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THE EPIDEMIOLOGY OF INFECTIOUS DISEASES OF LIVESTOCK

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ABSTRACT

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From the time of the first modern studies of infectious diseases, by Koch, Pasteur, Theiler and their colleagues, it has been clear that laboratory investigation must be complemented by epidemiologic investigation. The measurement of all aspects of the natural history of a disease in naturally affected populations is necessary if we are to rationally design control regimens. Building upon a historic perspective, this paper presents a view of the present status of epidemiology as it pertains to animal disease control, and presents a view of the merits of expanding the use of this science in future animal disease control programs, internationally, in developed and developing countries. The basis for this view lies in adaptation of principles employed in human infectious disease epidemiology, and principles which guide the organization of international disease control agencies.

INTRODUCTION

The era of microbiological discovery, starting just about 100 years ago, had an immediate effect on the prevalence of many infectious diseases of man and domestic animals. In the initial flourish of discovery, Louis Pasteur, Robert Koch, then Walter Reed, Arnold Theiler, Theobald Smith, David Bruce and their colleagues moved from one disease to the next, isolating and characterizing etiologic agents and proving their causative association with disease. They considered the mechanisms by which micro-organisms and viruses cause disease and the mechanisms by which they are transmitted in nature. They set into place a pattern of inquiry which we still follow. We tend to focus on the early attempts by the founders of microbiology to control diseases by immunoprophylaxis, but it must be remembered that many of the first reductions in the incidence of particular diseases and even the first local elimination of some diseases were accomplished without contributions from the sciences of immunology and therapeutics (Waterson & Wilkinson, 1978).

Many important diseases yielded to principles of hygiene, arthropod control, and quarantine, principles which complemented the founding discoveries in microbiology. For example, by the end of the first decade of this century, vector control was well developed in many urban centres as an effective basis for the prevention of yellow fever, stray dog control was well developed in many places for the prevention of human rabies (and had even been used as the basis for eliminating rabies from Great Britain), and quarantine and slaughter programs were well developed in many places for the control of several livestock diseases, including foot-and-mouth disease and rinderpest. Theiler and his colleagues here in the Transvaal, as early as 1896, managed a partly effective rinderpest control program based upon quarantine and slaughter, and as early as 1907, initiated a "dip, fence, isolate or slaughter" program which was partly successful in controlling East Coast fever (Gutsche, 1979).

It is hard to believe how much later specific immunoprophylactic and therapeutic disease control weaponry came into use. Just 50 years ago, the specific prophylactic and therapeutic biologics and pharmaceuticals for use in man consisted primarily of quinine for malaria, arsenicals for syphilis and trypanosomiasis, vaccinia vaccine for smallpox and crude rabies vaccine for post-exposure treatment. At the same time, just 50 years ago, our armamentarium for use in animal diseases included a few modestly effective virus vaccines such as Theiler's rinderpest vaccine and a few modestly effective bacterins for livestock and poultry. These animal products were used in a setting which perpetuated the use of innumerable products containing gunpowder, turpentine, plant extracts of unknown nature, and heavy metal salts.

The founders of microbiology were "generalists", working one day in the laboratory and the next in the field. Their successes depended on their broad viewpoint. Nevertheless, primary credit for the earliest applications of the founding principles of microbiology belong to individuals who were practising the science which today we call epidemiology. These individuals studied the natural history of diseases in naturally affected populations and considered all possible approaches in efforts to bring about control.

In this paper, I shall attempt to cover some of the historical perspective of epidemiology as it applies to infectious diseases. I would then like to comment on the present status of the science and its use in animal disease control, and lastly, I would like to comment on the merits of expanding the use of the science in future animal disease control programs. My tack shall be to use comparisons between animal and human disease epidemiology; there are important lessons to be learned from the more advanced state of development and application of the latter.

In most instances, this topic would be covered by an epidemiologist, but my perspective is that of a laboratory virologist. I consider this exercise in "role reversal" to be most valuable. If more laboratory virologists and epidemiologists were to make an effort to take the role of their opposite number, to learn about and to come to appreciate each other's viewpoint, then their common concern for the actual control of diseases would emerge as a clear basis for better communication and collaboration. Clearly, all of the easy infectious disease problems have already been dealt with; those remaining pose many different conceptual, practical, technical and logistical problems. They can only be attacked by focusing all appropriate disciplines, basic and applied, laboratory and field based, in a coordinated way (Murphy, 1979).

HISTORICAL PERSPECTIVE

Starting in the 1930's, biomedical science began to deliver pharmaceutical and biological products such as sulfonamides, antibiotics and effective, safe vaccines; attention became focused on these means to prevent and treat infectious diseases. At the same time, in many places, scientifically based and professionally managed public health and animal disease control organizations began to attain necessary scope and sophistication. In fact, it was the combined use of new, effective prevention and treatment products and new, effective hygiene practices managed by well-structured organizations which brought about the major reduction in the prevalence of many diseases of man and animals at this time. This, in turn, led to a public enthusiasm in many countries which was sustained by promises of even more and better disease control products and programs (Yekutiel, 1980).

By the late 1940's and early 1950's a belief had grown that elimination of many diseases over large areas could be achieved by simple scaling up of local campaigns and widening use of then current biological and pharmaceutical products and disease control practices. Successful local campaigns against yellow fever, malaria, yaws, rabies, foot-and-mouth disease, pleuropneumonia and several other microbial, viral and protozoal diseases were influential in this regard. By extension, a belief evolved that even larger and more comprehensive campaigns could attain complete worldwide eradication of many diseases. The concept of eradication was first formalized in the WHO Global Malaria Eradication Program, which reached its peak in 1962. This was followed by the U.S. government-sponsored *Aedes aegypti* eradication program which reached its peak in 1964. The key to these programs, of course, was the great immediate effectiveness of DDT on vector populations.

These, and other campaigns started with the conceptual optimism of the day, but most were quickly brought down to the reality of real-world settings. Failures in most programs led to across-the-board criticism and a polarization of views at extreme positions for and against the continuation of eradication campaigns. In some instances, overoptimism led disease control agencies to continue campaigns without supporting any ongoing research. The U.S. Department of Agriculture's Brucellosis Eradication Program is an example; for years shortcomings in the vaccine and the diagnostic tests used in the campaign were recognized, but until recently, no research was supported to improve them. In other instances, overpessimism led disease control agencies to delay or cancel feasible, cost-effective programs. The WHO/UNICEF Yaws Eradication Program is an example.

In 1966, into this sort of confused conceptual situation, the WHO World Health Assembly interjected a resolution to eradicate smallpox from the earth. At that time, smallpox was endemic in more than 30 countries and importation was a constant threat elsewhere. The eradication of the virus was a spectacular endeavour, and the people of the world owe a great debt to those who had a role in the Program. Today, smallpox is the most exotic virus in the world, existing only in a few freezers. Future generations should be reminded of the nature and magnitude of the disease which has been eradicated. The disease was of such significance that many of our general principles of virus disease control derive from knowledge, myth and opinion relating to smallpox. It is no wonder that even today, consciously or unconsciously, the science of epidemiology is influenced by memories of the Smallpox Eradication Program (Fenner, 1977).

There is an important legacy of expectation left from the WHO Smallpox Eradication Program. People in all countries expect international, national and local disease control agencies to continue where the Smallpox Eradication Program left off. This expectation is pointed firstly at human disease control agencies, but the expectation is pervasive and should be recognized as well by animal disease control authorities. The keys for fulfilling this expectation, worldwide, include international cooperation, technology transfer, infrastructure development, education and training, and financial support. There must be an expanded international research base for human and animal diseases. Clearly, the costs in terms of money, talent and energy for such activities are modest in relation to the benefits which would be derived. The cost benefit ratio of the WHO Smallpox Eradication Program is an object lesson in this regard. So are the cost benefit ratios of pleuropneumonia and bovine tuberculosis elimination programs in many countries, the hog cholera (swine fever) and vesicular exanthema elimination programs in the U.S. and the foot-and-mouth disease elimination program in Europe and South Africa.

Priorities for Animal Disease Control

At a conference on "Animal Agriculture—Research to Meet Human Needs in the 21st Century", held in 1980 and sponsored by the American Association for the Advancement of Science and other organizations, a group of scientists attempted to set research priorities for maximum impact upon the world's livestock industries (Pond, Merkel, McGilliard & Rhodes, 1980). Unlike most such exercises, this one cut through the question of how to deliver present technology worldwide, and concentrated on new "research imperatives"—new scientific approaches to major problems.

The report of this conference has become quite influential in the U.S. Under the heading "Animal Health", four subject areas were identified as having the highest priority for research support: (a) Intergrated Food Animal Health Systems—the interdisciplinary approach to identifying and quantifying factors responsible for losses in the intensive production environment; (b) Food Animal Toxicology—the interdisciplinary approach to identifying and controlling the spectrum of chemicals (pesticides, herbicides, pollutants, natural toxins) which decrease yields in the intensive production environment; (c) Human Health Hazards—the interdisciplinary approach to identifying and removing from animals and animal products pathogens, toxic chemicals, therapeutic drugs, growth promotants, growth permittants, hormones, etc. (substances derived from intensive production practices); (d) Genetic Engineering for Disease Prevention and Resistance.

The first three of these "research imperatives" reflect the great change occurring in animal agriculture in many parts of the world—the change to large-scale corporate or collective production units. The demand from producers is to switch the emphasis in research from the epidemic or exotic diseases to the endemic or endogenous diseases associated with stress in the intensive production setting. For example, in the U.S. there is a demand for shipping fever (*Pasteurella pneumonia*), mastitis, and new-born diarrhea research, not for vesicular disease or vector-borne disease (bluetongue, Rift Valley fever, Venezuelan equine encephalitis, etc.) research. The inclusion of Genetic Engineering for Disease Prevention and Control in this list also serves the purposes of intensive production agriculture, especially since the most common diseases associated with this kind of agriculture have proven refractory to conventional prevention and treatment approaches. However, the application of genetic engineering promises to help all livestock producers, worldwide, whether they be large corporations or collectives, family farm units, or peoples surviving by subsistance farming (Murphy, Brown & Obijeski, 1983).

If the promise of comprehensive programs for livestock disease control is to be organized rationally, one need is to establish priorities for research support. Priorities should be set in accord with the relative importance of particular diseases—in the intensive production environment and in the production environment of developing countries. One attempt at this was made at a workshop on "Priorities in Biotechnology Research for International Development", held in 1982 and sponsored by the National Research Council and the Agency for International Development (U.S.A.), the World Bank, and the Rockefeller Foundation (BOSTID, 1982). In the report of this international workshop high priority is given to research support for new or better vaccines in general and for vaccines for the following diseases in particular: (a) Neonatal diarrheas—including viral diarrheas; (b) bovine respiratory disease complex—including viral pneumonias; (c) African swine fever; (d) hemotropic protozoa—trypanosomiasis, East Coast fever, babesiosis, anaplasmosis; (e) tuberculosis. The next priority category included vaccine research for Rift Valley fever, bluetongue, hog cholera (swine fever), African horse sickness, the equine encephalitides, pulmonary adenomatosis and related retrovirus diseases of sheep and goats, pseudorabies, and vesicular stomatitis. Rabies and foot-and-mouth disease vaccine research was also recognized as very important, but it was considered that research on these is well funded at present. This grouping of priorities is always subject to revision according to needs of the area, but the overall hope is that this list, and similar lists developed by others, will be used by international agencies as they consider support for research. Any such list will emphasize the animal pathogens of Africa.

Priorities for Human Disease Research

At the same workshop as cited above (Priorities for Biotechnology Research for International Development; BOSTID, 1982), priorities were set for human diseases also, and again, the emphasis was on prevention/control strategies based upon vaccines. The highest priority for vaccine research was reserved for rabies (human vaccine only), dengue, Japanese encephalitis, bacterial respiratory diseases (*Streptococcus pneumoniae, Hemophilus influenzae* Type B, *Bordetella pertussis*), bacterial enteric diseases (*Campylobacter jejuni*, enterotoxogenic *Escherichia coli, Salmonella, Shigella, Vibrio cholerae*), chlamydial infections, malaria, and leishmaniasis. This list is interesting from several standpoints: First, unlike the animal disease priority list developed by the same committee, the human disease list places extra emphasis on epidemic diseases such as dengue and Japanese encephalitis. Second, the human disease list emphasizes more the diseases of the developing world. Third, the human disease list includes several zoonotic diseases. Unlike many other human disease priority lists, this one is not dominated by the endemic infectious, degenerative and neoplastic disease problems of urban, developed world societies.

I do not believe that these differences in focus were intended; they are simply reflections of (1) the current vaccine status for particular diseases of man and animals, (2) the real impact of particular diseases of man and animals on human welfare (serious morbidity, mortality, interruption of food supply, etc.), (3) the current funding situation for research on particular diseases, worldwide, (4) the feasibility of vaccine development for particular diseases (including financial feasibility), and (5) the economic loss represented by particular animal diseases or the economic cost of control of particular human diseases. A major influence upon our thinking about research needs is the excellent quality (safety, efficacy, but at high cost) of current vaccines for most of the epidemic human diseases (measles, rubella, mumps, diphtheria, polio, and now hepatitis B) versus the poor quality (with poor quality control and poor cost: benefit ratios) of vaccines for livestock. The difference in focus between the human disease and animal disease lists suggests a widening of the gap between human and animal disease research activity, and between research efforts directed at disease problems of developed versus developing countries.

Modern Epidemiology

Epidemiology is the study of the distribution and dynamics of disease in populations. The word "distribution" implies that study is focused on characteristics of the individuals attacked by the disease agent, and the word "dynamics" implies that study is focused on the element of time—trends, intervals, cycles, etc. By introducing quantitative measurements of disease trends, epidemiology has come to have a major role in alerting and directing disease control activities and agencies. Despite this rather political reputation, the most important use of epidemiology lies in its service to medical and veterinary science—its most important use is to improve our understanding of disease. In this regard, it stands together with disciplines like pathology and the other basic medical and veterinary sciences. Epidemiological study is particularly effective in (1) clarifying the role of micro-organisms or environmental determinants as aetiologic agents, (2) in deciding factors of susceptibility, (3) in unravelling modes of transmission, and (4) in field testing of prophylactic and therapeutic measures (Sartwell & Last, 1980).

[While reviewing the basic approaches of modern epidemiology, I could not help but think of how Arnold Theiler might have used the powerful analytic techniques of today. In some of his early studies, roadblocks were based upon the technical impossibility of isolating and characterizing aetiologic agents (e.g., rinderpest, African horse sickness). In these cases, it is amazing how much ecologic information he developed without the advantages which derive from having aetiologic agents isolated and behaving well in the laboratory. In some other of his early studies, aetiologic agents were identified and assays for their presence were used to unravel the natural history of diseases (e.g., East Coast fever, babesiosis). In such cases, the approaches of modern epidemiology might have added significantly to Theiler's understanding of the full scope of the complex diseases he dealt with. However, my imagination peaked when considering how Theiler would have been helped by modern epidemiology in his lamziekte studies. The subtlety of his early field and experimental evidence, the problem he had in judging the contribution of multiple determinants of disease, the frustration he experienced with the elusiveness of the primary aetiologic agent in an impossible background flora, and his difficulty in trying to sort all the variables of climate, weather, plant life, soil composition, and the variable presence of carrion, all would have been worthy targets for the methods of modern epidemiology (Gutsche, 1979).]

It has been said that because the science of epidemiology extends the perspective of the physician and veterinarian beyond personal experience, it "completes the clinical picture." It is clear from this thought that the product of epidemiologic investigation must not only serve organized disease control agencies, but must serve medical and veterinary practitioners as well. [Again, Theiler is a role model. He pioneered in communicating his findings to the farmers of the Transvaal and all of South Africa (Gutsche, 1979).]

The methods of modern epidemiology are based on clinical investigation, laboratory testing and field observation. The methods overlap with those of demography and biostatistics; at the centre of this overlap is the measurement of rates, that is the measurement of numbers of events (e.g., cases, deaths, etc.) per the population at risk. Rates are most valuable when measured in ways as to be explicit relative to time, place, and case characteristics, but often there are problems in obtaining sound numerator and denominator figures. Human disease epidemiology has evolved reliable data for measuring populations at risk (e.g., mortality statistics which are kept in nearly every country, morbidity statistics which are kept in few countries). It is a significant failing that we have no such data available for animal morbidity and mortality in any country.

The reporting system which yields morbidity and mortality statistics can become part of a disease surveillance system, which simply means a systematic regular scheme for the ascertainment of disease incidence. Surveillance systems represent the most powerful means to detect changes in disease trends or distributions. They can integrate mortality and morbidity data, but can also use laboratory data, case records, disease reporting registries, sentinel reports, epidemic reports and other health statistics. All of these epidemiologic systems and methods and many others are used at the Centres for Disease Control in the U.S.; in addition, communication is greatly helped by the weekly publication of Morbidity and Mortality Weekly Reports (MMWR), wherein tabular incidence statistics and narratives on current issues keep everyone interested in human disease control informed. Internationally, the WHO Weekly Epidemiological Record serves the same purpose.

In the U.S., a livestock morbidity/mortality reporting system, perhaps ultimately resembling the CDC's Morbidity and Mortality Weekly Report, has been discussed many times over many years. A few years ago in the U.S., there even was a national symposium on this subject. More modest, state-wide and regional systems have also been considered, as a way to get started—but, in fact, little has been done. It is true that the development of a useful system, one that would overcome incompatibilities of computers and incompatibilities of personalities (we call this the issue of "turf"), would be difficult, at all levels of organization needed, but then again, it was also difficult to bring the MMWR to its present level of reliability and value. Internationally, would it not be of great value to have OIE statistics match in quality those of the Weekly Epidemiological Record? I believe that such a system for livestock morbidity/mortality statistics would be cost effective. In the U.S. such a system would show that disease losses in livestock are so costly that increased research support would be quickly justified. In the international community, such a system would help agencies and foundations realize the true impact of livestock diseases on human welfare and would help focus resources thereby allocated on the most important problems.

Ongoing regularized surveillance must be complemented by surveys of disease incidence. Surveys, carefully conceived and run, serve to fine-tune the information base for some diseases, and help to expose, quantitatively, some more subtle disease conditions. In developed countries, where focus is turning more to endemic, chronic, opportunistic and subclinical infections, in the wake of control of the acute, epidemic diseases, this approach is most important. For example, in order to identify appropriate risk populations for most effective use of hepatitis B vaccine in developed countries, demographic/serologic surveys are being conducted. In this case, initial focus was on the risk faced by health care workers, but surveys are showing that they represent only a small part of the population at risk. Now, a conscious decision must be made in regard to expanded vaccination programs (S. Hadler, 1983, personal communication). As another example, herd-health studies in the swine industry in Denmark, using survey-based and other data, revealed an economically important impact of pneumonias upon weight-gain on some farms, in circumstances where conventional veterinary care failed to indicate any problem. Now, a conscious decision must be made in regard to disease prevention (via barn design improvement) and control (via antibiotic usage, etc.) (O. Aalund, 1981, personal communication).

This kind of herd-health approach to livestock disease analysis and control is the basis for innovative programs being developed at 2 colleges of veterinary medicine in the U.S., the University of California and the University of Minnesota. Epidemiology is the central science in these programs—quantitative population studies, with integrated, interdisciplinary inputs for assessing all factors responsible for livestock production losses, and for designing strategies for optimizing production. The herd or flock is the unit studied, not the individual animal—the approach is rather like that used in the poultry industry for many years. Inputs from some veterinary sciences are important: reproduction and reproductive diseases, nutrition and nutritional diseases, microbiology and infectious diseases (especially pneumonias, diarrheas, foetal and neonatal infections, mastitis, metritis, and similar "endemic" infections common in the intensive production environment). Non-veterinary sciences form a major part of this approach also: agricultural economics, industrial management, statistics and computer science, animal housing engineering, genetics (population genetics, Mendelian genetics, molecular genetics), etc.

The promise of this approach is great; it fits in with the corporate or collective organization of modern agriculture in developed countries. By contrast, traditional veterinary medicine as practised in some countries, with its focus on the individual animal, might be judged as somewhat out of touch with the economic realities of modern livestock agriculture. In this regard, the dichotomy between companion animal and livestock veterinary medicine promises increasing difficulties in designing curricula, organizing clinical training, and integrating postgraduate programs in the veterinary colleges of the developed world.

In the past, epidemiologic surveys and other such studies were descriptive in nature, but now they are more analytic. That is, they allow formal testing of hypotheses. In the jargon of epidemiology, analytic surveys or studies are divided into two types: One is "the cohort study", often referred to as the prospective study; in this case, a population at risk and a control population are chosen, and then followed over time to identify the determinants of the disease in question. New data are obtained, new records are created. Such studies are slow, expensive, complex, but suffer less from intrinsic biases. The second type of analytic study is "the case-control study", often referred to as the retrospective study; in this case, a review of available records and data on an involved population and a matched control population is undertaken with the aim of quantifying differences which point to the determinants of the disease in question. Such studies are quick, inexpensive, often simple in design, but must be controlled carefully to avoid biases (usually derived from the choice of the control population) (Brachman, 1979).

Case-control studies form the bulwark of modern medical epidemiology—they allow timely estimation of many important factors which predict disease incidence, disease spread, disease prevention and control. The design, and therefore the power, of case-control studies has improved greatly in the past few years, partly because of continuing experience and partly because of improved methods of data analysis. For example, in the U.S. at the CDC, analyses of case-control studies (and of surveillance data, *per se*) of AIDS (acquired immunodefficiency syndrome) is yielding more and more information about risk factors, transmissibility and aetiology. In this case, where aetiology is unproven, laboratory tests are of only presumptive significance, animal models are nonexistent, and public hysteria is high, the value of modern epidemiology stands out sharply.

One would hope that more use would be made of case-control studies in veterinary medicine, but at least in the U.S., this is not the case. The key to changing this failing lies in education—individuals entering careers in animal disease control should be trained in basic epidemiologic methods and then should be supported to obtain advanced experience in those centres practising the science at a "state-of-the-art" level. The same goes for individuals entering fields which support animal disease epidemiology, such as veterinary diagnostics, immunology, pathology, toxicology, "vaccinology", etc. A fine model of this approach is that of the Australian National Animal Disease Laboratory (ANAHL), soon to be opened at Geelong, Victoria. The developers of this laboratory intend to develop the very best competence in each science appropriate to the mission of the laboratory; toward this end, staff appointees are (or will be) obtaining training, experience and perspective in the best places possible, not only in the other animal disease laboratories of the world (I. Parsonson, 1983, personal communication).

Epidemic Investigations

When there is an outbreak of disease, it must first be recognized, hopefully at the level of primary medical or veterinary care. When a disease emerges in a new setting, there are shortcomings in recognition, but the only way this can be avoided is by an elevation in the "level of suspicion" which is instilled as part of professional training. Beyond recognition, most further activities appropriate in the face of a growing outbreak or epidemic depend upon professional organization and specialized expertise. The time has passed when the well-meaning individual can be seen to play a central role. Early in an outbreak or epidemic there must be focused investigation: this must include (1) a characterization of clinical features as the basis for diagnosis and differential diagnosis (epidemiologists are taught to personally verify clinical observations), (2) an identification of the etiologic agent, (3) a description of the incubation period, period of illness and period of communicability, (4) a measure of population susceptibility and acquired immunity, (5) a quantitation of the magnitude of the outbreak and the kinetics of its spread, and (6) a search for reservoirs and modes of transmission (Murphy, 1979).

Just as such an investigation requires several different professional expertises, so does the delivery of prevention and control efforts. In usual endemic circumstances, disease control may be based upon routine activities such as prophylactic immunizations or control of arthropods and rodents, etc.; however, in epidemic circumstances, control programs more commonly require delivery of a whole package of resources, including technically trained personnel, special equipment, supplies, transportation, and funds. Resource needs might be of such magnitude as to support large-scale tasks such as the limitation of movement of people and/or animals, the curbing of contacts by isolation of the immediate environment, or even the implementation of quarantine under national or international regulations.

The concept of quarantine has an ancient basis, but it must not be seen as the ultimate control measure. First, the value of quarantine is often limited, especially with zoonotic or arthropod-borne disease agents, and second, there is little help provided to the people or animals caught on the wrong side of a quarantine line. Wisdom is called for; for example, there would be little value in applying smallpox quarantine strategy in a yellow fever epidemic in West Africa, and there would be little value in applying the standard foot-and-mouth disease quarantine and slaughter policy in a Rift Valley fever epidemic in sheep in Egypt.

This is not a trite comment; in 1971, in the U.S., in the face of an epidemic of Venezuelan equine encephalitis crossing the border from Mexico, APHIS, the agency of the U.S. Department of Agriculture charged with animal disease control, behaved very much as if dealing with foot-and-mouth disease. That is, the agency exhibited little sensitivity to the particular problems involved in controlling a vector-borne disease, with the result that there were major failings in diagnostics, entomology, and particularly in field activities. The fortuitous availability of vaccine from the U.S. Army and the experience of the U.S. Public Health Service in dealing with vector-borne disease control saved the day. Little has changed since then; in 1982 there was a major vesicular stomatitis epidemic in the western mountain states of the U.S., but APHIS did nothing other than to determine that it was not foot-and-mouth disease. The U.S. Public Health Service initiated studies which have begun to unravel the mysterious natural history of this virus. In 1983, an exotic serotype of bluetongue virus was discovered in Florida; again, APHIS reacted with confusion, and relatively little has been done to ascertain the risk to U.S. livestock represented by this virus. In none of these examples did the U.S. Department of Agriculture react by conducting or supporting new research or by developing new control technology—this would have caused more "turf" problems between APHIS, the animal disease control agency, and ARS, the agricultural research agency. I wonder if the same kinds of problems occur in other countries?

It seems clear that there is no substitute for systematized capacity to deliver comprehensive disease control measures of many kinds into environments of many kinds. However, what is the means by which this might be done internationally? For some epidemic human diseases, a central structure, the communicable disease unit of WHO, Geneva, is already in place and working well. This unit responded well to the Ebola virus epidemics in The Sudan and Zaire in 1976, to the yellow fever epidemic in The Gambia in 1979, and it has responded well in many other episodes. I am not sure that there is any parallel resource in place or planned by FAO for responding to animal disease epidemics. The great epidemics of African horse sickness, Rift Valley fever, rinderpest, African swine fever, and others, seem to have gone unnoticed at FAO. In any case, there needs to be more discussion of international cooperation through a central organization with appropriate expertise for epidemic livestock disease control. The present epidemic of rinderpest now sweeping sub-Saharan Africa, at a time when financial resources are in desperate condition, could serve as a focus for such discussion.

Clearly, the costs for such disease control organization and for action programs would be modest in relation to benefits—just as they were for the WHO Smallpox Eradication Program or the U.S. hog cholera elimination program.

The Expanded Use of Epidemiological Methods in Animal Disease Control Programs

The problem restated

There will be a continuing change in the kind of animal diseases we see most often as agricultural practices change. Intensive production systems involve: (1) high concentrations of animals in small spaces; (2) a high asynchronous turnover of stock; (3) fewer and less well trained personnel; (4) more mechanization and more elaborate housing systems; (5) limitation of the husbandry system to one species; (6) manipulation of natural biological rhythms (artificial daylight, oestrus synchronization, etc.); (7) use of premixed, easily digestible foodstuffs; (8) improved hygienic conditions; and (9) isolation of closed animal populations (Bachmann, 1978). Two consequences follow upon this situation; one, these conditions favor the emergence and spread of infectious diseases, usually endemic, opportunistic or chronic diseases (the hardest kind of diseases to diagnose or treat, and the hardest kind of diseases to study), and two, these conditions favor multiple infections working synergistically (further compounding diagnostic, therapeutic and research activities).

Intensive livestock production systems make use of much vaccine, some of which is the cause of more trouble than the original diseases thought to be prevented. Live-virus vaccines may be dead, inactivated-virus vaccines may be live, and vaccines may carry other pathogens. The care which Arnold Theiler took to avoid the latter has not been matched around the world in recent years (Bachmann, 1978).

Intensive livestock production systems are associated with fast transport, and with international movement of animals and animal products. Problems associated with rapidity of animal movement, semen movement, biologics movement, etc., are complemented by the scale of populations rendered immediately at risk upon introduction of a pathogen from a distant source. For example, a modern cattle or lamb feedlot is large, indeed (in Colorado the largest cattle feedlot can feed 500 000 animals). High concentrations of animals in one place occur in the modern swine farrowing house (in Iowa the typical swine production unit holds 300-500 sows), the modern large dairy (in California the typical dairy milks 5000 cows), and the modern broiler house (in Georgia the typical broiler house houses 50 000 birds). It seems clear that because of legal and illegal transport, disease problems will be the same wherever in the world such production schemes are tried.

None of the basic characteristics of intensive livestock production systems are going to change because of disease constraints, the economics of these systems is such that losses due to diseases are small relative to gains due mainly to feed efficiency. Human welfare must be served by improving the systems, minimizing disease losses, and thereby increasing the amount of animal derived food and fibre available.

The solution

The chief constraint for developing better health management in intensive livestock production systems is methodological. The key is the introduction of modern epidemiologic methods into the training and experience of veterinarians and other animal scientists concerned with livestock production. For example, the following is a list of "research imperatives" outlined under the heading Animal Health in the proceedings of the 1980 conference on Animal Agriculture; Research to meet Human Needs in the 21st Century (Pond *et al.*, 1980). Modern epidemiology is the key to accomplishing each of these worthy goals:

(1) Develop combined disease and production monitoring systems to measure the effects of diseases, disease determinants, and production practices in the actual production environment.
(2) Develop integrated (interdisciplinary-multifactorial) methods to determine and quantify factors responsible for losses and inefficiencies in the production environment.
(3) Devise analytic systems to support the development of practical strategies for control of production diseases.
(4) Develop computer simulation models for production diseases to assist in the development of control procedures and to predict biologic and economic consequences of particular strategies for disease control.

Since this far-reaching set of recommendations was made, nothing has been done to assure progress. No new epidemiology research or training programs have been started by the U.S. Department of Agriculture. Still, the concept is an excellent one, and the "research imperatives" stand as certain needs. Perhaps something might one day be done.

Internationally, the concept underpinning better cooperative disease control organization deserves further discussion. Such discussion must allow for differences in the structure of agriculture and of agricultural research and disease control agencies in different parts of the world. Perhaps there will be opportunity to discuss this matter here in Onderstepoort, today. This would be fitting; it would be in keeping with the respect we all share for the memory of Arnold Theiler.

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