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## Superbugs in veterinary medicine: A comprehensive review

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### Abstract

Antimicrobial resistance (AMR) has emerged as one of the greatest threats to animal and public health, leading to the rapid emergence and dissemination of multidrug-resistant (MDR) bacterial pathogens, commonly referred to as "superbugs." In veterinary medicine, these organisms—including methicillin-resistant *Staphylococcus aureus* (MRSA), methicillin-resistant *Staphylococcus pseudintermedius* (MRSP), extended-spectrum  $\beta$ -lactamase (ESBL)-producing Enterobacterales, carbapenem-resistant bacteria, resistant *Salmonella*, *Campylobacter*, and *Enterococcus* spp.—compromise therapeutic success, increase treatment costs, reduce livestock productivity, and pose significant zoonotic risks. This review highlights the major drivers of antimicrobial resistance in veterinary practice, including inappropriate antimicrobial use, intensive livestock production, and environmental dissemination of resistant organisms and resistance genes. The impact of veterinary superbugs on livestock, poultry, companion animals, and human health is discussed within the context of the One Health approach. Challenges in diagnosis, antimicrobial susceptibility testing, and therapeutic management are examined, along with current antimicrobial stewardship strategies, biosecurity measures, vaccination, and emerging alternatives such as bacteriophage therapy and antimicrobial peptides. The review also explores future research priorities, including genomic surveillance, rapid diagnostics, precision antimicrobial therapy, and implementation science. Effective control of veterinary superbugs requires coordinated global efforts integrating responsible antimicrobial use, improved surveillance, strengthened infection prevention, and multidisciplinary collaboration across veterinary, medical, agricultural, and environmental sectors to safeguard both animal and human health.

**Keywords:** Antimicrobial resistance (AMR), Superbugs, Multidrug-resistant (MDR) bacteria, One Health, Antimicrobial stewardship, Biosecurity

### Introduction

In veterinary medicine, superbugs are bacterial pathogens that are resistant to multiple antimicrobial classes, often including drugs critical to both animal and human health (Prescott *et al.*, 2018; WHO, 2024) [13, 19]. These organisms are commonly described as multidrug-resistant (MDR), extensively drug-resistant (XDR), or, in rare cases, pandrug-resistant (PDR), depending on the extent of resistance across antimicrobial categories (Magiorakos *et al.*, 2012) [8].

Veterinary superbugs include organisms such as methicillin-resistant *Staphylococcus aureus* (MRSA), methicillin-resistant *Staphylococcus pseudintermedius* (MRSP), ESBL-producing Enterobacterales, carbapenem-resistant bacteria, resistant *Salmonella*, *Campylobacter*, and resistant *Enterococcus* spp. These pathogens threaten animal health, complicate treatment, increase costs, and create zoonotic and environmental risks within a One Health framework (WOAH, 2024; FAO, 2022; WHO, 2024) [20, 6, 19].

### Etiology and Amplifying Factors

#### Veterinary antibiotic usage patterns and rationales

Antibiotics in veterinary practice are used for treatment, metaphylaxis, and prophylaxis, and historically in some systems for growth promotion (Prescott *et al.*, 2018; EMA, 2019) [13, 5]. Therapeutic use is intended for animals with clinical bacterial disease, while metaphylaxis

treats a group when some animals are infected, and prophylaxis is used to prevent disease in high-risk settings (Prescott *et al.*, 2018) <sup>[13]</sup>. Each of these practices can select for resistant bacteria, especially when drugs are used broadly, frequently, or without diagnostic confirmation (WHO, 2024; WOA, 2024) <sup>[19, 20]</sup>.

In food-producing systems, group medication through feed or water can create selection pressure across entire populations, and suboptimal dosing can further accelerate resistance development (Chantziaras *et al.*, 2014; van Boeckel *et al.*, 2015) <sup>[4, 16]</sup>. Use of critically important antimicrobials in animals is a particular concern because resistance in animal bacteria can reduce the utility of related or identical drugs in human medicine (WHO, 2024; EMA, 2019) <sup>[19, 5]</sup>.

### Agricultural practices

Intensive livestock and poultry production systems amplify resistance through high animal density, frequent animal movement, and routine antimicrobial use (Marshall & Levy, 2011; van Boeckel *et al.*, 2015) <sup>[9, 16]</sup>. Crowding and stress increase infection risk, which in turn often leads to greater antibiotic use, creating a reinforcing cycle of disease and antimicrobial exposure (Robinson *et al.*, 2016; WOA, 2024) <sup>[14, 20]</sup>.

Prophylactic and metaphylactic use is common in some production systems, especially during transport, weaning, or early life, when disease risk is high (EMA, 2019; WOA, 2024) <sup>[5, 20]</sup>. Although these approaches may reduce short-term losses, they also increase the likelihood that resistant strains will be selected and disseminated across herds or flocks (Chantziaras *et al.*, 2014; Lhermie *et al.*, 2019) <sup>[4, 7]</sup>.

### Environmental factors

Antimicrobial residues, resistant organisms, and resistance genes can enter soil and water through manure, slurry, runoff, effluent, and contaminated bedding (FAO, 2022; Berendonk *et al.*, 2015) <sup>[15, 1]</sup>. Environmental reservoirs support the persistence and exchange of resistance genes through horizontal gene transfer, helping create a broader resistome that extends beyond the farm or clinic (Berendonk *et al.*, 2015; O'Neill, 2016) <sup>[1, 11]</sup>.

Heavy metals, disinfectants, and other co-selective agents can also favor bacteria carrying resistance determinants, including those unrelated to the original antimicrobial exposure (Berendonk *et al.*, 2015; FAO, 2022) <sup>[1, 6]</sup>. Wildlife, insects, and contaminated waterways can then disseminate resistant organisms between farms, communities, and ecosystems (WHO, 2024; WOA, 2024) <sup>[19, 20]</sup>.

### Impact on Animal Health and Welfare Livestock

In cattle, superbugs are especially important in mastitis, respiratory disease, and calf diarrhea. MDR *Staphylococcus aureus*, MRSA, and resistant coliforms can cause chronic mastitis, reduced milk yield, and increased culling (Prescott *et al.*, 2018; Olde Riekerink *et al.*, 2008) <sup>[13, 10]</sup>. Resistant respiratory pathogens such as *Mannheimia haemolytica* and *Pasteurella multocida* complicate bovine respiratory disease, particularly in feedlots (Prescott *et al.*, 2018) <sup>[13]</sup>.

In swine, resistant *Escherichia coli* can cause neonatal and post-weaning diarrhea, while resistant respiratory pathogens contribute to pneumonia and poor growth performance (Marshall & Levy, 2011; WOA, 2024) <sup>[9, 20]</sup>. These infections increase mortality, reduce productivity, and often

require repeated or more expensive therapy (Prescott *et al.*, 2018) <sup>[13]</sup>.

### Poultry

Poultry are important reservoirs and transmission vehicles for resistant *E. coli*, *Salmonella*, *Campylobacter*, and *Enterococcus* spp. (WHO, 2024; FAO, 2022) <sup>[19, 6]</sup>. Resistant colibacillosis can cause high mortality and carcass condemnation, while resistant *Salmonella* and *Campylobacter* have major food safety implications (Van Boeckel *et al.*, 2019; WHO, 2024) <sup>[17, 19]</sup>.

Because broiler and layer production relies on high-density housing and short production cycles, resistance can spread rapidly through a flock and into processing environments (van Boeckel *et al.*, 2015; FAO, 2022) <sup>[16, 15]</sup>. Subclinical colonization is especially important because it may not be detected clinically but can still contaminate food products (WHO, 2024) <sup>[19]</sup>.

### Companion animals

In dogs and cats, MRSP, MRSA, resistant *E. coli*, and resistant *Pseudomonas aeruginosa* are frequent causes of skin, wound, urinary, and ear infections (Weese *et al.*, 2019; Pomba *et al.*, 2017) <sup>[18, 12]</sup>. These infections are often recurrent, require culture-guided treatment, and may fail standard first-line therapy (Weese *et al.*, 2019) <sup>[18]</sup>.

Companion animals matter for public health because they live in close contact with humans, allowing bidirectional transfer of resistant organisms in households and veterinary clinics (Pomba *et al.*, 2017; WHO, 2024) <sup>[12, 19]</sup>. This makes companion-animal AMR both a clinical and zoonotic concern.

### Public Health Intersections and One Health

Veterinary superbugs can affect human health through direct contact, foodborne transmission, and environmental spread (Marshall & Levy, 2011; WHO, 2024) <sup>[9, 19]</sup>. Farm workers, veterinarians, pet owners, and slaughterhouse personnel are at higher risk of exposure through handling animals, bites, scratches, aerosols, or contaminated surfaces (Pomba *et al.*, 2017; WOA, 2024) <sup>[12, 20]</sup>.

Foodborne transmission is especially important for resistant *Salmonella*, *Campylobacter*, and ESBL-producing *E. coli*, which may contaminate meat, milk, eggs, or food-processing environments (FAO, 2022; WHO, 2024) <sup>[6, 19]</sup>. The danger is not only infection, but also colonization and spread of resistance genes into human microbial communities (Berendonk *et al.*, 2015; WHO, 2024) <sup>[1, 19]</sup>.

The One Health approach recognises that human, animal, and environmental health are interconnected and that AMR control requires coordinated action across sectors (WHO, 2024; FAO, 2022; WOA, 2024) <sup>[19, 6, 20]</sup>. In practice, this means integrated surveillance, harmonised antimicrobial-use policies, shared diagnostics, and coordinated stewardship programs (WHO, 2024) <sup>[19]</sup>.

### Diagnostic Complexities and Hurdles

Veterinary AMR diagnosis is limited by access, cost, and laboratory capacity. Many clinics and farms lack rapid microbiology services, which encourages empirical treatment rather than culture-based therapy (Prescott *et al.*, 2018; Weese *et al.*, 2019) <sup>[13, 18]</sup>. This slows detection of resistant infections and reduces the chance of selecting the most appropriate drug. Interpretive breakpoints are another challenge because susceptibility standards are not equally available for all

animal species, pathogens, and drugs (CLSI, 2024). Some laboratories must rely on human breakpoints or extrapolated criteria, which may not match animal pharmacology or disease-specific outcomes (Prescott *et al.*, 2018) <sup>[13]</sup>. Additional hurdles include poor sample quality, polymicrobial infections, biofilm-associated disease, and limited access to molecular detection of resistance genes such as ESBLs and carbapenemases (Weese *et al.*, 2019; CLSI, 2024) <sup>[18]</sup>. These limitations make it harder to distinguish colonization from true infection and to confirm the presence of a clinically meaningful superbug.

### Therapeutic Modalities and Associated Constraints

Current treatment of veterinary superbug infections relies on culture-guided therapy, topical or local treatment when appropriate, supportive care, and, when necessary, second-line antimicrobials (Prescott *et al.*, 2018; Weese *et al.*, 2019) <sup>[13, 18]</sup>. Combination therapy may be used in some cases, especially when synergy is expected or when broadening coverage is necessary (Prescott *et al.*, 2018) <sup>[13]</sup>.

However, therapeutic options are constrained by resistance, toxicity, regulatory restrictions, and withdrawal-time requirements in food animals (EMA, 2019; WOA, 2024) <sup>[5, 20]</sup>. Some critically important human antimicrobials are avoided or tightly restricted in animals to preserve their value for human medicine (WHO, 2024; EMA, 2019) <sup>[19, 5]</sup>.

Emerging resistance to second-line agents is a growing problem. For example, increased use of fluoroquinolones, higher-generation cephalosporins, and aminoglycosides can drive further resistance, while biofilms reduce drug penetration and increase persistence (Weese *et al.*, 2019; Berendonk *et al.*, 2015) <sup>[18, 1]</sup>. In many chronic infections, surgery, drainage, debridement, and improved hygiene are as important as antimicrobial choice.

### Prevention and Mitigation

#### Antimicrobial stewardship

Antimicrobial stewardship in veterinary medicine aims to use antibiotics only when necessary, in the right dose, route, and duration, and preferably based on diagnostic evidence (WHO, 2024; WOA, 2024) <sup>[19, 20]</sup>. Stewardship also means preferring narrow-spectrum agents when suitable, avoiding routine prophylaxis, and reserving critically important antimicrobials for exceptional cases (EMA, 2019; WHO, 2024) <sup>[5, 19]</sup>.

Stewardship is most effective when combined with record-keeping, audit and feedback, clinician education, and farm-level benchmarking of antimicrobial use (WHO, 2024; FAO, 2022) <sup>[19, 6]</sup>. In production animals, stewardship must be supported by management changes that reduce disease pressure rather than simply restricting drugs.

#### Biosecurity

Biosecurity reduces disease transmission and therefore antibiotic need. Core measures include quarantine of new animals, cleaning and disinfection, all-in/all-out production, controlled movement of people and equipment, vector control, and isolation of sick animals (WOA, 2024; FAO, 2022) <sup>[20, 6]</sup>. In clinics, this also includes hand hygiene, patient cohorting, environmental cleaning, and barrier nursing (Weese *et al.*, 2019) <sup>[18]</sup>.

Better housing, nutrition, ventilation, and stress reduction also reduce infection susceptibility and help lower antimicrobial demand (FAO, 2022; Robinson *et al.*, 2016) <sup>[15, 14]</sup>. These interventions are often more sustainable than repeated

antimicrobial use.

### Alternative approaches

Vaccination is one of the most important alternatives because it reduces disease incidence and lowers the need for treatment (FAO, 2022; WOA, 2024) <sup>[6, 20]</sup>. Probiotics, prebiotics, competitive exclusion products, and nutritional interventions may also support gut health and reduce colonization by resistant organisms, especially in poultry and swine (FAO, 2022) <sup>[6]</sup>.

Phage therapy, antimicrobial peptides, immunomodulators, and targeted topical antiseptics are active research areas, but they still require stronger evidence for routine large-scale use (Cisek *et al.*, 2017) <sup>[2]</sup>. Their future role will likely depend on species-specific efficacy, manufacturing standards, and regulatory approval.

### Future Directions and Research Frontiers

Genomic surveillance is transforming AMR control by allowing researchers to trace resistance genes and bacterial lineages across animals, humans, and ecosystems (Berendonk *et al.*, 2015; WHO, 2024) <sup>[1, 19]</sup>. Whole-genome sequencing and metagenomics can identify transmission routes, emerging resistance mechanisms, and outbreak sources more precisely than traditional methods.

Research is also needed on better veterinary diagnostics, rapid resistance testing, pharmacokinetic and pharmacodynamic optimisation, and new non-antibiotic therapeutics (Prescott *et al.*, 2018; Weese *et al.*, 2019) <sup>[13, 18]</sup>. Digital decision-support tools may improve prescribing quality by helping veterinarians choose the narrowest effective therapy and avoid unnecessary treatment.

A major frontier is implementation science: understanding why farmers, veterinarians, and pet owners use antimicrobials the way they do, and which interventions produce durable change (FAO, 2022; O'Neill, 2016) <sup>[15, 11]</sup>. Without social, economic, and regulatory alignment, technical solutions alone will not be enough.

### Conflict of Interest

Not available

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