# Role of Companion Animals in Zoonotic Transmission of Antimicrobial Resistant *Escherichia coli*

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## Abstract

Antimicrobial resistance is a growing issue all over the world which drastically reduces the effectiveness of antibiotics against infection. Increased antimicrobial resistant *Escherichia coli* (AMR *E. coli*) in humans can be attributed to a variety of factors, one of these factors is the close contact of humans with companion animals, mainly cats and dogs. Research has indicated that pets harbor multiple strains of resistant *E. coli* and these resistant bacteria can be transmitted by direct and indirect contact to humans. Risk factors responsible for transmission of AMR *E. coli* include lack of hygiene practices, inappropriate antimicrobial use in pets, and contamination of household environment with resistant *E. coli* contained by pets, feeding raw meat diet to pets and lack of public awareness about AMR in pets and its transmission to humans. Similar strains of resistant *E. coli* have been found in pets and their owners in a number of studies indicative of zoonotic transmission. A variety of strategies need to be adopted to prevent this transmission including improving one health surveillance strategies for tracing and managing transmission of resistant bacteria, development of vaccines against AMR *E. coli*, promoting appropriate antimicrobial use in veterinary practice, improving people awareness and pet hygiene.

Keyword: Antimicrobial resistance, Close contact, Hygiene, Public awareness, Zoonotic transmission, Vaccines, One health surveillance

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## Introduction

As a health care problem towards human and animals, antimicrobial resistance or AMR is a worrisome one as it compromises the efficacies of antibiotics. It is one of the major devastating threat to global health, and should be addressed from one health perspective for effective control (Morrison & Zembower, 2020). Zoonotic pathogens, such as *Escherichia coli*, are at the center of this emergency, and their resistance genes can be transmitted horizontally between humans, animals and the environment (Poirel et al., 2018). Pets such as dogs and cats are found to be the reservoir and vector of AMR bacteria as a result of their constant and direct contact with human beings (Pomba et al., 2017; Gwenzi et al., 2021).

Resistant strains of *E. coli* in domestic pets originate from an environmental source, diet, and through veterinary antibiotic use and are often found in their gut microbiota. It is known that there are substantial similarities in resistomes of humans and their pets, so the cross transmission is facilitated by contact (Belas et al., 2020; Røken et al., 2022; Habib et al., 2023). Transmission is usually direct person to person, such as through exposure to body fluids (handling or ingestion), and indirect through contaminated surroundings (soil or objects), from objects used by one or more individuals (shared bedding or feeding dishes), or as a result of contact with feces (Bhat, 2021). Especially when humans live in typical housing units of urban life where pets and their owners are likely to reside in a confined space, this proximity increases newfound public health concerns (Mukerji et al., 2017; Binek et al., 2019).

AMR *E. coli* has grown in rate within companion animals due to over-administration of antibiotics in animal practice. For example, the regular prescription of broad spectrum antibiotics in pets has been found to result in emergence of multidrug resistant (MDR) bacteria that makes treatment of diseased people and animals arduous (Chirila et al., 2017; Marques et al., 2020). In addition, some of these water resistant strains may infiltrate the society making the recirculating zoonotic cycle even wider (Leite-Martins et al., 2015; Bhat, 2021).

These challenges are increasingly necessitating the need to develop antimicrobial stewardship program for human and animal antimicrobial use. Therefore, general increasing of public awareness and introduction of changes in people's behavior are needed, along with specific researches on animals and on vectors of zoonotic AMR bacteria (Yu et al., 2020; Ding et al., 2023). This article offers an overview of companion animals' interactions in the zoonotic dissemination of antibiotic resistance (AMR) *E. coli* with regard to the transmission routes, potential consequences to human health, and potential intervention measures. Knowing these factors helps ascertain multi-sectoral approaches to tackle AMR for the sake of human and animal welfare.

## Overview of Zoonosis and Role of Companion Animals in Disease Transmission

Diseases transmissible from animals to humans, known as zoonosis, have been recognized as a large intersection between veterinary and human medicine (Pal, 2005; Chomel, 2014). They can be caused by bacterial, viral, parasitic and fungal agents and spread by direct contact, vectors or contaminated environment. The zoonotic proportion of new and resurgent infectious diseases is 60% with vast implications for public health necessitating One Health solutions (Hugh-Jones et al., 2008).

Companion animals, i.e., cats, dogs, and other companion animals, are very important in the spread of zoonotic diseases to humans because of the close contact between humans and animals. Common zoonotic diseases include: rabies, cat scratch fever (*Bartonella henselae*), toxoplasmosis and leptospirosis in dogs (Chomel, 2014). Not only do these diseases put peoples' health at risk, but they also incite significant economic burden of treatment (Taylor et al., 2001). Methods of mitigation that prove to be viable include vaccination, deworming, regular visit to a vet, and educating the public on how to handle animals safely (Kisling & Das, 2023). Increased knowledge of these pathways of zoonosis reinforces the importance of concerted action by veterinarians, physicians, and policymakers to protect humans and animals (Aggarwal & Ramachandran, 2020; Kelly et al., 2020; Erkyihun & Alemayehu, 2022).

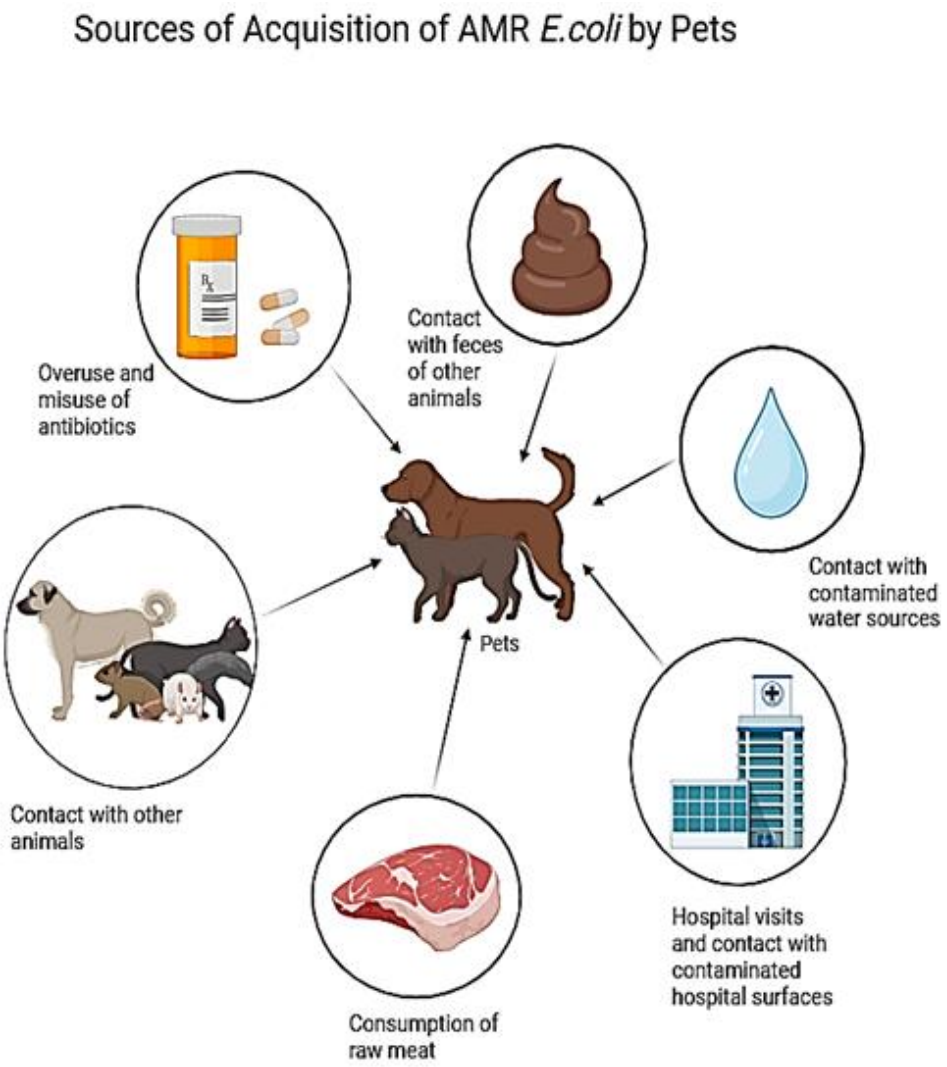


Fig. 1: Sources of acquisition of antimicrobial resistant *E. coli* (AMR *E. coli*) by pets

## Mechanisms of Antimicrobial Resistance in *E. coli* and Implications for Zoonotic Spread

The potential of *E. coli* to acquire and disseminate resistance genes is of concern in both human and veterinary medicine as such a development would confer resistance to effective treatment against *E. coli* acquired infections. Beta-lactamase enzymes, DNA gyrase mutations, efflux pump, cell alteration of antibiotic receptor sites, decreased drug entry, and the use of enzymes to inactivate the drug comprise *E. coli* resistance mechanisms (Reygaert & applications, 2017; Galindo-Méndez & Treatment, 2020; Jariremombe, 2022). Repeated exposure of pets to antibiotics make their bacteria resistant to them, as a result these bacteria persist in companion animals, rendering them potential sources of spread of such bacteria to humans (Schwarz et al., 2017).

AMR *E. coli* can be carried by animals as reservoirs, and can transfer to human bacterial population, through horizontal gene transfer involving plasmids, transposons, and integrons (Vinayamohan et al., 2022). AmpC beta-lactamase producing *E. coli* and ESBL-producing *E. coli*, have especially been detected in pets, which are usually closely related to those identified in humans (Carvalho et al., 2016; Toombs-Ruane et al., 2020).

Environmental infection through pet feces and through contact with animals also helps spread these resistant strains. It has been suggested by research that resistant *E. coli* strains can stay in households and can pass through utensils or common areas of shared use and consequently be transmitted to other animals and humans (Leite-Martins et al., 2015).

Understanding of how AMR *E. coli* genetics are transmitted and spread will enable appropriate interventions to be developed. Risk control measures include surveillance of resistance patterns in veterinary isolates, optimal use of antibiotics in pets and education of pet owners on appropriate methods of pet hygiene. Adoption of these measures into the One Health intervention assures an all-inclusive plan to address the AMR *E. coli* spread across species and settings (Marco-Fuertes et al., 2022).

## Companion Animals as Reservoirs of Antimicrobial-Resistant *E. coli*

Pets especially dogs and cats are a significant source of antimicrobial-resistant (AMR) *E. coli*. Their ability to reside close to human beings allow the bidirectional exchange of resistant strains that question marks the health of the general public. Several publications have revealed that AMR *E. coli* is widespread among pets (Saputra et al., 2017; Marchetti et al., 2021; Zhou et al., 2022; Moon et al., 2023). Dogs and cats are often colonized with ESBL-producing *E. coli* strains that are resistant to a wide spectrum of antibiotics, including cephalosporins and carbapenems (Salgado-Caxito et al., 2021; Zhou et al., 2022). Surveillance reports indicate evidence of genetic relatedness between resistant *E. coli* found in pets and comparable strains in humans (Flament-Simon et al., 2020).

Antecedent risk factors for colonization in companion animals are prior use of antibiotics, underlying illness and exposure to hospital environment (Figure 1). Research also indicates a disproportionate number of resistant cases from animals fed raw food or those in frequent contact with other animals such as in the case of multiple animals in the same household or animals during boarding (Schmidt et al., 2015; Wedley et al., 2017; Ekakoro et al., 2022).

## Transmission Pathways of Antimicrobial Resistant *E. coli* between Pets and Humans

Dogs, cats and other domestic animals increase the circulation of AMR bacteria including *E. coli*. Under normal circumstances, people and their companion animals come into close contact daily. Hence, chances of the possible transfer of AMR bacteria through direct physical contact or contact with infected soil, water and or food increase (Damborg et al., 2016).

Multidrug-resistant *E. coli* strains or strains that bear the ESBL-enzyme are transferable between humans and their pets. Such resistant strains constitute a constantly increasing threat to public health by making it challenging to treat infection in veterinary medicine and human medicine (Chung et al., 2017; Naziri et al., 2022).

Transmission of AMR *E. coli* between companion animals and humans occurs through several pathways (Figure 2):

1. Direct Contact: The resistant *E. coli* can be transferred from pets to humans through social contact such as petting or grooming, or kissing pets. Direct contact of the human skin or mucosal surfaces with pets may transfer AMR *E. coli* from them and can lead to infections (Bhat, 2021).
2. Fecal-Oral Route: As a commensal, *E. coli* is found in the intestinal tract and is excreted by way of the animals' feces. Ingestion of the resistant strains is likely to result from disposal of pet waste or contact with surfaces contaminated with pet feces. In addition, this can be more dangerous for children and people with a compromised immune system (Ratti et al., 2023).
3. Environmental Contamination: Since AMR *E. coli* lives in the urine and feces, it can exist on house surfaces; litter, and other commonly touched surfaces like doorknobs and floors, and pets can transfer it to other household surfaces through their saliva or contact after they lick themselves, their urine or feces, or the litter. Such contamination increases danger of the indirect transmission of AMR *E. coli* (Gwenzi et al., 2021).
4. Shared Veterinary and Human Healthcare Practices: Similar antibiotics are given in both humans and animals in many instances, thus creating the opportunity to develop resistant bacterial strains with the same resistance genes in both humans and companion animals and to pass the infection between them (van den Bogaard & Stobberingh, 2000; Moulin et al., 2008).

## Risk Factors for Transmission of Antimicrobial-Resistant *E. coli* from Pets to Humans

### 1. Close Human-Pet Contact

Pets are always in close contact with the owner, so there is a high potential for spreading AMR *E. coli* because aspects such as caressing or hugging, sleeping with pets or letting the pets lick human skin enable the transmission of the resistant bacteria (Damborg et al., 2016). Such desirable psychosocial contacts have the negative effect of transferring diseases from pets to people.

### 2. Inappropriate Antimicrobial Use in Pets

The misuse or overuse of antibiotics in veterinary care plays a significant role in the development of AMR bacteria. Antibiotic use without prescription or, in other words, the use of broad spectrum antimicrobials when not necessary, will assist in developing resistant *E. coli* transmitted to humans. Exposure to animals with these organisms can spread MDR *E. coli* from pets to people. It is difficult to treat infection caused by such strains in veterinary as well as human medicine that are a persistently emerging threat to public health (Chung et al., 2017; Naziri et al., 2022).

### 3. Poor Hygiene Practices

Furthermore, failure to wash ones' hands after coming in contact with pets, cleaning litter or even dealing with wastes increases chances of acquiring AMR *E. coli* from pets. It can also happen if hands are not sanitized after handling food and water bowls of pets (Damborg et al., 2016). Good prevention depends on health promotion, or teaching people about hygiene.

4. Environmental Contamination

Contaminated areas, in other words, areas where pets are likely to pass feces such as rooms, gardens and shared living spaces are also sources of *E. coli*. Since they are commonly found on surfaces around humans and in soil unintentional contact with humans occurs (Wedley et al., 2017). Waste from pets should be properly disposed of, spaces where pets are kept should be washed to reduce possibility of contamination and pet movement should be localized to individual spaces where no one else visits.

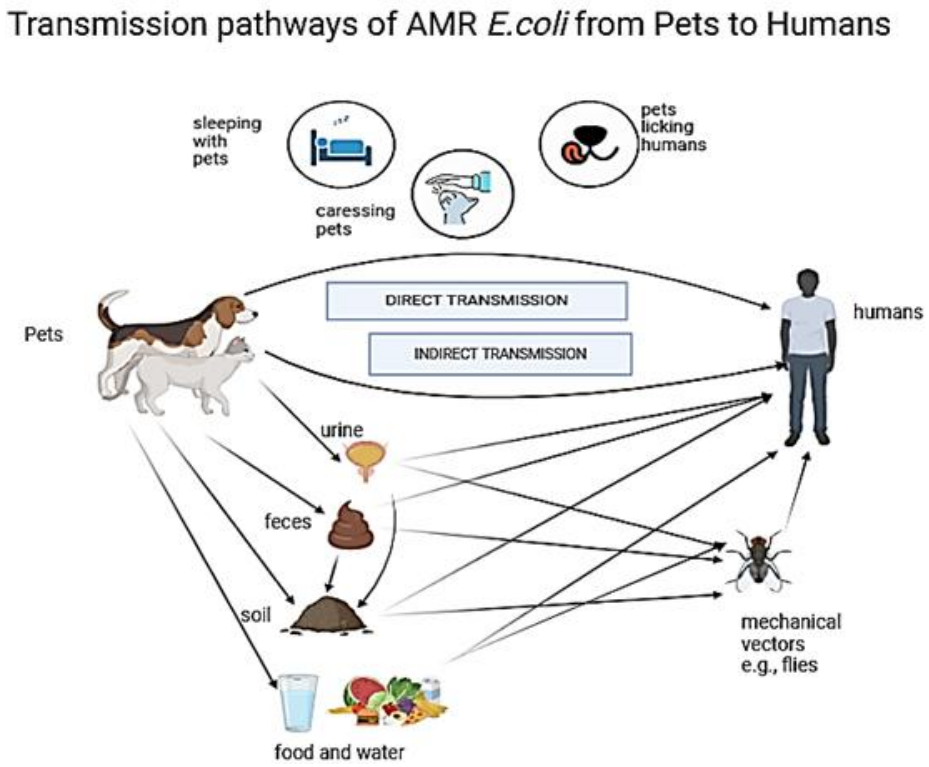


Fig. 2: Transmission pathways of AMR *E. coli* from pets to humans

5. Immunocompromised Individuals in Households

Those who have compromised immune systems can get an AMR infection from their pets. These include old people, children, or those patients taking other drugs like chemotherapeutic agents. There are higher risks of infection acquisition by direct or indirect exposure to resistant pathogens in such people (Faires et al., 2009).

6. Feeding Raw Meat Diets to Pets

Pets consuming raw meat diets showed very high risks of AMR *E. coli* colonization in their gut. Such diets can contain resistant bacteria that pets ingest and then pass some of these bacteria out in their feces. Some of these bacteria can then pass on to humans that encounter pet feces. This is why feeding cooked meat to pets can actually help prevent pets from getting AMR *E. coli* and spreading it to humans (Abbas et al., 2019; Groat et al., 2022; Morgan et al., 2024).

7. Multi-Pet Households

The probability of bacterial transfer is greater if multiple pets are contained within the same household and the likelihood of transfer of resistance genes among animals also increases. This encourages higher bacterial loads that can transmit to humans (Damborg et al., 2016).

8. Limited Awareness of AMR Risks in Pets

Research has shown that pet owners do not know enough about the role of pets in the transmission of antimicrobial resistant bacteria and therefore, do not practice adequate hygiene and biosecurity. However, equally alarming is that the public is not adequately informed on the mode of zoonotic transmission of AMR bacteria, making transmission more likely. In addition, very few researches have been done to measure antimicrobial resistance in pets, indicating a decreased level of understanding and consciousness about it (Smith et al., 2018).

Impact on Human Health: Case Studies and Public Health Implications

Pets, both in contact and at a distance, bear a considerable responsibility for spreading antimicrobial resistant (AMR) *E. coli* to humans and affecting human health and public health systems worldwide. Current research has revealed that humans and their companion animals share similar resistant *E. coli* species. A study done in Romania demonstrated that dogs harboring Extended Spectrum Cephalosporin Resistant *Enterobacterales* were shedding the pathogens back to their owner thus reflecting the possibility of zoonotic transmission of resistant bacteria from pets to owners (Cozma et al., 2022). Likewise, coexistence of ESBL *Enterobacterales* in dogs and their owners who live together in same house was also confirmed by a study carried out in the year 2020 (Van den Bunt et al., 2020).

A study done on households in Portugal and the United Kingdom showed that there was transmission of ESBL producing *E. coli* between the pets and their owners. Longitudinal transmission of *E. coli* strains between pets and their owners was also identified (Menezes et al., 2024). Another study aimed at establishing the co-carriage of ESBL *E. coli* and AmpC Beta lactamase producing *E. coli* established that co-carriage of these *E. coli* was present in 11 out of 27 households with pets, which implies that such resistant bacteria might be transferred from pets to their owners (Toombs-Ruane et al., 2020).

The consequences for public health systems are therefore significant. AMR infections make treatment more challenging because effective antibiotics become scarce, hence longer hospital stays, higher treatment costs, and higher mortality rates occur (Ferri et al., 2017; Dadgostar, 2019). Continued population-based surveillance determined that pets play a significant role in the transmission of MDR bacteria in the community, including urban areas characterized by high human and companion animal interaction. Furthermore, animals that often go to recreational areas, including parks, spread AMR pathogens in urban environments, and therefore raise the threat of more extensive community infections (Damborg et al., 2016).

### Measures to Prevent Zoonotic Transmission of AMR *E. coli* from Companion Animals

Companion animals which live in close proximity to humans are a critical source of public health concern for transmission of AMR *E. coli*. A multisector model has to be integrated across veterinary practices, public health policy makers, and communities to address this risk. Below are detailed strategies to reduce the risk of zoonotic transmission:

#### 1. Improving One Health Surveillance Strategies

Above all, One Health field is necessary for following and managing circulation of AMR *E. coli*. This is an information approach that covers information from human and animal health and environment. Surveillance systems should include routine sampling of companion animals in veterinary clinics, animal shelters and areas of high human population density. Public health practitioners would be able to utilize the given AMR patterns of *E. coli* isolates from pets and their owners seen at the given veterinary clinics to establish zoonotic transmission pathways and they may develop related interventions. Whole genome sequencing is one of many genomic technologies that can complement surveillance to detect the spread of resistance genes between species, organisms, and environments (Singh et al., 2021; Djordjevic et al., 2024).

#### 2. Promoting Knowledge of Appropriate Use of Antimicrobial Drugs in Veterinary Practice

Veterinary antimicrobial stewardship is fundamental approach since proper antimicrobials use in animals is essential to reduce AMR. Most standard-treatment protocols involve use of antibiotics, animal doctors should always search for other forms of treatment and use those types of treatment before using antibiotics. Medicines such as third generation cephalosporin and fluoroquinolone should only be used where alternatives are unavailable. In the practice of appropriate antibiotic use in the veterinary sector, cross-sector collaboration between veterinarians; researchers and policymakers can be practiced (Caneschi et al., 2023).

#### 3. Improving People's Awareness and Promoting Pet Hygiene

Accumulated evidence has also made another point — that pet owners should be held accountable for stopping zoonotic transmission. According to research, interventions to prevent spread of AMR bacteria should also include a need to wash hands and clean surfaces after contacting with pets (Harbarth et al., 2015). Because pets' feces can serve as a reservoir for AMR *E. coli*, people should make sure of proper pet waste disposal. Additionally, some aggressive dangerous behaviors that can result in decreased health standards are allowing the pets to lick human faces and feeding them raw food diets. Since resistant bacteria are transferred from animals to humans (zoonotic transfer), these practices need to be eliminated to prevent zoonotic spread (Collignon et al., 2019).

#### 4. Developing and Promoting Vaccines against Antimicrobial Resistant Bacteria

Creating vaccines that target AMR *E. coli* strains in companion animals is the best way to prevent diseases from these strains. Vaccination also reduces bacterial load in pet meaning the chance of zoonotic transmission is reduced. Through studies of the immunology and molecular biology potent vaccines could be developed towards resistance mechanisms such as beta lactamase production (Alghamdi et al., 2021).

#### 5. Waste Management for the Reduction of Environmental Contamination

A study also found that the majority of the spread of AMR *E. coli* into the environment was contributed by pet waste. Local governments can, however, legally ban poor disposal procedures, so they can put in place ordinances on how to catch up on animal waste. Information, education, and communication on the risks of polluting the environment will always be the case for supporting municipal formal systems for waste collection. Dealing with animal waste, technologies should be seen as and searched for as methods for sustainability (Palma et al., 2020; Gwenzi et al., 2021).

#### 6. Community Level Biosecurity Measures

Also in areas of high rates of pet ownership physical barriers should be used for separation of pet areas, especially in risky areas such as playgrounds and parks, to help minimize contact. The zoonotic transmission is lowered by minimizing pet contact such as by avoiding sleeping with them. For populations with AMR susceptible infections, guidelines for interaction with pets need to be established (Stull et al., 2015; Damborg et al., 2016).

#### 7. Focusing on Research regarding Zoonotic AMR Dynamics

Determining how AMR transits between companion animals and humans is vital for policy making. Areas for future research priorities

include mechanisms for transfer of AMR genes between species, the role of microbiota in AMR dynamics and identification of long term sustainable intervention strategies. Multi subject cooperation and interest alliances could improve work (Cheng et al., 2024).

## Conclusion

Antimicrobial resistance is one of the major public health concerns. It is increasing over time due to a variety of reasons one of which is contact with companion animals. Companion animals inevitably play important role in zoonotic transmission of AMR *E. coli*. Therefore, there is a need to adopt important preventive measures such as judicial use of antibiotics in pets, limited contact between pets and owners, increased public education and awareness about AMR, good hygiene practices and implementation of community-level biosecurity measures to reduce zoonotic spread of AMR *E. coli* from companion animals to humans. A one health approach for surveillance of antimicrobial resistance spread is necessary to contain the issue prior to further spread.

## References


Abbas, G., Khan, I., Mohsin, M., Sajjad Ur, R., Younas, T., & Ali, S. (2019). High rates of CTX-M group-1 extended-spectrum beta-lactamases producing *Escherichia coli* from pets and their owners in Faisalabad, Pakistan. *Infection and Drug Resistance*, *12*, 571-578. https://doi.org/10.2147/IDR.S189884

Aggarwal, D., & Ramachandran, A. (2020). One health approach to address zoonotic diseases. *Indian Journal of Community Medicine, 45*(1), S6-S8.

Alghamdi, S. (2021). The role of vaccines in combating antimicrobial resistance (AMR) bacteria. *Saudi Journal of Biological Sciences*, *28*(12), 7505-7510.

Belas, A., Menezes, J., Gama, L. T., Pomba, C. (2020). Sharing of clinically important antimicrobial resistance genes by companion animals and their human household members. *Microbial Drug Resistance, 26*(10), 1174-1185.

Bhat, A. H. (2021). Bacterial zoonoses transmitted by household pets and as reservoirs of antimicrobial resistant bacteria. *Microbial Pathogenesis, 155*, 104891.

Binek, M., Kizerwetter-Świda, M., Rzewuska, M., Chrobak-Chmiel, D., & Sałamaszyńska-Guz, A. (2019). Antibiotic resistance of bacteria a growing threat for animals and public health. *58*(3), *Postępy Mikrobiologii-Advancements of Microbiology, 58*(3), 259-270.

Caneschi, A., Bardhi, A., Barbarossa, A., & Zaghini, A. (2023). The use of antibiotics and antimicrobial resistance in veterinary medicine, a complex phenomenon: A narrative review. *Antibiotics*, *12*(3), 487.

Carvalho, A. C., Barbosa, A. V., Arais, L. R., Ribeiro, P. F., Carneiro, V. C., & Cerqueira, A. M. F. (2016). Resistance patterns, ESBL genes, and genetic relatedness of Escherichia coli from dogs and. owners *Brazilian Journal of Microbiology*, *47*, 150-158.

Cheng, G., Fang, L. X., Feng, J., Li, X., & Wu, Z. (2024). Antimicrobial resistance in zoonotic bacteria. *Frontiers in Microbiology*, *15*, 1362380.

Chirila, F., Tabaran, A., Fit, N., Nadas, G., Mihaiu, M., Tabaran, F. & Dan, S. D. (2017). Concerning increase in antimicrobial resistance in Shiga toxin-producing Escherichia coli isolated from young animals during 1980–2016. *Microbes and Environments*, *32*(3), 252-259.

Chomel, B. B. (2014). Emerging and re-emerging zoonoses of dogs and cats. *Animals*, *4*(3), 434-445.

Chomel, B. B. (2014). Zoonoses. *Encyclopedia of Microbiology, 2009*; 820-829.

Chung, Y. S., Park, Y. K., Park, Y. H., & Park, K. T. (2017). Probable secondary transmission of antimicrobial-resistant *Escherichia coli* between people living with and without pets. *Journal of Veterinary Medical Science, 79*(3), 486-491.

Collignon, P. J., & McEwen, S. A. (2019). One health—its importance in helping to better control antimicrobial resistance. *Tropical Medicine and Infectious Disease, 4*(1), 22.

Cozma, A. P., Rimbu, C. M., Zendri, F., Maciuca, I. E., & Timofte, D. (2022). Clonal dissemination of extended-spectrum cephalosporin-resistant Enterobacterales between dogs and humans in households and animal shelters of Romania. *Antibiotics, 11*(9), 1242.

Dadgostar, P. (2019). Antimicrobial resistance: implications and costs. *Infection and Drug Resistance, 12*, 3903-3910.

Damborg, P., Broens, E. M., Chomel, B. B., Guenther, S., Pasmans, F., Wagenaar, J. A., & Guardabassi, L. (2016). Bacterial zoonoses transmitted by household pets: state-of-the-art and future perspectives for targeted research and policy actions. *Journal of Comparative Pathology, 155*(1), S27-S40.

Ding, D., Wang, B., Zhang, X., Zhang, J., Zhang, H., Liu, X., & Yu, Z. (2023). The spread of antibiotic resistance to humans and potential protection strategies. *Ecotoxicology and Environmental Safety, 254*, 114734.

Djordjevic, S. P., Jarocki, V. M., Seemann, T., Cummins, M. L., Watt, A. E., Drigo, B., & Howden, B. P. (2024). Genomic surveillance for antimicrobial resistance—a One Health perspective. *Nature Reviews Genetics, 25*(2), 142-157.

Ekakoro, J. E., Hendrix, G. K., Guptill, L. F., & Ruple, A. (2022). Antimicrobial susceptibility and risk factors for resistance among Escherichia coli isolated from canine specimens submitted to a diagnostic laboratory in Indiana, 2010–2019. *PLoS One, 17*(8), e0263949.

Erkyihun, G. A., & Alemayehu, M. B. (2022). One Health approach for the control of zoonotic diseases. *Zoonoses*, *2*(1), 963.

Faires, M. C., Tater, K. C., & Weese, J. S. (2009). An investigation of methicillin-resistant Staphylococcus aureus colonization in people and pets in the same household with an infected person or infected pet. *Journal of the American Veterinary Medical Association*, *235*(5), 540-543.

Ferri, M., Ranucci, E., Romagnoli, P., & Giaccone, V. (2017). Antimicrobial resistance: A global emerging threat to public health systems. *Critical reviews in Food Science and Nutrition*, *57*(13), 2857-2876.

Flament-Simon, S. C., De Toro, M., García, V., Blanco, J. E., Blanco, M., Alonso, M. P., & Blanco, J. (2020). Molecular characteristics of extraintestinal pathogenic E. coli (ExPEC), uropathogenic E. coli (UPEC), and multidrug resistant E. coli isolated from healthy dogs in Spain. Whole genome sequencing of canine ST372 isolates and comparison with human isolates causing extraintestinal infections. *Microorganisms*, *8*(11), 1712.

Galindo-Méndez, M. (2020). Antimicrobial resistance in Escherichia coli. In Rodrigo, L. (Ed.), *E. Coli Infections-Importance of Early Diagnosis*

*and Efficient Treatment,* (pp 179-198), Books on Demand.

Groat, E. F., Williams, N. J., Pinchbeck, G., Warner, B., Simpson, A., & Schmidt, V. M. (2022). UK dogs eating raw meat diets have higher risk of Salmonella and antimicrobial-resistant Escherichia coli faecal carriage. *Journal of Small Animal Practice*, *63*(6), 435-441.

Gwenzi, W., Chaukura, N., Muisa-Zikali, N., Teta, C., Musvuugwa, T., Rzymski, P., & Abia, A. L. K. (2021). Insects, rodents, and pets as reservoirs, vectors, and sentinels of antimicrobial resistance. *Antibiotics*, *10*(1), 68.

Habib, I., Mohteshamuddin, K., Mohamed, M. Y. I., Lakshmi, G. B., Abdalla, A., & Bakhit Ali Alkaabi, A. (2023). Domestic pets in the United Arab Emirates as reservoirs for antibiotic-resistant bacteria: a comprehensive analysis of extended-spectrum beta-lactamase producing Escherichia coli prevalence and risk factors. *Animals*, *13*(10), 1587.

Harbarth, S., Balkhy, H. H., Goossens, H., Jarlier, V., Kluytmans, J., Laxminarayan, R., & World Healthcare-Associated Infections Resistance Forum participants. (2015). Antimicrobial resistance: one world, one fight!. *Antimicrobial resistance and Infection Control, 4,* 1-15.

Hugh-Jones, M. E., Hubbert, W. T., & Hagstad, H. V. (2008). *Zoonoses: Recognition, Control, and Prevention*. John Wiley & Sons.

Jariremombe, R. C. (2023). Mechanisms of antimicrobial resistance of E. coli. In Starčič Erjavec, M. (Ed.), *Escherichia coli-Old and New Insights,* (pp 197-205), IntechOpen.

Kelly, T. R., Machalaba, C., Karesh, W. B., Crook, P. Z., Gilardi, K., Nziza, J., & Mazet, J. A. (2020). Implementing One Health approaches to confront emerging and re-emerging zoonotic disease threats: lessons from PREDICT. *One Health Outlook*, *2*, 1-7.

Kisling, L. A., & Das, J. M. (2023). Prevention strategies. In *StatPearls*. StatPearls Publishing.

Leite-Martins, L., Meireles, D., Beça, N., Bessa, L. J., de Matos, A. J., & da Costa, P. M. (2015). Spread of multidrug-resistant Escherichia coli within domestic aggregates (humans, pets, and household environment). *Journal of Veterinary Behavior*, *10*(6), 549-555.

Marchetti, L., Buldain, D., Gortari Castillo, L., Buchamer, A., Chirino-Trejo, M., & Mestorino, N. (2021). Pet and stray dogs as reservoirs of antimicrobial-resistant Escherichia coli. *International Journal of Microbiology*, *2021*(1), 6664557. https://doi.org/10.1155/2021/6664557

Marco-Fuertes, A., Marin, C., Lorenzo-Rebenaque, L., Vega, S., & Montoro-Dasi, L. (2022). Antimicrobial resistance in companion animals: a new challenge for the One Health approach in the European Union. *Veterinary Sciences*, *9*(5), 208.

Marques, C., Belas, A., & Pomba, C. (2020). Antimicrobial Resistance Trends in Dogs and Cats with Urinary Tract Infection. In Duarte, A. F. & Costa L. L. da. (Eds.), *Advances in Animal Health, Medicine and Production: A Research Portrait of the Centre for Interdisciplinary Research in Animal Health (CIISA), University of Lisbon, Portugal,* (pp. 246-264). Springer International Publishing.

Menezes, J., Frosini, S. M., Weese, S., Perreten, V., Schwarz, S., Amaral, A. J., & Pomba, C. (2024). Transmission dynamics of ESBL/AmpC and carbapenemase-producing Enterobacterales between companion animals and humans. *Frontiers in Microbiology*, *15*, 1432240.

Moon, B. Y., Ali, M. S., Kwon, D. H., Heo, Y. E., Hwang, Y. J., Kim, J. I., Lee, Y. J., Yoon, S. S., Moon, D. C., & Lim, S. K. (2023). Antimicrobial Resistance in *Escherichia coli* Isolated from Healthy Dogs and Cats in South Korea, 2020-2022. *Antibiotics*, *13*(1), 27.

Morgan, G., Pinchbeck, G., Haldenby, S., Schmidt, V., & Williams, N. (2024). Raw meat diets are a major risk factor for carriage of third-generation cephalosporin-resistant and multidrug-resistant E. coli by dogs in the UK. *Frontiers in Microbiology*, *15*, 1460143.

Morrison, L., & Zembower, T. R. (2020). Antimicrobial resistance. *Gastrointestinal Endoscopy Clinics*, *30*(4), 619-635. https://doi.org/10.1016/j.giec.2020.06.004

Moulin, G., Cavalié, P., Pellanne, I., Chevance, A., Laval, A., Millemann, Y., & Chauvin, C. (2008). A comparison of antimicrobial usage in human and veterinary medicine in France from 1999 to 2005. *Journal of Antimicrobial Chemotherapy*, *62*(3), 617-625.

Mukerji, S., O'Dea, M., Barton, M., Kirkwood, R., Lee, T., & Abraham, S. (2017). Development and transmission of antimicrobial resistance among Gram-negative bacteria in animals and their public health impact. *Essays in Biochemistry*, *61*(1), 23-35.

Naziri, Z., Poormaleknia, M., & Ghaedi Oliyaei, A. (2022). Risk of sharing resistant bacteria and/or resistance elements between dogs and their owners. *BMC Veterinary Research*, *18*(1), 203.

Pal, M. (2005). Importance of zoonoses in public health. *Indian Journal of Animal Sciences*, *75*(5), 586-591.

Palma, E., Tilocca, B., & Roncada, P. (2020). Antimicrobial resistance in veterinary medicine: An overview. *International Journal of Molecular Sciences*, *21*(6), 1914.

Poirel, L., Madec, J. Y., Lupo, A., Schink, A. K., Kieffer, N., Nordmann, P., & Schwarz, S. (2018). Antimicrobial Resistance in *Escherichia coli*. *Microbiology Spectrum*, *6*(4), 10.1128/microbiolspec.arba-0026-2017. https://doi.org/10.1128/microbiolspec.ARBA-0026-2017

Pomba, C., Rantala, M., Greko, C., Baptiste, K. E., Catry, B., Van Duijkeren, E., & Törneke, K. (2017). Public health risk of antimicrobial resistance transfer from companion animals. *Journal of Antimicrobial Chemotherapy*, *72*(4), 957-968.

Ratti, G., Facchin, A., Stranieri, A., Giordano, A., Paltrinieri, S., Scarpa, P., & Lauzi, S. (2023). Fecal Carriage of Extended-Spectrum β-Lactamase-/AmpC-Producing Escherichia coli in Pet and Stray Cats. *Antibiotics*, *12*(8), 1249.

Reygaert, W. C. (2017). Antimicrobial mechanisms of Escherichia coli. In Samie, A. (Ed.), *Escherichia coli-recent advances on physiology, pathogenesis and biotechnological applications*, (pp 81-97), Books on Demand.

Røken, M., Forfang, K., Wasteson, Y., Haaland, A. H., Eiken, H. G., Hagen, S. B., & Bjelland, A. M. (2022). Antimicrobial resistance—Do we share more than companionship with our dogs?. *Journal of Applied Microbiology*, *133*(2), 1027-1039.

Salgado-Caxito, M., Benavides, J. A., Adell, A. D., Paes, A. C., & Moreno-Switt, A. I. (2021). Global prevalence and molecular characterization of extended-spectrum β-lactamase producing-Escherichia coli in dogs and cats–a scoping review and meta-analysis. *One Health*, *12*, 100236.

Saputra, S., Jordan, D., Mitchell, T., San Wong, H., Abraham, R. J., Kidsley, A., & Abraham, S. (2017). Antimicrobial resistance in clinical Escherichia coli isolated from companion animals in Australia. *Veterinary Microbiology*, *211*, 43-50.

Schmidt, V. M., Pinchbeck, G. L., Nuttall, T., McEwan, N., Dawson, S., & Williams, N. J. (2015). Antimicrobial resistance risk factors and characterisation of faecal E. coli isolated from healthy Labrador retrievers in the United Kingdom. *Preventive Veterinary Medicine*, *119*(1-2), 31-40. https://doi.org/10.1016/j.prevetmed.2015.01.013

Schwarz, S., Loeffler, A., & Kadlec, K. (2017). Bacterial resistance to antimicrobial agents and its impact on veterinary and human

medicine. *Advances in Veterinary Dermatology*, *8*, 95-110.
Singh, K. S., Anand, S., Dholpuria, S., Sharma, J. K., Blankenfeldt, W., & Shouche, Y. (2021). Antimicrobial resistance dynamics and the one-health strategy: a review. *Environmental Chemistry Letters*, *19*(4), 2995-3007.
Smith, M., King, C., Davis, M., Dickson, A., Park, J., Smith, F., & Flowers, P. (2018). Pet owner and vet interactions: exploring the drivers of AMR. *Antimicrobial Resistance & Infection Control*, *7*, 1-9.
Stull, J. W., Brophy, J., & Weese, J. S. (2015). Reducing the risk of pet-associated zoonotic infections. *Canada Medical Association Journal*, *187*(10), 736-743.
Taylor, L. H., Latham, S. M., & Woolhouse, M. E. (2001). Risk factors for human disease emergence. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *356*(1411), 983-989.
Toombs-Ruane, L. J., Benschop, J., French, N. P., Biggs, P. J., Midwinter, A. C., Marshall, J. C., & Burgess, S. A. (2020). Carriage of extended-spectrum-beta-lactamase-and AmpC beta-lactamase-producing Escherichia coli strains from humans and pets in the same households. *Applied and Environmental Microbiology*, *86*(24), e01613-20.
van den Bogaard, A. E., & Stobberingh, E. E. (2000). Epidemiology of resistance to antibiotics: links between animals and humans. *International Journal of Antimicrobial Agents*, *14*(4), 327-335.
Van den Bunt, G., Fluit, A. C., Spaninks, M. P., Timmerman, A. J., Geurts, Y., Kant, A., & Hordijk, J. (2020). Faecal carriage, risk factors, acquisition and persistence of ESBL-producing Enterobacteriaceae in dogs and cats and co-carriage with humans belonging to the same household. *Journal of Antimicrobial Chemotherapy*, *75*(2), 342-350.
Vinayamohan, P. G., Pellissery, A. J., & Venkitanarayanan, K. (2022). Role of horizontal gene transfer in the dissemination of antimicrobial resistance in food animal production. *Current Opinion in Food Science*, *47*, 100882.
Wedley, A. L., Dawson, S., Maddox, T. W., Coyne, K. P., Pinchbeck, G. L., Clegg, P., & Williams, N. J. (2017). Carriage of antimicrobial resistant Escherichia coli in dogs: Prevalence, associated risk factors and molecular characteristics. *Veterinary Microbiology*, *199*, 23-30.
Yu, T., Jiang, G., Gao, R., Chen, G., Ren, Y., Liu, J., & Busscher, H. J. (2020). Circumventing antimicrobial-resistance and preventing its development in novel, bacterial infection-control strategies. *Expert Opinion on Drug Delivery*, *17*(8), 1151-1164.
Zhou, Y., Ji, X., Liang, B., Jiang, B., Li, Y., Yuan, T., & Sun, Y. (2022). Antimicrobial resistance and prevalence of extended spectrum β-lactamase-producing Escherichia coli from dogs and cats in Northeastern China from 2012 to 2021. *Antibiotics*, *11*(11), 1506 https://doi.org/10.3390/antibiotics11111506