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Disease Control, Prevention and On-Farm Biosecurity: The Role of Veterinary Epidemiology

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ABSTRACT

Domesticated and non-domesticated animals, including wildlife, deliver significant financial and nonfinancial benefits to the human community; however, disease can have a dramatic impact on the morbidity, mortality, and productivity of these animal populations and hence can directly and indirectly affect the human communities associated with them. This manuscript provides an overview of the important features to consider for the prevention and control of disease, with a focus on livestock diseases, and highlights the key role veterinary epidemiology plays in this endeavor. Measures of disease frequency and the type of epidemiological studies required to identify risk factors for diseases are summarized, with a focus on the use of these in the implementation of measures to control disease. The importance of biosecurity in maintaining disease-free flocks/herds is discussed and the steps taken to implement good biosecurity measures are outlined. It is concluded that a sound knowledge of veterinary epidemiology is required when developing control programs for disease and implementing biosecurity programs at a farm, regional, and national level.

1. Introduction

Domesticated and non-domesticated animals deliver significant financial and nonfinancial benefits to the human population. Livestock plays an important economic role for communities and families by providing food, fiber, hides, manure for fuel and fertilizer, and draught power, as well as having cultural significance and playing a role in the status of individuals in certain societies [1,2]. Pet animals, particularly dogs and cats, are important companions in many households, and contribute to the physical, social, and emotional development of children and the well-being of their owners [3–7], while non-domesticated animals (wildlife) provide a range of benefits to humans, including economic, health, recreational, scientific, and ecological values [8]. However, disease can have a significant impact on the productivity of livestock and the quality of product produced [9], the lifespan and quality of the life of pets, and the biodiversity of wildlife, with the potential for many disease pathogens to be transmitted to humans [4]. Furthermore, 60% of emerging infectious diseases in humans are estimated to be zoonotic, with over 70% of these originating from wildlife [10].

With recent emphasis on improving food safety, food security, biodiversity, and improving animal and public health, measures are increasingly being taken to reduce the risk of disease introduction or spread within animal populations and from animal to human populations [11]. The control (i.e., reduction in the incidence and/or prevalence to a locally acceptable level), prevention (i.e., preventing entry) and/or eradication (i.e., total elimination) of diseases in animal and human populations require a thorough understanding of epidemiology [12]. Veterinary epidemiology provides the tools to investigate disease outbreaks, identify risk factors for disease, investigate diseases of unknown etiology, undertake disease surveillance and monitoring, implement herd health programs, and develop and implement biosecurity measures [13]; hence, this discipline is an essential component of disease control, eradication, and prevention [12].

This manuscript focuses on the role and significance of veterinary epidemiology in the control, prevention, and eradication of diseases in domesticated and non-domesticated animals and in the implementation of biosecurity programs in farmed livestock populations.

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2. Key concepts of epidemiology

A key principle of veterinary epidemiology is that disease does not occur randomly in a population, but is more likely to occur in certain members/groups of a population, at certain times, and in specific locations; in other words, disease follows specific patterns [12,14]. Central to disease control is the identification of these patterns and the risk factors that increase the likelihood of disease, as well as factors that reduce the likelihood of disease, so that measures can be implemented to reduce the frequency, severity, and impact of disease [9,12,13,15].

Diseases are multifactorial with direct and indirect causes, factors, or attributes working together to produce disease; this interrelationship is often displayed graphically as a causal web for clarity purposes [15]. A number of models of disease causation, which are suitable for both infectious and non-infectious diseases, have been proposed. Among the simplest of these is the epidemiologic triad, which is the traditional model for infectious disease [12,14]. The triad consists of an external agent (bacteria, virus, parasite, fungi, or prion), a susceptible host, and an environment, including management and husbandry practices, which bring the host and agent together. In this model, disease results from the interaction between the agent and the susceptible host in an environment that supports transmission of the agent from a source to that host [14–16].

By manipulating the environment, such as by reducing fecal contamination, reducing overcrowding, or eliminating the carriers or vectors of pathogens, we can reduce disease [4,12,14,17–19]. Similarly, by selecting animals that are resistant to disease or by increasing the resistance of the population through natural or artificial means [1,14], we can reduce the severity of disease and hence the disease's impact. In contrast, although some host factors—particularly age and gender—are closely linked with many diseases, we cannot manipulate these factors within a population. For example, Fentie et al. [2] observed that females and younger animals were more at risk of sheep and goat pox than males and older animals, respectively, and Zeng et al. [20] reported an increasing prevalence of brucellosis in yaks with age. Such information is useful in predicting infection within a population or group of animals, but is difficult or impossible to act upon in a disease-control program, as these animal attributes cannot be manipulated or totally removed from a population.

Agents that result in disease in only one or a small number of species are more amenable to control, prevention, or eradication [12] than pathogens that lack host specificity, such as foot-and-mouth disease (FMD) and cystic echinococcosis [18,21]. Similarly, the mode of transmission, presence, and survival of environmental stages, and the presence of reservoirs, carriers, and vectors all influence the distribution and measures adopted for disease control [12,14]. The presence of wildlife can play an important role in the transmission of certain diseases to both humans and other animals by acting as carriers for agents such as lyssaviruses and Henipah viruses and leptospirosis [22–25], or as hosts for parasites such as *Echinococcus* spp. [4,18]. Vectors that are key to the transmission of certain pathogens and diseases, such as blue-tongue, have been affected by increasing vector distribution through the effects of global warming [26]. The long-term survival of pathogens, such as *Clostridium botulinum* [27] and *Bacillus anthracis* [28], in the environment is critical to the distribution and continuation of these specific diseases and is also useful in predicting disease occurrence [14].

Although the agent, host, and environmental features of a disease are useful in predicting disease location and occurrence, in order to evaluate the impact or success of a disease-control or preventive program, the frequency of a disease must be measured [12,14].

3. Disease frequency

The two measures of disease frequency used in epidemiology are prevalence and incidence, and the change in these parameters is a key outcome of disease-control programs.

Prevalence is a static measure of disease and is usually reported as the proportion of individuals that are infected/positive with the pathogen, or the proportion that are seropositive on a serological assay. This measure is usually reported as a percentage, and should include 95% confidence intervals (CIs) to provide estimates of the disease frequency in the sampled total population and for comparing results between studies. In a study of brucellosis in yaks in three counties of the Tibet Autonomous Region, China, Zeng et al. [20] reported a test prevalence in individual yaks of 2.8% (95% CI: 2.0–3.7) and 18.2% (95% CI: 12.9–24.6) in herds using a Rose Bengal Test (RBT) and a competitive immune-enzymatic assay (C-ELISA) interpreted in parallel. However, a test prevalence is influenced by the sensitivity and specificity of the tests used; consequently, many studies adjust test prevalence for these features of a diagnostic test(s) using the formula true prevalence = (test prevalence + specificity − 1) ÷ (sensitivity + specificity − 1) [14]. For example, after adjusting for test uncertainty, Dukpa et al. [29] reported a true animal-level prevalence for FMD in cattle from Bhutan of 17.6 (95% CI: 15.6–19.5). Estimation of a disease's true prevalence allows the comparison of control measures in different locations when different diagnostic tests are utilized, and is critical when attempting to demonstrate a population's disease-free status [30,31].

In contrast to prevalence, which measures the current frequency of a disease or antibodies, and which is a static measure, *incidence* is a dynamic measure that measures the spread of disease. Incidence is usually reported as either an incidence risk (cumulative incidence) or incidence rate (incidence density) [14]. For example, the study by Bran et al. [32] reported a cumulative incidence (incidence risk—new cases of disease during a set period of time) of lameness in dairy cattle over a four-month period of 29.6% (indicating that nearly one third of the dairy cattle under study developed lameness during the study period). Their study highlighted the importance of specific risk factors for lameness, with animals having a lower body condition score, higher parity, and lesions on the hooves being more likely to develop lameness.

In contrast to incidence risk, incidence rate is the number of new cases of disease in a population divided by the total number of animal time units at risk. In a study investigating cow- and herd-level risk factors for elevated somatic cell counts (eSCC) in stall-housed dairy cows, Watters et al. [33] reported a mean herd incidence rate of 0.91 eSCC per cow-year at risk for all study herds. These dynamic measures indicate the risk or likelihood of animals contracting a disease during a specific period of time [14].

The prevalence and incidence of a disease can alter through changes in disease terminology, disease recording, and diagnostic techniques [14], as well as through changes in the disease's frequency resulting from true disease spread, or in its control resulting from successful implementation of a disease-control program. A successful disease-control program should result in a cost-effective reduction in disease prevalence and incidence through the manipulation of risk factors for the specific disease [34].

4. Identification of risk factors for disease

Identifying factors that increase the risk of disease or those that reduce the risk of disease (protective factors) is important so that potential measures can be implemented to either reduce disease or prevent its entry [12,14,35].

Risk or protective factors for a disease can be demographic, husbandry/management, environmental, or socioeconomic factors, and are assessed by conducting descriptive epidemiological studies (cross-sectional, case-control, or cohort studies). The strength of the association between a putative risk factor and a disease is most commonly assessed using the calculated odds ratio (OR) and their 95% CIs [12,14].

4.1. Cross-sectional studies

Cross-sectional studies are frequently used to assess a disease's prevalence or seroprevalence and to identify risk factors for that disease; however, they are of less use for rare diseases and can be subject to confounding [12,14].

Miyama et al. [36] reported a test herd prevalence of 65% to leptospirosis in a cross-section of 109 dairy herds in southern Japan. In that study, they identified larger herds and herds that contained introduced animals from Hokkaido as risk factors for seropositivity. However, their findings highlight some of the challenges in disease control, as larger herds offer economic benefits and economies of scale compared with smaller herds. Similarly, in a large study of oesophago–gastric ulcers (OGU) in pigs in Australia, Robertson et al. [34] reported that most risk factors for herds with a high level of OGU (i.e., feeding a ration *ad libitum*: OR 13.7; using an automated feeding system: OR 7.8; and feeding a pelleted ration: OR 384) could not cost-effectively be manipulated because of their association with decreased feed wastage, improved growth rate, and reduced labor costs. In contrast, other factors associated with a higher prevalence of OGU (i.e., using water sourced from a dam rather than from an underground bore: OR 3.8; a change in ration formulation for finisher pigs: OR 1.5) were amenable to manipulation.

Similarly, in a study of obesity in dogs [37], it was found that overweight dogs had higher odds of being neutered (OR 2.8), being fed snacks (OR 1.5), being fed once a day (OR 1.4), and living in a single-dog household (OR 1.6). In contrast, for each hour of weekly exercise, the odds of obesity decreased (OR 0.9)—that is, exercise was protective in reducing the risk of obesity. From such findings, it was recommended that owners be advised to stop offering snacks, to divide the current meal into halves and feed these at two separate times of the day, and to increase exercise for their dogs [37].

4.2. Case-control studies

Case-control studies are well suited for rare diseases and involve selecting cases (diseased animals/farms/herds) and randomly selecting or matching with controls (non-diseased animals/farms/herds) [12,14]. Jiang et al. [38] undertook a case-control study of avian infectious diseases in household flocks in the Poyang Lake region, China, in which cases and controls were identified based on a history of poultry deaths. In that study, they showed that adopting a vaccination program was a protective factor reducing the likelihood of being a case (OR 0.4), while contact with other backyard flocks increased the risk of deaths in the flock (OR 1.72), as did poultry-housing density within a 20 m radius of the farmer's house (OR 1.08).

White et al. [39] used a case-control study to identify risk factors for congenital chondrodystrophy of unknown origin in beef cattle herds in Australia. That study highlighted the use of the epidemiological approach to investigate risk factors for diseases of unknown etiology with the type of pasture, terrain, and presence of soil potassium levels influencing the disease's presence. These findings provided evidence of an association between maternal nutritional disturbance and the disease.

Toyomakia et al. [40] similarly used a case-control approach to identify risk factors for porcine epidemic diarrhea (PED) during the early phase of an epidemic in Japan. They found that the occurrence of porcine reproductive and respiratory syndrome within the preceding five years (OR 1.97), the use of a common compost station for carcasses and waste (OR 2.51), and the use of a pig excrement disposal service (OR 2.64) increased the likelihood of PED. These findings highlight the impact of management factors plus intercurrent disease on the presence of PED, as has been reported with many other diseases [14].

Puerto-Parada et al. [41] undertook a retrospective case-control study to evaluate the association between selected risk factors and infection of dairy cattle herds with *Mycobacterium avium* subsp. *paratuberculosis* (MAP). Herd size (OR 1.17) and the proportion of cows purchased per year in the last five years to the total herd size (OR 5.44) were significantly associated with a positive MAP herd status. The latter finding highlights the risk of introducing MAP into a MAP-free herd through the introduction of animals, which is also a risk for many other infectious diseases.

4.3. Cohort studies

Cohort studies—albeit costly and time-consuming to implement and not suitable for rare diseases—offer the advantages of providing data to allow the calculation of incidence and generally minimizing confounding results [12,14]. In a study by Pires et al. [42], a longitudinal cohort study involving eight repeat samplings of 900 pigs was undertaken to assess *Salmonella* shedding by the animals. Cold exposure (temperatures below the animal's thermal neutral zone) and exposure to a temperature humidity index (THI) > 72 were both positively associated with *Salmonella* shedding. The researchers concluded that their data suggested that the pig's thermal environment was a component of the causal pathway for salmonellosis, and that reducing the exposure of pigs to suboptimal thermal parameters should decrease *Salmonella* in swine; this conclusion highlighted the role of environment in this disease.

Similarly, Pinchbeck et al. [43] undertook a prospective cohort study of racing injuries over a two year period and measured the incidence of injuries in a cohort of horses in the United Kingdom (28.8 per 1000 starts). They found that risk factors for injuries were associated with the speed of the race and the horse's foot conformation. These findings again emphasize that not all disease risk factors can be manipulated.

The key outcome of undertaking epidemiological studies similar to those listed has been to identify risk factors for disease. Knowledge of these risk factors allows recommendations to be developed to control disease, and this knowledge is subsequently incorporated into biosecurity programs developed for the relevant livestock species.

5. Biosecurity

In the 21st century and late 20th century, there has been a shift from treating individuals toward disease prevention, which has led to an increasing emphasis on the implementation of biosecurity [44]. To maintain a farm, region, or country free from disease, biosecurity is critical. Biosecurity has been described as the management of the risk of pests and diseases entering, emerging, establishing, or spreading and causing harm to animals, plants, human health, the economy, the environment, or the community [45]. Although this concept operates at a national and international level, most veterinarians are involved in evaluating and preventing the spread of disease on individual farming enterprises under their care [17]. A key component of farm-level biosecurity is biocontainment or internal biosecurity, which has been described as the series of management practices that prevent the spread of infectious agents between animal groups on a farm or the management practices designed to prevent the infectious agent from leaving the farm [46–48].

To facilitate the adoption and emphasize the key concepts of biosecurity and biocontainment within enterprises, a series of acronyms have been developed including isolation, resistance and sanitation (IRS) [49] and sanitation, traffic control, assessment, isolation, resistance, and security (STAIRS) [50]. Education, training, and the involvement of all stakeholders are essential for the success of biosecurity at the enterprise, regional, and national levels; these stakeholders include the owners, managers, and workers on livestock enterprises, industry bodies, and rural and urban communities [51–53]. Numerous articles and websites are available on biosecurity at the national and international levels [51,54,55]. This section focuses on the implementation of biosecurity at a farm or enterprise level.

Development and implementation of a biosecurity plan in a livestock enterprise require a documented approach, and scoring systems have been developed to rank biosecurity protocols and their implementation [56,57].

Carr and Howells [17] summarized biosecurity requirements for poultry and pig enterprises, and emphasized that the introduction of animals of the same species presented the highest danger of introducing disease. Fèvre et al. [58] similarly highlighted the importance of animal trade in the introduction of pathogens to previously disease-free herds/areas, while Siengsanan-Lamont et al. [59] demonstrated the increased risk of avian influenza in poultry flocks in Thailand through introduced birds, Dukpa et al. [29] reported an increased risk of FMD in communally grazed herds in which mixing of multiple herds occurred, and La et al. [60] and Phillips et al. [61] showed the dangers of introducing *Brachyspira hyodysenteriae* into piggeries through the introduction of live pigs. If live animals are introduced into a unit, the introduced animals should be maintained in isolation from the resident population for at least one month during which time their health status can be assessed and the new animals can be exposed to the flora present in their new location [17].

The danger of disease entry through the introduction of live animals has led to the recommendation that intensive livestock industries should be maintained as closed herds/flocks/units [62]. However one of the challenges of maintaining a closed-herd system is the introduction of new superior genetics in a safe manner. Although this has traditionally been undertaken through the use of imported semen or embryos, such an approach can still present a risk of disease introduction [63,64]; for example, de Smit et al. [65] reported the presence of classical swine fever virus in the semen of boars without any evidence of clinical disease.

Contact of livestock with neighboring or feral/wild animals of the same species has also been identified as a risk for disease entry [60,61,66,67]. This risk can be minimized through barrier fencing and population control in the case of feral and wild animals [68,69]. Secure perimeter fencing—particularly for intensive livestock industries—to minimize the entry of other animals, people, and vehicles is considered essential [17].

The role of species other than that being raised—including both domesticated animals and wildlife—in introducing a range of diseases has been reported in a large number of studies. La et al. [60] reported the detection of *Brachyspira hyodysenteriae* in domesticated dogs, rodents, and birds and proposed that these animals could either introduce the agent or new strains into piggeries. On detecting similar strains of *Salmonella enteritidis* in mice, rats, flies, and foxes to those in layer poultry, Liebana et al. [70] proposed that these animals and vectors could introduce and transmit the bacterium between poultry enterprises. Multiple authors [23,59,71] have also highlighted the potential for wild birds to act as carriers of avian influenza viruses, and minimizing contact between livestock and all wild or feral animals is recommended [17]. Similarly, control of vectors—particularly of birds, rodents, flies, and other insects—that have the potential to transfer pathogens to livestock should be implemented [23,59–61,70,71].

People visiting livestock enterprises—including veterinarians, livestock advisors, inseminators, hoof-trimmers, and feed suppliers—are also a potential risk for disease introduction into a unit [17,57,62,72]. To reduce this risk, only essential visitors should be allowed to visit the area/buildings where animals are housed, and protective clothing and footwear should be provided by the enterprise to these visitors [62,73,74]. Such protective clothing and footwear should be provided for all workers and visitors, and should not be worn on any other unit or outside the enterprise [62]. Similarly, visitors and workers should be required to shower-in and shower-out of enterprises in order to reduce the risk of disease introduction and escape from an enterprise.

Dead animals should be removed and disposed of by burning, burial, or composting to decrease the survival of pathogens and to avoid access by scavengers [17,18,75]. Manure and used litter/bedding material should also be composted and disposed of to prevent access by other animals [75–77].

The dangers of pigs having access to (i.e., eating) uncooked meat or food products (i.e., swill) have been highlighted for several pandemic diseases including African swine fever, classical swine fever (hog cholera), and FMD [78–80]. Consequently, swill feeding has been banned in many countries in order to minimize these disease risks.

Contaminated feed and water can result in the introduction of diseases such as toxoplasmosis from contamination with *Toxoplasma gondii* cysts from cats [81–83], and ingestion of pasture contaminated with eggs of *Echinococcus* spp. is important in the infection of small ruminants [18]. Ensuring that feed sheds and water sources are protected from vermin and other animals is essential in reducing these risks.

Only essential vehicles should have access to livestock enterprises, and the entry of these can be minimized through the erection of perimeter fencing. Building infrastructure to allow feed to be delivered externally to an enterprise and then moved via augers into storage bins/silos and laneways that are used to direct animals from buildings to outside the perimeter fencing are useful in decreasing disease-entry risk from potentially contaminated feed trucks and livestock-transport vehicles. Vehicles that are required to enter an establishment should be required to enter and exit only via a single point through facilities to wash and disinfect the wheels and, ideally, the whole vehicle [67].

The introduction of equipment contaminated with feces and other animal products (e.g., hair, feathers, saliva) to a farm is also a potential disease introduction risk [67], with many studies highlighting the risk of the introduction of diseases, such as Newcastle disease, through the entry of contaminated equipment and fomites [72,74].

Workers on livestock enterprises should be discouraged or prevented from working at other livestock enterprises or from keeping similar livestock [17,62,70]. Staff should also be discouraged from visiting other livestock units, animal markets, animal shows, and slaughterhouses, or if they do, should have no contact with animals on the employing enterprise for at least three days after such events [17,84,85].

The density of livestock enterprises, proximity to neighboring same-species units, and proximity to slaughter houses and major transport routes have also been proposed to influence the risk of disease introduction to a herd/flock [21,77].

Traditionally intensive industries have been able to implement biosecurity more effectively than small-holder or extensive industries; however, Compo et al. [86] emphasized that although many farmers were aware of biosecurity practices, many failed to adopt the protocols recommended for their establishments. Several authors have also highlighted lower levels of biosecurity in hobby or small-scale enterprises that are more likely to have a poor understanding of the needs for biosecurity, poorer confinement of animals, and inferior infrastructure in comparison with larger commercial enterprises [57,87]. Others [53,88] have emphasized the important role of education in ensuring that biosecurity practices are adopted by the livestock industries to reduce the risk of disease entry in order to enable maximum productivity from these industries.

Disease control and prevention require a multifaceted approach with a thorough knowledge of the current disease situation in an enterprise, the likely disease threats, and how the risk of introduction can be minimized. Such an approach requires a sound knowledge of the discipline of veterinary epidemiology, with an understanding of disease transmission and spread, risk factors for disease, and methods to prevent disease. It is concluded that biosecurity is critical to ensuring the health and productivity of livestock within an enterprise, region, and country, and that a knowledge of veterinary epidemiology is essential for developing sound biosecurity practices.

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