Veterinary & Life Science Innovations

Veterinary & Life Science Innovations 2024;1(1):36-48

Review Article

Antimicrobial Resistance in Companion Animals: A Growing One Health Concern

Devita Audina SARI [1(*)]

[1] Vet Internal "Klinik Lingkar Satwa", jl. Raya Mastrip no 31, Kedurus, Surabaya

[(*)] Corresponding author:
Devita Audina SARI
E-mail: devitaaudina97@gmail.com

Received: 05-03-2025 | Accepted: 07-12-2024 | Published: 06-12-2024

Abstract

Antimicrobial resistance (AMR) in companion animals is a growing public health concern, with multidrug-resistant (MDR) bacterial infections increasingly affecting dogs and cats. The misuse of antibiotics in veterinary practice contributes to resistant pathogens, including *Staphylococcus pseudintermedius*, *Escherichia coli*, *Enterococcus spp.*, *Salmonella*, and *Campylobacter*. These infections complicate treatment and increase the risk of zoonotic transmission. The One Health approach highlights the link between human, animal, and environmental health, emphasizing the need for collective action. Veterinary clinics and households serve as key sites for resistant bacteria, necessitating stronger infection control and antimicrobial stewardship. AMR leads to more severe diseases, prolonged hospitalization, and higher healthcare costs, often resulting in treatment failures. Mitigation strategies should focus on antimicrobial stewardship programs, improved surveillance, and alternative therapies such as phage therapy and probiotics. Future research should promote global policy alignment, strengthen One Health collaborations, and enhance public awareness of responsible antibiotic use. Addressing AMR in companion animals is vital to protecting both veterinary and human health while preserving antimicrobial efficacy.

Keywords: Antimicrobial resistance, One Health approach, Multidrug-resistant

INTRODUCTION

Antimicrobial resistance occurs when microorganisms—including bacteria, viruses, fungi, and parasites—evolve mechanisms that render antimicrobial treatments ineffective, leading to persistent infections (Puvača 2022). On a global scale, AMR is increasingly recognized as a significant public health threat. In 2019, bacterial AMR was directly associated with approximately 1.27 million deaths and contributed to nearly 4.95 million fatalities worldwide (Moro 2023). If left unchecked, projections suggest that AMR could result in over 39 million deaths globally by 2050 (Capozzi *et al*. 2019).

In veterinary medicine, AMR represents a growing challenge, particularly among companion animals such as dogs and cats. The overuse and improper administration of antimicrobials in these animals are major factors driving the emergence of resistant bacterial strains. These resistant pathogens complicate the treatment of common infections in pets and present a zoonotic risk, as they can be transmitted between animals and humans in shared environments (Köck *et al*. 2021).

The One Health approach emphasizes the interconnectedness of human, animal, and environmental health, illustrating how AMR propagates through direct contact, environmental contamination, and the food supply chain (Martak *et al*. 2024). For instance, antimicrobial use in pets can contribute to the emergence and spread of resistant strains, which may subsequently affect human populations. This underscores the necessity of a collaborative, multidisciplinary approach to effectively combat AMR (Marco-Fuertes *et al*. 2022).

This review aims to examine the prevalence and implications of AMR in companion animals, explore the potential transmission of resistant bacteria to humans, and discuss strategies for mitigation within the One Health framework. Understanding the role of pets in the AMR landscape is essential for developing targeted interventions that safeguard public health.

EPIDEMIOLOGY OF AMR IN COMPANION ANIMALS

Antimicrobial resistance in companion animals, particularly in dogs and cats, represents an escalating challenge to both veterinary and public health. The spread of MDR pathogens complicates treatment protocols and increases the risk of zoonotic transmission. Among the most concerning MDR bacteria in companion animals is *Staphylococcus pseudintermedius*, especially its methicillin-resistant variant (MRSP) (Lynch and Helbig 2021). This bacterium, a natural resident of canine skin and mucous membranes, is a leading cause of infections such as pyoderma, otitis externa, and post-surgical wound complications (Priyantha 2020; Lynch and Helbig 2021; Fàbregas *et al*. 2023). Methicillin-resistant strains demonstrate significant resistance to beta-lactams and various other antibiotic classes, rendering them increasingly difficult to treat (Donkor and Codjoe 2019). Studies indicate that approximately 55% of *S. pseudintermedius* isolates in cats and 60% in dogs exhibit MDR, with notable resistance to aminoglycosides, tetracyclines, and fluoroquinolones (Gómez-Beltrán *et al*. 2020).

Another critical MDR pathogen in companion animals is *Escherichia coli*, particularly strains that produce extended-spectrum beta-lactamases (ESBLs) (Cui *et al*. 2022). *E. coli* is a common causative agent of urinary tract infections (UTIs) in dogs and cats, and the emergence of ESBL-producing variants has substantially diminished the efficacy of beta-lactam antibiotics (Jańczak *et al*. 2024). A decade-long study in Italy observed a rising incidence of ESBL-producing *E. coli* in uropathogenic isolates from dogs and cats, with resistance rates reaching 82% in feline samples and 72% in canine samples. Alarmingly, resistance to first-line treatments such as amoxicillin-clavulanate and cephalosporins underscores the urgent need for alternative therapeutic options (Zhou *et al*. 2022).

Enterococcus species, which are naturally present in the gastrointestinal tracts of dogs and

cats, have also exhibited concerning resistance patterns. Vancomycin-resistant *Enterococcus* (VRE) has been identified in pet infections, presenting significant treatment challenges due to the limited therapeutic options available (Shaker *et al*. 2024). Surveillance studies in China from 2018 to 2021 found that 14.39% of enterococcal isolates from companion animals displayed multidrug resistance, with some strains exhibiting resistance to vancomycin. The detection of VRE in veterinary settings raises concerns about potential transmission to immunocompromised pet owners, highlighting the need for stringent infection control protocols (Wada *et al*. 2021).

In addition to infections primarily affecting animals, zoonotic pathogens such as *Salmonella* and *Campylobacter* contribute to the AMR burden in companion animals. These bacteria, typically associated with gastrointestinal illnesses, can be transmitted to humans through direct contact or environmental contamination (Thépault *et al*. 2020). Research indicates that antimicrobial-resistant *Salmonella* and *Campylobacter* are increasingly prevalent in companion animals, with resistance to fluoroquinolones and macrolides raising significant concerns (EFSA 2023). One study found that over 40% of *Salmonella* and *Campylobacter* isolates from dogs were resistant to fluoroquinolones, a class of drugs critical in human medicine (Moser *et al*. 2020).

The rising prevalence of MDR bacteria in veterinary medicine has been closely linked to antimicrobial usage patterns and regional variations in resistance rates (Cocca *et al*. 2021). A study on antimicrobial prescriptions in companion animals from 2019 to 2021 recorded 2,772 cases of antibiotic use, with 99.7% of these cases involving dogs and only 0.3% involving cats (Joosten *et al*. 2020). The study also highlighted a higher reliance on broad-spectrum antibiotics in dogs, which may contribute to the observed increase in resistance trends in canine bacterial infections (Pedersen *et al*. 2007). Moreover, geographical disparities in MDR pathogen distribution reflect differences in antimicrobial stewardship practices and infection control strategies, with certain MRSP clonal lineages being more prevalent in specific regions (Worthing *et al*. 2018).

The growing presence of MDR bacteria in companion animals underscores the urgent need for effective antimicrobial stewardship, ongoing surveillance, and rigorous infection control measures within veterinary practice. The increasing resistance observed in MRSP, ESBL-producing *E. coli*, VRE, and zoonotic *Salmonella* and *Campylobacter* pathogens highlights the broader implications of AMR within the One Health framework. Addressing these challenges requires a coordinated, multidisciplinary effort involving veterinarians, pet owners, and public health authorities to implement comprehensive strategies aimed at controlling the spread of antimicrobial resistance and safeguarding both animal and human health.

DRIVERS OF ANTIMICROBIAL RESISTANCE IN VETERINARY MEDICINE

Antimicrobial resistance in veterinary medicine is a complex and multifactorial issue, driven by several contributing factors, including the overuse and improper administration of antibiotics in pets, the absence of robust antimicrobial stewardship programs (ASPs), and various transmission routes that facilitate the spread of resistant bacteria (Endale *et al*. 2023). A primary driver of AMR is the inappropriate prescription of antibiotics, with research indicating that a significant proportion of veterinary antibiotic use is either unnecessary or deviates from established guidelines. A survey found that more than half of veterinarians only moderately adhere to domestic or international guidelines when prescribing antibiotics, highlighting inconsistencies in the application of best practices (Chan *et al*. 2024). This lack of consistency fosters the selection of resistant strains, as pathogens are frequently exposed to suboptimal antimicrobial regimens. Additionally, the challenge of administering

oral medications—particularly in cats—has led to an increased reliance on long-acting injectable antibiotics, such as cefovecin. While these formulations are preferred for improving compliance, their widespread use contributes to higher antibiotic exposure, further promoting the development of resistance (Cazer 2023).

The inadequate implementation of ASPs within veterinary medicine exacerbates the AMR crisis. ASPs are vital for promoting the judicious use of antibiotics; however, their integration into companion animal practice remains limited. Although guidelines exist to encourage responsible antibiotic use, studies indicate that many veterinarians do not consistently apply these guidelines in routine practice (Best *et al*. 2023). The absence of uniform protocols and the frequent reliance on empirical treatments, without conducting culture and sensitivity testing, contribute to inappropriate prescribing patterns. Organizations such as the American Animal Hospital Association (AAHA) and the American Association of Feline Practitioners (AAFP) have developed recommendations to support responsible antibiotic use, including regular antimicrobial audits and continuous education for veterinary professionals. However, the real-world adoption of these measures faces several barriers, including time constraints, limited resources, and resistance to behavioral change among practitioners (Frey *et al*. 2022).

The spread of resistant bacteria is further facilitated by multiple transmission routes, including direct pet-to-human contact and environmental contamination. Close interactions such as petting, licking, and sharing living spaces increase the risk of bacterial transmission, especially to immunocompromised individuals (Jin *et al*. 2023). In addition to direct contact, environmental contamination is a significant concern, as antibiotics and resistant bacteria can enter ecosystems through improper disposal of medications, pet waste, and contaminated surfaces. Research indicates that certain human activities, such as the use of flea treatments containing fipronil and imidacloprid, contribute to environmental contamination and may drive bacterial resistance (Perkins *et al*. 2021). Another emerging concern is the increasing popularity of raw meat-based diets (RMBDs) for pets, which may serve as a vehicle for the transmission of antimicrobial-resistant bacteria. Studies have detected multidrug-resistant *Escherichia coli* and *Salmonella* spp. in commercial raw pet foods, posing potential infection risks to both animals and humans (Ribeiro-Almeida *et al*. 2024).

To effectively address AMR in veterinary medicine, a comprehensive strategy is required—one that prioritizes responsible antibiotic use, strengthens antimicrobial stewardship programs, and mitigates transmission pathways. Collaboration among veterinarians, pet owners, policymakers, and environmental agencies is essential to develop and implement measures that curb the emergence and spread of antimicrobial resistance, ultimately safeguarding both animal and human health.

CLINICAL IMPLICATIONS OF AMR IN PETS

Antimicrobial resistance in companion animals presents significant clinical challenges, particularly in the treatment of infections such as pyoderma, UTIs, and pneumonia (Joosten *et al*. 2020; Smoglica *et al*. 2022). The increasing prevalence of multidrug-resistant (MDR) pathogens complicates treatment strategies, often resulting in more severe disease outcomes, higher mortality rates, and increased healthcare costs.

Pyoderma, a common skin condition in dogs, is frequently associated with *Staphylococcus pseudintermedius*. The emergence of MRSP has markedly diminished the efficacy of traditional therapeutic options (Nocera and De Martino 2024). MRSP strains exhibit resistance to multiple antibiotic classes, including beta-lactams, macrolides, and fluoroquinolones, thereby limiting the available treatment options (Frank and Loeffler 2012). Research suggests

that MRSP infections often necessitate alternative antimicrobial agents, which may be less effective or associated with a higher risk of adverse effects (Nocera and De Martino 2024). Furthermore, failure to manage underlying predisposing conditions can lead to recurrent infections, which further complicate treatment and exacerbate the clinical challenge.

A notable case involved a dog that developed a postoperative wound infection caused by MRSP. Initial empirical treatment with cephalexin proved ineffective, as the infection persisted, necessitating antimicrobial susceptibility testing. The results indicated resistance to multiple commonly used antibiotics (Bryan *et al*. 2012). Consequently, the treatment regimen was adjusted to include chloramphenicol, an antimicrobial agent associated with a higher risk of adverse effects. Despite its potential drawbacks, this targeted approach ultimately led to the resolution of the infection. This case highlights the critical role of culture and sensitivity testing in guiding effective treatment strategies for multidrug-resistant infections, reinforcing the need for evidence-based antimicrobial selection in veterinary medicine.

Urinary tract infections, often caused by *Escherichia coli*, have become increasingly difficult to treat due to the rising prevalence of ESBL-producing strains (Woerde *et al*. 2023). These bacteria exhibit resistance to a wide range of beta-lactam antibiotics, including penicillins and cephalosporins, significantly limiting treatment options (Poirel *et al*. 2018). The presence of ESBL-producing *E. coli* in companion animals has been associated with treatment failures and prolonged infection durations. In severe cases, veterinarians may need to resort to carbapenems—antibiotics typically reserved for critical human infections—raising concerns about antimicrobial stewardship and the potential for cross-species transmission (Cole *et al*. 2022).

Another notable case involved a cat presenting with a severe UTI that failed to respond to standard amoxicillin-clavulanate therapy. Urine culture and susceptibility testing identified an ESBL-producing *Escherichia coli* strain, exhibiting resistance to multiple antibiotic classes (KuKanich *et al*. 2020; Woerde *et al*. 2023). Due to the limited treatment options, amikacin, an aminoglycoside with known nephrotoxic potential, was administered under strict monitoring protocols. While the infection ultimately resolved, this case underscores the complexities and risks associated with managing multidrug-resistant bacterial infections in companion animals, highlighting the need for judicious antimicrobial use and close therapeutic oversight.

Although less frequent, pneumonia in pets also presents a considerable treatment challenge when caused by MDR pathogens (Watkins and Van Duin 2019). Infections involving resistant bacteria often result in extended hospital stays, intensive medical care, and reliance on advanced antimicrobial therapies, some of which may not be readily accessible in veterinary practice. Given the limited availability of effective antibiotics for treating MDR respiratory infections, preventive strategies such as vaccination and environmental management play a crucial role in reducing disease incidence.

Beyond the clinical challenges, AMR in companion animals leads to increased morbidity and mortality. MDR bacterial infections are often associated with prolonged illness and a heightened risk of complications. For example, a study found that wound infections caused by resistant bacteria in dogs led to delayed healing and an increased likelihood of systemic illness (Menard *et al*. 2022). Managing these infections frequently requires more aggressive interventions, including specialized diagnostics, hospitalization, and the use of costly or off-label antimicrobial treatments.

The financial burden on pet owners is considerable, as treatment failures and recurrent infections escalate veterinary costs. Additionally, the emotional toll on pet owners, coupled with the potential for zoonotic transmission of resistant pathogens, underscores the broader public health implications of AMR in companion animals.

Addressing these challenges requires a multifaceted approach, encompassing improved antimicrobial stewardship, enhanced diagnostic capabilities, and increased public awareness of the risks associated with AMR in veterinary medicine.

ZOONOTIC AND PUBLIC HEALTH CONCERNS

Antimicrobial resistance in companion animals poses significant concerns for public health, particularly due to the potential for zoonotic transmission of resistant bacteria between pets and humans. This exchange of resistant pathogens can occur through direct contact, environmental contamination, or shared microbiota, often resulting in infections in humans that are more difficult to treat.

Multiple studies have documented the transmission of antimicrobial-resistant bacteria between pets and their owners. A comprehensive review examining bacterial transmission from humans to pets and vice versa revealed the widespread nature of this issue (Hamame *et al*. 2022). One prominent example is MRSP, a common bacterium in dogs, which has been identified as a zoonotic pathogen capable of infecting humans (Moses *et al*. 2023). Several reports have detailed cases where MRSP was transmitted from dogs to humans, causing infections such as endocarditis, post-surgical infections, and catheter-related bacteremia (van Duijkeren *et al*. 2011). These findings underscore the need for heightened awareness and preventive measures to mitigate the zoonotic transmission of resistant bacteria.

Homes play a crucial role in the spread of AMR pathogens between pets and humans. A study tracking 65 pet-owning households in the UK and Portugal found evidence of multidrug-resistant bacteria transmission between dogs, cats, and their owners (Menezes *et al*. 2024). The study sampled clinical and fecal specimens from pets with skin, soft tissue, or urinary tract infections, as well as from their healthy owners. The results indicated that close contact between pets and humans facilitates the exchange of resistant bacteria, further emphasizing the need for stringent hygiene practices and responsible antimicrobial use in homes to prevent transmission.

Veterinary clinics also serve as critical points for the spread of AMR. The routine use of antibiotics in veterinary settings contributes to the development of resistant strains. A study on the public health risks of AMR transfer from companion animals highlighted how frequent interactions between pets and humans in clinical environments can promote the spread of resistant bacteria (Willemsen *et al*. 2019). The study called for strict infection control measures, including regular handwashing, thorough disinfection, and cautious antibiotic prescribing, to reduce the risk of AMR transmission in veterinary clinics.

Several case studies illustrate the direct impact of pet-related resistant bacteria on human health. For instance, a Campylobacter outbreak linked to pet store puppies led to illnesses across multiple states (Francois Watkins *et al*. 2021). The strain responsible was resistant to common antibiotics, complicating treatment. This case underscores how commercial pet breeding and retail environments can serve as sources of resistant pathogens that spread to humans. Another study focused on the transmission of antimicrobial-resistant enteric bacteria between dogs and their owners. Researchers suggested that dogs treated with antibiotics may develop resistant bacteria in their feces, which can then be shared with humans in the same household (Beaulac *et al*. 2023).

These findings highlight the critical importance of comprehensive measures, including improved hygiene practices, responsible antimicrobial use, and stricter infection control protocols in both homes and veterinary settings, to prevent the transmission of antimicrobial-resistant pathogens between companion animals and humans.

In conclusion, the transfer of antimicrobial-resistant bacteria between companion animals and humans represents a significant public health concern. Research demonstrates that

close contact within homes and veterinary clinics facilitates the spread of resistant pathogens, leading to infections in humans that are increasingly difficult to treat. Addressing this issue necessitates a One Health approach, which integrates human and veterinary medicine to promote responsible antimicrobial use, enhance infection control practices, and implement ongoing surveillance to monitor and reduce the transmission of AMR. Such a coordinated effort is essential to mitigating the growing threat of antimicrobial resistance and safeguarding both animal and human health.

CURRENT STRATEGIES TO COMBAT AMR IN COMPANION ANIMALS

The increasing prevalence of AMR in companion animals has necessitated the development of targeted strategies to mitigate its impact. These strategies primarily focus on antimicrobial stewardship, advancements in detection and surveillance, and the exploration of alternative treatment options.

Antimicrobial stewardship programs play a critical role in optimizing antibiotic use, reducing the emergence of resistant bacteria, and preserving the efficacy of existing antimicrobials. Veterinary organizations, including the World Small Animal Veterinary Association (WSAVA), the American Veterinary Medical Association (AVMA), and the Federation of Veterinarians of Europe (FVE), have established guidelines to promote the judicious use of antibiotics in companion animals (Teale and Moulin 2012). These guidelines emphasize prudent prescribing practices, infection prevention strategies, and routine antimicrobial susceptibility testing to ensure appropriate therapeutic interventions.

A fundamental aspect of ASPs is the restriction of critically important antibiotics (CIAs) to safeguard their effectiveness in both human and veterinary medicine. The World Health Organization (WHO) and the World Organisation for Animal Health (WOAH) have identified several antibiotic classes, including carbapenems, fluoroquinolones, and third generation cephalosporins, as CIAs. Their use in veterinary practice should be strictly regulated to minimize the risk of cross-resistance between human and animal pathogens (Gehring *et al*. 2023). A study examining antimicrobial prescriptions in European veterinary clinics found that fluoroquinolones and third-generation cephalosporins were prescribed in 10–20% of cases, underscoring the need for more stringent regulatory measures (Goggs *et al*. 2021).

Early detection of resistant bacteria is crucial for the effective management of AMR. Molecular diagnostic techniques such as polymerase chain reaction (PCR), matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS), and whole-genome sequencing (WGS) have emerged as valuable tools for identifying resistant bacterial strains and monitoring resistance gene dissemination (Kaprou *et al*. 2021). Among these, WGS has proven particularly effective in tracking the spread of resistant bacteria in veterinary settings.

Regional and global AMR surveillance programs have been established to monitor resistance trends in companion animals. The European Antimicrobial Resistance Surveillance Network in Veterinary Medicine (EARS-Vet) collects data from 11 European countries, providing critical insights that inform targeted interventions (Lagrange *et al*. 2023). Similarly, the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) monitors AMR trends across animals, humans, and food sources, offering a comprehensive framework for identifying emerging resistance threats associated with veterinary antibiotic use (Avery *et al*. 2014). Expanding such surveillance initiatives on a global scale is essential for the early detection and containment of resistant pathogens.

Given the concerns surrounding antibiotic overuse in veterinary medicine, increasing attention has been directed toward non-antibiotic alternatives for managing bacterial infections in companion animals. Bacteriophage therapy, which employs viruses

that selectively target bacterial pathogens, has demonstrated potential as a treatment modality. Studies have shown that phage cocktails can effectively reduce MRSP infections in dogs, with some reporting up to a 90% reduction in bacterial load (Li *et al*. 2022).

Other emerging alternatives include probiotics and antimicrobial peptides (AMPs). Probiotics, such as Lactobacillus and Bifidobacterium species, have been shown to inhibit the colonization of multidrug-resistant Escherichia coli and Salmonella in companion animals (Fijan *et al*. 2018). Likewise, AMPs—short peptides derived from host defense proteins—exhibit broad-spectrum antibacterial properties and a lower likelihood of inducing resistance (Mahlapuu *et al*. 2016).

In addition, immunomodulators and microbiome-based interventions are being investigated as potential strategies to combat bacterial infections while minimizing antimicrobial use. Research suggests that modifying the gut microbiota with prebiotics can enhance immune responses and reduce the expression of AMR genes in companion animals (Mooyottu 2023). Fecal microbiota transplantation (FMT) has also gained interest as a method for restoring microbial diversity and limiting AMR gene transfer among bacterial populations (Takáčová *et al*. 2022).

Effectively addressing AMR in companion animals requires a multifaceted approach that integrates antimicrobial stewardship, advanced diagnostics, and the development of alternative therapies (Marco-Fuertes *et al*. 2022). Strengthening international collaborations and adopting a One Health framework—which fosters cooperation between veterinary, human, and environmental health sectors—will be critical to ensuring sustainable antibiotic use and mitigating the risks associated with antimicrobial resistance.

FUTURE PERSPECTIVES AND RESEARCH GAPS

Addressing antimicrobial resistance in companion animals requires a multifaceted approach that integrates global policy harmonization, the development of innovative therapeutic alternatives, enhanced One Health collaborations, and targeted public awareness initiatives. Although the World Organisation for Animal Health has reported a 13% reduction in antimicrobial use in animals, significant disparities remain, highlighting the need for standardized international regulations governing antibiotic prescriptions (Orand 2024). Given the stagnation in antibiotic development—with only one new class introduced since 1990—there is an urgent need to explore alternative treatment modalities such as phage therapy, AMPs, and antimicrobial photodynamic therapy (aPDT) to effectively manage resistant infections (Mulani *et al*. 2019).

Strengthening One Health collaborations among veterinarians, healthcare professionals, and policymakers is critical for improving AMR surveillance, facilitating data sharing, and optimizing treatment protocols. Global initiatives such as the CIPARS and the EARS-Vet serve as models for coordinated efforts in monitoring and addressing AMR (Deckert *et al*. 2015; Mader *et al*. 2021). Veterinary clinics, as high-risk environments for the transmission of resistant pathogens, necessitate the implementation of stricter infection control measures and comprehensive antimicrobial stewardship programs to mitigate the spread of AMR.

Public education initiatives also play a pivotal role in combating AMR. Organizations such as the AVMA actively promote responsible antibiotic use in pets, underscoring the importance of adherence to prescribed treatments, the avoidance of unnecessary antibiotic use, and the adoption of preventive healthcare measures. Increasing awareness among pet owners regarding these best practices is essential for reducing the emergence and transmission of resistant pathogens.

The successful integration of these efforts is imperative for effectively addressing AMR in companion animals. A coordinated approach that combines regulatory oversight, scientific innovation, cross-sector collaboration, and

public engagement will be essential in safeguarding both animal and human health while ensuring the sustainable use of antimicrobials in veterinary medicine.

CONCLUSION

Antimicrobial resistance in companion animals is an increasingly pressing issue with significant implications for both veterinary and public health. The rising prevalence of multidrug-resistant pathogens, including MRSP, ESBL-producing *Escherichia coli*, and vancomycin-resistant *Enterococcus*, underscores the urgent need for responsible antibiotic stewardship, stringent infection control measures, and comprehensive global surveillance. Given the interconnected nature of AMR across animal, human, and environmental health, a One Health approach is essential to fostering collaboration between veterinarians, healthcare professionals, and policymakers. While existing strategies—such as antimicrobial stewardship programs, advanced diagnostic technologies, and alternative therapeutic approaches—have contributed to mitigating the spread of resistant bacteria, critical gaps remain. Notably, there is a pressing need for further research into novel antibiotic development and sustainable treatment alternatives. Additionally, strengthening public awareness and educational initiatives is vital to ensuring that both pet owners and veterinary professionals adhere to responsible antimicrobial practices. Effectively addressing AMR in companion animals will require the harmonization of global AMR policies, increased investment in surveillance infrastructure, and the promotion of interdisciplinary research efforts. A coordinated, evidence-based approach is essential not only for maintaining the efficacy of antimicrobial treatments in veterinary medicine but also for safeguarding human health and ensuring the long-term sustainability of antimicrobial therapies.

REFERENCES

1. Avery BP, Parmley EJ, Reid-Smith RJ, Daignault D, Finley RL, Irwin RJ. Canadian integrated program for antimicrobial resistance surveillance: Retail food highlights, 2003-2012. *Can Commun Dis Rep*. 2014;40(Suppl 2):29-35. doi: 10.14745/ccdr.v40is2a05
2. Beaulac K, Fellman CL, Wayne AS, McDermott LA, Snydman DR, Doron S. Impact of antimicrobial use in dogs on antimicrobial resistance and shared flora with human owners. *Antimicrob Steward Healthc Epidemiol*. 2023;3(1):e1. doi: 10.1017/ash.2022.323
3. Best CM, Bard AM, Rees GM, Reyher KK. Validation, visibility, vagueness and variation: A qualitative assessment of existing veterinary guidelines for antimicrobial use in cattle and sheep in the UK. *PLoS One*. 2023;18(11):e0294733. doi: 10.1371/journal.pone.0294733
4. Bryan J, Frank LA, Rohrbach BW, Burgette LJ, Cain CL, Bemis DA. Treatment outcome of dogs with meticillin-resistant and meticillin-susceptible *Staphylococcus pseudintermedius* pyoderma. *Vet Dermatol*. 2012;23(4):361-368. doi: 10.1111/j.1365-3164.2012.01034.x
5. Capozzi C, Maurici M, Panà A. Antimicrobico resistenza: è crisi globale, “un lento tsunami” [Antimicrobial resistance: it is a global crisis, "a slow tsunami"]. *Ig Sanita Pubbl*. 2019;75(6):429-450.
6. Cazer CL, Lawless JW, Frye A, Gonzalez L, Safi AG. Divergent veterinarian and cat owner perspectives are barriers to reducing the use of cefovecin in cats. *J Am Vet Med Assoc*. 2023;261(12):1810-1819. doi: 10.2460/javma.23.08.0487
7. Chan OSK, Wu P, Cowling B, Lee E, Yeung M, St-Hilaire S, Tun H, Wernli D, Lam W. Prescribing antibiotics prudently-A survey of policy implementation drivers among physicians and veterinarians. *One Health*. 2024;18:100752. doi: 10.1016/j.onehlt.2024.100752
8. Cocca G, Piva S, Magno SD, Scarpellini R, Giacometti F, Serraino A, Giunti M. Prevalence and patterns of antimicrobial resistance among *Escherichia coli* and *Staphylococcus* spp. in a Veterinary University Hospital. *Vet Sci*. 2021;8(12):308. doi: 10.3390/vetsci8120308
9. Cole SD, Perez-Bonilla D, Hallowell A, Redding LE. Carbapenem prescribing at a veterinary teaching hospital before an outbreak of carbapenem-resistant *Escherichia coli*. *J Small*

Anim Pract. 2022;63(6):442-446. doi: 10.1111/jsap.13481
10. Cui L, Zhao X, Li R, Han Y, Hao G, Wang G, Sun S. Companion animals as potential reservoirs of antibiotic resistant diarrheagenic *Escherichia coli* in Shandong, China. *Antibiotics*. 2022;11(6):828. doi: 10.3390/antibiotics11060828
11. Deckert A, Agunos A, Avery B, Carson C, Daignault D, Finley R, Gow S, Léger D, Mulvey M, Parmley J, Reid-Smith R, Irwin R. CIPARS: A one-health approach to antimicrobial resistance surveillance. *Online J Public Health Inform*. 2015;7(1):e68. doi: 10.5210/ojphi.v7i1.5734
12. Donkor E, Codjoe F. Methicillin resistant and extended spectrum beta-lactamase producing: A therapeutic challenge in the 21 century. *Open Microbiol J*. 2019;13. doi: 10.2174/1874285801913010094
13. Endale H, Mathewos M, Abdeta D. Potential causes of spread of antimicrobial resistance and preventive measures in one health perspective-a review. *Infect Drug Resist*. 2023;16:7515-7545. doi: 10.2147/IDR.S428837
14. European Food Safety Authority (EFSA); European centre for disease prevention and control (ECDC). The European union summary report on antimicrobial resistance in zoonotic and indicator bacteria from humans, animals and food in 2020/2021. *EFSA J*. 2023;21(3):e07867. doi: 10.2903/j.efsa.2023.7867
15. Fàbregas N, Pérez D, Viñes J, Cuscó A, Migura-García L, Ferrer L, Francino O. Diverse populations of *Staphylococcus pseudintermedius* colonize the skin of healthy dogs. *Microbiol Spectr*. 2023;11(2):e0339322. doi: 10.1128/spectrum.03393-22
16. Fijan S, Šulc D, Steyer A. Study of the in vitro antagonistic activity of various single-strain and multi-strain probiotics against *Escherichia coli*. *Int J Environ Res Public Health*. 2018;15(7):1539. doi: 10.3390/ijerph15071539
17. Francois Watkins LK, Laughlin ME, Joseph LA, Chen JC, Nichols M, Basler C, Breazu R, Bennett C, Koski L, Montgomery MP, Hughes MJ, Robertson S, Lane CG, Singh AJ, Stanek D, Salehi E, Brandt E, McGillivary G, Mowery J, DeMent J, Aubert RD, Geissler AL, de Fijter S, Williams IT, Friedman CR. Ongoing outbreak of extensively drug-resistant *Campylobacter jejuni* infections associated with US pet store puppies, 2016-2020. *JAMA Netw Open*. 2021;4(9):e2125203. doi: 10.1001/jamanetworkopen.2021.25203
18. Frank LA, Loeffler A. Meticillin-resistant *Staphylococcus pseudintermedius*: Clinical challenge and treatment options. *Vet Dermatol*. 2012;23(4):283-291. doi: 10.1111/j.1365-3164.2012.01047.x
19. Frey E, Costin M, Granick J, Kornya M, Weese JS. 2022 AAFP/AAHA antimicrobial stewardship guidelines. *J Am Anim Hosp Assoc*. 2022;58(4):1-5. doi: 10.5326/1547-3317-58.4.1
20. Gehring R, Mochel JP, Schmerold I. Understanding the background and clinical significance of the WHO, WOAH, and EMA classifications of antimicrobials to mitigate antimicrobial resistance. *Front Vet Sci*. 2023;10:1153048. doi: 10.3389/fvets.2023.1153048
21. Goggs R, Menard JM, Altier C, Cummings KJ, Jacob ME, Lalonde-Paul DF, Papich MG, Norman KN, Fajt VR, Scott HM, Lawhon SD. Patterns of antimicrobial drug use in veterinary primary care and specialty practice: A 6-year multi-institution study. *J Vet Intern Med*. 2021;35(3):1496-1508. doi: 10.1111/jvim.16136
22. Gómez-Beltrán DA, Villar D, López-Osorio S, Ferguson D, Monsalve LK, Chaparro-Gutiérrez JJ. Prevalence of antimicrobial resistance in bacterial isolates from dogs and cats in a veterinary diagnostic laboratory in Colombia from 2016-2019. *Vet Sci*. 2020;7(4):173. doi: 10.3390/vetsci7040173
23. Hamame A, Davoust B, Cherak Z, Rolain JM, Diene SM. Mobile colistin resistance (MCR) genes in cats and dogs and their zoonotic transmission risks. *Pathogens*. 2022;11(6):698. doi: 10.3390/pathogens11060698
24. Jańczak D, Górecki P, Stryjek R, Zasada A. Multidrug resistance of Escherichia coli isolated from the urinary bladder of dogs and cats with suspected urinary tract infections. *Ann Agric Environ Med*. 2024;31(2):178-184. doi: 10.26444/aaem/176843
25. Jin M, Osman M, Green BA, Yang Y, Ahuja A, Lu Z, Cazer CL. Evidence for the transmission of antimicrobial resistant bacteria between humans and companion animals: A scoping review. *One Health*. 2023;17:100593. doi: 10.1016/j.onehlt.2023.100593
26. Joosten P, Ceccarelli D, Odent E, Sarrazin S, Graveland H, Van Gompel L, Battisti A, Caprioli A, Franco A, Wagenaar JA, Mevius D, Dewulf J. Antimicrobial usage and resistance in companion animals: A cross-sectional study in three European countries. *Antibiotics*. 2020;9(2):87. doi: 10.3390/antibiotics9020087

27. Kaprou GD, Bergšpica I, Alexa EA, Alvarez-Ordóñez A, Prieto M. Rapid methods for antimicrobial resistance diagnostics. *Antibiotics*. 2021;10(2):209. doi: 10.3390/antibiotics10020209
28. Köck R, Herr C, Kreienbrock L, Schwarz S, Tenhagen BA, Walther B. Multiresistant gram-negative pathogens—a zoonotic problem. *Dtsch Arztebl Int*. 2021;118(35-36):579-589. doi: 10.3238/arztebl.m2021.0184
29. KuKanich K, Lubbers B, Salgado B. Amoxicillin and amoxicillin-clavulanate resistance in urinary *Escherichia coli* antibiograms of cats and dogs from the Midwestern United States. *J Vet Intern Med*. 2020;34(1):227-231. doi: 10.1111/jvim.15674
30. Lagrange J, Amat JP, Ballesteros C, Damborg P, Grönthal T, Haenni M, Jouy E, Kaspar H, Kenny K, Klein B, Lupo A, Madec JY, Salomonsen CM, Müller E, Madero CM, Nilsson O, Norström M, Nykäsenoja S, Overesch G, Pedersen K, Pohjanvirta T, Slowey R, Justo CT, Urdahl AM, Zafeiridis C, Zini E, Cazeau G, Jarrige N, Collineau L. Pilot testing the EARS-Vet surveillance network for antibiotic resistance in bacterial pathogens from animals in the EU/EEA. *Front Microbiol*. 2023;14:1188423. doi: 10.3389/fmicb.2023.1188423
31. Li X, Chen Y, Wang S, Duan X, Zhang F, Guo A, Tao P, Chen H, Li X, Qian P. Exploring the benefits of metal ions in phage cocktail for the treatment of methicillin-resistant *Staphylococcus aureus* (MRSA) infection. *Infect Drug Resist*. 2022;15:2689-2702. doi: 10.2147/IDR.S362743
32. Lynch SA, Helbig KJ. The complex diseases of *Staphylococcus pseudintermedius* in canines: Where to next? *Vet Sci*. 20218(1):11. doi: 10.3390/vetsci8010011
33. Mader R, Damborg P, Amat JP, Bengtsson B, Bourély C, Broens EM, Busani L, Crespo-Robledo P, Filippitzi ME, Fitzgerald W, Kaspar H, Madero CM, Norström M, Nykäsenoja S, Pedersen K, Pokludova L, Urdahl AM, Vatopoulos A, Zafeiridis C, Madec JY; EU-JAMRAI. Building the European antimicrobial resistance surveillance network in veterinary medicine (EARS-Vet). *Euro Surveill*. 2021;26(4):2001359. doi: 10.2807/1560-7917.ES.2021.26.4.2001359
34. Mahlapuu M, Håkansson J, Ringstad L, Björn C. Antimicrobial peptides: An emerging category of therapeutic agents. *Front Cell Infect Microbiol*. 2016;6:194. doi: 10.3389/fcimb.2016.00194
35. Marco-Fuertes A, Marin C, Lorenzo-Rebenaque L, Vega S, Montoro-Dasi L. Antimicrobial resistance in companion animals: A new challenge for the one health approach in the European union. *Vet Sci*. 2022 Apr 24;9(5):208. doi: 10.3390/vetsci905020
36. Martak D, Henriot CP, Hocquet D. Environment, animals, and food as reservoirs of antibiotic-resistant bacteria for humans: One health or more? *Infect Dis Now*. 2024;54(4):104895. doi: 10.1016/j.idnow.2024.104895
37. Menard J, Goggs R, Mitchell P, Yang Y, Robbins S, Franklin-Guild RJ, Thachil AJ, Altier C, Anderson R, Putzel GG, McQueary H, Goodman LB. Effect of antimicrobial administration on fecal microbiota of critically ill dogs: Dynamics of antimicrobial resistance over time. *Anim Microbiome*. 2022;4(1):36. doi: 10.1186/s42523-022-00178-9
38. Menezes J, Frosini SM, Weese S, Perreten V, Schwarz S, Amaral AJ, Loeffler A, Pomba C. Transmission dynamics of ESBL/AmpC and carbapenemase-producing Enterobacterales between companion animals and humans. *Front Microbiol*. 2024;15:1432240. doi: 10.3389/fmicb.2024.1432240
39. Mooyottu, S. 2023. Faecal microbiota transplantation (FMT) in veterinary medicine: A mini review. *J Vet Anim Sci*. 54(3):617-622. doi: 10.51966/jvas.2023.54.3.617-622
40. Moro DD. Global threat of bacterial antimicrobial resistance. *PriMera Scientific Medicine and Public Health*. 2023;3(6):20-22. doi: 10.56831/PSMPH-03-104
41. Moser S, Seth-Smith H, Egli A, Kittl S, Overesch G. *Campylobacter jejuni* from canine and bovine cases of campylobacteriosis express high antimicrobial resistance rates against (fluoro) quinolones and tetracyclines. *Pathogens*. 2020;9(9):691. doi: 10.3390/pathogens9090691
42. Moses IB, Santos FF, Gales AC. Human colonization and infection by *Staphylococcus pseudintermedius*: An emerging and underestimated zoonotic pathogen. *Microorganisms*. 2023;11(3):581. doi: 10.3390/microorganisms11030581
43. Mulani MS, Kamble EE, Kumkar SN, Tawre MS, Pardesi KR. Emerging strategies to combat ESKAPE pathogens in the era of antimicrobial resistance: A review. *Front Microbiol*. 2019;10:539. doi: 10.3389/fmicb.2019.00539

44. Nocera FP, De Martino L. Methicillin-resistant *Staphylococcus pseudintermedius*: epidemiological changes, antibiotic resistance, and alternative therapeutic strategies. *Vet Res Commun*. 2024;48:3505-3515. doi: 10.1007/s11259-024-10508-8
45. Orand JP. One hundred years of success in antimicrobials: but what will the next 100 years bring? *Rev Sci Tech*. 2024:103-112. doi: 10.20506/rst.SE.3564
46. Pedersen K, Pedersen K, Jensen H, Finster K, Jensen VF, Heuer OE. Occurrence of antimicrobial resistance in bacteria from diagnostic samples from dogs. *J Antimicrob Chemother*. 2007;60(4):775-781. doi: 10.1093/jac/dkm269
47. Perkins R, Whitehead M, Civil W, Goulson D. Potential role of veterinary flea products in widespread pesticide contamination of English rivers. *Sci Total Environ*. 2021;755(Pt 1):143560. doi: 10.1016/j.scitotenv.2020.143560
48. Poirel L, Madec JY, Lupo A, Schink AK, Kieffer N, Nordmann P, Schwarz S. Antimicrobial resistance in *Escherichia coli*. *Microbiol Spectr*. 2018;6(4). doi: 10.1128/microbiolspec.ARBA-0026-2017
49. Priyantha MAR. Review of *Staphylococcus pseudintermedius* infection in dogs and humans. *Sri Lanka Veterinary Journal*. 2020;67(1-2):1-9. doi: 10.4038/slvj.v67i1-2.51
50. Puvača N. Antimicrobial resistance and treatment in companion, food and exotic animals. *Antibiotics*. 2022;11(10):1360. doi: 10.3390/antibiotics11101360
51. Ribeiro-Almeida M, Mourão J, Magalhães M, Freitas AR, Novais C, Peixe L, Antunes P. Raw meat-based diet for pets: A neglected source of human exposure to *Salmonella* and pathogenic *Escherichia coli* clones carrying *mcr*, Portugal, September 2019 to January 2020. *Euro Surveill*. 2024;29(18):2300561. doi: 10.2807/1560-7917.ES.2024.29.18.2300561
52. Shaker AA, Samir A, Zaher HM, Abdel-Moein KA. Emergence of virulent extensively drug-resistant vancomycin-resistant enterococci among diarrheic pet animals: A possible public health threat on the move. *Vector-Borne and Zoonotic Diseases*. 2024;24(9). doi: 10.1089/vbz.2023.0167
53. Smoglica C, Evangelisti G, Fani C, Marsilio F, Trotta M, Messina F, Di Francesco CE. Antimicrobial resistance profile of bacterial isolates from urinary tract infections in companion animals in Central Italy. *Antibiotics*. 2022;11(10):1363. doi: 10.3390/antibiotics11101363
54. Takáčová M, Bomba A, Tóthová C, Michaľová A, Turňa H. Any future for faecal microbiota transplantation as a novel strategy for gut microbiota modulation in human and veterinary medicine? *Life*. 2022;12(5):723. doi: 10.3390/life12050723
55. Thépault A, Rose V, Queguiner M, Chemaly M, Rivoal K. Dogs and cats: Reservoirs for highly diverse *Campylobacter jejuni* and a potential source of human exposure. *Animals*. 2020;10(5):838. doi: 10.3390/ani10050838
56. Teale CJ, Moulin G. Prudent use guidelines: a review of existing veterinary guidelines. *Rev Sci Tech*. 2012 Apr;31(1):343-54. doi: 10.20506/rst.31.1.2119
57. van Duijkeren E, Catry B, Greko C, Moreno MA, Pomba MC, Pyörälä S, Ruzauskas M, Sanders P, Threlfall EJ, Torren-Edo J, Törneke K. Scientific advisory group on antimicrobials (SAGAM) Review on methicillin-resistant *Staphylococcus pseudintermedius*. *J Antimicrob Chemother*. 2011;66(12):2705-2714. doi: 10.1093/jac/dkr367
58. Wada Y, Irekeola AA, E A R ENS, Yusof W, Lih Huey L, Ladan Muhammad S, Harun A, Yean CY, Zaidah AR. Prevalence of vancomycin-resistant *Enterococcus* (VRE) in companion animals: The first meta-analysis and systematic review. *Antibiotics*. 2021;10(2):138. doi: 10.3390/antibiotics10020138
59. Watkins RR, Van Duin D. Current trends in the treatment of pneumonia due to multidrug-resistant gram-negative bacteria. *F1000Res*. 2019;8:F1000. doi: 10.12688/f1000research.16517.2
60. Willemsen A, Cobbold R, Gibson J, Wilks K, Lawler S, Reid S. Infection control practices employed within small animal veterinary practices-A systematic review. *Zoonoses Public Health*. 2019;66(5):439-457. doi: 10.1111/zph.12589
61. Woerde DJ, Reagan KL, Byrne BA, Weimer BC, Epstein SE, Schlesener C, Huang BC, Sykes JE. Characteristics of Extended-Spectrum β-Lactamase Producing Enterobacterales Isolated from Dogs and Cats, 2011-2021. *Vet Sci*. 2023;10(3):178. doi: 10.3390/vetsci10030178
62. Worthing KA, Abraham S, Coombs GW, Pang S, Saputra S, Jordan D, Trott DJ, Norris JM. Clonal diversity and geographic distribution of methicillin-resistant *Staphylococcus*

pseudintermedius from Australian animals: Discovery of novel sequence types. *Vet Microbiol*. 2018;213:58-65. doi: 10.1016/j.vetmic.2017.11.018

63. Zhou Y, Ji X, Liang B, Jiang B, Li Y, Yuan T, Zhu L, Liu J, Guo X, Sun Y. Antimicrobial resistance and prevalence of extended spectrum β-lactamase-producing *Escherichia coli* from dogs and cats in Northeastern China from 2012 to 2021. *Antibiotics*. 2022;11(11):1506. doi: 10.3390/antibiotics11111506