of humans and warm-blooded animals. As other mammals, dogs and cats are colonized with *E. coli* during the first days of their life [74]. Among the *E. coli* species, some strains are known to cause enteric or extra-intestinal infections in humans and animals. Moreover, some pathogenic *E. coli* strains are transmitted between different host species and may cause disease in one host but not in the other. *E. coli* as a pathogen in dogs and cats was the subject of two earlier review articles [15, 56]. The aim of this review is to summarize the current state of knowledge regarding *E. coli* as a pathogen in dogs and cats and to discuss findings on the relationships between *E. coli* strains which were isolated from dogs, cats, other animals and humans.

2. INTESTINAL *ESCHERICHIA COLI* INFECTIONS

Diarrhoeagenic *E. coli* which were isolated from animals and humans were shown to be heterogeneous for their virulence markers, their specificity for certain hosts and age groups, and for the diseases caused in human and animal patients. In regard to the virulence markers which are associated with diarrhoea, five groups of enteral pathogenic *E. coli* were established:

1) enteropathogenic *E. coli* (EPEC) expressing colonization factors such as bundle forming pili (*bfp*) and intimin (*eae*);
2) enterotoxigenic *E. coli* (ETEC) expressing heat-stable (ST) and heat-labile (LT) enterotoxins and different host-specific colonization antigens;
3) enteroinvasive *E. coli* (EIEC) carrying the genes for invasion of intestinal epithelial cells;
4) shiga-toxin producing *E. coli* (STEC) expressing one or more different types of cytotoxins (Stx1 and Stx2);
5) enteroaggregative *E. coli* (EAggEC) showing a distinct aggregative pattern of adherence to epithelial cells.

Strains belonging to either group of EPEC, ETEC or STEC are known to cause disease in humans and in some species of animals, whereas EIEC and EAggEC were only isolated from infected humans. Besides the recognized groups of diarrhoeagenic *E. coli*, certain *E. coli* strains were described which express other types of cyto- and enterotoxins, or adherence factors. The role of these *E. coli* strains and their virulence factors in diarrhoeal disease is not well known and requires further investigation. This chapter describes what is known about *E. coli* as an agent of diarrhoea in dogs and cats.

2.1. Verocytotoxic *E. coli* and shiga-toxin-producing *E. coli* (STEC)

Verocytotoxic *E. coli* were first described in 1977 by their ability to cause damage to cultured Vero cells [43]. Many, but not all verocytotoxic *E. coli* strains produce shiga-toxins (Stx1, Stx2 and Stx2 variants) [31] and the latter strains are called shiga-toxin-producing *E. coli* (STEC) [17].

Cytotoxic *E. coli* were isolated from faeces of healthy and diarrhoeic dogs and cats in a number of different studies (*table I*). STEC, however, were only detected among isolates from dogs [11, 12, 26, 32] (*table I*). Canine STEC were shown to produce different types of shiga-toxins and some of these strains showed an enterohaemolytic phenotype and were positive for the plasmid encoded haemolysin of enterohaemorrhagic *E. coli* (EHEC-haemolysin) [12]. Other STEC strains from dogs carried both the genes for heat-stable enterotoxins STap and STb together with *stx*1 or *stx*2-

Table I. Prevalence of cytotoxic *E. coli* strains and shiga-toxin producing *E. coli* (STEC) in diarrhoeic and in healthy dogs and cats.

Animals (no. investigated)	Percentage of animals with		Reference
	Cytotoxic *E. coli*[a]	STEC[b]	
Healthy cats (40)	40.0	ND[c]	[1]
Diarrhoeic cats (23)	95.0	ND	[1]
Healthy cats[d] (23)	4.3	ND	[14]
Healthy cats (29)	ND	0[e]	[26]
Healthy cats (65)	13.8	0[e]	[10, 11]
Diarrhoeic dogs (50)	6.0	ND	[2]
Healthy dogs (49)	4.1	ND	[2]
Healthy dogs (63)	4.7	3.2[e]	[10, 11]
Healthy dogs (25)	ND	4.0[e]	[26]
Healthy dogs (57)	ND	12.3[e]	[32]
Diarrhoeic dogs (45)	ND	8.9[e]	[32]

[a] *E. coli* strains showing cytotoxicity on Vero cells; [b] *E. coli* strains carrying genes for shiga-toxins (Stx); [c] ND = not investigated; [d] 13 (52 %) of the cats yielded CNF-producing *E. coli*; [e] investigated by DNA-hybridization with Stx-specific gene probes or by Stx-PCR.

sequences [32]. The combined expression of shiga-toxins and enterotoxins was not found in STEC from cattle or humans but was observed in some porcine STEC strains which are agents of post-weaning diarrhoea in pigs [33]. The ST-producing STEC strains were all isolated from diarrhoeic dogs and were not found in the healthy control group [32]. In contrast, other types of ST-producing ETEC from diarrhoeic dogs were found to be negative for shiga-toxins [60, 63].

STEC carrier rates were not significantly different between groups of asymptomatic dogs (3.2–12.3% positive) and dogs with diarrhoea (8.9 % positive) (*table I*). In one study, however, an association between diarrhoeal disease in dogs and Stx2-producing STEC strains was found [32]. Further investigations on larger numbers of healthy and diarrhoeic animals are needed in order to learn more about the role of STEC strains as possible enteric pathogens in dogs.

Among STEC, strains of serotype O157:H7 are regarded as the most virulent for humans and these strains frequently cause bloody diarrhoea and haemolytic uremic syndrome [28]. Two cases were published where STEC O157:H7 were isolated from dogs [41, 76]. The dog STEC O157:H7 strains belonged both to the same phage type PT4 which was found associated with 21.0 % of STEC O157:H7 isolates from human patients in Canada [41]. In an outbreak investigation, epidemiologically related O157:H7 strains were isolated from a dog, other farm animals and from a child who developed bloody diarrhoea after infection [76]. Thus, asymptomatic dogs might function as vectors of transmission for STEC O157:H7 to humans and other animals.

Verocytotoxic *E. coli* were isolated at a high frequency from healthy and diarrhoeic cats [1, 11]. *Stx*-genes were not detected, however, in these strains [12] or were not investigated [1]. STEC were not reported to occur in cats but it is noteworthy to remark that these organisms were investigated in only a small number of cats. The cytotoxins produced by some *E. coli* isolates from cats were not further characterized for their pheno- and genotypes; however, heat-stable (ST) or heat-labile enterotoxins (LT) were not detected in these strains [1, 14]. This finding and the observation that

E. coli producing uncharacterized cytotoxins were frequently isolated from faecal samples of the healthy control group makes it unlikely that such *E. coli* strains are closely associated with diarrhoea in cats.

2.2. Cytotoxic necrotizing toxin (CNF)-producing *E. coli*

E. coli inducing necrotizing lesions in rabbit skin and morphological changes in HeLa and Vero cell lines were first described in the mid 1980s [31]. Two types of cytotoxic necrotizing factors (CNF), CNF1 and CNF2 were described and CNF-producing *E. coli* strains were isolated from healthy and diseased humans and from different species of animals [21, 31, 58]. Production of CNF1 was shown to be closely associated with alpha-haemolysin production and with certain serotypes of *E. coli* strains isolated from dogs and cats [14, 21, 57, 58, 60]. Two lines of genetically closely related CNF1 producing *E. coli* O6 strains could be established by analysing isolates from dogs, pigs, cows and humans [21]. Among CNF1 strains from cats and dogs, O4 and O6 serogroups were the most frequent [14, 21, 57, 58, 60]. In healthy cats, CNF1 production was frequently associated with *E. coli* O6:K53:H1 strains [14]. In an earlier study, strains belonging to the same serotype were described as verocytotoxic *E. coli* and these were isolated from healthy and from diarrhoeic cats [1]. Thus, it appears possible that some of the cytotoxic strains which were not further characterized for their toxin types might belong to the CNF-producing group of *E. coli* (*table I*).

CNF1-producing *E. coli* were isolated from intestinal and extra-intestinal infections in dogs and cats but also from faeces of asymptomatic animals [14, 58, 60]. The CNF-producing strains were found to be negative for other virulence markers associated with diarrhoeal disease such as shiga-toxins and enterotoxins. In conclusion, these data do not indicate that CNF production in *E. coli* is associated with diarrhoea in dogs and cats. In contrast, the production of CNF1 is closely associated with *E. coli* strains which cause extra-intestinal infections in dogs and cats but the contribution of CNF1 to extra-intestinal diseases is not well known and has to be further investigated.

E. coli producing CNF2 were only rarely isolated from cats and were not detected in dogs [14, 58, 60]. In contrast, CNF2-producing *E. coli* were more associated with bovines [58].

2.3. Enteropathogenic *E. coli* (EPEC)

Enteropathogenic *E. coli* (EPEC) belong to different serotypes and are known to be agents of gastro-enteritis in young infants and in neonatal farm animals [24, 36, 56]. According to their virulence markers, some strains belonging to the EPEC group were later reclassified as enterotoxigenic *E. coli* (ETEC), shiga-toxin-producing *E. coli* (STEC) and enteroaggregative *E. coli* (EAggEC). Classical EPEC strains are negative for shiga-toxins and enterotoxins but carry the *eae*-gene which is located on the chromosomal locus of enterocyte effacement (LEE) [24]. *Eae*-positive EPEC strains can cause intimate adherence and attaching and effacing (AE) lesions in intestinal epithelial cells of infected humans and animals. Besides *eae*, a second virulence marker is present in classical EPEC strains which is a plasmid-encoded (*bfp*A) bundle forming pilus mediating localized adherence of EPEC on epithelial cells. The *eae*-gene was also found in *E. coli* strains which do not belong to the EPEC serotypes and which are negative for shiga-toxins. These strains are also called attaching and effacing *E. coli* (AEEC).

E. coli belonging to some of the classical human EPEC serogroups (O26, O44, O55, O86, O111, O114, O119, O125, O126, O127, O128, O142 and O158) were occasionally isolated from diarrhoeic cats [85] and dogs [25, 70, 88]. Because there is only

little data available on these strains, the significance of the classical EPEC types as possible diarrhoeal agents in dogs and cats is not known.

AE-lesions were detected in the intestine of two cats with diarrhoea but the causative agent of the disease was not isolated [59]. Except in this study, EPEC were not associated with diarrhoea in cats. In contrast, EPEC belonging to different serotypes were isolated from diarrhoeic dogs [9, 15, 25, 38, 78]. Some of the *eae*-positive *E. coli* strains from dogs were also positive for the *eae*B gene (now termed *esp*B), for plasmid-determined EPEC-adherence factor sequences (EAF) and the *bfp*A-gene, and thus resembled human EPEC strains. Enterotoxins, shiga-toxins and haemolysins were not detected in canine EPEC strains [9, 25, 78]. The serotypes of the few canine EPEC isolates were heterogeneous (O45, O49:H10, O115, O118:NM; O119 and O-untypable) and most of these were different from those of human EPEC [25, 78]. In another study, the similarity between cloned *eae* genes from EPEC isolates originating from dogs, pigs and humans was investigated. An overall homology between 81 and 84 % was found between the different *eae*-protein sequences. However, the *eae*-protein obtained from the dog strain was found to be serologically related to the *eae* of the human EPEC and not to that of the porcine EPEC strain [3].

The data indicate that EPEC are potential diarrhoeic agents, particularly in young dogs and that canine EPEC might be different from EPEC originating from other sources. However, these findings need further confirmation by examination of larger numbers of diarrhoeic and healthy dogs. At present, not much is known on the epidemiology of EPEC in dogs nor on their clinical significance for cats.

2.4. Enterotoxigenic *E. coli* (ETEC)

Enterotoxigenic *E. coli* (ETEC) produce one or more different types of enterotoxins which stimulate intestinal fluid secretion. ETEC infections cause non-bloody, watery diarrhoea in humans and in young farm animals [36, 51]. ETEC strains are serologically very diverse and express different adhesion factors which determine their host specificity [51, 54, 91]. The toxins produced by ETEC are divided into two major groups: heat-labile toxins (LT) and heat-stable toxins (ST). Two types of LT are known, LTI and LTII which show partial homology in their A-subunit, but no homology in their B-subunit. In a similar way, two biochemically unrelated types of heat-stable enterotoxins were described which are designated as STa and STb. The STa toxin group is further divided into two related subtypes called ST-porcine (STIa) and ST-human (STh, STIb) [30, 51].

ETEC were isolated as diarrhoeal pathogens from neonatal calves, lambs, kids and pigs. An association between the animal host and bacterial properties such as serotypes, production of enterotoxins and specific colonization factors was found [16, 33, 35, 36, 56]. ETEC were also isolated from diarrhoeic dogs and were characterized by a number of methods including bioassays, such as the infant mouse assay and the ligated ileal loop assay, by serological tests and by nucleic acid-based detection methods. ETEC were found to be associated with 2.7–31.1 % of cases of diarrhoea, particularly in young dogs and were not isolated from healthy control groups (*table II*). Most canine ETEC strains were found to express heat-stable enterotoxins which were detected with the infant mouse assay [40, 63]. By the use of DNA-specific detection methods, most ST-producing canine ETEC were shown to carry the genes for STa, and fewer strains were positive for STb, sometimes both toxin types were present in the same strain [25, 32, 60, 65, 80].

ETEC producing the heat-labile enterotoxin LTI were not found in dogs (*table II*). Canine *E. coli* strains which stimulated intestinal fluid secretion in the ligated ileal loop assay or exerted cytotonic effects on

Table II. Prevalence of enterotoxigenic *E. coli* (ETEC) in dogs with diarrhoea and in healthy control groups.

Dogs (no.)	Percentage of dogs with			Reference
	ETEC	ST-producing ETEC	LT-producing ETEC	
Diarrhoeic (55)	18.2	18.2[a]	ND[b]	[40]
Diarrhoeic (42)	21.4[c]	not specified	not specified	[81]
Healthy (118)	0[c]	0	0	[81]
Diarrhoeic (148)	2.7	0.7[a]	2.0[d]	[53]
Healthy (15)	0	0	0	[53]
Diarrhoeic (45)	31.1	31.1[e]	0[f]	[32]
Healthy (57)	0[e,f]	0	0	[32]
Diarrhoeic (114)	7.0	7.0[a]	0[g]	[64]

[a] Detected by the infant mouse assay; [b] not investigated; [c] detected by the infant mouse and by the piglet ileal loop assays; [d] detected by the CHO-cell test, the strains were negative in the rabbit ileal loop assay; [e] detected by DNA-hybridization with STap- and STb-specific gene probes and by PCR; [f] detected by DNA-hybridization with an LTI-specific gene probe; [g] detected by the vero cell assay.

CHO cells in culture were, however, detected in different investigations [8, 52, 53, 81]. The biological activity of these strains resembled heat-labile enterotoxin although they reacted negatively in other tests specific for LT [52, 53, 60]. It is therefore possible that uncharacterized types of enterotoxins, which are different from those found in ETEC from humans and other animals, are produced by some canine *E. coli*. In experimental infections, dogs were found to be susceptible to LT produced by human ETEC strains although they were resistant to colonization with these ETEC types [66]. In contrast to the moderate effect caused by LT, the dogs were found to be more susceptible and did not develop immunity to ST [50, 66]. These findings could explain why ST-producing strains predominate in natural infections of dogs with ETEC.

The ETEC isolated from dogs were different from ETEC isolated from other animals or humans by some phenotypical traits. Canine ETEC were attributed to serotypes which are rarely or not found among ETEC isolated from humans, pigs and calves [54, 91]. Among canine ETEC, ST-producing O42:H37 strains were most frequently found and were isolated at different geographical locations [60, 63, 80]. Some canine ETEC were investigated for their fimbriae which serve in intestinal colonization. None of the ETEC isolates examined was positive for K88 (F4), K99 (F5) or CFAI (F2) and CFAII (F3) antigens except some ST-producing O42:H37 ETEC strains from Norway which were positive for K99 fimbriae [25, 53, 63, 64, 80]. The fimbrial antigen K99 is strongly associated with bovine ETEC but it is sporadically found in ETEC strains originating from other animals [16].

ETEC from human and animal sources carry their enterotoxin genes on plasmids of different sizes [91]. This was also found with ST-producing ETEC strains from dogs [60, 80]. Like porcine ETEC, ETEC from dogs were frequently found to produce alpha-haemolysin which is not found in human ETEC strains [12, 33, 60, 63, 80]. The alpha-haemolysin genes were found to be encoded on 48 MD size transferable plasmids in canine ETEC O42:H37 and on 52 MD size plasmids in ETEC O70:H– strains. The genes for ST and for alpha-haemolysin were located on different plasmids [60].

In contrast to dogs, there is only very little information available on ETEC in cats.

ETEC were not found among 22 diarrhoeic and 25 healthy cats which were investigated for ST by the infant mouse assay and for LT by the Y1 adrenal cell test [1]. In another study, LT-positive *E. coli* were not found among 159 bacterial isolates which originated from 23 healthy cats [14].

3. EXTRA-INTESTINAL INFECTIONS WITH *ESCHERICHIA COLI*

Certain strains of *E. coli* can behave as opportunistic pathogens causing extra-intestinal infections in humans and animals. In dogs and cats, facultative pathogenic *E. coli* were shown to cause urinary tract infection (for reviews see [15, 56]), prostatitis, vaginitis and pyometra [13, 79, 84], perinatal infections and puppy death [13, 67, 94], otitis externa [7], cardiovascular infections [18], cholecystititis [47], septicaemia and endotoxaemia [37, 77].

3.1. Urinary tract infections (UTI)

E. coli is the bacterium most commonly isolated from the urine of dogs and cats with urinary tract infections (UTI) [4, 34, 42, 56, 92]. The incidence of bladder infection in bitches was found to increase particularly with their age. In most cases of UTI, the infecting *E. coli* strain was isolated in pure culture from urine and a level of 100 000 bacteria/mL or more was proposed as a basis for distinguishing significant bacteriuria from contamination [42, 56]. *E. coli* was also found to be a cause of pyelonephritis in dogs and cats showing non-significant bacteriuria [23, 45, 82]. In contrast, *E. coli* was not found to play a role in canine or feline urolithiasis [69, 83].

3.2. Genital infections

Besides its role in UTI, *E. coli* is the major pathogen in male dogs with prostatitis [84] and in bitches with chronic purulent metritis (pyometra). *E. coli* was isolated in 50–85 % of bitches suffering from pyometra [13, 29, 68, 79] and was also detected as a cause of pyometra in cats [22]. In dogs with pyometra, quantitative determination of live *E. coli* in the uterine contents yielded high numbers (10^9–10^{11}/mL) and the infective *E. coli* strain was generally present in the pure culture [68, 79]. Frequently, bitches with pyometra were found to suffer simultaneously from UTI and in most of these cases the same *E. coli* strain type was isolated from urine and the uterine content [68, 71, 79].

3.3. Systemic infections

Besides *Staphylococcus aureus*, *E. coli* is an important cause of perinatal death of puppies and kittens [49, 67, 94]. The infective *E. coli* strains can be transmitted intrauterine or by the infected genital tract leading frequently to abortion or to a septicaemic death of the puppies in the first days of life [13, 44, 67]. Furthermore, subclinical mastitis of the bitch was found as another important source of bacterial infection in newborn puppies [67]. Septicaemic colibacillosis caused by *E. coli* strains of the normal intestinal flora was observed as a frequently occurring complication in dogs with parvoviral enteritis [37, 77]. Bacterial endocarditis may result from systemic *E. coli* infection in dogs and UTI was discussed as a source of these blood-borne infections [18]. *E. coli* were also isolated from infected organs and shown to be a cause of septicaemia in cats [57, 58, 62].

3.4. Characteristics of *E. coli* strains from the normal faecal flora and from extra-intestinal infections in dogs and cats

E. coli strains causing extra-intestinal infections in dogs and cats were found to be associated with a few O-groups which were also frequently found in the normal

faecal flora of these animals. It was therefore suggested that the faecal flora serves as a major reservoir and a source of infection with these strains [22, 29, 46, 89, 90]. Basically the same observations were made for *E. coli* strains causing extra-intestinal infections in humans [39].

Serological typing of O-, K- and H-antigens of faecal and extra-intestinal *E. coli* from cats and dogs was performed in a number of different studies [1, 5, 10, 14, 21, 27, 57, 60, 62, 88–90]. Strains belonging to a small number of O-serogroups (O2, O4, O6, O8, O9, O22, O25, O75 and O83) were found to dominate among faecal and extra-intestinal isolates from dogs and cats [1, 14, 22, 27, 60, 62, 73, 86]. Among these strains, *E. coli* of serogroups O4 and O6 were most frequently isolated. Some *E. coli* serotypes, such as O4:H–, O4:H5, O6:K53:H1 and O6:H31 strains were isolated from extra-intestinal and faecal samples of both dogs and cats [1, 10, 14, 21, 27, 60, 62].

Other faecal and extra-intestinal *E. coli* isolates from dogs and cats were found to be positive for the K1 or K5 capsular antigens. The *E. coli* K1 strains belonged to groups O2, O7, O18, O21 and O83 [1, 10, 21, 27, 60, 73, 86]. The K5 antigen was found in O6, O21 and O75 strains. Strains belonging to O2:K1:H6 and O6:K5:H1 serotypes were isolated in different studies from both dogs and cats [1, 21, 27, 73, 86]. *E. coli* expressing K1 and K5 are also frequently occurring in the human faecal flora and are highly associated with neonatal meningitis, bacteremia and pyelonephritis in humans [39, 55].

Faecal and extra-intestinal *E. coli* isolates from dogs and cats were also found to be similar for the expression of different virulence attributes. Most of these strains show haemolytic activity and further investigations revealed that they carry chromosomally encoded alpha-haemolysin determinants [10, 60, 61]. *E. coli* O4, O6 and O75 strains from dogs and cats were found to be similar for the production of alpha-haemolysin, CNF1, P-fimbriae and aerobactin [14, 27, 60, 61, 62, 86]. Enterotoxins or shiga-toxins were not detected among faecal and uropathogenic *E. coli* isolates from dogs or cats [14, 57, 60].

3.5. Relationships between faecal and uropathogenic *E. coli* isolated from dogs, cats and humans

The *E. coli* strains isolated from the faecal flora and from extra-intestinal infections of dogs, cats and humans were found to have a similar frequency of certain O-types, of some K- and H-antigens and of typical virulence attributes such as alpha-haemolysin, P-fimbriae, production of CNF1 and aerobactin [19, 39, 55]. Moreover, some *E. coli* strains from dogs, cats and humans sharing identical serotypes such as O4:H5 and O6:K13: H1, were also found to have highly related P-fimbriae serotypes (F12, F13). Uropathogenic *E. coli* strains from humans, dogs and cats were shown to be highly genetically related and could be assigned to six major *E. coli* clonal groups [87]. The predominating serotypes within different uropathogenic clones were O4:H–, O4:H5, O6:H1; and O6:H31 [21, 87]. Dog and human *E. coli* O2, O4 and O6 strains were also found to be similar for the chromosomal position and for the DNA sequences of alpha-haemolysin determinants and P-fimbriae [46, 61]. It was, therefore, suggested that the clonally related human and canine *E. coli* strains might be transmitted as urinary pathogens between dogs and humans [46, 86].

Other studies indicated, however, that the genetically related canine and human uropathogenic *E. coli* strains had different adhesins (minor fimbrial subunit) which determine the receptor specificity of P-(F12) fimbriae [27, 72, 73, 75]. Phenotypically, most uropathogenic *E. coli* from dogs were found to agglutinate dog but not human erythrocytes and to adhere to canine but not to human uroepithelial cells, whereas most

human *E. coli* strains showed the opposite picture [27, 73]. It was therefore suggested that the variation in the Galα1-4Gal receptor specificity is a mechanism for shifting host specificity in *E. coli* from humans and dogs and that this variation has evolved in response to the topography of host cellular receptors [75]. The differences found in the fimbrial receptor specificity between uropathogenic *E. coli* from dogs and humans could indicate that these strains are specific for their host, despite their clonal relatedness.

4. CONCLUSION

There is little information available about *E. coli* causing disease in dogs and cats compared to the number of investigations which were performed on *E. coli* as a pathogen of humans, pigs and cattle. Among the five groups of diarrhoeagenic *E. coli*, only ETEC and EPEC strains were clearly associated with gastro-intestinal disease in young dogs and very little is known on the epidemiology of these strains, their adhesion mechanisms and their host specificity. Although *E. coli* belonging to the STEC group were already isolated from dogs, it is not clear if these are associated with disease in dogs or cats. Further research on this subject is needed, particularly in view of a global health problem which is caused by STEC infections in humans [93]. Further investigations are also necessary on those *E. coli* strains which were isolated from diarrhoeic dogs and which were shown to produce 'unconventional' enterotoxins or cytotoxins.

Very few data are available on *E. coli* as a possible agent of diarrhoea in cats. *E. coli* strains belonging to one of the five different pathogroups associated with diarrhoeal disease were not found among clinical isolates from cats. However, only a small number of diarrhoeic and healthy cats were investigated, and epidemiological studies involving larger numbers of animals and appropriate detection methods are needed. Studies for detection of diarrhoeal pathogens should be based on the identification of virulence markers which are associated with diarrhoeal disease. In contrast, serotyping of clinical isolates was not found to be suitable as a screening method for diarrhoeagenic *E. coli* strains in dogs and cats [6, 88].

Uropathogenic *E. coli* from dogs and cats were found to be similar to human uropathogenic strains with regard to their serotypes, clonal types and virulence attributes. The role of alpha-haemolysin, P-fimbriae, capsular antigens and aerobactin in the pathogenicity of these strains is already well known. However, further studies are needed on the role of CNF1 which is closely associated with normal faecal and extra-intestinal *E. coli* strains in dogs, cats and humans.

Dogs and cats might also play an important role as *E. coli* transmission vectors to other animals or man. Several studies indicate that transmission of clonally related faecal and uropathogenic *E. coli* types between humans, dogs and cats has occurred and might still happen [20, 81, 87]. However, the frequency of transmission of uropathogenic *E. coli* between different mammalian hosts is not known and the differences found between the P-fimbrial adhesins of *E. coli* strains from dogs and humans indicate that these strains are host specific.

Recent findings indicate that the transmission of diarrhoeagenic *E. coli* strains occurs between dogs and humans. Asymptomatic dogs were identified as carriers of human pathogenic STEC including *E. coli* O157:H7 strains and could thus play a role in outbreaks of STEC infections in humans [41, 76]. Diarrhoeic dogs were identified as an important source of bacterial contamination of the environment in apartments of dog holders which might contribute to the spread and transmission of pathogenic *E. coli* strains [48]. Thus, further research should be directed towards detecting and characterizing diarrhoeagenic *E. coli* types

in dogs and cats, their host specificity and the possible exchange of pathogenic strains between animals and humans.

REFERENCES

[1] Abaas S., Franklin A., Kuehn I., Orskov F., Orskov I., Cytotoxin activity on Vero cells among *Escherichia coli* strains associated with diarrhea in cats, Am. J. Vet. Res. 50 (1989) 1294–1296.

[2] Adesiyun A.A., Campbell M., Kaminjolo J.S., Prevalence of bacterial enteropathogens in pet dogs in Trinidad, Zentralbl. Veterinarmed. Reihe B 44 (1997) 19–27.

[3] An H., Fairbrother J.M., Dubreuil J.D., Harel J., Cloning and characterization of the *eae* gene from a dog attaching and effacing *Escherichia coli* strain 4221, FEMS Microbiol. Lett. 148 (1997) 239–245.

[4] Apel J., Hamann H.P., Weiss R., Zu Vorkommen und Antibiotika-Resistenz bakterieller Infektionserreger in Urinproben von Katzen, Kleintierpraxis 34 (1989) 467–472.

[5] Askaa J., Jacobsen K.B., Sorensen M., Neonatal infections in puppies caused by *Escherichia coli* serogroups 04 and 025, Nord.Veterinarmed. 30 (1978) 486–488.

[6] Awad-Masalmeh M., Youssef U., Silber R., Zur Charakterisierung hämolysierender *E. coli* Stämme aus an Diarrhöe bzw. Enteritis erkrankten oder verendeten Hunden und Katzen, ihre Virulenzfaktoren und Antibiotikaempfindlichkeit, Wien. Tierärztl. Monatsschr. 77 (1990) 254–258.

[7] Baba E., Fukata T., Saito M., Incidence of otitis externa in dogs and cats in Japan, Vet. Rec. 108 (1981) 393–395.

[8] Baljer G., Saito M., Mayr A., Nachweis von Enterotoxinbildenden *E. coli* Stämmen (ETEC) bei Hunden mit akuter Gastroenteritis, Der praktische Tierarzt 67 (1986) 472–476.

[9] Beaudry M., Zhu C., Fairbrother J.M., Harel J., Genotypic and phenotypic characterization of *Escherichia coli* isolates from dogs manifesting attaching and effacing lesions, J. Clin. Microbiol. 34 (1996) 144–8.

[10] Beutin L., Montenegro M., Orskov I., Orskov F., Prada J., Zimmermann S., Stephan R., Close association of verotoxin (shiga-like toxin) production with enterohemolysin production in strains of *Escherichia coli*, J. Clin. Microbiol. 27 (1989) 2559–2564.

[11] Beutin L., Geier D., Steinrueck H., Zimmermann S., Scheutz F., Prevalence and some properties of verotoxin (Shiga-like toxin)-producing *Escherichia coli* in seven different species of healthy domestic animals, J. Clin. Microbiol. 31 (1993) 2483–2488.

[12] Beutin L., Geier D., Zimmermann S., Karch H., Virulence markers of Shiga-like toxin-producing *Escherichia coli* strains originating from healthy domestic animals of different species, J. Clin. Microbiol. 33 (1995) 631–635.

[13] Bjurstroem L., Aerobic bacteria occurring in the vagina of bitches with reproductive disorders, Acta Vet. Scand. 34 (1993) 29–34.

[14] Blanco J., Blanco M., Wong I., Blanco J.E., Haemolytic *Escherichia coli* strains isolated from stools of healthy cats produce cytotoxic necrotizing factor type 1 (CNF1),Vet. Microbiol. 38 (1993) 157–165.

[15] Broes A., Les *Escherichia coli* pathogènes du chien et du chat, Ann. Méd. Vét. 137 (1993) 377–384.

[16] Butler D.G., Clarke R.C., Diarrhoea and dysentery in calves, in: Gyles C.L. (Ed.), *Escherichia coli* in Domestic Animals and Humans, CAB International, Wallingford, 1994, pp. 91–116.

[17] Calderwood S.B., Acheson D.W.K., Keusch T., Barrett T.J., Griffin P.M., Strockbine N.A., Swaminathan B., Kaper J.B., Levine M.M., Kaplan B.S., Karch H., O'Brien A.D., Obrig T.G., Takeda Y., Tarr P.I., Wachsmuth I.K., Proposed new nomenclature for SLT (VT) family, Am. Soc. Microbiol. (ASM) News 62 (1996) 118–119.

[18] Calvert C.A., Greene C.E., Hardie E.M., Cardiovascular infections in dogs: epizootiology, clinical manifestations, and prognosis, J. Am. Vet. Med. Assoc. 187 (1985) 612–616.

[19] Caprioli A., Falbo V., Ruggeri F.R., Minelli F., Orskov I., Donelli G., Relationship between cytotoxic necrotizing factor production and serotype in hemolytic *Escherichia coli*, J. Clin. Microbiol. 27 (1989) 758–761.

[20] Caugant D.A., Levin B.R., Selander R.K., Distribution of multilocus genotypes of *Escherichia coli* within and between host families, J. Hyg. 92 (1984) 377–384.

[21] Cherifi A., Contrepois M., Picard B., Goullet P., Orskov I., Orskov F., De Rycke J., Clonal relationships among *Escherichia coli* serogroup O6 isolates from human and animal infections, FEMS Microbiol. Lett. 64 (1991) 225–230.

[22] Choi W.P., Kawata K., O group of *Escherichia coli* from canine and feline pyometra, Jap. J. Vet. Res. 23 (1975) 141–143.

[23] Christie B.A., The occurrence of vesicoureteral reflux and pyelonephritis in apparently normal dogs, Investig. Urol. 10 (1973) 359–366.

[24] Donnenberg M.S., Enteropathogenic *Escherichia coli*, in: Blaser M.J., Ravdin J.I., Greenberg H.B., Guerrant R.L. (Eds.), Infections of the Gastrointestinal Tract, Raven Press, New York, 1995, pp. 709–726.

[25] Drolet R., Fairbrother J.M., Harel J., Helie P., Attaching and effacing and enterotoxigenic *Escherichia coli* associated with enteric colibacillosis in the dog, Can. J. Vet. Res. 58 (1994) 87–92.

[26] Gallien P., Klie H., Lehmann S., Protz D., Helmuth R., Schaefer R., Ehrler M., Nachweis verotoxinbildender *E. coli* in Feldisolaten von Haus- und landwirtschaftlichen Nutztieren in Sachsen-Anhalt (Detection of verotoxin-producing *E. coli* in field isolates from domestic and agricultural animals in Sachsen-Anhalt), Berl. Muench. Tierarztl. Wochenschr. 107 (1994) 331–334.

[27] Garcia E., Bergmans H.E., Van den Bosch J.F., Orskov I., Van der Zeijst B.A., Gaastra W., Isolation and characterisation of dog uropathogenic *Escherichia coli* strains and their fimbriae, Antonie Leeuwenhoek 54 (1988) 149–163.

[28] Griffin P.M.D., *Escherichia coli* O157:H7 and other enterohemorrhagic *Escherichia coli*, in: Blaser M.J., Ravdin J.I., Greenberg H.B., Guerrant R.L. (Eds.), Infections of the Gastrointestinal Tract. Raven Press, New York, 1995, pp. 739–761.

[29] Grindlay M., Renton J.P., Ramsay D.H., O-groups of *Escherichia coli* associated with canine pyometra, Res. Vet. Sci. 14 (1973) 75–77.

[30] Gyles C.L., *Escherichia coli* enterotoxins, in: Gyles C.L. (Ed.), *Escherichia coli* in Domestic Animals and Humans, CAB International, Wallingford, 1994, pp. 337–364.

[31] Gyles CL., *Escherichia coli* verotoxins and other cytotoxins, in: Gyles C.L. (Ed.), *Escherichia coli* in domestic animals and humans, CAB International, Wallingford, 1994, pp. 365–398.

[32] Hammermueller J., Kruth S., Prescott J., Gyles C., Detection of toxin genes in *Escherichia coli* isolated from normal dogs and dogs with diarrhea, Can. J. Vet. Res. 59 (1995) 265–270.

[33] Hampson D.J., Postweaning *Escherichia coli* diarrhoea in pigs, in: Gyles C.L. (Ed.), *Escherichia coli* in Domestic Animals and Humans, CAB International, Wallingford, 1994, pp. 171–191.

[34] Hirsh D.C., Multiple antimicrobial resistance in *Escherichia coli* isolated from the urine of dogs and cats with cystitis, J. Am. Vet. Med. Assoc. 162 (1973) 885–887.

[35] Hodgson J.C., Diseases due to *Escherichia coli* in sheep, in: Gyles C.L. (Ed.), *Escherichia coli* in Domestic Animals and Humans, CAB International, Wallingford, 1994, pp. 135–150.

[36] Holland R.E., Some infectious causes of diarrhea in young farm animals, Clin. Microbiol. Rev. 3 (1990) 345–375.

[37] Isogai E., Isogai H., Onuma M., Mizukoshi N., Hayshi M., Namioka S., *Escherichia coli* endotoxemia in dogs with parvovirus infection, Jpn. J. Vet. Sci. 51 (1989) 597–606.

[38] Janke B.H., Francis D.H., Collins J.E., Libal M.C., Zeman D.H., Johnson D.D., Attaching and effacing *Escherichia coli* infections in calves, pigs, lambs, and dogs, J. Vet. Diagn. Invest. 1 (1989) 6–11.

[39] Johnson J.R., Virulence factors in *Escherichia coli* urinary tract infection, Clin. Microbiol. Rev. 4 (1991) 80–128.

[40] Josse M., Jacquemin E., Kaeckenbeeck A., Présence chez le chien, d'*Escherichia coli* productrices d'une enterotoxine thermostable (Sta), Ann. Méd. Vét. 124 (1980) 211–214.

[41] Khakhria R., Duck D., Lior H., Extended phagetyping scheme for *Escherichia coli* O157:H7, Epidemiol. Infect. 105 (1990) 511–520.

[42] Kivistoe A.K., Vasenius H., Sandholm M., Laboratory diagnosis of canine pyometra, Acta Vet. Scand. 18 (1977) 308–315.

[43] Konowalchuk J., Speirs J.I., Stavric S., Vero response to a cytotoxin of *Escherichia coli*, Infect. Immun. 18 (1977) 775–779.

[44] Linde C., Partial abortion associated with genital *Escherichia coli* infection in a bitch, Vet. Rec. 112 (1983) 454–455.

[45] Ling G.V., Cullen J.M., Kennedy P.C., Ruby A.L., Brooks D.L., Relationship of upper and lower urinary tract infection and bacterial invasion of uroepithelium to antibody-coated bacteria test results in female dogs, Am. J. Vet. Res. 46 (1985) 499–504.

[46] Low D.A., Braaten B.A., Ling G.V., Johnson D.L., Ruby A.L., Isolation and comparison of *Escherichia coli* strains from canine and human patients with urinary tract infections, Infect. Immun. 56 (1988) 2601–2609.

[47] Matthiesen D.T., Lammerding J., Gallbladder rupture and bile peritonitis secondary to cholelithiasis and cholecystitis in a dog, J. Am. Vet. Med. Assoc. 184 (1984) 1282–1283.

[48] Mayr A., Goetz S., Schels H., Untersuchungen ueber die Hygiene bei der Haltung von Hunden in staedtischen Wohnungen (The hygiene of keeping dogs in city apartments), Zentralbl. Bakteriol. Mikrobiol. Hyg. Ser. B, Umwelthyg. Krankenhaushyg. Arbeitshyg. Praev. Med. 183 (1986) 240–253.

[49] Muennich A., Gruessel T., Leopold T., Erfahrungen in der Diagnostik und Therapie von Welpenerkrankungen in den ersten Lebenstagen (Experiences in diagnosis and therapy of puppy diseases in the first days of life), Tieraerztliche Praxis 23 (1995) 497–501.

[50] Nalin D.R., Levine M.M., Young C.R., Bergquist E.J., McLaughlin J.C., Increased *Escherichia coli* enterotoxin detection after concentrating culture supernatants: possible new enterotoxin detectable in dogs but not in infant mice, J. Clin. Microbiol. 8 (1978) 700–703.

[51] Nataro J.P., Kaper J.B., Diarrheagenic *Escherichia coli*, Clin. Microbiol. Rev. 11 (1998) 142–201.

[52] Olson P., Hedhammar A., Wadstroem T., Enterotoxigenic *Escherichia coli* infection in two dogs with acute diarrhea, J. Am. Vet. Med. Assoc. 184 (1984) 982–983.

[53] Olson P., Hedhammar A., Faris A., Krovacek K., Wadstroem T., Enterotoxigenic *Escherichia coli* (ETEC) and *Klebsiella pneumoniae* isolated from dogs with diarrhoea, Vet. Microbiol. 10 (1985) 577–589.

[54] Orskov I, Orskov F., Significance of surface antigens in relation to enterotoxigenicity of *E. coli*, in: Ouchterlony O., Holmgren J. (Eds.), Cholera and Related Diarrheas. Molecular Aspects of a Global Health Problem, Karger, Basel, 1978, pp. 134–141.

[55] Orskov I., Orskov F., *Escherichia coli* in extraintestinal infections, J. Hygiene (Cambridge), 95 (1985) 551–575.

[56] Peeters J.E., *Escherichia coli* infections in rabbits, cats, dogs, goats and horses, in: Gyles C.L. (Ed.), *Escherichia coli* in Domestic Animals and Humans, CAB International, Wallingford, 1994, pp 261–283.

[57] Pohl P., Mainil J., Devriese L.A., Haesebrouck F., Broes A., Lintermans P., Oswald E., *Escherichia coli* productrices de la toxine cytotoxique nécrosante de type 1 (CNF1) isolée à partir de processus pathologiques chez des chats et des chiens, Ann. Med. Vet. 137 (1992) 21–25.

[58] Pohl P., Oswald E., Van Muylem K., Jacquemin E., Lintermans P., Mainil J., *Escherichia coli* producing CNF1 and CNF2 cytotoxins in animals with different disorders, Vet. Res. 24 (1993) 311–315.

[59] Pospischil A., Mainil J.G., Baljer G., Moon H.W., Attaching and effacing bacteria in the intestines of calves and cats with diarrhea, Vet. Pathol. 24 (1987) 330–334.

[60] Prada J., Baljer G., De Rycke J., Steinrueck H., Zimmermann S., Stephan R., Beutin L., Characteristics of alpha-hemolytic strains of *Escherichia coli* isolated from dogs with gastroenteritis, Vet. Microbiol. 29 (1991) 59–73.

[61] Prada J., Zimmermann S., Stephan R., Beutin L., Restriction fragment length polymorphisms associated with alpha-hemolysin determinants are correlating with the expression of alpha-hemolysin in strains of *Escherichia coli*, Zentralbl. Bakteriol. 276 (1992) 152–164.

[62] Rhoades H.E., Saxena S.P., Meyer R.C., Serological identification of *Escherichia coli* isolated from cats and dogs, Can. J. Comp. Med. 35 (1971) 218–223.

[63] Richter T., Hellmann E., Vorkommen und Eigenschaften enterotoxinbildender *Escherichia coli*-Staemme beim enteritiskranken Junghund (Occurrence and properties of enterotoxigenic *Escherichia coli* strains from young dogs with enteritis), Zentralbl. Veterinarmed. Reihe B 32 (1985) 446–453.

[64] Richter T., Grund S., Hellmann E., Zum Vorkommen von enterotoxischen *E. coli* beim Junghund. Beschreibung mutmasslicher Pathogenitaetsfaktoren (Occurrence of enterotoxic *E. coli* in the young dog. Description of probable pathogenicity factors), Berl. Muench. Tierarztl. Wochenschr. 97 (1984) 37–43.

[65] Riley L.K., Caffrey C.J., Identification of enterotoxigenic *Escherichia coli* by colony hybridization with nonradioactive digoxigenin-labeled DNA probes, J. Clin. Microbiol. 28 (1990) 1465–1468.

[66] Sack R.B., Johnson J., Pierce N.F., Keren D.F., Yardley J.H., Challenge of dogs with live enterotoxigenic *Escherichia coli* and effects of repeated challenges on fluid secretion in jejunal Thiry-Vella loops, J. Infect. Dis. 134 (1976) 15–24.

[67] Sager M., Remmers C., Ein Beitrag zur perinatalen Welpensterblichkeit beim Hund. Klinische, bakteriologische und pathologische Untersuchungen (Perinatal mortality in dogs. Clinical, bacteriological and pathological studies), Tierarztliche Praxis 18 (1990) 415–419.

[68] Sandholm M., Vasenius H., Kivistoe A.K., Pathogenesis of canine pyometra, J. Am. Vet. Med. Assoc. 167 (1975) 1006–1010.

[69] Schechter R.D., The significance of bacteria in feline cystitis and urolithiasis, J. Am. Vet. Med. Assoc. 156 (1970) 1567–1573.

[70] Schiff L.J., Barbera P.W., Port C.D., Yamashiroya H.M., Shefner A.M., Poiley S.M., Enteropathogenic *Escherichia coli* infections: increasing awareness of a problem in laboratory animals, Lab. Anim. Sci. 22 (1972) 705–708.

[71] Schwarz J., Zur Beteiligung von *E. coli* an Erkrankungen des Urogenitaltraktes des Hundes. 1. Mitteilung: Kulturelle Untersuchungen, Kleintierpraxis 36 (1991) 179–184.

[72] Senior D., Baker N., Cedergren B., Falk P., Larson G., Lindstedt R., Eden C.S., Globo-A-a new receptor specificity for attaching *Escherichia coli*, FEBS Lett. 237 (1988) 123–127.

[73] Senior D.F., deMan P., Svanborg C., Serotype, hemolysin production, and adherence characteristics of strains of *Escherichia coli* causing urinary tract infection in dogs, Am. J. Vet. Res. 53 (1992) 494–498.

[74] Smith H.W., The development of the flora of the alimentary tract in young animals, J. Pathol. Bacteriol. 90 (1965) 495–513.

[75] Stroemberg N., Marklund B.I., Lund B., Ilver D., Hamers A., Gaastra W., Karlsson K.A., Normark S., Host-specificity of uropathogenic *Escherichia coli* depends on differences in binding specificity to Gal alpha 1-4Gal-containing isoreceptors, EMBO J. 9 (1990) 2001–2010.

[76] Trevena W.B., Hooper R.S., Wray C., Willshaw G.A., Cheasty T., Domingue G., Vero cytotoxin-producing *Escherichia coli* O157 associated with companion animals, Vet. Rec. 138 (1996) 400.

[77] Turk J., Miller M., Brown T., Fales W., Fischer J., Gosser H., Nelson S., Shaw D., Solorzano R., Coliform septicemia and pulmonary disease associated with canine parvoviral enteritis: 88 cases (1987–1988), J. Am. Vet. Med. Assoc. 196 (1990) 771–773.

[78] Wada Y., Kondo H., Nakaoka Y., Kubo M., Gastric attaching and effacing *Escherichia coli* lesions in a puppy with naturally occurring enteric colibacillosis and concurrent canine distemper virus infection,Vet. Pathol. 33 (1996) 717–720.

[79] Wadas B., Kuehn I., Lagerstedt A.S., Jonsson P., Biochemical phenotypes of *Escherichia coli* in dogs: comparison of isolates isolated from bitches suffering from pyometra and urinary tract infection with isolates from faeces of healthy dogs, Vet. Microbiol. 52 (1996) 293–300.

[80] Wasteson Y., Olsvik O., Skancke E., Bopp C.A., Fossum K., Heat-stable-enterotoxin-producing *Escherichia coli* strains isolated from dogs, J. Clin. Microbiol. 26 (1988) 2564–2566.

[81] Wastlhuber U.H., Baljer G., Daimon H., Huebert P.H., Mayr A., Vergleichende Untersuchungen ueber die Plasmidverteilung bei *Escherichia coli* (*E. coli*)-Staemmen von gesunden und durchfallkranken Hunden sowie von Hundebesitzern (Comparative studies of plasmid distribution in *Escherichia coli* (*E. coli*) strains from healthy and diarrheic dogs and their owners), Zentralbl. Veterinarmed. Reihe B 35 (1988) 218–229.

[82] Watson A.D., Culvenor J.A., Middleton D.J., Rothwell T.L., Distal renal tubular acidosis in a cat with pyelonephritis, Vet. Rec. 119 (1986) 65–68.

[83] Weaver A.D., Pillinger R., Relationship of bacterial infection in urine and calculi to canine urolithiasis, Vet. Rec. 97 (1975) 48–50.

[84] Weaver A.D., Pillinger R., Lower urinary tract pathogens in the dog and their sensitivity to chemotherapeutic agents, Vet. Rec. 101 (1977) 77–79.

[85] Weber A., Wachowitz R., Roth M., Serotypisierung und Antibiotikaempfindlichkeit von *E. coli*-Stämmen, isoliert von enteritiskranken Katzen, VET 4 (1990) 17–19.

[86] Westerlund B., Pere A., Korhonen T.K., Järvinen A.K., Siitonen A., Williams P.H., Characterisation of *Escherichia coli* strains associated with canine urinary tract infections, Res. Vet. Sci. 42 (1987) 404–406.

[87] Whittam T.S., Wolfe M.L., Wilson R.A., Genetic relationships among *Escherichia coli* isolates causing urinary tract infections in humans and animals, Epidemiol. Infect. 102 (1989) 37–46.

[88] Wilk S., Amtsberg G., Meier C., Serotypisierung und Resistenzpruefung von *Escherichia-coli*-Staemmen aus gesunden und enteritiskranken Hunden (Serotyping and drug resistance of *Escherichia coli* strains in healthy dogs and dogs with enteritis), Berl. Muench. Tierarztl. Wochenschr. 95 (1982) 271–275.

[89] Wilkinson G.T., O-groups of *E. coli* in the vagina and alimentary tract of the dog, Vet. Rec. 94 (1974) 105.

[90] Wilson R.A., Keefe T.J., Davis M.A., Browning M.T., Ondrusek K., Strains of *Escherichia coli* associated with urogenital disease in dogs and cats, Am. J.Vet. Res. 49 (1988) 743–746.

[91] Wolf K.W., Occurrence, distribution and associations of O and H- serogroups, colonization factor antigens, and toxins of enterotoxigenic *Escherichia coli*, Clin. Microbiol. Rev. 10 (1997) 569–584.

[92] Wooley R.E., Blue J.L., Bacterial isolations from canine and feline urine, Mod. Vet. Pract. 57 (1976) 535–538.

[93] World Health Organization, Prevention and control of enterohaemorrhagic *Escherichia coli* infections, Report of a WHO Consultation, WHO/FSF/FOS/97.6 Geneva, Switzerland, 28 April–1 May, 1997.

[94] Young C., Preweaning mortality in specific pathogen free kittens, J. Small Anim. Pract. 14 (1973) 391–397.