Disease outbreak response: why epidemiology plays a central role

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Summary

The rationale for controlling transboundary animal disease outbreaks and the need for evidence-based decisions regarding which control measures to implement is widely recognised. Key data and information are required to inform this evidence base. To ensure effective communication of the evidence, a rapid process of collation, interpretation and translation is required. This paper describes how epidemiology can provide the framework through which relevant specialists can be engaged to this end, and the central role of epidemiologists, with their unique combination of skills, in this process. It provides an example of the National Emergency Epidemiology Group of the United Kingdom that was established to address this need. It then goes on to consider the different strands of epidemiology, the requirements for a wide multi-disciplinary approach, and the importance of training and preparedness activities to facilitate rapid response.

Keywords

Animal disease control – Epidemiology – Evidence-based decisions – Rapid response – Transboundary.

Introduction

The case for controlling outbreaks

Transboundary animal diseases have been defined as highly contagious epidemic diseases that can spread extremely rapidly, irrespective of national borders [1]. The need to control them is recognised internationally. New contagious diseases introduced into naïve livestock populations can have serious public health, animal welfare and societal consequences and in extreme cases affect the national economy of a country. This led to the creation of the World Organisation for Animal Health (WOAH, founded as OIE) in 1924 to enhance preparedness and standardise control of transboundary livestock diseases at a global level. Today, the Organisation provides a standardised reference frame of diseases, surveillance and control mechanisms for the WOAH-listed diseases [2]. The Food and Agriculture Organization of the United Nations also recognises the potential disastrous consequences that animal diseases can have on society, and established the Emergency Prevention System for transboundary animal and plant pests and diseases to support early warning and early reaction to transboundary infectious animal diseases [3]. The argument for 'early' is to limit the consequences, including the potential for the pathogen to jump into populations, where control is more complicated e.g. wildlife, or has greater impact e.g. zoonoses.

The case for understanding outbreaks in order to control

Once a WOAH-listed transboundary disease is detected in a member country (outwith quarantine), an outbreak is declared, and emergency control plans are triggered. There is a need to quickly identify, contain and eradicate the infection, and in many cases the outbreak is controlled by managing the primary case and possibly a few traced contacts. However, uncertainty is inherent in outbreak control and during the outbreak it is difficult to predict the ultimate size due to uncertainty around identification of infected holdings. Without an understanding of the primary (initial introduction) *versus* the index (first detected) case, mode of introduction, spread, pathogen and population, control efforts will be reactive rather than preventive. As understanding of the outbreak grows during the control stages, identification of infected premises is likely to become less reactive, and more targeted surveillance and control measures can be implemented. Reducing uncertainty and enhancing understanding of the epidemiology of the outbreak will reduce the risk of inefficient or ineffective use of resources, by more appropriately focusing and prioritising control efforts in a proportionate, risk-based manner, such as the concentric rings of differential surveillance around the foot and mouth disease (FMD) outbreak in the United Kingdom (UK) in 2007 [4, J. Gibbens, personal communication, 2022]. Haphazard or 'blanket' control efforts can prolong an outbreak, increase the impact on public finances and lead to dissatisfaction or worse e.g. mistrust in the measures from trading partners, livestock industries and the public.

Evidence informed decisions

Disease control decisions during an outbreak are often taken by budget-holders and policymakers, guided by scientists, economists, operational staff and other technical experts. The high inherent uncertainty and initially limited understanding of the outbreak during the emergency, complicate decision-making. Control measures based on incomplete information can have wide-ranging negative impacts on the size of the outbreak and use of public funds and may affect the future trust between government and stakeholders. Therefore, it is paramount that decisions are based on evidence so they are as effective as possible and will stand up to scrutiny and demands for proof and audits [5].

Interpretation and communication of evidence to decision makers

Decisions informed by broadly sourced but imperfect evidence are usually better than decisions informed by one sided or no evidence, particularly if uncertainties are made clear. This generates a need for real-time processing and interpretation of all the information captured during every stage of an outbreak. Such information must be rapidly collated, analysed, interpreted and translated into understandable advice to support decision making because disease control decisions are made rapidly and continuously during an outbreak [6]. It is equally important that decision makers understand the inherent uncertainty around the evidence on which they make decisions. As noted by Pfeiffer 'uncertainty can then be handled by risk managers through introduction of more complex risk management strategies or by applying the 'precautionary principle'' [7].

Materials and methods: identifying and defining evidence requirements

Information captured as the basis for decision making

Throughout an outbreak, from detection of the index case to control and recovery, many different types of information are collected by various individuals or professions. All information collected can be considered as pieces of a puzzle and each piece tells part of the story, but is associated with uncertainty or even fallacies, if used in isolation to understand the outbreak. Anyone party to a piece of information generates opinions and advice based on that particular piece of information. It is important that the different strands of information required are identified and that each piece of information is generated by experts within that field of science to minimise the uncertainty around it e.g. samples should be analysed by competent laboratories to ensure valid results. Similarly farm production and tracing data on infected premises should be collected by someone familiar with animal husbandry and farm practices such as a veterinarian or a trained animal health investigator. These data need to be captured in an accessible and useable format in which linkages can be made. Even if these pieces of information are high quality, they do not explain the outbreak and therefore further analysis, collation and interpretation of all strands of information are needed to transform it into epidemiological evidence and further communicate this.

Types of information

The types of information commonly generated during an outbreak include:

- population data and maps showing animal density and location;
- clinical history;
- test results;
- pathogen characteristics;
- disease epidemiology and relevant risk factor information such as assessment of wild bird presence in relation to avian influenza;
- premise information including production data, production chains, husbandry practices and farm layout;
- disease timeline, tracing and contact information detailing movements on/off the farm;
- predictive modelling.

Actions needed to understand outbreaks and inform control measures

From a disease control perspective, once the index case is identified and contained, a critical next step is to identify and contain further transmission of infection. A timeline for the likely source and spread period must be estimated so that high risk contacts for potential spread and likely source of infection can be identified. Surveillance must be designed to ensure the detection and containment of locally transmitted infection. Equally to help understand wider related impacts, modelling may be commissioned to predict the likely size of the outbreak and determine the relative impact of potential control options.

Interpretation and communication of the information

The information needed must be elicited from a variety of sources and may not be standardised. However, it needs to be rapidly collated and interpreted, acknowledging the existing assumptions and uncertainty. The types of uncertainty often relate to the quality and timeliness of the data, test availability and characteristics, understanding of the pathogen including factors such as infectious dose, survival time and conditions, on-farm recording including personnel and vehicle movements. This collated evidence then needs to be communicated to decision-makers in a timely and easily assimilated way, including through the production of risk assessments to aid understanding of the uncertainties. Additional information may need to be sought to reduce outstanding uncertainty, such as further laboratory testing or interviews with the animal keepers about on-farm events or practices.

Results: the need for a central evidence team and the National Emergency Epidemiology Group example

The requirement for a central evidence team

A central team is needed to identify and engage with data providers, bring these strands of information together and to standardise definitions and format to aid collation and interpretation of the evidence. This team needs to include representation from the evidence providers but also those involved in the communication of the evidence to policy makers and operational colleagues. These relationships need to be built and nurtured between outbreaks. Whilst deep expertise is important, the individual findings need to be synthesised and contextualised with conclusions presented to decision makers on the current understanding of the animal disease outbreak, highlighting key areas of uncertainty. As the understanding of the outbreak develops, regular updates need to be provided to inform activities related to surveillance and control. International guidelines and legislative requirements will need to be adhered to but within this framework, adjustments may need to be made to account for resourcing, infrastructure and logistical limitations, as well as the trade-off between the cost and impact of different interventions and their potential to control disease. This is also needed to inform discussions on the wider impact of the outbreak on the primary production chain, animal welfare, international trade, public health and the wider economy and environment.

The case for epidemiology leading the central evidence team

The epidemiology discipline provides a good framework for bringing together, weighting, comparing and challenging conflicting evidence, as well as understanding, interpreting and communicating uncertainty. An epidemiological approach can also make best use of the varying levels of quantification in information from qualitative risk assessments to more in-depth quantitative analysis and modelling.

Epidemiologists are well placed to identify and bring these disparate sources of information together. Whilst understanding the various disciplines and information sources, they seldom generate the primary evidence e.g. test results or production data. This may help prevent confirmation bias, which could arise when scientists find evidence for a favoured theory, and may become insufficiently critical of their own results or cease searching for contrary evidence [8].

Example: the National Emergency Epidemiology Group

In the United Kingdom, a group called the National Emergency Epidemiology Group (NEEG) was established to address this requirement for a central evidence team, partly in response to the experience of the FMD outbreak in 2001 and to address a European Union requirement in the FMD Directive for Member States to maintain an expert group to conduct epidemiological investigations. The NEEG's purpose is to deliver high quality epidemiological advice and expertise in the event of an outbreak, so that the causes, level and extent of disease are described, high impact risks are flagged and future disease patterns are predicted. This supports and enables the development of policy, the management of resources and the implementation of successful control measures. A key function of the NEEG framework is the process for rapid, efficient channelling and translation of field information all the way from the affected epidemiological group of animals on the individual holding to the senior decision makers. Along the way it brings in technical expertise and analysis as part of the translation process.

This core group is comprised of three main teams:

- the field epidemiology team comprising veterinarians with field epidemiology experience and training;
- the analytical epidemiology team including quantitative epidemiologists, modelling co-ordinator and data scientists;
- the business management team, which is key to ensuring management of documents and meetings, maintenance of staff resourcing and welfare, audit and assurance.

The NEEG also includes representatives from the international disease monitoring team, risk analysts, disease and laboratory test specialists, species experts and wildlife/ecological experts as part of the wider science team. It sits both within the central outbreak co-ordination centre working in close collaboration with policy, laboratory experts and operational teams as well as the Chief Veterinary Officers (CVOs) of the UK administrations, but also within the field offices where the local activity is co-ordinated [9].

The NEEG is responsible for leading and co-ordinating the national epidemiological investigation of animal disease outbreaks. It designs surveillance plans, identifies risk factors and higher risk tracings and reviews modelling outputs to inform control measures. It identifies the most likely source of infection, outbreak timelines and knowledge gaps. It communicates its analysis of the outbreak through frequent, short epidemiology briefs for the CVOs, policy and operational senior managers and inputs to reports to WOAH. It also produces longer published epidemiology reports for wider stakeholders as well as regular verbal updates at strategic and operational meetings. It maintains preparedness between outbreaks through transboundary disease outbreak exercises, review of lessons identified, delivery of training and by involvement in endemic animal disease outbreaks.

A reduced version of the NEEG, known as the 'NEEG Lite' allows subsequent rapid scaling-up of response to highly suspicious report cases of notifiable diseases, such as FMD. It also facilitates the response to complex outbreaks of slowly transmitting notifiable animal disease and/or non-notifiable zoonotic diseases, such as bovine tuberculosis or *Salmonella* where an efficient structure is required from the outset to ensure effective management of the response, but potentially needs less resource to respond. The guiding principle is to apply the same organisational processes for all disease outbreaks. This can be escalated to the full NEEG structure if required. An important strength of the NEEG is its working plan which documents how to fit in with the wider 'battle rhythm' in an outbreak, ensuring the availability of the right people for attendance at the wide range of meetings, defining the frequency and purpose of meetings and outputs with pre-drafted agendas and templates, and *aide-mémoires* to guide members in their contribution to other parts of the outbreak response. This enables rapid deployment and a common understanding of purpose.

Table I shows proposed deliverables which were part of the working plan when the NEEG was established and demonstrates the central role played by epidemiologists in the evidence team. A further important NEEG deliverable is the production of qualitative and quantitative risk assessments to answer key risk questions such as the likelihood of equine infectious anaemia spreading beyond the original infected premises in southwest England, which was assessed as negligible in 2012 [10]. An adaptation of the qualitative risk assessment, known as 'the veterinary risk assessment', is also used to help frame advice in terms understood by non-technical policy decision makers. This includes describing the potential risk pathways, risk factors and mitigating factors, impacts and remaining residual risk as well as documenting any uncertainties.

Discussion

Could other professions/disciplines lead the central evidence team?

Leadership of the central evidence team is needed to co-ordinate and guide the epidemiological investigation of transboundary animal disease outbreaks, bringing together the evidence from a range of sources/experts and communicating it to key stakeholders. Whilst in the UK example, epidemiologists assumed this leadership role, there are also arguments for other disciplines doing so. Veterinarians have training in animal production systems, pathology and disease transmission. However, there may be less familiarity with population medicine, sensitivity of surveillance, interpretation of test and other data, the use of modelling and more complex analytical techniques. Disease specialists may also be candidates for leading this central team having deep understanding of the pathogen, its host, transmission and interaction with environment. However, as noted by Sutherland *et al.* multiple, independent sources of evidence and replication are much more convincing and disease specialists may not be best placed to bring all this together [8]. There is also the question as to whether separation from the production of the primary evidence is needed to ensure unbiased collation and analysis of evidence which is not unduly weighted. Equally the role of economists in helping to inform the use of limited resources provides an argument for leadership of this evidence team. However, there is a need to understand the different transmission pathways of infection/disease, and their relative probability, to inform the most suitable control measures which in turn contributes to the economic case.

The need for a multi-disciplinary team

More widely the central role of epidemiology is supported by Zepeda *et al.* who notes that a closer link between national animal health authorities and the scientific community should be established through epidemiologists when considering the implementation of the World Trade Organization’s Agreement on the Application of Sanitary and Phytosanitary Measures [11]. King also highlights the ‘importance of epidemiology in helping to define the parameters of an acceptable level of risk' [12]. The value of epidemiologists working alongside policy-makers and as part of a wider multi-disciplinary team has also been highlighted in a number of papers [12, 13, 14, 15, 16]. Hueston notes that 'animal health problems cannot be addressed by considering only biological and physical factors, but that applied epidemiology demands knowledge of the policy-making process and a wide range of social skills, including listening strategies, written and verbal communications, conflict resolution, negotiation abilities and an appreciation of cultural differences and diversity. The veterinary epidemiologist must be able to work as a member of an interdisciplinary team' [6].

This discussion focuses on transboundary animal disease outbreaks; however, it is suggested that the central role of epidemiology is also important in human health. The role of epidemiology and particularly field epidemiology in human disease outbreak response was reinforced by the World Health Organization's Joint External Evaluation tool, part of the International Health Regulations (2005) monitoring and evaluation framework which sets a target of one trained field epidemiologist (or equivalent) per 200,000 population and the establishment of the Field Epidemiology Training Programme initiative [17, 18, 19]. Another such example is the UK Public Health Rapid Support Team (UK-PHRST) established in 2016 following the 2013–2016 West African Ebola epidemic [20]. As well as noting the role of epidemiology in the UK-PHRST outbreak response, Raftery *et al.* highlights the need for a multi-disciplinary team including social and political science input as well as the need for local investigators leading on operational research [21]. The key role of epidemiology as part of a wider multidisciplinary team in human disease outbreak response has also been identified in several other publications [22, 23, 24].

Types of epidemiologists

In the NEEG example, epidemiologists are separated into two key areas:

- the field epidemiologists;

– the analytical epidemiologists.

The field epidemiologists lead the on-farm epidemiological investigations and input to local control measures, whilst the analytical epidemiologists input at a wider national level e.g. design of surveillance strategies, risk factor studies, review of modelling outputs and evaluating control measures. However, there is marked overlap, as the national level surveillance and control measures are informed by local findings and equally a national strategy needs to be deliverable in the field. There is therefore a question over the skills and experience required for each of these roles and the need for exchange of knowledge and common understanding. Both types of epidemiologists have interaction with policy-makers for strategic decision making and operational implementation of policies. For small, contained outbreaks the focus is more on the field epidemiology and operational considerations, whereas for larger outbreaks there is increasing importance placed on analytical epidemiology and modelling where forecasting and analysis to inform surveillance design and the selection and evaluation of control options is required.

Whilst it is argued that epidemiology is central to outbreak response, this is not to say that all functions should be located in one place and modern technology enables a geographically dispersed team to work effectively together. An important aspect of the field epidemiologist role is regional expertise which informs understanding of the local aspects of transmission of infection and source/spread.

Similarly, the need for analytical epidemiologists, who can withdraw from the hustle of the outbreak management, to carry out advanced analyses or key, in-depth research-type investigations is important during an outbreak. The closer to policy, the faster things move during a crisis, but a disease outbreak will often have an additional requirement for some profound and well-researched decision-support, alongside the rapid interpretations and advice. This emphasises the need for access to available analytical scientists, slightly away from outbreak management.

Maintaining expertise between outbreaks

To be able to rapidly respond to outbreaks of transboundary animal disease, sufficient training and preparedness activities need to continue between outbreaks [25]. For the NEEG, these include workshops and exercises involving different diseases, species and production systems which members of the team help to design alongside laboratory, disease and industry experts. These help to practice and test delivery of NEEG requirements. Equally as important is their role in ensuring continued awareness of changes in personnel and routes of communication with other teams and disciplines with which the NEEG works. Ongoing training of the existing team and new members is essential to maintain expertise and remain abreast of new developments in the evidence base e.g. understanding of pathogen survival and newer techniques such as whole genome sequencing. A further important activity is review of the lessons identified from previous outbreaks and measures taken to address these for the future.

Conclusions

The case for the central role of epidemiology in leading the provision of evidence to inform transboundary animal disease outbreak response has been presented in this paper. It underlines the relevance of the mix of different skills that are unique to epidemiology training and the importance of the impartiality that derives from not being a generator of the primary data. It illustrates how epidemiology binds together a wider multi-disciplinary team and enables collation, translation, and communication of the evidence to inform the rapid decision making often required during outbreaks. It is noted that whilst the rationale for the central role of epidemiology has been described, this does not mean that all epidemiological functions need be in one location with substantial benefit observed from some regional activities. Finally, the importance of preparedness and training activities is stressed to ensure rapid response. This not only includes epidemiological skills, expertise, information sources and outputs but also understanding of the linkages with other teams and disciplines that are key to effective outbreak response.

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Table I

Proposed National Emergency Epidemiology Group deliverables

Deliverable	Product and procedure	Expected deadline
Chief Veterinary Officers's brief	Brief report on epidemiological aspects of the outbreak e.g. suspected source, potential spread and risk factors	By 9.45 on 2nd morning following confirmation then daily or as agreed thereafter
Outbreak sampling strategy	Sampling strategy for infected premises, protection zones, surveillance zones, monitoring zones, other premises if required	Prior to and minimising delays to culling or other activities that would prevent sampling
Input to drafting of emergency instructions to operations	Defined details of sample strategy, collection frequency, testing laboratories, etc. in liaison with disease consultants	In time to be carried out before culling or other activities would prevent its implementation
First epidemiology report	Draft circulated to senior managers	8th day after confirmation or to fit international reporting demands negotiated in outbreak
International reports	Provide input into reports to international bodies including WOAH on the disease outbreak, often derived from the epidemiology reports	Linked to the 1st epidemiology report; delivery defined at start of outbreak

Commissioning of urgent, *ad hoc* reports on premises assessed as very high risk	Instructions to field epidemiologists to undertake onsite veterinary assessment sent via local operations leader	As soon as possible to prevent further disease transmission
Commission and produce additional epidemiology reports when required	Further epidemiology reports as agreed, including a final one that addresses all outstanding questions posed in previous reports, including a report of the final outcome of surveillance	Interim reports as agreed; final report within one month of declared freedom from disease
Attendance and informed/expert contribution at meetings	Amber telecom, bird tables and National Expert Group meetings [(a)]	As per battle rhythm
Returns to inform financial and resource outbreak management	A record of the time recorded by members of staff to ensure working hours are regulated and paid correctly	

(a) as defined in the Contingency Plan for Exotic Notifiable Diseases of Animals in England [9]
WOAH: World Organisation for Animal Health