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Role of Veterinary Medicines in Animal Health: A Review

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Abstract

Veterinary medicines (such as antibiotics, antiparasitics, vaccines, hormones, and vitamins) play a pivotal and indispensable role in maintaining animal health and welfare. Their most important functions include: Prevention, such as vaccines that protect against serious infectious diseases and antiparasitics that prevent infection by worms and external parasites. Treatment, such as antibiotics, antivirals, and antifungal drugs to combat diseases, as well as analgesics and anti-inflammatories to relieve pain and suffering. Control, such as drugs that help manage chronic diseases or control the spread of diseases among herds. Enhancing growth and productivity, such as certain drugs that improve feed conversion efficiency.

Keywords: Animal Health, Veterinary Medicines, Antibiotics, Vaccines, Antiparasitics.

1. Introduction

Veterinary medicines play a pivotal role in treating and preventing infectious diseases in animals, thereby sustaining animal health (1). The maintenance of animal health hinges on effective treatment and prevention strategies. Antibiotics, vaccines, antiparasitics, and non-steroidal anti-inflammatory drugs constitute the main categories of veterinary medicines used to uphold animal health (2). These categories form the basis of veterinary pharmacology, providing exposure to the pharmacological treatment of a broad spectrum of animal health problems (3).

2. Types of Veterinary Medicines

Veterinary medicines are classified into several key types, each serving a distinct function in maintaining animal health (4). Antibiotics eliminate or inhibit the growth of infectious bacteria and are essential for effective control of bacterial diseases (5). Vaccines confer immunity and prevent viral and bacterial infections (6). Antiparasitics control internal and external parasites (7). Analgesics and anti-inflammatory drugs relieve pain and counteract inflammation (8).

2.1. Antibiotics

Antibiotics are used in the treatment of bacterial diseases, for controlling bacterial infections, and as an aid in surgical procedures (9). Antimicrobials are believed to be the most important inventions of the twentieth century; nothing else has had such a major effect on controlling infections (10). The commonly used antibiotics in veterinary medicine are penicillins, cephalosporins, aminoglycosides, tetracyclines, chloramphenicol, macrolides, and

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lincosamides. These chemicals are used for disease treatment, growth promotion, or as feed supplements. Antibiotics are also available in local and systemic forms, depending on the type of infection (11).

2.2. Vaccines

Vaccination programmes and biosecurity measures are the most effective and most widely used methods of preventing disease (12). Veterinary vaccines are available for the prevention of numerous viral, bacterial, fungal, rickettsial, and protozoal infections (13). Vaccines are an integral part of most farm-animal health plans, since no other veterinary medicines are licensed for the control of many contagious and serious diseases that affect animals. Although their availability is more limited, vaccines are also important as a means of preventing disease in companion animals, including exotic pets and fish (14).

Veterinary vaccines are generally of three types: inactivated, attenuated live, and those produced using recombinant technology (15). To date, these categories have mainly been used in combination, rather than singly, in most commercial veterinary vaccine preparations. The major classes of vaccines that have been used for almost a century are inactivated and attenuated live (16). The fits and starts in vaccine development result from the difficulty of applying methodologies and technologies originally developed for human use to animals (17). Agent specificity is much less important in animal populations, since a major objective of animal health programmes is to protect the herd or flock and not restrict protection solely to the individual. Immunity conferred by inactivated and recombinant vaccines generally covers a similar spectrum, mostly moderate to high. However, some significant gaps exist, particularly in feline calicivirus immunity and canine coronavirus (18,19). Vaccines based on the same agent delivered using different technologies induce differing immune responses; in some cases, both humoral and cell-mediated immunity, in others, predominantly humoral immunity. Whether or not a vaccine elicits cell-mediated immunity is reflected in its relative efficacy in protection against common veterinary pathogens, whether bacterial or viral. Immune protection of vaccinated animals depends primarily on the production of antibodies. Veterinary vaccines induce antibodies that mediate opsonization, complement fixation and activation, neutralization, and antibody-dependent cell cytotoxicity (16,20). The development of the antibody response depends upon a well-differentiated immune system and the successful interaction between phagocytic cells, antibodies, antigen-presenting cells, and processed B- and T-lymphocytes (21). Affinity maturation and memory are generated as a function of these interactions (22). The potency and longevity of the veterinary-antibody response depend on the quality and degree of antibody response generated (23).

Despite large-scale vaccinations involving several million animals each year, relatively few veterinary vaccines are recognised as providing consistently high levels of protection (13). Those that do include canine distemper virus, rabies, feline panleukopenia virus, canine adenovirus, and feline herpesvirus or feline rhinotracheitis virus (24).

2.3. Antiparasitics

Parasitic infections present a widespread concern in veterinary medicine across all species, including sheep, cattle, horses, and companion animals. Endoparasites affect animals directly and influence overall health, production, and welfare. Gastrointestinal parasites represent a major challenge in sheep-health management, especially considering the high prevalence of anthelmintic resistance noted in Europe and the Baltic states (25,26). Drug tolerance often extends beyond a single drug to multiple classes of anthelmintics. Such resistance leads to decreased productivity and increased economic losses. The growing use of prescription-only antiparasitic drugs has not fully

controlled the issue; however, some anthelmintic drugs are licensed for sheep in Latvia (27,28). Available treatments include the broad-spectrum ivermectin (introduced in 1981), albendazole (effective against respiratory and gastrointestinal nematodes), closantel (active against Haemonchus sp. and Oestrus ovis in ruminants), and monepantel (a newer broad-spectrum drug active against resistant gastrointestinal nematodes) (29,30). Antiparasitic drug resistance poses a global threat to the sustainability of sheep production. A better understanding of prescription trends is thus imperative to minimize overuse or misuse. Key factors contributing to resistance include incomplete parasitic examinations, incorrect drug selection, inappropriate dosing or route of administration, or inaccurate calculations of substance activity (31,32). These errors hamper parasite control and facilitate the selection of resistant strains, with important medical and economic consequences for sheep and goat farms (33).

Parasitic diagnostic methods remain underutilized. In ruminant clinics, diagnostic resources are only rarely employed, and regional laboratories are still only rarely consulted, whereas use is markedly more common in pet clinics. Some clinics have never used such resources at all. Parasitic infections thus pose ongoing diagnostic and treatment challenges to veterinarians, even when some argue that diagnostic methods do not present major difficulties (34,35). Accurate diagnosis, together with appropriate choice and use of anthelmintics, is of fundamental importance in the management of parasitic disease (36). After parasites, large livestock species, cats, and dogs constitute the main targets of antiparasitic treatments. Of the wide variety of parasite species that infect these animals, gastrointestinal nematodes, tapeworms, ectoparasites, and coccidiosis deserve special attention. Ticks, rumen flukes, and heartworm are secondary concerns. Preventive antiparasitic programs thus represent the most practical and economically effective strategy for combating parasitic infections (37). Around half of clinicians administer antiparasitic drugs at least twice yearly as a preventive measure. Nevertheless, diagnostic deficiencies and the irregular and irresponsible use of antiparasitic agents continue to hamper parasite control and facilitate the emergence of drug resistance among parasite populations throughout Türkiye (38).

Antiparasitic resistance arises as a heritable insensitivity in a parasite population to a drug previously effective at the recommended dose rate. The phenomenon is related to the prolonged use of the same anthelmintic within a parasite population over a time period extending over successive generations. Claiming the lives of millions of animals throughout the world every year, parasitic infections continue to cause severe morbidity and mortality (39,40). The parasites, especially endoparasites, most severely affect the gastrointestinal system, causing a progressive decrease in productivity and incurring an enormous annual economic loss. Proper control of parasitic infections remains critically important in facilitating sustained animal production (41). The most common method is chemotherapy, which has several important disadvantages, including the potential development of parasite resistance and the risk of drug residues in food products and the environment. Effective control requires integrated measures that combine grazing management, biological control, genetic improvement for host resistance, and parasitic vaccines (42,43). Of these alternatives, vaccination of animals represents the most sustainable and economic approach. Providing long-lived immunity to animals without inducing drug resistance and leaving no residues in food, vaccination is considered a cheaper and more effective option for the long-term control of parasitic infections in animals (44). Despite the broad spectrum of drugs that are apparently available for treatment, the development of successful vaccines against parasitic infections

continues to represent an urgent need for the livestock sector (45).

2.4. Analgesics and Anti-inflammatories

In intensive livestock production, multifactorial diseases are prevalent. These diseases influence the spatio-temporal distribution of medications in tissues and can alter interstitial and intracellular pH, thus modifying the pharmacokinetic profile of drugs. Livestock is often exposed to severe pain associated with injury, disease, postpartum complications, and mastitis (46). Analgesics are typically administered as premedication or during postoperative recovery, with non-steroidal anti-inflammatory drugs (NSAIDs) being the most commonly used (47).

3. Regulatory Framework

Veterinary medicinal products play a vital role in safeguarding human and animal health, as well as animal welfare. Globally, the veterinary medicines market and the European regulatory framework for these medicines continue to evolve, influencing the availability of veterinary medicinal products and their pattern of use (48). Despite the essential nature of these products, there is a worldwide issue regarding their limited availability for treating certain minor species and a defined range of diseases (49). This scarcity stems primarily from the small size and fragmentation of the market across various species, a situation exacerbated by increasing regulatory and scientific requirements (50). The French regulatory system aligns closely with European Union legislation, which is based on three key directives. Directive 81/851/EEC harmonizes the procedures and conditions for authorization and marketing of veterinary medicinal products; Directive 81/852/EEC governs the manufacture, importation, and distribution of these products; and Directive 81/853/EEC outlines the control, supervision, and monitoring protocols. The European Medicines Agency (EMEA), established in 1993, facilitates coordination among EU member states to strengthen the existing regulatory framework. In this context, public authorities, manufacturers, and practitioners recognize the need for a comprehensive, long-term programme that encourages the extension of existing products to minor species and indications through changes to the summary of product characteristics. Such a programme would also stimulate the development of new products for minor species or indications, including vaccine and non-vaccine alternatives, without relaxing the current safety standards. Where a veterinary medicinal product is authorized at the national level, the prescription and use of the product must comply with the conditions of the marketing authorization during practical use in animal health. These factors collectively shape the regulation of the veterinary medicines market and the pattern of use of veterinary medicinal products (51-53).

3.1. Global Regulations

The availability of veterinary medicinal products depends on a complex system of rules at a national, international, and supranational level (50). A regulatory framework has gradually emerged and proved essential for ensuring the quality, safety, and efficacy of veterinary medicinal products, also facilitating the free movement of these products within the EU and protecting the health of both animals and humans (54).

Following the issuance of Regulation (EEC) 2377/90 on maximum residue limits (MRLs), veterinary medicinal products for food-producing animals placed on the European market and containing active substances not included in the relevant list must be used according to a specific authorization (55). A regulation on pharmacovigilance is available, but it is not yet fully operational. Further efforts have been made in recent years aimed at refining the legislation related to veterinary medicinal products, developing guidelines for a common approach to residues and clandestine use of medicated feed and banned substances, harmonising provisions on the

prescription and usage of antimicrobials, and defining supplementary monitoring requirements for residues and maximum limits for veterinary residues in water (56,57).

3.2. National Regulations

The veterinary-medicine market is not worldwide standardized, and the registration of veterinary medicinal products is ruled at the national level, under the coordinated framework of the World Organization for Animal Health (OIE). Drug-use patterns depend on several other factors, such as animal husbandry and practice, and the national legislation regarding animal health and welfare (50). For those products that are still under patent by the manufacturer, a basic foundation for the market licensing process is laid down by the Food and Drug Administration (FDA) Center for Veterinary Medicine (CVM) (58,59). When the patent of the innovator expires, a generic drug can apply for approval via an abbreviated FDA process featuring the submission of a "Bioequivalence" study to be marketed. The availability of veterinary medicines is related to population size and economic size. In fact, the number of veterinary medicinal products on the European market is higher in countries with larger populations and bigger economies (55). The legislation on veterinary medicinal products is in many respects similar to human medicine legislation. However, some specific provisions are necessary to ensure that the food produced in animals treated with veterinary medicinal products is safe. Furthermore, additional provisions for the environment have to be taken into account when dealing with veterinary medicines (57). Again, it has to be noticed that animal species differ very much, and several formulations that can be administered to animals are not found in the human field. In the EU, the legislative framework covering veterinary medicinal products is now well established and ensures the quality, efficacy, and safety of the medicines that are placed on the market. The limited availability of veterinary medicinal products, especially in the case of minor species or minor diseases, is a problem encountered worldwide (55,60). The problem is mainly related to the number of animals concerned and to market considerations. The market for these products is very much fragmented, since the pharmaceutical company has to register the product, or refer to a registration from a company having marketing rights, in each country (3). Furthermore, the increasingly stricter regulatory and scientific requirements have made the maintenance of existing marketing authorizations very costly and difficult. The solution of the problem can only be envisaged at a global level in order to avoid relocating the problem from one country to another (61).

4. Pharmacology of Veterinary Medicines

Veterinary medicines are substances or compounds intended for the treatment and control of animal diseases or growth promotion. They are used extensively to prevent and/or treat a wide variety of animal diseases through oral, topical, or injectable routes. Common veterinary medicines include antibiotics, anthelmintics, vaccines, anti-inflammatory agents, and hormones (55,62). Antibiotics serve as the main agents in the treatment of disease and have been employed as growth promoters in a broad range of livestock operations (63,64). Vaccines, on the other hand, confer immunity on an individual when the host is exposed to a vaccine-producing agent (65). The extensive use of veterinary medicines has raised concerns over the potential risks of antibiotic resistance and residues of veterinary drugs in animal products (2). Therefore, there is a critical need to understand the mechanisms of action and relative efficacy of different classes of veterinary medicines to protect public health, animal health, and welfare (4).

4.1. Mechanisms of Action

The pharmacology of antibiotics, vaccines, analgesics/anti-inflammatories, and antiparasitics

plays a major role in the maintenance of animal health. Antibiotics inhibit the growth of, or kill, micro-organisms (66). Vaccines stimulate the immune system to protect from, or reduce the effects of, infection. Analgesics and anti-inflammatories reduce pain, fever, or inflammation caused by illness or injury. Antiparasitics eliminate or reduce the effects of parasites on animals. The pharmacokinetic and pharmacodynamic properties of the different medicine classes influence their use in disease prevention programmes and disease treatments (67,68).

4.2. Pharmacokinetics

Pharmacokinetics plays a critical role in understanding the disposition of veterinary medicines within animals and ensuring these products are administered safely and effectively (69). Pharmacokinetic principles govern the absorption, distribution, metabolism, and elimination of compounds following exposure. For example, the concentration-time–time profile in target animals following administration is a function of the physicochemical properties of the molecules, the formulation employed, and the route of exposure (70). Both pharmacokinetics and pharmacodynamics are used to design dosing regimens that achieve efficacy without toxicity, while also avoiding the promotion of drug resistance (71). A clear understanding of pharmacokinetic and pharmacodynamic properties is therefore essential to ensure that effective and safe products reach the marketplace promptly (72). Drug effectiveness depends on the introduction of active compounds into the systemic circulation at concentrations sufficient to allow passage to the sites of action. Most veterinary medicines are intended for oral or parenteral administration, but some types of dosage form, such as pour-on formulations and medicated feed, are exposed to the external environment before distribution within the animal (73).

4.3. Pharmacodynamics

Pharmacodynamics studies the biochemical and physiological effects of veterinary medicines on animals and the mechanisms of their action. Antibiotics work by exhibiting bacteriostatic or bactericidal activity that either slows bacterial replication, permits the immune system to eliminate the infection, or kills bacteria through various mechanisms (66). Vaccines stimulate a protective immune response to prevent the occurrence of disease. Antiparasitic medicines can both repel and kill a range of parasite types. Analgesics and anti-inflammatories decrease pain sensation and the accompanying physical and physiological effects (67,74).

Antibiotics achieve their therapeutic effect by exploiting structural and functional differences between microbial and host cells—providing selective toxicity. Among their mechanisms are the inhibition of bacterial cell-wall synthesis, disruption of membrane permeability, interference with nucleic acid synthesis or function, inhibition of protein synthesis, and blockage of key metabolic pathways (75,76). Few antibiotics exhibit both bacteriostatic and bactericidal effects since the levels required for killing generally far exceed those that simply inhibit replication. A compound is usually assigned a designation in accord with its most readily achieved activity (77). For vaccine-preventable diseases, strategic vaccination programmes constitute the cornerstone of disease control (1).

5. Role in Disease Prevention

The control of infectious diseases has relied primarily on vaccination and biosecurity measures, with antibiotics used only for treatment. Regular vaccination programs against salmonellosis, paratuberculosis, foot and mouth disease, pasteurellosis, clostridial diseases, and tissue invasion nematodes have reduced or eliminated many costly diseases in Old World farming and often support the marketing of animals and animal

products (78,79). Regulations generally limit the range of veterinary medicines freely available to farmers. Other biosecurity measures include removal of dead stock, discharge of effluent, farm traffic, animal purchase and re-stocking protocols, feed sourcing and storage, rodent control, and professional advice and education of owners and staff, supported by veterinary inspection and certification (80).

5.1. Vaccination Programs

Vaccination programs constitute a primary method for preventing disease in animals, alongside biosecurity measures aimed at limiting exposure to infectious agents (81,82). The widespread use of veterinary vaccines has significantly reduced morbidity and mortality in livestock, contributing to the avoidance of economic losses across the agricultural and livestock sectors (24). Vaccines described in veterinary practice encompass a broad spectrum of pathogenic organisms, including viruses, bacteria, protozoa, and helminths (13). The availability of vaccines against some major bacterial pathogens has led to the decreased use of antibiotics for disease control, particularly in food-producing animals, with an estimated 25% reduction in antibiotic consumption over recent decades in the European Union; nevertheless, concerns regarding antimicrobial resistance persist (83). Advances in genomic and proteomic technologies have provided new tools for vaccine development, projected to enhance the efficacy of vaccines that have historically been challenging to formulate (84).

5.2. Biosecurity Measures

Farm biosecurity refers to all measures implemented to prevent the introduction and spread of infectious agents in populations. Bioexclusion, biocontainment, and biomanagement are the three components of a biosecurity system. Bioexclusion focuses on preventing the entry of infectious agents; biocontainment, on preventing the dissemination within the herd; and biomanagement, on reducing the impact of endemic diseases and preventing reintroduction of pathogens (82,85). Vaccines should be incorporated with care into biosecurity protocols, and a holistic approach combining several control strategies (including quarantine, cleaning, and disinfection) is often necessary to be effective (86). A large number of on-farm biosecurity measures exist to mitigate the risk of the introduction and spread of pathogens; however, even if farmers, veterinarians, and other people working on farms recognize the importance of biosecurity to improve herd health, biosecurity protocols in practice are often limited and apparently insufficient with respect to pathogen transmission routes (87). Both of the most effective and the most practical measures involved a veterinarian: “Keep a closed herd by obtaining animals only from farms in the same health status” and “Regularly involve your veterinarian” (88).

6. Role in Disease Treatment

Veterinary medicines are available to treat animals clinically affected by a range of bacterial and parasitic infections. Effective use of antimicrobials requires identification of the clinical problem through diagnostic examination of the animal. Diagnostic tests ranging from simple on-farm observations to microbiological and serological techniques in veterinary laboratories are available. Many of the techniques used to monitor health and diagnose disease vary substantially depending on the farming sector and the species of livestock. Any treatment protocols should be developed in conjunction with a veterinary surgeon (89,90).

Appropriate medication requires an accurate diagnosis so that appropriate treatment can be administered to obtain an effective cure and good recovery. It is important to recognize early that there is a problem and identify diseased individuals for treatment (91). Failure to do so can increase transmission risk for others, expand the range of pathogens, and pathogens worsen or become more difficult to cure (92). Early and appropriate

treatment can reduce production losses and unnecessary animal suffering. Effective treatment regimes of antibiotics (antibacterials) and/or anthelmintics have long been the foundation of many successful veterinary animal health programs (4). Veterinary medicines play a crucial role in combating diseases, and such severe outbreaks remain within a certain scale. Veterinary medicines are one important tool in the armoury available to livestock keepers for maintaining and improving animal health. In many developing countries where veterinary medicines are not widely available, diseases are the main reason for reduced levels of productivity (93). They are crucial for urban and peri-urban dairying, where the ownership of even a few cattle can be an important income earner or source of milk, and where the risks associated with disease losses are greatly increased. Disease-treatment programmes, when combined with proper vaccination and other preventative programmes, have proved an effective way of improving animal health and productivity (94). The results obtained by Livestock Service officers are often remarkable and demonstrate that once disease problems are brought under control, livestock keepers are quick to adopt improved breed types, husbandry, feeds, and management systems. Civil unrest and the associated disruption to many veterinary programmes have resulted in a high disease incidence in some parts of the world where, in the humanitarian aid sector, veterinary organizations such as the World Organization for Animal Health operate (95).

6.1. Treatment Protocols

Six million preventatives and curative treatments are authorised today in the European Union. The four most frequently consumed are antibiotics, vaccines, antiparasitics, and analgesics/anti-inflammatories. To understand their role, it is necessary to understand their mechanisms of action, pharmacokinetics, and pharmacodynamics. Treatment, in ferrets, for instance, uses metronidazole with similar dosing strategies and guidelines as in other veterinary practices (96,97).

6.2. Case Studies

Additional information and case studies highlight the important role of veterinary medicines in animal health (3). Their pivotal function in successful health management extends to biomedicines such as vaccines and immunological medicinal products (98). Maintaining dairy herds in good health using the most appropriate methods and treatments underpins farm efficiency. Self-selected veterinary homeopathy based on personal experience or the advice of non-professionals can impair therapeutic success (99). Maintaining the healthy status of a herd is critical for sustainable farming, but has become extremely difficult due to changing environmental conditions. Assistance is increasingly required to understand and implement current regulations and welfare requirements (100).

7. Challenges in Veterinary Medicine

The veterinary medicine industry confronts critical challenges—chiefly antimicrobial resistance and drug residues—which may compromise veterinary medicine effectiveness (4).

While antibiotics have certainly enhanced the ability to prevent and cure infectious diseases, the injudicious use of antibiotics has given rise to the development of microbial resistance to antibiotics. Bacteria possessing antibiotic-resistant genes are increasing in number and becoming widely disseminated. In addition, a growing number of resistant bacteria are presently found in a wide variety of environments (101,102).

Residues refer to drugs and their metabolites that remain in meat, milk, and eggs after therapeutic use. Most countries adopt stringent regulations for the control of residual veterinary drugs in food to preserve consumer safety and to maintain the international market for animal products. Veterinary medicines often have a narrow margin of safety, so it is important that residues are

prevented. Such residues can be toxic and pose serious health hazards (103).

7.1. Antimicrobial Resistance

Antimicrobial resistance (AMR) poses an increasing public health threat in human and veterinary medicine. Mechanisms involved in bacterial resistance to antimicrobials have reduced treatment options for many bacterial infections. Preserving the effectiveness of antimicrobials and limiting infections caused by resistant bacteria, therefore, represents an urgent priority (104). The livestock sector is perceived as the primary contributor to the spread of bacterial resistance in humans and the environment. Recent data indicate the global biomass-adjusted amount of antimicrobials used in farm animals slightly exceeds the human equivalent, but the contribution of farm animals to the transmission of AMR mechanisms to humans is likely lower than initially estimated (105,106). Collaboration between veterinary and human medicine is essential, as prescribed by the One Health approach, to preserve the efficacy of antimicrobials (107).

The inappropriate use of antibiotics in food animals and in medical practice has potentiated the risk of untreatable infections (108). The emergence of AMR is accompanied by a concerning decline in the discovery of new antimicrobial agents. Most antibiotics currently employed in human and animal infections are expected to become ineffective within 5 to 10 years (9). Although antimicrobials are mainly used for therapy and prevention of disease, they continue to be employed for growth promotion in food animals in some countries. This indiscriminate use has contributed to bacterial resistance in hospitals, communities, and livestock environments. AMR may spread from animals to humans and vice versa, directly or indirectly, through the circulation of resistance genes. Bacteria of animal origin constitute a reservoir of AMR genes. Several of these resistance determinants have been identified within ESKAPE/ESCAPE pathogens that represent the leading causes of nosocomial infections (109,110).

7.2. Drug Residues in Food Products

Food-producing animals are regularly administered veterinary medicines to maintain health and production yield, and to increase the safety of food of animal origin. Various drugs are used to treat or prevent diseases, the most important ones being anti-infectives (antibiotics, antimicrobials, antifungals, antivirals, vaccines, antimycoplasmals and antiparasitics) (111). Antibiotics may be given for treatment, prevention of infections, and as growth promoters to improve feed utilization and production. Parallel to the increased use of veterinary medicines, drug residues are an important concern, as their presence in meat, milk, and eggs is harmful to consumer health. Residues of veterinary drugs—including antibiotics, anthelmintics, β-receptor agonists, and steroids—have been detected in foods and food products; these substances should not be permitted in food intended for human consumption. Other concerns relate to chronic toxicity, carcinogenicity, teratogenicity, allergy, and mutagenicity in humans, and to bacterial resistance (112). Antibiotics considered critically important for human medicine—such as colistin, which is commonly used in veterinary therapeutics—pose concerns regarding their presence in the environment, where they may create a selective pressure for maintaining resistance genes and resistant bacteria both in animals and humans (113).

Veterinary drugs are regulated with strict requirements related to quality, efficacy, and safety, with particular regard to animal and human health and a mandatory risk assessment for the environment. Marketing authorization is granted only after an evaluation of the quality, safety, and efficacy of the product, and also includes an environmental risk assessment. Pharmacovigilance aims to collect information on the adverse effects of pharmaceutical agents in order to guarantee

enhanced safety and quality of the products. In view of the potential hazard of drug residues for consumers, pharmaceuticals are tested on the target species according to different protocols of exposure using the therapeutic dose. When agents have a physiological or pharmacological effect, a maximum residue level (MRL) is set in foodstuffs of animal origin. The detection and control of residues also includes substances that may be toxicologically relevant, such as stabilizers, antioxidants, solvents, and colouring agents (54,55,60).

8. Impact on Public Health

Human health is directly impacted by reference to the organoleptically observable world, including worker healthcare and health aspects of food safety. For example, it is estimated that zoonotic diseases, and those transmitted naturally from animals to humans, account for more than 60 % of all human communicable diseases worldwide. Zoonoses may be caused by pathogenic (bacterial, viral, and parasitic) microorganisms and can result in a wide range of morbidities and mortalities in both humans and animals, which can seriously affect production and economic development, especially in developing countries (114,115). Consequently, veterinary public health programmes aim at better control of zoonoses in animal populations and their transmission to people. Second, animal products that enter the food chain may be contaminated with pesticide residues, antimicrobial residues, mycotoxins, and other veterinary drug residues resulting from treatment of the animals or from deliberate or accidental contamination before or after slaughter (116,117). Meat and milk products may become contaminated through infected food animals or as a result of poor environment and hygienic practices during production, processing, and preparation. The health hazards to man posed through these transmissible diseases and products in the food chain are extensive (118).

8.1. Zoonotic Diseases

Approximately six out of every ten infectious diseases in humans are capable of transmission between animals and people (119). Zoonoses constitute infections and infectious diseases that are naturally transmissible from vertebrate animals to humans, perpetuating in both populations (120). Transmission between humans and animals can take place through direct contact, vectors, or consumption of animal products, including undercooked meat, fish, milk, and eggs (121).

Since animal health is closely linked to human health, as animals provide food, income, and companionship to people, individuals in the livestock industry, such as farmers, animal health workers, slaughterhouse workers, and meat inspectors, are grouped in an “occupationally exposed” group. A zoonotic disease is naturally transmissible between animals and man (122,123). These diseases account for approximately 60% of infectious diseases, causing illnesses in humans. Based on data from the Centers for Disease Control and Prevention, over 70% of all emerging and re-emerging pathogens originate from animals. Animal reservoirs play an important role in maintaining zoonotic pathogens in the environment. Globalization and global trade of animal products increase the risk of zoonotic pathogen spread in food and the environment (124,125). The significance of some zoonotic diseases varies on a global and local scale according to geographic location, hygiene standards, dietary practices, livestock populations, and legal regulations. A comprehensive knowledge of the epidemiology of zoonotic diseases is very important for preparation, risk assessment, mitigation, control planning, and rapid response (126,115).

8.2. Food Safety

Veterinary medicines contribute to four key areas: animal health and welfare; prevention of residue contamination in food and unsafe exposure to humans; improved production efficiency; and

protection of the environment (111). The extensive use of veterinary medicines in animal production, combined with a less well-organised market and limited resources to enforce regulations, presents considerable challenges (127). The therapeutic or prophylactic use of these compounds can be a source of contamination of both food products and the environment 128. Veterinary drugs must respect national and international regulations to ensure consumer safety. Certain natural contaminants, such as mycotoxins, plant toxins, and algal toxins, are not fully regulated, but attention is paid to food safety hazards to balance benefits and risks (54,55).

9. Conclusion

Veterinary medicines play a vital role in safeguarding the health and welfare of animals. They are indispensable in disease prevention through vaccination and biosecurity and in treatment protocols utilizing antibiotics, antiparasitics, and other therapeutic agents. Pharmacological understanding of these medicines underpins their effective application, while regulatory compliance ensures their safe and responsible use. Addressing challenges such as antimicrobial resistance and drug residues remains crucial to maintaining the efficacy of veterinary medicines and protecting Food Safety. Given the close relationships between humans and animals, veterinary medicine is also integral to One Health initiatives and the management of zoonotic diseases. Continued progress in veterinary pharmaceutical science, thoughtful regulation, and wise utilisation of these medicines will maintain animal health as a cornerstone of global wellbeing and food security.

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