Animal health and food safety assessments

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Summary

Animal health risk assessment is one of the key tasks of Veterinary Services. There are well-established protocols created by the World Organisation for Animal Health and Codex Alimentarius Commission for assessing risk. The areas covered include terrestrial and aquatic animals and zoonotic infectious diseases, food safety, and environment at the interface.

Much effort has been made in developing methods to estimate the probability of, and the consequences of infectious disease incursion to disease-free countries through legal or illegal trade or via the movements of insects and wildlife. Additional efforts have been made in the design of prevention strategies and contingency plans. Concerns about possible pandemics of avian influenza continue to be important motivation for monitoring viruses for selection of vaccine candidate strains. The recent COVID-19 pandemic has a zoonotic nature and caused extreme confusions to the world. Tools are becoming available for quantitative food safety risk assessments for bacteria, toxins, viruses, and antimicrobial resistance genes, including tools that allow simulations for the selection of effective control options. The application of participatory techniques facilitates the conduct of risk analysis in low- and middle-income countries. In internationally established frameworks, risk assessment has been considered a first step towards eradication of important infectious diseases in endemic countries; such assessments contribute to the reduction of disease risks. Quantitative and qualitative socio-economic and behavioural studies have been developed to design risk management options that may be acceptable and sustainable for the actors throughout value chains.

Keywords

Animal health – Aquatic animal – Food safety – Risk analysis – Risk assessment – Terrestrial animal.

Introduction

Animal health risk assessment is one of the key tasks of Veterinary Services. Risk is a probability of occurrence of an unfavourable event and its impact (1), and is a highly useful concept for management of terrestrial and aquatic animals and of zoonotic diseases. Trade in livestock and commodities of animal origin are vital to the global economy and have effects on the intensification of livestock systems of exporting countries. However, an importing country faces the risks of introduction of disease into domestic animal populations, and of food-borne diseases (FBDs) into the domestic human population; such risks must be carefully assessed before approval of importation. Such risks are encountered even when working within the legal framework for import/export trade. For instance, a recent risk assessment report suggested that the spread of African swine fever (ASF) into western and eastern European countries was due to legal trade in pigs and to the movement of wild boar, respectively (2). Moreover, pork products contaminated with ASF virus are being illegally carried in international passengers' luggage, as demonstrated by detection at customs check points in the international airports of several ASF-free countries (3). The risk from illegal importation of meat and meat products is not a new discussion, as outbreaks of foot and mouth disease (FMD), ASF, classical swine fever (CSF), and swine vesicular disease in countries formerly free from these diseases have been attributed to the feeding of waste meat to domestic pigs (4, 5, 6, 7, 8).

Over 60% of pathogens infecting humans are zoonotic (9), and terrestrial and aquatic animal-source foods are the most important causes of FBDs in humans. Health authorities are generally responsible for the prevention and control of FBDs, but under the One Health concept, Veterinary Services are important stakeholders in conducting food safety risk assessments, particularly at the production phase. The global threat of antimicrobial resistance (AMR) is associated with FBDs, but AMR is a much more complex problem due to relationships with antimicrobial use (AMU) in animals, mobile genetic elements, and factors in humans, including travel, antimicrobial availability, nosocomial infection, and immune status.

Hereafter, risk assessment frameworks, their challenges and benefits, and the latest developments in this field are discussed.

Frameworks for risk assessment

There are useful frameworks of risk analysis for Veterinary Services in designing, implementing, and evaluating risk management. The World Organisation for Animal Health (OIE) import risk analysis framework consists of hazard identification, risk assessment, risk management, and risk communication (Fig. 1) (10).

Hazard identification involves identifying the pathogenic agents that potentially could produce adverse consequences associated with the importation of a commodity. Risk assessment comprises four steps, including:

- release assessment (or entry assessment): assessing the probability of introduction of the agent with the commodity
- exposure assessment: the probability of exposure of the agent to the animal population of the importing country
- consequence assessment: the magnitude of the consequence caused to the importing country (e.g. expected final size of the infection, number of animals to be culled, or economic damage)
- risk estimation: an integration of the three assessments.

The assessment results can be presented either qualitatively (for example, extremely high, high, medium, low, extremely low, and negligible) or quantitatively. When the qualitative approach is taken, overall risk can be assessed using a risk estimation matrix, by identifying the cell where the probability row and the consequence column meet (Fig. 2). There is no uniform format for conducting a risk assessment, and the approaches can be flexible.

The OIE import risk analysis framework has been applied to AMR (11). In the risk assessment for AMR, release assessment evaluates the probability of selection of AMR bacteria by the use of antimicrobials at a farm, exposure assessment examines the probability that an individual ingests the AMR bacteria of animal-source food origin, and consequence assessment shows the effect of AMR in reducing the efficacy of antimicrobials that a physician may prescribe for a patient infected with the agent. The consequences can include an increase in days of illness, or an elevation in the deaths due to poor drug efficacy against the infection.

Another useful framework is the Codex Alimentarius Commission (CAC) risk analysis framework for food safety. The CAC risk analysis comprises three components: risk assessment, risk management, and risk communication, as summarised in Figure 3. The risk assessment starts when a food safety problem with an associated hazard is identified and a health authority decides to commission an assessment, which requires a clear statement of the specific purpose of the analysis. The risk assessment consists of four steps: hazard identification, hazard characterisation, exposure assessment, and risk characterisation. Hazard identification is the identification of biological, chemical, and physical agents that are capable of causing adverse health effects, and that may be present in a particular food or group of foods covered by the assessment. Hazard characterisation is the qualitative and/or quantitative evaluation of the nature (e.g. severity and duration) of the adverse health effects associated with those agents. If data are available, a dose-response assessment should be performed. Exposure assessment is the qualitative and/or quantitative evaluation of the likely intake of the agent via food, as well as exposures from other sources, if relevant. The quantitative information may include the frequency and volume of ingestion of the food by the population. The prevalence and concentration of the agent gives the actual frequency and volume of the agent consumed. Risk characterisation is the qualitative and/or quantitative estimation, including uncertainties, of the probability of occurrence and severity of known or potential adverse health effects in a given population based on hazard identification, hazard characterisation, and exposure assessment (12). The CAC guidelines for risk analysis of AMR also have been published (13). In this framework, AMU at farms, selection of AMR bacteria, and ingestion of the bacteria are included in the exposure assessment.

Challenge and benefits of risk assessment frameworks

The risk assessment frameworks are powerful tools for identifying and understanding the steps of how a disease event occurs in animal and/or human populations. Usually, a qualitative assessment may be conducted at the beginning of a risk assessment. This exercise is very useful for identifying knowledge gaps before proceeding to quantitative analysis, and for discussing the range of the risk assessment to be addressed, even if the risk question has been stated clearly. A quantitative risk assessment further provides the relevant authorities with a quantitative prediction of the risk, reduction of disease burden, and costs and time taken with a priori uncertainty for designed control options.

Risk assessment is complicated by several common challenges. One such challenge is a lack of information for risk assessment. Shortcomings may include unintroduced surveillance and monitoring schemes, failure to reliably maintain the data collection during surveillance, illegal and informal activities that escape legal monitoring frameworks, and gaps in biological and technical knowledge. A second challenge is the high level of quantitative skills required for reliable quantitative risk assessment. As research progresses on biology, socio-economics, and ecology, increasingly complex but very useful findings for risk assessment are discovered on a daily basis. The risk assessors always have to be developing new approaches to facilitate the needs of the risk manager, who in turn must be aware of such scientific developments and international discussions. This challenge also requires the risk manager to maintain current and correct understanding of technical developments in the field. A third challenge is that of assembling a good risk assessment team, one that includes high-standard experts of different backgrounds who can respond to such needs. A fourth challenge is engagement with real-world conditions to facilitate realistic risk assessment, which can provide the authorities with information for practical considerations in risk management. Finally, an excellent risk assessment may not result in designing and implementing effective risk management, unless careful and dedicated risk communications with stakeholders, sometimes including general population are taken. All of these challenges are associated with resource availability in each country; international cooperation is critically important for low- and middle-income countries, as well as for high-income countries, to provide a reduction in global disease risk.

Latest developments in animal health and food safety risk assessments

As described above, OIE import risk analysis may be implemented in any OIE member countries, permitting management of the risk from hazards associated with formal trade in animals and livestock products among OIE Members. However, illegal import of livestock, meat and meat products can pose significant risks to the livestock industry and public health. The framework of quantitative risk assessment through illegally imported meat was proposed in 2006 (15); this framework was applied soon thereafter to assess the risks from illegal importation to the United Kingdom (UK) of meat contaminated with FMD (4). The risk from illegally imported bushmeat also has been the subject of attention (8), as wild animals are a large and uncharacterised reservoir of unknown zoonotic and non-zoonotic disease agents (16). To overcome the lack of information on the numbers of illegal importation events and detailed travel records, the estimated weight of pork products in air passenger's luggage has been used in calculating the risk of ASF and CSF entry into the United States of America (USA) and Japan (3, 17).

Infectious disease modelling has had a long history since the development of the Kermack and McKendrick susceptible/infectious/recovered (SIR) model (18). Detailed predictive models were developed during the 2001 FMD outbreaks in the UK to understand the patterns of disease spread, and to plan and evaluate proposed control policies (19, 20, 21). Later, simulation models for FMD were used to assess the consequences of FMD virus entry into FMD-free countries (22), and a spatial and stochastic computer programme, InterSpread Plus, became available for epidemic contingency planning for infectious diseases such as FMD, avian influenza, and CSF (23). More recent transmission network models have combined genomic and epidemiological data to reconstruct transmission patterns (who infected whom) during infectious disease outbreaks (24).

Bluetongue (BT) has a significant global distribution in regions where the insect vector, *Culicoides*, is present (25), and the qualitative risk assessment for BT virus entry into the UK considered scenarios that incorporated incursion and overwintering of the vector, as well as the spread of the virus in animal populations in central and northern Europe (26). The use of detailed entomological and ecological study results may increase precision and preparedness in risk management for vector-borne diseases, including BT (27). Additional scenarios, including future predictions of the effects of climate change, are becoming available (28).

The world is currently suffering from a pandemic of SARS coronavirus 2 (SARS-CoV-2). Similarities in genome sequences suggest that SARS-CoV-2 may have originated in animals such as pangolins (29) and bats (30), and animal health is critically important in preparing for future pandemics in humans. Highly pathogenic avian influenza has caused several pandemics in the recent past, and the Influenza Risk Assessment Tool (IRAT) was developed by the Centers for Disease Control and Prevention of the USA. The Influenza Risk Assessment Tool permits assessment of the potential pandemic risk posed by influenza A viruses that are not currently circulating in people, facilitating decision-making for pre-pandemic vaccine production (31). The IRAT consists of ten evaluation criteria across three categories: properties of the virus, attributes of the population, and ecology and epidemiology (31), involving assessments of both animals and humans. The H7N9 avian influenza A viruses have caused human infection, notably via exposure in live bird markets in China since 2013 (32), and the H7N9 viruses isolated in Hong Kong and Shanghai in 2016 and 2017 were assessed as having moderate-high risk to cause pandemics (33). The Tool for Influenza Pandemic Risk Assessment (TIPRA), which involves the assessments of three components (the hazard, the possible exposure to the hazard, and the context in which the event is occurring), was modelled in 2016 after the development of IRAT (34). The TIPRA was intended to provide a standardised and transparent approach to support the risk assessment of influenza viruses with pandemic potential.

Understanding of the value chain greatly helps in predicting disease spread. A social network analysis in poultry market chains in southern China was found to be useful in risk-based surveillance for avian influenza (35), and network analysis has been elaborated further to calculate probabilities of infection at live bird markets and subsequent spread in Vietnam, considering the dynamics of poultry movement in that country (36). The volume of poultry trade has seasonal variations, and changes in the risk of avian influenza spread in poultry in Thailand has been analysed using exponential random graph models (37). In other work, a combination of network analysis in poultry value chain and genome analysis has provided a clear picture of the risk of avian influenza spread in China (38).

Risk analysis, particularly OIE import risk analysis, has been used in the management of aquatic animal health for international trade and for the spread of diseases between rivers, from farmed to wild stocks and vertical transmission, and disease emergence (39, 40). Ecological risk assessments have been conducted for antibiotics applied in fish farms and derived from hospital waste, looking at the effects on aquatic bacteria, green algae, invertebrates, and fish (41, 42). Contamination of ocean with plastics is a global issue, and risk assessments have been conducted for physical and chemical toxicity in humans through ingestion of microplastics in seafood (43).

Animal health risk assessment also is used for reducing disease risks in endemic countries. The Progressive Control Pathway for FMD control starts with risk assessment including value chain analysis, and based on the results, a national control programme is designed and implemented. The goal is to achieve and maintain freedom from FMD without vaccination. This process is jointly supported by the Food and Agriculture Organization of the United Nations, the OIE, and the Global Framework for the Progressive Control of Transboundary Animal Diseases (44).

Risk assessment has been applied for the harmonisation of multi-state policy. For instance, the countries of western Europe were declared free of rabies in nonflying mammals in 2015, following the risk assessment for travel-associated rabies in pets and residual rabies (45). This declaration indicates that costly post-exposure prophylaxis can be avoided, permitting optimisation of resource allocation (45).

A large number of cost-benefit analysis studies have been conducted for FMD control and eradication programmes (46). Cost-benefit ratio and risk can be considered together. The OIE import risk assessment and disease modelling have been applied for cost-benefit analysis on the scenario of rabies incursion in a disease-free country where mandatory dog rabies vaccination persists (47, 48). In a rabies-endemic country, Chad, a cost effectiveness study showed that the average cost per disability-adjusted life year (DALY) averted becomes cheaper than solely relying on post-exposure prophylaxis in humans in five years after implementation of dog rabies vaccination (49).

Disease control in outbreaks of exotic animal disease causes social and psychological impacts among farmers (50, 51) and veterinarians (52, 53). Assessment tools such as Impact of Event Scale-Revised for post-traumatic stress disorder (54) and Kessler 6 (K6) and K10 for psychological distress (55), based on a self-administered questionnaire about associated symptoms, are available and have been used for assessing the psychological impacts of animal disease outbreaks (51, 52).

The methodology of CAC quantitative microbiological risk assessment (QMRA) for *Salmonella* in eggs and broiler chickens was developed in 2002, following two years of international efforts in data collection (data used for analysing the dose-response relationship were obtained from outbreak investigation records in Japan since 1997) and analysis (56). Since the establishment of this methodology, many QMRAs have been conducted; however, such risk assessments represent a large challenge in countries where informal food chains dominate the food supply, and surveillance data are scarce. Participatory risk analysis offered a new paradigm to bring communities and food safety implementers together in assessing and managing risks in informally marketed animal-source foods, considering gender and other socio-economic aspects (57). Using participatory techniques, structures of formal and informal value chains were identified, and QMRAs suggested points of intervention at the farm, processing, distribution, and household levels (58, 59, 60). For example, a participatory QMRA for staphylococcal food poisoning through consumption of raw dairy milk and homemade yoghurt found that traditional fermentation reduced 93.7% of the risk, and interventions at farm such as mastitis control and milking hygiene are effective (58). Another example of participatory QMRA for salmonellosis in smallholder pig value chains in urban of Vietnam involving risk factor analysis and an experiment identified intervention points: weak biosecurity at farms, lack of clear separation between lairage and slaughter area in slaughterhouses, presence of flies and wiping pork with a cloth at pork shops, and use of same cutting board between raw and cooked pork in households (60, 61, 62). Quantitative risk assessment has been applied for toxins (63) using the OIE framework, and for viruses (64) using the CAC framework, although finding sound dose-response relationships is a challenge. In 2015, the World Health Organization estimated the global burden of foodborne diseases in 2010 as 33 million DALYs, a value comparable to the 'big three' infectious diseases of human immunodeficiency virus, acquired immunodeficiency syndrome (HIV/AIDS) (92 million DALYs), malaria (55 million DALYs), and tuberculosis (44 million DALYs) in 2012 (65).

The first quantitative risk assessment for AMR used a potential linear relationship between the proportion of chicken meat contaminated with fluoroquinolone-resistant *Campylobacter* and the number of human cases (66). However, AMR involves complex resistance mechanisms, including mobile resistance genes. The OIE risk assessment framework has been used to qualitatively assess the risks of pleuromutilin use in swine in Denmark, and this assessment incorporated co-selection of other AMR than pleuromutilin, multiple pathogens, and human-to-human transmission, including foodborne transmission (*enterococci*) and occupational exposure (methicillin-resistant *Staphylococcus aureus*) (67). A large number of AMR risk assessments have been conducted using the CAC framework as well (68). Mathematical modelling has started to be used to quantify the behaviour of resistance genes (69); however, it has been argued that existing gaps in our knowledge of AMR biology preclude the accurate use of such techniques (70). An individual-based simulation model was used for the quantitative release assessment of *mcr*-mediated colistin-resistant *Escherichia coli* from pigs, which enabled a priori assessments of intervention effects of different management options (71).

While guidelines and techniques for quantitative risk assessments continue to advance rapidly, the science related to the relevant behaviour of humans also is being developed; such behavioural analyses are expected to effectively reduce the risks. Systems approaches consider resource allocation, cost-effectiveness, and behavioural aspects of actors along the livestock supply chain; these behaviours may change dynamically, in non-linear ways, over time (72, 73), and can predict the applicability of intervention programmes in terms of economics. At the farm level, analyses have been conducted to evaluate decision-making processes in the context of farm biosecurity; such an approach may help in designing targeted intervention programmes (74). The 'nudge' theory, which describes how individuals can be encouraged to act in ways that produce net social benefits without restricting freedom of choice, has been used to design intervention programs for the actors along the pork value chain in Vietnam, thereby reducing the burden of FBD in that country (75).

In the near future, several approaches such as QMRA, mathematical modelling, genome sequencing, quantitative and qualitative socio-economics, and even artificial intelligence, all may be integrated into risk assessment to improve animal and public health while enhancing participation by the actors in the livestock and animal industries, as well as by communities.

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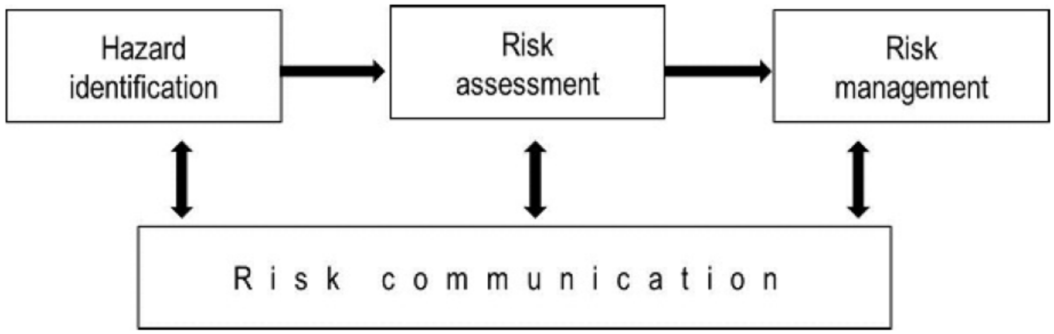

Fig. 1

The four components of World Organisation for Animal Health import risk analysis (10)

Probability						
High	Negligible	Very low	Low	Moderate	High	Extreme
Moderate	Negligible	Very low	Low	Moderate	High	Extreme
Slight	Negligible	Very low	Low	Moderate	High	Extreme
Low	Negligible	Negligible	Very low	Low	Moderate	High
Very low	Negligible	Negligible	Negligible	Very low	Low	Moderate
Extremely low	Negligible	Negligible	Negligible	Negligible	Very low	Low
Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Very low
	Negligible	**Very low**	**Low**	**Moderate**	**High**	**Extreme**

Consequence

Fig. 2

An example of a risk estimation matrix

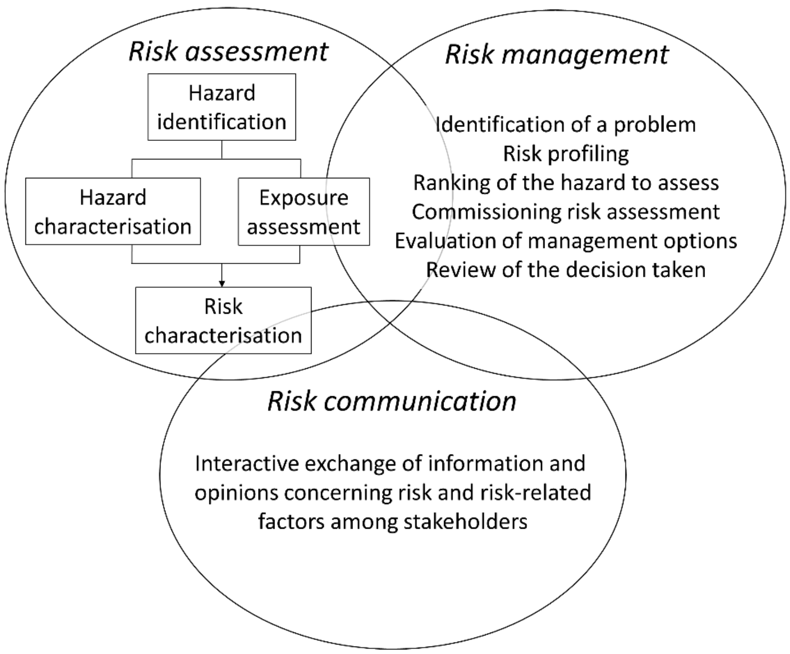

Fig. 3

Codex Alimentarius Commission risk analysis (14), based on (12)