Population Dynamics and Herd Immunity

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Abstract

Understanding the population dynamics of pathogen transmission is critical to developing control programs for disease. Controlling contagious pathogens in human populations through vaccination has been successfully used to stop spread of disease and ultimately control outbreaks. This effect is termed "herd immunity". This concept needs to be well understood by veterinarians as they are called upon to provide disease control recommendations and advice to livestock businesses.

Résumé

Il est essentiel de comprendre la dynamique de population dans la transmission des agents pathogènes pour développer des programmes de contrôle pour les maladies. Le contrôle des agents pathogènes contagieux par la vaccination dans les populations humaines a été utilisé pour enrayer la propagation des maladies et circonvenir les flambées. Cet effet s'appelle l'immunité de troupeau. Ce concept doit être bien compris par les médecins vétérinaires qui ont pour mission de conseiller les industries du bétail en matière de contrôle des maladies.

Introduction

Methods to control disease in beef cattle populations have traditionally been focused on immunization to prevent clinical disease. While prevention of clinical disease is a direct effect of immunization, the indirect effect of disease prevention by decreasing transmission is of primary importance with pathogens that are transmitted from animal to animal.[11]

In medical literature, the concept of population/herd immunity has successfully been used to implement vaccination programs designed to protect populations against disease pathogens. Specifically, they include diphtheria, tetanus, pertussis (DPT), measles, mumps, rubella (MMR) and poliomyelitis.[2] While we are concerned about each individual being protected against disease, the greater purpose is to immunize as many as possible within the population such that susceptible individuals within a population are also protected. A greater level of population protection can be achieved by:

1. Reducing the number of animals shedding disease pathogens.
2. Decreasing the amount of pathogens shed by infected animals.
3. Decreasing the duration of shedding
4. Increasing the infectious dose necessary to cause infection.

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The percentage of immune individuals in a population necessary to achieve herd protection varies by disease pathogen, but will range from 83 to 94%.[13] This concept is the basic premise of herd vaccination programs.

Currently, there is some debate within the veterinary medicine community over the practice of annual booster vaccinations in companion animals as some boosters may no longer be necessary for clinical disease prevention due to very low risk.[4] For veterinarians in food animal practice there are questions regarding efficacy, duration of immunity and number of doses needed to achieve a significant level of population and individual animal protection.[7,10] Veterinarians are called upon to make recommendations concerning vaccination protocols for multiple diverse livestock businesses. To do so they require in-depth herd knowledge regarding some assessment of risk for specific diseases, management, genetics, nutritional status and handling facilities. For example, in beef cattle breeding herds, purchased females or bulls may be introduced into new herds without benefit of a quarantine period, biosecurity testing or knowledge of purchased animals herd disease status.

Even when vaccination programs are specifically outlined, it is uncommon for buyers to seek veterinary advice about the quality of the program. In BHV-1 vaccinated animals, some level of protective immunity against clinical diseases is assumed regardless of the type of vaccine. However, published comparisons between types of vaccines points to a clear advantage with modified-live vaccines providing superior clinical disease and herd protection.[3,4] Yet, in many cowherds safety and convenience seem to be the overriding concern. While the issue of safety, convenience, duration of immunity and herd protection may be debated, perhaps the larger issue for veterinarians is one of risk analysis and risk management.

What is the risk of the herd being exposed to a field challenge with either IBR or BVD virus? For most beef cattle businesses this risk exists, and quantifying the risk centers around the control of animal movements.[8] However, in a business with a system in place for disease control, the veterinarian will likely recommend methods to both lower the risk of exposure and increase specific immunity to the pathogens considered to be of greatest risk. For example, reducing the exposure risk to common calf diarrhea pathogens has provided positive results when applied to calving systems.[15] In addition, the indirect population effects of vaccination influences the number of immune animals within a herd which can result in reducing the spread of pathogen transmission within a herd, and ultimately results in the infection dying out or becoming extinct.[6] The veterinarian performs a vital service in this arena when making informed recommendations regarding the type of vaccine, the timing of boosters and the frequency of vaccination.

The spread of pathogens within a population depends on the basic reproductive rate ($\mathbf{R}_0$). The basic reproduction number $\mathbf{R}_0$ is the number of secondary infections resulting from one primary case in a susceptible population. The basic reproduction number is a feature of both the infectious agent and the host population without a control measure being active. If $\mathbf{R}_0$ in a vaccinated population is larger than one, then the vaccine cannot totally prevent the spread of infection, and additional biosecurity principles must be employed.[14]

It has been estimated that for BHV-1 infections the $\mathbf{R}_0$ is approximately 7.0. After using two different vaccines it was estimated that $\mathbf{R}_0$ was 2.4 and 1.1.[2] This means that within these immunized populations, 2.4 and or 1.1 new cases will arise from one case. In this citation, population transmission could not effectively be prevented. Within real populations these numbers must be considered within the context that as animals become infected and are contagious, the number of susceptible animals will decline and the number that are recovered and immune will increase.

It has been estimated that the critical proportion of immune animals needed to prevent transmission is expressed by the equation, critical proportion = $1 - 1/\mathbf{R}_0$. The higher the $\mathbf{R}_0$ the greater the number of animals that must be immune in order to prevent spread of the infectious agent. If $\mathbf{R}_0 = 7.0$ for a specific pathogen, then the proportion of immune animals within that population must be proportion = $1 - (1/7)$. This means that approximately 86% of the population must be immune in order to prevent transmission. Estimates for limiting the spread of BVD within a population have been made based on mathematical models. In herds without persistently infected (PI) animals, 57% of the animals must be immune in order to stop transmission. For herds with PIs, 97% must be immune.[5] Of course this issue of herd immunity to BVDV is further complicated by the amount of cross protection afforded by commercial vaccines, and to the desired level of protection.

Protection against respiratory infection and clinical disease is less difficult to achieve than protecting the dam and developing fetus from infection.[9] In addition, vaccines must contain the major genotypes in order to adequately prevent transmission by reducing the number of animals shedding virus and the amount of virus shedding by individual animals.[16] A sound recommendation for vaccines can only be made based on actual challenge model and field trials utilizing sound science and proper design.

Conclusions

The challenge of making sound vaccination recommendations as part of an overall herd health program falls under the responsibility of food animal veterinarians. Making those recommendations requires an in-depth knowledge of the risk of disease, management ability, facilities, nutritional requirements, and in the case of breeding herds the current genetic base. In addition, veterinarians must have a working knowledge of the relative efficacy, duration of immunity, and the impact on transmission by available commercial vaccines. With this as a working tool, the veterinarian can utilize the concept of population dynamics and herd immunity when making specific herd recommendations about the timing and frequency of vaccination administration.

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