Collection "Les savoirs partagés®"

Foot-and-mouth disease

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■ The point of view of the livestock farmer in a developing country ■ The point of view of the veterinarian in a developing country ■ The point of view of the livestock farmer in a developed country ■ The point of view of the veterinarian in a developed country ■ The point of view of the cow before 1961 ■ The point of view of the cow between 1961 and 1991 ■ The point of view of the cow after 1991 ■ The point of view of the wild animal ■ The point of view of the sick person ■ The point of view of the virus ■ The point of view of the vaccine ■ The point of view of the journalist ■ The point of view of the economist.

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Published with the financial support of several institutional partners, this educational handbook on foot-and-mouth disease is not meant for sale. It is meant to be distributed among diverse audiences with the aim of contributing to the dissemination of scientific knowledge and to supporting teaching projects reaching the greatest number of people possible.

Foreword

Partnership-oriented agricultural, pastoral, silvicultural, and veterinarian research aiming to support developing countries, which is the heart of Cirad's work, is constantly confronted with diverse ecological, socio-economic, and cultural environments.

When research outputs need to be converted into development actions, our researchers and their counterparts in developed and developing countries rely on multifactorial approaches to collect field study data and take into account local conditions.

Aware of the need to transfer scientific culture to diverse audiences, we have chosen to develop knowledge vectors using innovative scientific mediation processes that aim to be appreciated by both thematic experts and readers from very different backgrounds.

The focus of this handbook is foot-and-mouth disease, an extremely contagious viral animal disease affecting cattle, pigs, sheep and goats, which continues to be a health priority.

Although a number of European countries consider it to be a relic of the past, foot-and-mouth disease is endemic in some one hundred countries around the world. Countries recognized as being disease-free consequently face a constant threat, and their sanitary status could be called into question at any moment, with catastrophic consequences for international trade in animals and animal products.

The topic is addressed through a "multi-actor" or "points of view" narrative method. The central idea of the SAVOIRS team *(Service d'appui à la valorisation opérationnelle de l'information sur la recherche scientifique)* at CIRAD is to have each actor express his or her own perception of the scourge, which naturally varies depending on their position: livestock farmers and veterinarians in developing and developed countries, domestic and wild animal hosts, the virus, the vaccine, a journalist, and an economist.

Following a well-received French edition, this educational handbook now is being proposed in English to transmit knowledge about this re-emerging disease on an international scale. Over the course of 2011, designated as the World Veterinary Year, there have been numerous outbreaks of foot–and-mouth disease in North and South Korea, China, Vietnam, Japan, eastern Russia, Mongolia, South Africa, Botswana, Zimbabwe, Israel, Bulgaria and most recently in Paraguay, Tibet, and Malawi.

Confronted with this situation, the publication of the handbook is particularly significant because in 2012 initiatives will be taken to control this disease at a global level. The SEAFMD (South East Asia Foot-and-Mouth Disease) regional programme, which aims to eradicate foot-and-mouth disease from South East Asia by 2020, bases its activities on awareness building and communication campaigns for local populations.

The English version of this pedagogic contribution, supported by sixteen partner institutions, offers an innovative approach, one that I hope is convincing, to learning about the sciences and opens new pedagogical ways to understanding and making understood emerging and re-emerging diseases involved in contemporary global health scourges.

Gérard MATHERON
President-Director General
French Agricultural Research Centre
for International Development (CIRAD)

Partner institutions

AFD, the **French Development Agency** *(Agence Française de Développement)* is a public development finance institution that has worked to fight poverty and support economic growth in developing countries and the French Overseas Provinces for 70 years. AFD executes the French government's development aid policies. Through offices in more than fifty countries and nine French Overseas Provinces, AFD provides financing and support for projects that improve people's living conditions, promote economic growth and protect the planet: schooling, maternal healthcare, help for farmers and small business owners, clean water supply, tropical forest preservation, and fighting climate change, among other concerns. In 2010, AFD approved more than €6.8 billion for financing aid activities in developing countries and the French Overseas Provinces. The funds will help 13 million children go to school, improve drinking water access for 33 million people and provide €428 million in microloans benefiting more than 700,000 people. Energy efficiency projects financed by AFD in 2010 will save nearly 5 million tons of carbon dioxide emissions annually.

CIRAD, the **French Agricultural Research Centre for International Development** Development *(Centre de coopération internationale en recherche agronomique pour le développement)* is a French scientific organization specialized in agricultural research in developing countries and overseas departments of France. It works throughout the tropics and subtropics. Its mission is to contribute to the sustainable development of these regions through research, experiments, training, communication, innovation, and the provision of expertise. Its skills in life, social and engineering sciences are applied to food and agriculture, the management of natural resources, and social issues. Operating under the Languedoc-Roussillon regional office, the mission of SAVOIRS (Service d'appui à la valorisation opérationnelle de l'information sur la recherche scientifique) is to bring educational value to scientific, technical, and practical knowledge through innovative means.

CIRDES, the **International Centre for Research and Development of Animal Husbandry in the Sub-humid Zone** *(Centre international de Recherche-Développement sur l'Elevage en zone Subhumide)* is a regional, interstate body born out of the political will of seven member West African countries (Benin, Burkina-Faso, Ivory Coast, Guinea-Bissau, Mali, Niger, Togo). Its mandate is to conduct research aiming to improve the health and productivity of domestic animals to satisfy growing demand, notably for meat and milk, and increase incomes. CIRDES also aims to reduce poverty in member countries in such a way as to respect ecological equilibriums. In close collaboration with the national agriculture research systems of each member country, it conducts research, training, and output dissemination activities in the following fields: improved animal health and production, genetic conservation of species, environmental preservation, training, and technology transfers.

Partner institutions

CTA, the **Technical Centre for Agricultural and Rural Cooperation,** *(Centre technique de cooperation agricole et rurale)* is a joint international institution of the African, Caribbean and Pacific (ACP) Group of States and the European Union (EU). Its mission is to advance food and nutritional security, increase prosperity and encourage sound natural resource management in ACP countries. It provides access to information and knowledge, facilitates policy dialogue and strengthens the capacity of agricultural and rural development institutions and communities. CTA operates under the framework of the Cotonou Agreement and is funded by the EU.

EISMV, the **Interstate School of Veterinary Science and Medicine** Medicine *(Ecole Inter-Etats des Sciences et Médecine Vétérinaires)* of Dakar, founded in 1968, now groups together fourteen member states of sub-Saharan Africa: Benin, Burkina Faso, Cameroon, Central African Republic, Congo, Ivory Coast, Gabon, Mali, Mauritania, Niger, Rwanda, Senegal, Chad and Togo. The first task of EISMV was to provide training to veterinarian doctors that took into account actual conditions in Africa. Since 1994, it has expanded its teaching and research areas of expertise. In addition to its first task, the school provides continuing professional education, post-graduate training (Masters degree in veterinary public health, human food quality, and animal production/sustainable development), PhD training programmes (animal health and biotechnologies, animal production and biotechnologies, pastoralism) through the graduate school (life, health, and environmental sciences) of Cheikh Anta Diop University in Dakar. Furthermore, EISMV has defined four priority research avenues: aviculture, food security and safety, veterinarian medicines, and the development of local breeds. This institution, which has a regional vocation, thus puts its skills at the service of member States and partners through multiple forms of expertise.

FESASS, the **European Federation for Animal Health and Sanitary Security** *(Fédération Européenne pour la Santé Animale et la Sécurité Sanitaire)*, created in 2001, currently brings together national and regional professional federations responsible for animal health and the quality of animal products. The organization's aim therefore is to gather together all bovine, pig, sheep and goat producers in Europe, not forgetting other species like poultry, bees or fish. The primary objective of FESASS is the defense and the improvement of the European livestock's health status as well as its promotion among consumers in the European Union. As a technical organization, the FESASS acts first and foremost in the area of animal health. Thanks to the experience of its members, it contributes to the European discussion on regulated and unregulated diseases and takes part in devising action to fight these.

Partner institutions

FESASS also keeps watch on the expectations of the sector and consumers. It contributes to the discussion on the health quality of products and is active in creating guidelines for food safety, the use of veterinary medicines and for animal welfare. FESASS acts in conjunction with the EU Institutions and other European professional organizations. It contributes in partnership with other stakeholders in the animal health sector, to the devising and implementing of European animal health policy. At the international level, it participates in the discussions of the OIE, the World Organization for Animal Health.

FNGDS, the **National Federation of Livestock Health Protection Groups** *(Fédération Nationale des Groupements de Défense Sanitaire)* aims to ensure the overall national and international representation of Health Defense Groups (HDG), which are farmer organizations focused on health issues recognized by the Ministry of Agriculture. Its role is to promote the sanitary actions of HDG member farmers; defend and represent their collective interests and, in collaboration with the HDG involved, their individual interests with regard to quality, security and safety of food for and derived from animals; facilitate and coordinate efforts and actions of HDG members; serve as a permanent liasion for HDG members and promote their development; organize, coordinate, and implement all kinds of actions allowing these objectives to be achieved and notably to organize, coordinate, and implement all forms of professional solidarity mechanisms through the HDGs and for their members.

IAV Hassan II, the **Hassan II Institute of Agronomy and Veterinary Medicine** *(Institut Agronomique et Vétérinaire Hassan II)* is a polytechnical center in charge of training and research in the fields of agriculture, livestock husbandry, agro-industry, fisheries and the environment. Under the Ministry of Agriculture and Maritime Fishing of Morocco, IAV Hassan II provides specialized training in life and earth sciences and technologies (engineers, veterinarian doctors, and Phd in agronomy). Alongside its training programmes, IAV Hassan II actively particpates in the modernization of agriculture through innovative research programmes and development actions focussed on professional training and upgrading of businesses, technology transfers, and the sustainable management of natural resources. Research activities cover life and earth sciences, agricultural engineering, agro-food, topography, and management fields.

IFAH, the **International Federation for Animal Health** *(Fédération Internationale pour la Santé Animale)* is the global representative body of companies engaged in research, development, manufacturing and commercialisation of veterinary medicines, vaccines and other animal health products in both developed and developing countries across the five continents.

Partner institutions

IFAH represents both animal health companies (11) and national/regional animal health associations (26). These associations comprise both local small and medium-sized enterprises and international companies. Overall, these companies represent approximately 80% of the global market for animal health products. IFAH is an international non-profit organisation registered under Belgian law based in Brussels, Belgium.

INMV, the **National Institute of Veterinary Medicine** *(Institut National de la Médecine Vétérinaire)* is a public administrative establishment created in 1976 under the Ministry of Agriculture and Rural Development. INMV aims to provide technical and scientific support to national veterinarian services. This support provided by the technical and scientific departments takes the form of a network of seven veterinarian laboratories: one central laboratory (the LCV) and six regional ones (the LVRs). It is focussed on monitoring the quality and safety of animal products and foods derived from animals, the experimental diagnosis of animal diseases, carrying out surveys and participating in the development of a national epidemiological map in order to design plans to fight important animal diseases. In addition to these tasks, INMV also trains students, veterinarians, and para-veterinarian technicians and contributes to information, awareness raising, and health education activities for livestock farmers and the general public regarding animal health, veterinarian medicine, and veterinary public health.

INRA, the **National Institute for Agricultural Research** *(Institut National de la Recherche Agronomique)* is a mission-oriented scientific research organisation jointly managed by the French Ministry of Higher Education and Research and the French Ministry of Food, Agriculture, and Fishing. INRA defines and conducts research in the fields of agriculture, food, and the environment following an agro-ecological approach that aims to meet global food demand. Established in 1946, it is today the leading European agronomic research center with 9 000 collaborators and 4 100 researchers. It includes 14 research departments and 19 regional centers located across mainland France and in the Caribbean. The “Animal Health” department coordinates INRA’s research on infectivity, epidemiology, toxicology and animal therapeutics. Its 700 collaborators and 100 PhD students strive to gain in-depth knowledge of pathogenic agents infecting animals, a better understanding of how animals defend themselves, recognize how animal diseases spread and design innovations allowing the simultaneous conservation of livestock and public health.

Partner institutions

IRESA, the **Institute of Agricultural Research and Higher Education** *(Institution de la Recherche et de l'Enseignement Supérieur Agricole)* is a public administrative body endowed with civil personality and financial autonomy operating under the Ministry of Agriculture, Hydraulic Resources and Fishing. IRESA aims to develop and find funding for national research programmes, monitor and evaluate activities, facilitate coordination and complementarity between research and higher education institutions in the field of agriculture, and to ensure that these institutions contribute to agriculture production and development.

MAAPRAT, the **French Ministry of Agriculture, Food, Fishing, Rural Affairs and Spatial Planning** *(Ministère de l'agriculture, de l'alimentation, de la pèche, de la ruralité et de l'aménagement du territoire)* prepares and implements government policy on agriculture, rural affairs, maritime fishing and maritime crops, forests and wood. Responsible for agriculture education and professional training policy, it helps define agronomic, biotechnical, and veterinary research policy; plant and animal health policy and the promotion of quality agricultural and food products; social policy concerning farm heads and salaried workers; agrofood industry policy; policies regulating monitoring quality and safety of agricultural and food products and policies promoting the countryside, as well as participating in European and international negotiations involving its fields of competence.

MERIAL SAS is an innovative world leader in animal health, offering a complete range of medicines and vaccines to improve the health, welfare, and performance of a large number of animal species. With a long history of working with governments to control infectious animal diseases, MERIAL provides vaccines, services and solutions for numerous serious diseases, on the top of the list being foot-and-mouth disease, for which MERIAL is the world leader in manufacturing vaccines. Recognized by governments, international organizations (OIE, FAO), and other sector partners for its expertise, experience in vaccine production development, and the assistance it gives to countries faced with the disease, MERIAL is considered to be a major actor in the fight against foot-and-mouth disease.

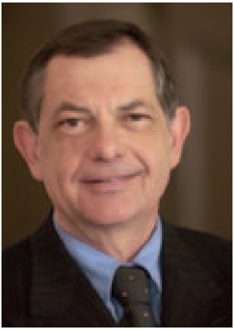
OIE, the **World Organization for Animal Health** *(Organisation mondiale de la santé animale)*, established in 1924, is the oldest intergovernmental organisation and, with 178 member countries, the most representative. In addition to its historic tasks of guaranteeing transparency with regard to the animal health situation around the world (managing an animal health surveillance and early-warning system), and of collecting, analyzing, and disseminating new scientific information concerning the fight against animal disease (through a network of 190 reference laboratories of excellence and 37 collaborating centers), OIE also is, under the terms of the WTO Sanitary and Phytosanitary Agreement, the reference organization charged with developing international standards for the sanitary safety of international trade in animals and animal products and helps determine the sanitary status of member countries with regard to certain diseases.

Partner institutions

OIE is a major actor in political and financial mechanisms of international cooperation assisting developing countries and those in transition. OIE actively seeks to reinforce the capacity of national veterinarian services and contributes to the development of animal health, veterinary public health, and animal welfare policies and to the structure of governance by investing significantly in new fields such as veterinarian education, relations between animal husbandry methods and climate and environmental change, research, and new technologies. OIE also is actively engaged in promoting initiatives at the global, regional, and national level for the development of laboratories to improve diagnostic and health data analysis capacities around the world, particularly in developing countries, through twinning programs with reference laboratories that have scientific expertise in the required field.

SIMV, the **Veterinary Medicines and Reagents Industry Syndicate** *(Syndicat de l'industrie du médicament vétérinaire et réactif)* is the French union representing pharmaceutical enterprises manufacturing medicines and reagents for pets and livestock. Veterinarian medicine exports are the equivalent of twice the French market, or 1.4 billion euros. SIMV is a member of France Vétérinaire International (FVI). SIMV aims to contribute to the ethical development of veterinarian medicines in France and for export to better meet demand for products satisfying international quality, effectiveness and safety standards.

SNGTV, the **National Society of Veterinary Technical Associations** *(Société Nationale des Groupements Techniques Vétérinaires)* is a technical veterinarian organisation regrouping nearly 80% of animal production practitioners. It contributes to the development and promotion of their skills. Its main tasks, carried out by its 15 specialized technical commissions are: - professional training (organization of conventions and training sessions; publishing a journal : the Bulletin des GTV); - creation and deployment of services, tools, and intervention methodologies on livestock farms (computer software, veterinarian medicine good practices guides, farm visit protocols); - involvement of practitioners in collective actions regarding animal health and veterinary public health; - technical representation of its members before the government, scientific organizations, and professional organizations.



Preface

Foot-and-mouth disease was the first animal disease shown to be transmitted by a filtrable infectious agent, before this same property had even been demonstrated for the agent of poliomyelitis in humans.

This infection thus has played an exceptional role in the history of biomedical sciences in general, and in veterinarian medicine in particular, for a very long time.

Since the establishment of the World Organization for Animal Health, previously named the Office International des Epizooties (OIE), foot-and-mouth disease has been the focus of much attention, particularly due to its exceptional transmission capacity, by direct and indirect routes, which makes it one of the most formidable cross-border diseases. In addition, the virus responsible occurs as numerous serotypes/topotypes and certain wild species, such as the African buffalo, are a reservoir for many of them, for example the SAT (South African Territories) strains.

Some countries, through considerable efforts combining animal health measures and vaccination, have succeeded in eliminating the disease from their territory and try to block it from reintroducing itself because this livestock disease is economically devastating and can dramatically upset international trade, which our organization seeks to safeguard through internationally recognized standards (Terrestrial Animal Health Code).

Unfortunately, foot-and-mouth disease still presents a mosaic of infection/disease situations at the international level.

Since May 1994, the OIE has put into place an official procedure to recognize the status of member states that are free of foot-and-mouth disease. Among the 178 OIE member states, only sixty can be officially recognized as being free of foot-and-mouth disease with or without vaccination.

Perceptions of foot-and-mouth disease vary according to whether a country is developed, developing, or in transition, whether it is disease-free or contaminated, and to the field actors: livestock farmers and veterinarians.

This handbook is a perfect illustration. It takes an original approach by presenting different points of view, from those of livestock farmers and veterinarians in developed and developing countries, to a journalist and an economist, while including with a light touch of humour those of cows, the virus, and the vaccine.

This timely work is intended for a very broad audience and will allow a wider understanding of the most important concepts regarding this disease.

One of the roles of our Organization is to guarantee the health safety of the international trade in foods of animal origin between countries with different sanitary status while trying to avoid unjustified trade barriers by importing countries. We do so through the scientific contributions of a network of collaborating centers and reference laboratories and the unflagging support of all 178 member countries.

I hope this handbook is distributed widely.

Bernard VALLAT
Director General
World Organization for Animal Health (OIE)

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The point of view of the livestock farmer in a developing country

Somewhere in Africa

As usual, I wait until the cows of the large herd owners have left the well before I lead our small herd of sheep and goats over to drink. It is the end of the dry season and there is little water left, so we can go to the well only once a day. My father entrusted this job to me because I do not go to the village school in the afternoon.

After filling the watering trough dug into a tree trunk, I notice that some of the animals are not drinking the way they usually do. One of the sheep stands with his head lowered and his muzzle hanging over the water, but he doesn't bother to open his lips. He usually pushes the others aside to be the first to drink. I pull him aside. He seems to have a problem with his feet. Could there be an acacia thorn stuck in his hoof ? I examine his feet and legs. When I touch him, the sheep starts. And yet I did not press very hard with my fingers. I find a wound on one of his legs just above the hoof. Could he have been hurt by a rock? Puzzled, I study him more closely. His skin is hot and his nostrils are dirty. I open his mouth and hold him firmly between my legs but he hardly struggles at all. His tongue is covered with small white spots, his gums too. When I release him, he limps gingerly back to the herd as if he was walking over coals.

Back in the village

I bring the herd back to an enclosure surrounded by walls woven out of thorny branches where the animals will be safe for the night. Along the way, I study the animals very carefully in order to report back to my father. I find him sitting outside our hut waiting for dinner. I tell him that a sheep has trouble walking, seems subdued and feverish, and has little white spots in his mouth that seem to bother him when he tries to chew cud.

I also tell him that a goat does not want to nurse her kid and that she pushes him away as soon as he tries to suckle. My father listens to my story attentively.

My brothers and sisters quickly sense that something important has happened. They approach, worried. One wife stops pounding the millet, another stops tending the fire where the evening porridge is cooking. Everyone waits for the head of the family to speak.

After a long moment of silence, he glances around to make sure that the neighbours are busy, and then he says he knows this disease, his father and grandfather knew it too. It is not a serious disease for sheep and goats, most of the affected animals will get better on their own after a few days, but some of the females might lose their babies and some newborns might die because of it.

It was very likely that all of the animals in the village and the surrounding area would become infected. It was almost certain that they would have to go to a neighbouring province to find a healthy animal for the feast next month.

What is slightly reassuring is that although survivors do not recover completely and remain thinner than they once were, they will resist another attack of the disease. We therefore should be left in peace for a few months! And then if there is plentiful rainfall, green pastures will allow them to regain their health.

All of this reminded a visiting cousin of problems that rice farmers encountered in the plains two months before when the same disease affected draught cattle just when their labour was needed. Since all of the animals fell ill at the same time, they had to go very far away to find other animals that were very expensive to rent, which took a large chunk out of the income they had hoped to earn from the harvest.

The decision

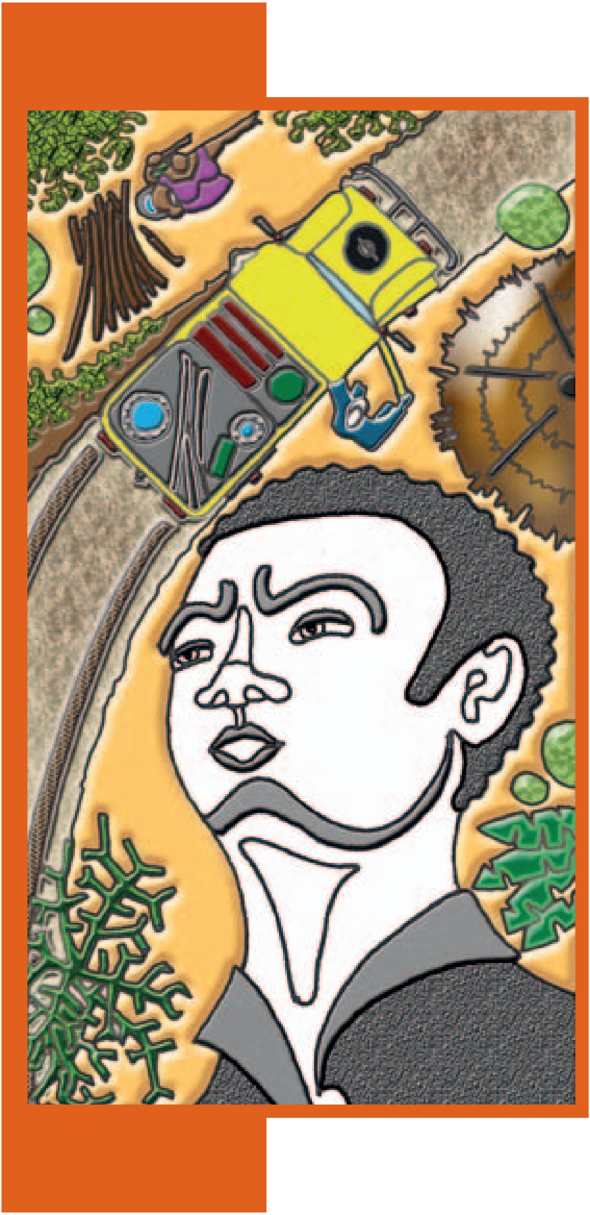
For this disease, my father says the tradition is to isolate infected animals to avoid contaminating other animals in the herd and other herds. For the time being, he decides to sort the animals and send those which are visibly infected to a distant nephew who lives deeper in the bush. They must avoid having the rest of the herd, which look healthy, to be forbidden access to pastures and the well.

My older brother who is studying in the city then speaks. He heard that livestock animals should not be sent into the bush because the disease could be transmitted to wild animals. His opinion is not heeded. The protection of wild animals is not a priority when it is hard to fill our own bowls with food.

When his first wife asks my father to sacrifice one of the infected sheep so that we all may eat a little better, he answers that it is not possible because the neighbours would invite themselves over and the more curious ones would quickly notice the grey-red and yellow spots on the muscles and heart. The clan's reputation had to be protected.

When the last fire went out in the village, I gather together the sick animals and lead them by the light of the moon to the place where they could convalesce. On the way, I had time to think and the memory of a meeting came back to me which had been organized by the district veterinarian three months before. He had spoken about a government programme to protect animals. My father had not wanted to participate in this vaccination campaign. I also wonder if the buffaloes in the photographs that the teacher had showed us, and which work in rice fields in Asia, could catch this disease.

When I returned home early the next morning, I had earned the right to a *café au lait* in the place of my usual bowl of millet gruel.



The point of view of the veterinarian in a developing country

Home again

To become a veterinarian, I left my home country to attend the Interstate School of Veterinarian Science and Medicine located in the capital of a country in the Sahel sub-region. Over the years I was there, the inter-African and international character of the school, where students and teachers of many different nationalities rubbed shoulders, led me to realize that many animal health problems are shared across borders and that to fight them, cross-border cooperation often is crucial. Internships and specialization courses at laboratories in several developed countries familiarized me with the most appropriate diagnostic and treatment methods for different health situations. A regional training course conducted by an international organization helped me understand how national epidemio-surveillance networks functioned and their importance in controlling animal diseases.

I observed that when veterinarian services, both public and private, are distributed correctly over a territory, and are well organized and competent, it is possible to control and even eradicate contagious diseases with major socio-economic consequences for livestock in Africa. And now here I am, ready to test this approach -- which for me is still theoretical -- with the reality of the field. I could have gone to work in an international, bilateral, non-governmental or private organization like many of my classmates, but my deepest wish was to work with the livestock farmers of my own country.

My first assignment

Alumni from classes of veterinarians who graduated before me helped develop the national animal health system. I went to meet these older veterinarians who, since graduating, have occupied high positions.

I explained to them my desire to enter into public service and become a mobile veterinarian. They received me with warmth and listened carefully to my story. They did not try to hide from me the fact that there were very few mobile veterinarians in the country, but they reassured me that they would be available to provide advice whenever I needed.

Nevertheless, I knew that sending myself out into the countryside would be a kind of initiation ordeal, and an inexhaustible source of questions.

My first assignment is to open a Regional Veterinarian Services office (RVS) in a medium size town in the heart of an extensive livestock region. I go to meet the chief veterinarian officer as soon as I am assigned and he reminds me that the creation of these regional units, one dozen throughout the country, is essential for the animal disease epidemiological surveillance network to function correctly. These units were part of an overall strategy for public health, notably to fight zoonoses, or diseases shared between animals and people, and to achieve food security, that was orchestrated under the auspices of the OIE (World Animal Health Organization), and with the help of the FAO (Food and Agriculture Organization of the United Nations).

Within this mechanism, the regional office acts as an intermediary level to disseminate health information to the field and, inversely, for the centralization and validation of information coming from the field that is sent to the Head Veterinarian Services office at the Ministry of Agriculture, Livestock and Sustainable Rural Development in the capital. The effectiveness of the regional office is judged by the speed by which data are transmitted and the quality of the data collected.

As an example, he refers to the epidemio-surveillance network for foot-and-mouth disease.

This highly contagious disease is feared by large farmers who raise improved cattle breeds because the disease heavily impacts the zootechnical performance of animals, in terms of milk and meat, and closes the door to exports.

The economic consequences of this disease are real, although certainly under-estimated, for small livestock farmers, who remain numerous in our country, but it is not fatal for hardy breeds even if "every animal in the herd is infected".

He mentions the first world conference on foot-and-mouth disease held in Paraguay in 2009, which deemed that the long term control of the disease was a realistic objective. To persuade me, he cites the example of bovine rinderpest whose global eradication, announced in 2011, is a source of inspiration for the fight against other diseases.

An assignment is called in

I hardly had moved into the office provided by local authorities when a telephone call from the prefecture informs me that a veterinary nurse at a distant post has noted worrying clinical signs in a zebu herd owned by a local notable.

Some of the animals are no longer eating and are drooling, are having trouble moving about, and are making odd noises with their tongues. The number affected is increasing every day. The herdsmen are worried and the owner is alarmed by the economic consequences of the disease: weight loss, drop in milk production, and abortions. The nurse asks for help.

Not yet one day on the job and already I must jump into action! I have strong suspicions: foot-and-mouth disease? I remember what the government service veterinarians whom I had met over the course of my studies told me: "The sooner you intervene, the sooner you will check the disease."

I ask the prefecture to inform the veterinary nurse that I will be visiting so that he can take the following steps: inform local officials and livestock farmers, and gather the animals together in such a way that sick animals do not mingle with healthy ones. For my part, I take care of the administrative formalities required for my departure: obtaining a mission order, booking a car and driver, packing veterinarian equipment, and arranging logistics. To facilitate similar emergency departures in the future, I will need to have crates ready to go and a pre-authorization system in place!

Two days later, I take my seat in a van that has official license plates but no spare tire, and set out with a driver familiar with the potholes and undulating lines of red dirt roads.

After an entire day of dust, a night spent under the light of the moon, a plate of rice and chicken and two *cafés au lait* on the roadside, we arrive in the hamlet and are greeted with the cheerful cries of children who have taken up posts on the outskirts of the village.

The clinical situation

The veterinary nurse welcomes me and leads me over to a group of village notables gathered under the palaver tree. I explain who I am, where I come from, and what I came to do and the types of help that I need. The head of the village extends his welcome, presents the people surrounding us, and offers me his hospitality for the length of my stay. Being able to speak the local dialect without the need of an interpreter facilitates our conversation and mutual understanding. After sealing our relationship with a glass of millet beer, I put on my white coat and a pair of purple gloves, and accompany the veterinary nurse to see the sick animals.

Herdsmen had just isolated a zebu who seems to be infected by the disease and were stopping it from running away with a rope tied around its head.

One herdsman grabs the animal’s sensitive nostrils so that it is immobilized by the pain while two others rapidly tie the feet and a fourth grips the tail and roughly pulls it towards him. The animal is drooling profusely and serous discharge soils his nostrils.

Once the animal has calmed down, I take hold of its tongue, which is very protractile, and pull it out of its mouth in a lateral direction. There are numerous, large lesions on the tongue. That confirmed the diagnosis that I mentally made when the telephone call first came through. This definitely was foot-and-mouth disease, known in the local dialect as *"saffa"*, or tongue burns. The livestock farmer nods his head when I pronounce this name.

I turn towards the veterinary nurse. He is wearing a green lab coat with several pens stuck in his chest pocket and has a stethoscope that is missing an earpiece hung around his neck. To boost his status in the eyes of the people watching, I let him examine the animal with his stethoscope, which must hurt one of his ears. He listens for a moment, then stands up and says: “The pulse is pounding.” Everyone approves with a nod of their heads. On my request, he gives me a vacuum tube so that I can take a blood sample from the jugular vein. Once the vacutainer is full, he puts it into the cooler that I brought with me, but which has no ice because there is no way of making it in this village. When I get back, I will send these samples to the animal disease diagnostic laboratory located in the capital for analysis. If the samples still can be used despite the way they were stored and transported, they probably will confirm the diagnosis and provide information on the virus serotype.

After waving back the children who had gathered close to observe the scene, I tell the herdsmen to set the zebu free. The animal snorts, spaying the ground with the drool flowing from his mouth, and limps over to rejoin his fellows. I decide to extend the blood sampling to other prostrate cattle and to complement this with the collection of samples from lesions in their mouths.

An on-site investigation

Over the course of two hours, I inspect the sick animals. I note fever, weight loss, sialorrhea, limps, mouth and podal ulcers, congested udders, and the presence of vesicles. I listen to livestock farmers talking about the drying up of milk in nursing females, bad smelling mouths, violent reactions of cows when their calves suckle and when they are milked, abortions in pregnant females, and the death of a young, unweaned calf. I wonder how the disease could have arrived in the village. My driver, who had negotiated our evening meal and lodging, assured me that there were no pigs in the village. This reassured me because pigs are a virus reservoir.

However, there are goats, some gathered in herds, others wandering about. I send the veterinary nurse to interview their owners in order to find out if they had noticed limping, abnormal mortality among kids or other characteristic signs of the disease, even if they were very slight. I watch him stride off, conscious of the importance of his mission and followed closely by a group of on-lookers of all ages. I see him adjust his cap, which has a long visor and must be envied by many people.

I continue my own investigation: when did the problems appear? Have there been movements of animals? Some murmur that the troubles started when the animals came back from a large cattle market. Others suspect a herd migrating south that stopped at the watering hole.

I know that it sometimes is difficult to determine the origin of the disease. I do not insist on this point to avoid creating tension. At present, the most urgent task is to establish control measures to limit the spread of the disease. I must be very persuasive to convince livestock farmers to accept isolating their animals and limiting their movements. However, I learn that small livestock farmers in a neighbouring village, fearing contagion, already sent their herds to family members in a far off area.

I will try to find the right words to cover all of this during the closing meeting. Women join into the conversation, mentioning that milk is lacking and the gossip of other villages that had heard the news. The men discuss whether the animals' market value would drop and whether the animals would be able to work in the fields. Vultures perched in the palaver tree cock their heads, following our meeting with interest. Some already have feasted on the corpse of a young calf abandoned in the bush.

Regarding the goats, nothing of note is reported. The veterinary nurse even was offered a gourd of fresh milk. I decide it is unnecessary to tell him that the foot-and-mouth disease virus is happy to infect humans, and although this is rare, he might find some sores in his mouth if the milk was contaminated. These lesions are not serious.

A justified suspicion

Rereading my notes in the hut loaned for the night by a *boubous* tailor, I note that a mild form of foot-and-mouth disease is involved, one which infects sturdy breeds. The animals probably will be able to deal with the virus and defend themselves.

According to people in the village, the disease emerges from time to time but disappears without their even having to call upon the services of the witch doctor. It often appears at the end of the rainy season or at the end of the harvest when the herds are put together to graze the fields. The infected animals recover in one or two weeks, remaining a little tired and thinner than the others, but they resist the disease better the next time it comes around. They become self-immunized or self-vaccinated.

In preparation for my departure the next day, I ask the veterinary nurse to reassure the large livestock owner, who had sent a message with a bush-bus driver that he had been retained at the border over a customs issue which he thought would be resolved rapidly.

Beneath a glowing evening sky, my driver sits outside the hut and breathes in the scents of village life while cleaning his teeth with a stick.

Required notification

Foot-and-mouth disease is a very contagious animal disease that is on the list of diseases that must be reported to the World Organisation for Animal Health (OIE).

The information that I will send in a well documented report to my hierarchical superior, the national director of veterinary services, must be sufficient to fill in the OIE's zoosanitary information system known as WAHIS (World Animal Health Information System).

As the disease has become enzootic in this region, it is not urgent to declare a new outbreak unless lab results or the evolution of the disease in the field demonstrate a major epidemiological change, such as, for example, the emergence of a new serotype or a sharp increase in the percentage of animals that die after contracting the disease.

I will keep a copy of the complete file in the regional office and indicate on a map the sanitary situation encountered with the observation date. The data from "my" outbreak should be on the internet within six months, available to everyone with authorized access, in the form of a report that can be downloaded. This epidemiological monitoring is necessary to keep track of the spread of the disease.

I remember that during my training, an experienced veterinarian told us that in the past, traditional sedentary and nomadic livestock farmers overlooked this disease in their local breeds of cattle because they said: "This is not a disease that kills."

Mortality, particularly among young animals, is nothing compared to that of the other contagious animal diseases, such as contagious bovine pleuropneumonia, rinderpest, trypanosomiasis, and even anthrax, which they had faced and which could decimate their entire herd. They defined it as “the only disease that can infect a herd without causing the owner sleepless nights.”

Today, although contagious bovine pleuropneumonia remains a preoccupying health problem in numerous countries of Africa, rinderpest has been eradicated, the impact of trypanosomiasis has diminished and cases of anthrax are spaced further and further apart. Consequently, it has become possible to focus efforts and resources on diseases that, due to their less visible economic impact, have appeared to be less important to both cross-border traders and small livestock farmers.

This holds especially true since the status of foot-and-mouth disease has changed. Once not a priority for cattle farming in Sahelian Africa, it has become a health constraint that absolutely must be taken into account in zootechnical cattle farming milk and meat production improvement programmes which rely on selected foreign breeds. I also remind myself that one must resist a false sense of security when major animal diseases seem to have disappeared, and that one must always remain wary of their latent threat.

In Southern Africa, where the cattle industry represents important economic stakes through intercontinental meat exports, I read that the regional epidemiological surveillance system for foot-and-mouth disease is based on sanitary zones: infected zones, vaccinated zones, and disease-free zones from which exports are possible. These measures match the commercial impact and financial losses that an epizootic of foot-and-mouth disease generates in countries of this region. Prevention is better than a cure!

I tell myself that I should review my course materials to learn more about diseases, animals infected in the bush, and the legislation underway to know how to obtain agreements from owners, whether provisions have been made for compensations and in what form, how infected animals should be slaughtered, what should be done with the meat and carcasses, and above all, how to get rid of the bodies in the bush. Could vultures be a possibility?

Vaccinate or not vaccinate?

I know that foot-and-mouth disease vaccines exist but they are thousands of kilometres away from the sick animals that I am taking care of. Furthermore, we would have to wait for the results of the antigenic characterisation of the virus to know which serotype and subtype are involved to choose the right vaccine. Ideally, one should wait for the lab results before taking any kind of decision, have a budget to order the correct vaccine if it exists, have the vaccines delivered by air, get them through customs while ensuring that they are stored at the correct temperature, and keep them cool when bringing them into the bush.

Furthermore, how can one identify the animals that need to be vaccinated from those that already have been since none wear an identification tag? The notches in the ears are not enough to recognize individual animals, particularly since some zebus have been passed between several owners who each added their marks to those made by their predecessors.

The vaccine also cannot help the animals that are sick even if it is meant to protect those at risk, at least for a few months. Considering that about fifteen days are needed for the antibody count to become high enough to ensure sustainable protection, most of the animals involved will have had the time to recover on their own if they have been infected.

The handful of deaths that could occur might have taken place for other reasons in the context of extensive livestock farming in an arid tropical region. And it is not impossible for antibodies discovered in the blood of vaccinated animals to be confused with antibodies resulting from a natural infection, which would suffice to stop cross-border trade.

After considering every angle, I decide this time to renounce the idea of vaccinating the herd I had inspected or those around it. This seemed like the wisest choice in the absence of a national or regional strategy such as the SEACFMD (South-East Asia and China Foot and Mouth Disease) programme underway in Southeast Asia that I heard about during my studies and which aims to eradicate foot-and-mouth disease in that region by 2020, including on small livestock farms.

Faced with the realities of the field, I realize that a sporadic intervention such as mine was not likely to vanquish the disease. To have some hope of success, questions of identifying animals, selecting vaccines, their availability, and many others, such as political will and communication tools, had to be addressed.

Before leaving

While the driver checks the water, oil, fuel, and condition of the chickens he was offered, and two kids pump the tires with a foot pump in the hope of a small recompense, we all sit in a circle, village leaders, livestock farmers, children, and curious on-lookers, and I give an on-the-spot report of the visit. I know very well that I cannot forbid the movement of the animals, so I provide recommendations that I know are feasible and which can slow the spread of the disease: go fetch water for the animals that have not yet been infected instead of bringing them to the watering trough, do not let sick animals graze alongside the rest of the herd, do not go the market in the neighbouring village before the clinical signs have disappeared.

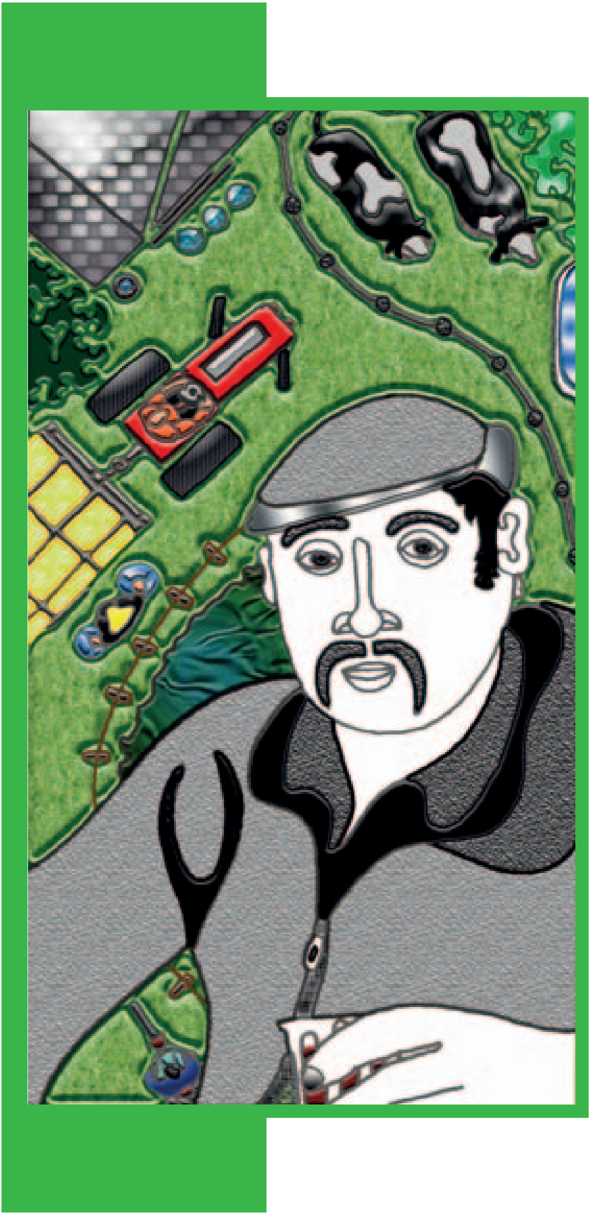
I also recommend that they give the sick animals some relief by making them more comfortable with better bedding until they stop dancing on their painful hooves. I speak especially to the children and make sure that they understand what I say because they will be shouldering most of responsibility of caring for the animals. And they are the future!

Of course, I know that traditional remedies are used by some herdsmen communities to speed the development of the sores such as rubbing them with honey, salt or sugar, or to relieve the pain and speed up the healing of wounds by applying a paste of cattle urine, dried bark, and carefully chosen plant leaves. As I do not know whether this knowledge is known to the elders of the village, I leave the veterinary nurse one bottle of tincture of iodine and one of methylene blue, as well as a large brush to daub the tongues and feet of the sick animals to speed the closure of wounds and to prevent secondary infections. When he notices that the first is yellow and the second blue, he asks if he may mix the two for certain cases. I do not encourage this but I guess he would like to have a green potion that might be more impressive in the eyes of the livestock farmers.

The veterinary nurse listens to these last instructions with a serious air, taking notes in a small, worn notebook, until I compliment him for having called me in and thank him for all of his help. His face suddenly lights up with a childlike smile. He then follows me when I get up to bid farewell to all of the village notables, punctuating each of my remarks with a sound of audible approval. I shake everyone's hands, brush everyone's fingers, caress some palms and wish everyone the best. When our car kicks up the orange dust of the road, I extend my hand to give one more wave through the open window.

I feel like I am leaving friends.

Young cattle in the Zimbabwe Lowveld. The ear tag indicates that the animal is part of a research protocol on the effectiveness of vaccination against foot-and-mouth disease.
Zimbabwe, 2008. - *© Alexandre Caron, Cirad.*



The point of view of the livestock farmer in a developed country

An unpleasant feeling

That morning, as I let the cows out of the stable, I had a bad feeling. They usually walk briskly over to the pasture. But today, many cows are slow to get moving and appear uncomfortable on their feet. Usually feisty, they seem reluctant to walk.

Once inside the enclosure, some chew grass, but others stand still, as if they already were exhausted. When I run my hands over them, I have the impression their bodies are feverish. I return at midday with my father and my paternal grandfather who help me run the family farm. Silently, we observe the animals. Two of the cows are chewing with empty mouths, making a kind of smacking sound. Threads of saliva hang from their mouths.

After a moment, my grandfather clicks his tongue too and announces: “It’s *la cocotte*”. In response to my interrogative silence, he adds: “In the old days, we use to call it that because the pain in their hooves made cows totter about like callgirls in high heels.” My father adds: “Yes, it’s the hoof disease.” That was easier for me to understand: foot-and-mouth disease!

I am stunned. Memories of animal production lessons at my agriculture highschool come back to me. It is a highly contagious, notifiable disease.

If confirmed, I was going to have to deal with a health problem with serious consequences for the first time since I took over the farm. And I recall the trauma that farms faced during the mad cow crisis, the memory of which was still fresh.

The collective memory of the elder generation

We gather around the long kitchen table in front of cups of coffee that slowly turn cold, swinging between discouragement and anger. Before calling the veterinarian, I question the old folk to better understand what to expect.

Grandfather remembers that his own father tried to treat the animals infected. He used vinegar, lemon juice when he could find it, or trypaflavine to clean tongues covered with blisters. For the feet, some farmers tried disinfectant solutions and wood tar. Owners of cows cut off the diseased parts of the hooves and forced their cows to ingest cod liver oil. Others used salts of arsenic, copper, bismuth, or even gold that were sold by peddlers, as well as other oddly named products: resorcine, emetine, gaiacol. Bonesetters also were involved. Nothing had much success.

During the 1937 panzootic, he read in a newspaper that Germany had over 700 different drugs to diminish the clinical signs of foot-and-mouth disease. Meaning that none did much except to make the venders rich. He added that even sulfa drugs and antibiotics were tried without having any effect on the virus.

He had lived back in the time when, in the absence of vaccines, farmers made sure that sick cows infected the rest of the herd because tradition held that the disease would run out of steam on its own if it was helped to spread. Some veterinarians even recommended artificially transmitting the virus from a sick animal to a healthy one through aphtisation, or using swabs dipped in lesions to accelerate its spread and the contamination of animals.

He also remembered 1952. That year, the epizootic caused thousands of outbreaks of foot-and-mouth disease. Preventive disease control measures did not exist. Not all of the outbreaks were declared. Some farmers tried to discretely manage the problem by hiding sick animals.

My father then spoke up, and explained that vaccination gradually was imposed on farmers. First recommended but optional, annual vaccination became obligatory for cattle in 1961. The result was that over time, the disease became increasingly rare. And then in 1991, everyone suddenly had to stop vaccinations without anyone really understanding why.

The only thing that remained unchanged was the requirement to declare this health problem the moment it emerged.

He remembers farmers who were obliged to pay heavy fines or who were sent to prison for having delayed contacting a veterinarian because they knew that when there was a suspicion of foot-and-mouth disease, all of their animals would be slaughtered. At that thought, I got knots in my stomach. I remember the media images of huge piles of cadavers being incinerated during the last epizootic of foot-and-mouth disease in the United Kingdom in 2001.

The call for help

Without waiting a moment longer, I call my public health veterinarian. As soon as I describe the situation, he says he will arrive as quickly as possible.

Questions circle around in my mind: “How could this have happened? How much compensation will there be? How much time will it take me to select a new herd with the same level of breeding?”

The point of view of the veterinarian in a developed country

A strange atmosphere

I am uneasy approaching the farm. Despite my experience as a public health veterinarian, I always dread what I am going to discover and the farmer's reaction when his preliminary diagnosis is confirmed. Like all of my "country" colleagues, I am on the frontline when an epidemic outbreak occurs. I hope it will be a false alarm, but as a precaution, I park my car at the farm entrance, change into a pair of boots, put on disposable overalls and gloves, and take the black "foot-and-mouth disease" kit holding the materials needed to take samples and authorized disinfectants.

Compulsory measures

After questioning the farmer and examining the cattle, I confirm his suspicion. Several cows show typical signs of the disease. I had thought, indeed hoped, I would find other pathologies such as the bovine viral diarrhea, infectious bovine rhinotracheitis, actinobacillosis, or various other disorders of the tongue and mouth mucosa. But it probably is foot-and-mouth disease.

This highly contagious disease is a listed World Organisation for Animal Health (OIE) disease because it falls in the category of "transmissible diseases that have the potential for very serious and rapid spread, irrespective of national borders, that are of serious socio-economic or public health consequence and that are of major importance in the international trade of animals and animal products."

I immediately notify the director of veterinarian services (DDSV) who informs the Directorate General for Food (DGAL).

I am delegated to sign an administrative act to put the farm under surveillance (named in France the *Arrêté Préfectoral de Mise sous Surveillance*, or APMS) while waiting for the diagnosis to be either confirmed or invalidated.

It is a rude shock for these three generations of farmers. The farm is quarantined. All animals, susceptible or not, must be kept inside the buildings. No unauthorized persons or vehicles may enter or leave the farm. Disinfection facilities are put in place at all entry and exit points (wheel dips for tires, foot baths for shoes). Without saying a word, the grandfather withdraws to read the list of safety rules that must be followed. The father calls the dairy to cancel the milk collection. This herd is the legacy of many years of work involving the entire family. It is a source of pride. Agriculture competition prizes nailed to a beam are evidence.

The young farmer copes. To identify the source of the problem and evaluate the risk of virus spread, I inventory with him all of the animals on the farm whether or not they are susceptible to foot-and-mouth disease. I note the animals' movements and where they graze, the movements of people, the entries and exits of vehicles (cattle trucks, collection and delivery trucks), material and products (hay, cattle feed...). In sum, there is an impressive number of ways by which the virus can spread!

To complete the epidemiological survey questionnaire as precisely as possible, one must look at records, ask questions about everything that has happened recently, particularly during the 14 days before the probable contamination date, because 95% of the time the incubation period is no longer than two weeks. Before leaving, I take samples from several animals: a swab of the lesions and a blood sample. I put them into airtight containers to be sent to the national reference laboratory at ANSES (*Agence Nationale de Sécurité Sanitaire*) which is specialized in the detection of foot-and-mouth disease and viral vesicular diseases.

I disinfect the material that is not disposable and put everything that is disposable in a plastic bag that I leave on-site along with my overalls and gloves. I disinfect my boots, cancel my other visits, and go straight home to take a shower and wash my workclothes. Starting tomorrow, I will install a foot bath at the entrance of my veterinarian clinic to avoid contamination.

I know that the news will spread quickly. Doubts will be voiced: is this veterinarian really sure of his diagnosis? Hypotheses will be formulated to identify the suspects responsible. Rumors will circulate. Old arguments will resurface. I prepare answers to the coming bombardment of questions.

Confirmation of the diagnosis

After a 48 hour wait, the DGAL receives the lab results and confirms the clinical diagnosis. The test results of samples taken from the sick cattle are positive. The laboratory formally identifies the viral type responsible: it is serotype O.

“While foot-and-mouth disease can ruin a small farmer, it also can ruin the economy of a country." This phrase crosses my mind as the fight against the virus begins. From this time on, I become part of a network of diverse actors, all involved at the departmental level in the application of a control campaign under the authority of the prefect: public services (prefecture, veterinarian services, DGAL, mayor’s office), regional authorities (general council), professional representatives (health protection group, Chamber of Agriculture), private stakeholders (renderers, disinfectant companies), etc.

The DDSV signs by delegation a declaration of infection known in France as an *Arrêté Préfectoral de Déclaration d’Infection* (APDI), resulting in the definition of a restricted zone around the outbreak: a protection zone with a minimum radius of 3 km around the infected farm and a 10 km surveillance zone around the protected zone.

This is communicated to all of the services and actors involved and to the local media which will quickly leap to cover the event.

Several dozen farms located within the perimeter now also are under quarantine as a precautionary measure. Access roads are sealed off and signs are put up to signal that the area is restricted. Animals and people are in quarantine. The public health machine is in operation. Other regulatory measures will be applied to avoid a spread of the outbreak:

- on-site euthanasia of all susceptible animals on the contaminated farm to avoid all risk of the virus being spread during the transport and disposal of the cadavers;

- collection of samples from condemned animals for a pre and post-mortem epidemiological survey;

- destruction of infected animal products and the litter, straw and hay stocks suspected of being contaminated;

- disinfection of buildings and livestock-related equipment;

- census, visit, and screening by public health veteriniarians of all farms holding susceptible species in the protection zone.

The simulation exercise conducted last year is still fresh in my mind, but the actual reality of this alert makes the situation dramatic. While re-reading the latest updates of the DGAL memorandum of 10 March 2003 concerning the foot-and-mouth emergency plan, I prepare myself for the most difficult task: telling the farmer as gently as possible that the diagnosis was confirmed and his herd must be slaughtered.

Since the information came out, my telephone has not stopped ringing. Cattle farmers as well as sheep and pig farmers worried by the occurence of an outbreak fear seeing their animals drooling or limping.

They know that despite all of the precautions taken, they remain at the mercy of the spread of the virus simply if the wind blows in the wrong direction. They ask: “Why were preventive vaccinations stopped? Why must perfectly healthy animals be slaughtered?”

I must explain the situation to each one, describe the sanitary measures, confirm that in adherence with the Ministerial Order of 22 May 2006, automatic ring vaccinations will not be conducted because for economic and trade reasons, this emergency vaccination is only planned if the disease spreads and cannot be controlled by sanitary measures and slaughter alone.

Like my colleagues, I also find myself on the frontline facing questions posed by journalists seeking juicy information: “How many farms are involved? Can people be contaminated? Are you going to slaughter all of the animals? What will happen to the dead bodies? What about pollution? Is contaminated meat already in circulation? How did the disease enter the country? Are livestock farmers compensated for their losses? Do you really believe that the compensation level is sufficient?"

Based on my past experience with avian influenza and bluetongue, I also expect that the Mayor’s office will ask me to conduct a public information meeting with other representatives of the crisis cell. That is an invitation that must be accepted despite my busy schedule.

All this because of a viral entity 100 million times smaller than me!

A strange atmosphere

When I arrive on the farm, accompanied by the director of the veterinarian services department, a veterinarian inspector and a farmer representing the health safety group, I have the impression that I am entering a fortified camp. A warning sign, “Restricted Access” is displayed prominently at the head of the road.

At the wheel dip, police check entry and exit authorizations.

Sitting in the family kitchen in front of a cold cup of coffee, I review the situation. The epidemiological survey carried out by the DDSV is looking at imported lambs that were shipped the week before by a sheep trading company situated several kilometers away. The weather conditions could have helped spread the virus through the air.

I realize how cruel this information must be, and hard for the farmers to accept. I then force myself to explain in simple terms what would happen next: the slaughter of their dairy cow herd and the disinfection of the farm.

I tried to minimize the psychological impact of these measures by insisting on the fact that the animals' welfare would be respected throughout. I will use a curare-based injection (T61). Everything would be over by the end of the afternoon. The bodies will be transported in a covered, decontaminated truck to the rendering plant where they will be incinerated.

The GDS representative (Health Protection Group) explained the compensation provisions designed to offset the economic losses and their implementation schedule.

I also answer other practical questions that reflect how this virus will turn the daily life of this family upside down: "And how will the farm get supplies? How will the children get to school? What about our plans to attend the next agricultural show? What about meetings with hunters? And contracts with the cooperative? And the postman? And the bills? When will everything return to normal?"

When we leave, I tell myself that in times of crisis, one must pay attention to the human factor.

Upper gum lesion of an adult water buffaloe (*Bubalis bubalis*) infected with foot-and-mouth disease. - Cambodia, Svay Rieng province, July 2010. - *© Timothée Vergne, Cirad*.

The point of view of the cow before 1961

Full of health

My life as a dairy cow is well organized: milking, delicately if possible, in the morning, leaving the stable for the pasture, without stress, following the herd's pace, pursuing my favorite pastimes (grazing grass, chewing the cud standing up or lying down, sunning myself or staying in the shade, depending on the weather, drinking alot, licking a salt rock), then heading back to the stable at sunset for more milking and a night divided between chewing cud and sleeping in the company of my fellow cows.

The beginning of discomfort

But this evening, I feel feverish. Shivers going down my spine are causing the hair in my coat to bristle. I must have a temperature of 40°C or more. Added to my general discomfort are aching joints and a real migraine just like humans feel, and for the same reasons: congested sinuses, abnormally high blood pressure, engorged ventricles, diffuse inflammation. I shake my head from time to time but it doesn't help. Although I usually have a reputation of being a delicate cow to milk, tonight I let the job be done without saying a word. I realize that I am not the only one feeling strange and some other cows seem even worse off. Head lowered, they drool profusely over the hay they are given, which they ignore.

Mouth lesions

Two days later, just when I notice a slight improvement in my general state, my mouth is invaded by painful vesicles of different sizes, from a few millimeters to a few centimetres wide, in the gingival crevice, on the dental pads, the soft palate, inside the cheeks, and even on the tongue, on which only the sides are spared.

Like my sisters, discharge flows unimpeded from my mouth and nostrils. The lesions burst, liberating a clear, yellow-coloured liquid, which smells bad even to me. They form scabs that split open. I breath through my nostrils, mouth closed, tongue stuck to the palate because cold air passing through is very painful on the bared mucosa. When I have to drink, unsticking my tongue makes a characteristic sucking noise that alerts the farmer. The diagnosis is given: like the other cows, I have foot-and-mouth disease.

Over the days that follow, I drool more and more, and shake my head to clear the mucus clogging my muzzle, even if it means contaminating everyone around me with the spray. The vesicules spread to the nostrils and the pharynx. Each time I blow my nose to clear out the mucus, I liberate thousands of virus particles. It is hard to swallow or feed myself. I chew with nothing in my mouth, my stomach completely empty. Yet the farmer is giving us tender hay and lukewarm water.

Lesions on the feet

Gradually, the lesions in my mouth heal naturally. But the virus that multiplied in my mouth lesions were transported by the lymph and blood to my lymph nodes and the epithelial tissues of my feet and teats. The pain in my mouth becomes a pain in my feet. Lesions open on my hooves in the interdigital space and on the coronary band on the edge between the horn and the skin. After bursting, they open the door to bacteria, resulting in secondary infections. I refuse to move. When it becomes too painful, I lift one foot after another to relieve the pain. Sometimes, I assume an odd position by gathering together my four feet and arching my back.

I lie down often to relieve the pressure on my open wounds. When some of my fellow cows move about, they walk, the children say, as if they are wearing sandles. Others say they are walking on needles.

I hope to be spared the deformations of the hooves that sometimes appear and persist after recovery.

Milk strike

Obviously, since I am no longer eating, my milk production has dropped considerably. But the main reason I refuse to give milk is the lesions on my teats. It is no different whether it is to suckle a calf or to be milked. I am no more cooperative with my calf than with the farmer. I know that I might develop mastitis, but milking is too painful. I will wait until my teats have healed.

Transmission of foot-and-mouth disease by virus inoculation in the lingual epithelium of a cow in order to obtain infected lesions that can serve to produce vaccines. - France, 1952. - *© Marc-Henri Cassagne, FNGDS.*

Healing naturally

By the end of ten days or so, I am skinny, probably anaemic, and my tongue is pealing due to the burst aphthous vesicules, but I feel a bit better. My appetite slowly is coming back and I start to eat. I do not chew cud with my usual efficiency, and it does not makes me feel good the way it use to, but my milk production has started again, to the satisfaction of the farmer.

My sturdy character allows me to survive, but at a certain price: a slight limp, a lesser quantity and quality of milk, scars on the teats. Everyone did not have the same luck.

Even if the disease is not itself mortal, its consequences can be. Some cows died because they could not eat, others aborted dead calves. Young calves were struck down by a heart condition called myocarditis or "tiger-heart" syndrome. At the autopsy, their hearts were a pale colour with grey, red or yellow streaks.

I know that I also escaped the lesions on the inside of my thighs and on the vulva and anus that required others to furiously shake their tails to try to relieve the pain. I also could have developed lesions on the liver, the marrow, and some nerve and respiratory forms of the disease.

The bull was not spared. His stride, walking with stiff hind feet, suggest his testicles are engorged and painful.

I now am immune for a few months against a new attack from the same strain of the virus. The farmer probably will keep me to reproduce because he knows I will transmit to my calf the antibodies I produced to fight the virus.

During my convalescence, I hear the farmer mention that the sow had shown clinical signs of foot-and-mouth disease. They are similar to ours with the distinguishing feature of developing enormous lesions on the groin. The farmer cared for her like us with a thick pile of straw and attentive care until the disease passed.

Cover page of an edition of the magazine, *Vie à la campagne* (Country Life) with pictures of two signboards posted in the hall of IFFA (*Institut Français de la Fièvre Aphteuse*) in the 1950s meant to inform farmers about foot-and-mouth disease. One shows the ravages caused by the disease and the other the means to fight it.
France, 1952. - *© Marc-Henri Cassagne, FNGDS.*

The point of view of the cow between 1961 and 1991

A tranquil life

I am the senior cow in a herd of 60 selectively bred dairy cows. I wear a plastic tag on each of my ears that identifies me because since 1978 we no longer are allowed to remain anonymous or travel incognito. With my fellow cows, I live outside in summer, savouring the best grass, and stay cosy inside during the winter. It would seem that intensive livestock husbandry conditions suit me well because I will soon be 10 years old and I am still producing plenty of milk.

An annual requirement

At the beginning of every year, we must bow to our health obligations and the ritual of a routine vaccination against foot-and-mouth disease. It has been obligatory in France for cattle of all ages since 1961, at first starting from 6 months of age, then from 4 months of age after 1980. We receive a dose of trivalent inactivated vaccine against the three most common serotypes (AOC) of the virus. In Europe, with the exception of cross-border and transhumant sheep, we are the only species susceptible to foot-and-mouth disease that must respect this prevention measure. Thanks to the vaccine, the annual number of outbreaks in France, which numbered over 7000 in 1960, fell close to zero in the 1970s, save for two mini-accidents in 1974 and 1981 that were controlled rapidly by slaughtering measures.

Without undue modesty, I thus do not hesitate to say that it is thanks to us, cattle, that foot-and-mouth disease no longer is epizootic in Western European countries, to the great relief of farmers. But everyone knows that if a new epizootic occurs, all susceptible species in the infected outbreak -- sick and healthy -- will be slaughtered. We also paid a heavy price for the production of the vaccine in the 1950s and many of my ancestors died for science.

The vaccination

I remember my first vaccination in 1970. I was a young heifer and the injection provoked an allergic rash. A lump formed on my dewlap where the injection had been given. The amount of liquid injected interdermally at the time was much greater than the doses that are used today.

Inoculation of cattle with the foot-and-mouth disease virus to produce a vaccine against the disease.
France, 1952. - *© Marc-Henri Cassagne, FNGDS.*

Tomorrow, I might have a bit of a fever and some aches and pains, but in a few days, my immune system will be reinforced with a higher antibody count against foot-and-mouth disease. I can lead the herd into the summer pastures with confidence.

Transhumance festival in Aubrac before going up to the summertime mountain pastures. - France, August 2010. - *© Raymonde Blondel.*

The point of view of the cow after 1991

All hope is lost

The sanitary authorities have made their decision: my life must end in the name of safety.

A few days ago, foot-and-mouth disease invited itself into a pig farm a few kilometres from the pasture. All of the pigs were slaughtered and our farm was declared at risk because we are in a high density livestock region. And yet none of us show any clinical signs of the disease or demonstrate the slightest danger for humans or other susceptible animals.

Another option could have been a ring vaccination around the infected outbreak, but cost-benefit analyses and decision support scenarios have ruled that the most cost-effective control strategy is pre-emptive collective slaughter, a concept developed in April 2001 during the foot-and-mouth disease outbreak in Great Britain.

This evening, the farmer lingers next to each of us, stroking our backs, remembering the years we've shared together, calling some of us by our nicknames.

Up until 1991, we received a preventive injection meant to protect us. Tomorrow, we will receive a lethal injection that will erase us as hypothetical hosts of the foot-and-mouth disease virus. Silence will take the place of our mooing. After the statutory time period, another herd will take our place and a new story will begin.

One of my last thoughts is to wonder whether indicators of the farmer's feelings and emotions figure in the socio-economic simulation models.

The point of view of the wild animal

A buffalo as a reservoir

I am a handsome African buffalo, *Syncerus caffer*, admired by ecotourists who visit this nature reserve in a Southern African country. For many years, I have lived in an area marked out by humans to keep us away from cattle herds because they have know since the 1970s that we are host-reservoirs of the foot-and-mouth disease virus.

Veterinarians actually believe we play an active role in the persistence of foot-and-mouth disease in Africa. They say we are natural carriers of one or several of the three exotic SAT virus types, SAT1, SAT2 and SAT3, with a preference for the first.

A hidden transmission

In this season, which is cool and dry, many watering holes dry up. Like every evening, we head over to drink from a muddy pool that attracts all of the animals in the area like a magnet. This is the period when young buffaloes born a few months earlier lose the protection of maternal antibodies and take turns falling ill with foot-and-mouth disease. The disease circulates within the herd somewhat like a childhood disease. During the acute phase of the infection, which lasts from 5 to 15 days, the buffalo calves are contagious and excrete the virus in all of their secretions without showing any visible clinical signs. They transmit the virus by touching their muzzles to the muzzles of the impalas and greater kudus which crowd in with us to quench their thirst. Even the trained eye of an experienced veterinarian would not be able to detect the infected animal among them! If there is a fever, it passes unnoticed. And who would have the courage to check for the presence of lesions in their mouths?

At the end of two weeks, the young buffaloes become, like us, silent carriers of the virus which persists in the area of their esophagus. When they are one year old, they develop antibodies against the 3 circulating SAT virus types.

Multiple suspects

Veterinarians counted nearly 70 mammal species belonging to over 20 different families as being ones likely to harbour the foot-and-mouth disease virus with varying degrees of susceptibility. Like me, the gnu (*Connochaetes taurinus)* rarely shows clinical signs of the disease, but the greater kudu (*Tragelaphus strepsiceros*), impala (*Aepyceros melampus*), and two wild suids, wart hogs (*Phacochoerus aethiopicus*) and bushpigs (*Potamochoerus porcus*), contract the severe clinical form of the disease, comparable to that of susceptible and infected domestic animals.

The virus persists for a very long time in the pharynx of my Asian cousin, the water buffalo (*Bubalis bubalis*), the greater kudu and domestic cattle. But I hold the record, being able to carry and transmit the virus for up to five years during which I do not show any clinical signs of disease, although in reality, it is mostly young buffalo which take care of transmission. This long carrier period enables the virus to maintain itself within the herd for over 20 years. The occassional sexual transmission of the virus within the herd could be possible but has not been proven; the same is true of mating between infected male buffaloes and female domestic cattle.

Livestock farmers fear us in particular because we infect the herds of impala that mingle with their cattle. These African antilopes are very susceptible to the foot-and-mouth virus and are telling indicators of the presence of foot-and-mouth disease. When they contract the disease, their coats bristle, which is a sign of fever, and they suffer from locomotive disorders.

Although they only carry the disease for a short period, their high population density makes them formidable virus transmitters among us and the domestic ruminants with whom they share pasture lands.

Different stakes

Although foot-and-mouth disease is endemic in most countries of sub-Saharan Africa, it is not always due to our presence. It is true that in Southern Africa, we are the main reason that the disease has not been eradicated. This does not hold true for West Africa, where our population is scattered and has little impact on the disease which maintains itself among domestic cattle without any intervention on our part. In East Africa, two transmission cycles, wild and domestic, probably co-exist.

The economic stakes of controlling the disease are less important in West African countries, where livestock systems mostly are extensive and supply domestic markets. In contrast, the stakes are high in Southern African countries which have developed intensive, export-oriented cattle livestock systems. For them, the challenge is to conciliate our presence with the maintenance of disease-free zones.

Health safety

To contain the threat we represent -- which is exaggerated in my view -- these countries have erected electrified fences over thousands of kilometres to keep us safely inside reserves, thereby preventing us from having any contact with cattle. These fences consist of a either a single barrier or a double barrier separated by a dozen meter gap. They are at least 2.4 meters high, which prevents antilopes, greater kudus, and impalas, all quite impressive jumpers, to leap over them.

These artificial barriers impede our traditional seasonal migrations, and that of other large herbivores, towards pasture lands that have become livestock areas, causing important ecological and sociological disruptions.

When the fences block our access to water, they leave us -- and all other wild hoofed species -- no chance of survival.

This is how in the past herds of several thousand gnus have died of thirst and exhaustion after running hundreds of miles down the fence without finding an opening to reach the water and pasture lands on the Okavango delta.

Despite a foot-and-mouth disease control policy based on regionalisation measures that keep us away from zones recognized as being disease-free, health officials still consider us to be a potential threat to domestic ruminants that live on the periphery of the nature reserves.

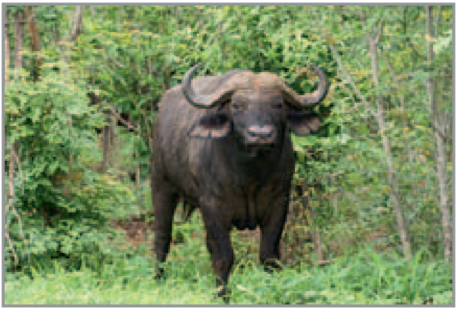
And yet those animals are given preventive vaccinations twice a year in this frontier area referred to by specialists as the "buffer zone".

To tell the full story

The country-level application of measures to manage cross-border diseases that circulate from wildlife to cattle is a complex task. A balance needs to be found between the traditional livestock practices of local communities and the commercial interests of farmers, the protection of wildlife and, in certain cases, ecotourism activities.

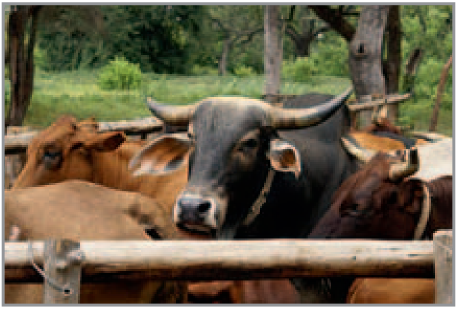
Closely supervised attempts to reintroduce farm-bred buffaloes that are not infected by foot-and-mouth disease into zones recognized as being disease-free could offer us some hope in the future.

In Europe, cases of foot-and-mouth disease found among wildlife such as deer, wild boar, roe deer, chamois, and ibex probably were caused by the transmission of the virus by cattle during an epizootic outbreak. At last an example where wild ungulates have more reason to fear from cattle than the reverse!



A male African buffalo (*Syncerus caffer*) in Chobe national park during the rainy season. - Botswana, 2007. - *© Alexandre Caron, Cirad.*

Male greater kudus in Hwange national park. Zimbabwe, 2009. - *© Alexandre Caron, Cirad.*



Cattle waiting to pass through a tick bath in a village close to Kruger park, an African buffalo reserve. - Zimbabwe, Sengwe Communal Land, 2008. - *© Alexandre Caron, Cirad.*

The point of view of the sick person

Slightly ill

For the past two days, I have felt feverish, with a slight headache and a sore throat. But this is not a good time to be sick. During this foot-and-mouth disease crisis, my working days are long. The rendering company where I work was requisitioned to destroy and bury the bodies of cattle that had been slaughtered on two contaminated farms in the canton.

But when I woke up this morning, my hands and feet were tingling, and I felt like my skin was burning, especially on the palms of my hands and the soles of my feet. During the night, sores several millimeters wide appeared in my mouth on the inside of my cheeks, my palate, and even on my tongue. I have lost my appetite and I threw up the spoonful of soup that I managed to swallow last night. I will have to call the doctor.

The clinical meaning

The doctor arrives quickly. Luckily for me, I live outside the restricted perimeter set up around the infected outbreaks. After listening to me, he scrutinizes my hands and feet, particularly the base of my nails and between my toes. The presence of vesicles makes him suspicious. He listens carefully to my heartbeat and is concerned about possible symptoms of tachycardia, which I luckily do not have. Then he firmly announces his diagnosis: “You have caught foot-and-mouth disease.” I am speechless! But he rapidly reassures me: “You are not contagious.” He predicts that the symptoms will clear up on their own and I would return to normal in a week or two, unless there are digestive or respiratory complications, but these are extremely rare. For the required treatment, he prescribes rest, antibiotics to avoid the risk of secondary bacterial infections, and an antiseptic mouth wash.

To be completely certain, he takes a sample of the epithelial tissue from the sores on my tongue and a blood sample for serological testing.

Recovery

After a 48 hour wait, as the infection subsides, the laboratory test results confirm that foot-and-mouth disease indeed was involved. The tests identified serotype O of the virus, the same that was behind the epizootic outbreak on the neighbouring cattle farms.

On the telephone, the doctor explains to me that foot-and-mouth disease is rare in humans and that clinically it can be confused with other vesicular disease such as vesicular stomatitis caused by the Coxsackie A16 virus or Enterovirus 71, or even a vesicular rash such as Herpes simplex.

Turning to science

Some time later, my neighbour, a retired epidemiologist, explains to me that foot-and-mouth disease is known as a zoonosis and, more precisely, as an anthropozoonosis.

Seeing that I have not understood, he explains: “This is a disease, like avian influenza and West Nile fever, that is transmitted from animals to humans. However, human cases of foot-and-mouth disease are rare. Only 37 cases have been documented in the world. That does not mean that there have not been more because the human infection can pass unnoticed or may not be diagnosed, particularly in developing countries.”

Encouraged by my rapt attention, he continues: “The first known human case dates back to 1695, and in 1834, veterinarians succeeded in infecting themselves by voluntarily drinking contaminated milk four times a day over the course of four days!” Seeing a worried expression cross my face, he adds that there is no risk of contamination when milk has been boiled. The same is true of infected meat that has been cooked and consumed because the virus is inactivated by the heat.

The production of the first foot-and-mouth disease vaccines. Harvesting the infected lymph from the epithelium of the tongues of cattle infected with foot-and-mouth disease. - France, 1952. - *© Marc-Henri Cassagne, FNGDS.*

And he adds: "It was at the beginning of the 20th century that the risk of foot-and-mouth disease was especially high for veterinarians who handled the tongues of infected cattle in order to prepare vaccines. Today, with the strict security measures that now are in place, it is extremely rare for anyone to be a victim of an accident like yours, and get splashed in the face by infected liquid while handling the carcasses. Your case definitely will be remembered."

I am not particularly delighted.

The point of view of the virus

A little lonely

The only known representative of the family *Picornaviridae*, genus *Aphthovirus*, I am a very small virus, never any bigger than 20 to 28 nm (nanometers), while some of my fellow viruses attain over 100 nm. If you consider that a nanometer is one billion times smaller than a meter, you realize that I am one of the smallest inhabitants of the planet. I am biological entity that is an obligate parasite of certain animal cells.

I am the same size as the polio virus, a cousin from the genus *Enterovirus*. Humans fear us both in equal measure, but for different reasons.

A multi-faceted structure

I am a non-enveloped virus, or a “naked” virus. This does not mean, however, that my architecture is not carefully designed. Although humans using state-of-the-art electronic microscopes only can see me as a berry-like, more or less spherical form, my protective shell, or capsid, is structured like an icosahedral. It has 60 faces, 30 edges and 12 vertices.

My heart is a single strand of ribonucleic acid, the famous RNA. According to scientists, who are one hundred million times bigger than I am, this single strand of RNA is composed of approximately 8 500 bases, or nucleotides. This macromolecule, which represents about 30% of my weight, is the central command unit of my pathogenic power. Thanks to it, I can infect the cells of cloven-hoofed mammals, otherwise known as even-toed ungulates or Artiodactyla.

After infiltrating my RNA into their cytoplasm, I modify the cellular instructions in order to orient their metabolism towards producing numerous copies of me and to organize the release of my “clones” into their blood and lymph.

The remaining 70% of my weight is made up of proteins. I therefore am immune to products that attack sugars and fats.

External and internal proteins

My capsid is formed by the assembly of 60 identical sub-units called capsomers or protomers that are about 7nm large, each constituted by a sample of my four structural proteins named VP1, VP2, VP3 and VP4 (VP standing for “Viral Protein”). My protomers associate themselves into groups of five to form a pentamer.

The first three proteins are exposed on the surface of my capsid. They have a remarkably identical three-part structure that is found in all picornaviruses. As for the fourth protein, it is buried inside, attached to the vertex of each of my 12 pentamers and in contact with my genetic material.

While thousands of copies of my RNA are being replicated, I also synthesize 7 non-structural, enzymatic action proteins.

Virologists have established a nomenclature of numbers and letters to identify my different proteins: 1A to 1D for my capsid proteins, 2A to 2C and 3A to 3D for my enzymatic proteins. Among the latter, protein 3B, otherwise known as protein VPg, and protein 3D, also known as RNA-dependent RNA polymerase, play a major role in expressing my genome and/or its replication.

My VP1 structural protein, five copies of which are bound around each vertex of my capsid, form a loop that protrudes from the surface. This carries a triplet of amino acids that serves as a key to bind me to transmembrane protein receptors named integrins located on the surface of the cells that I infect.

Its structure and composition give me a double antigenic and immunogenic power. The major antigenic determinant that it carries, and which is the favorite target of neutralizing antibodies, is endowed with a wide antigenic variability that allows me to escape the acquired immunity of my host and renders me particularly fearsome. I thus can contaminate an animal several times, either successively or simultaneously, by appearing in different molecular forms.

I consequently am unique in my structure and diverse from an antigenic and immunogenic perspective. This poses real problems for people in laboratories trying to develop vaccines. In 2010, I was recognized in the form of 7 serotypes, 64 subtypes, and some thousand variants.

A diplomatic entry, an explosive exit

Like all viruses, I ensure my reproduction at the expense of a cell.

When I am in the company of ruminants and suids whose tissue cells and pharyngeal mucuous membranes are susceptible to my presence, I attach myself to one of their membrane receptors thanks to the well researched molecular complementarity of my VP1 protein. I then trigger an invagination reaction in the cytoplasmic membrane, a little as if the cell would like to swallow me. This form of endocytosis is followed by an uncoating and injection of my RNA into the interior of the cell. The capsid/genome separation is critical. My genome must be free to express itself.

Like nearly all RNA viruses, I replicate myself in the cytoplasm of the host cell by taking control of its metabolism and diverting it to my own advantage to synthesize my own proteins. Starting from this moment, I become undetectable. Scientists call this step the eclipse phase.

My RNA is of positive polarity because it behaves like a RNA messenger. The message that it carries is recognized and translated directly into viral amino acids by the ribosomes of the cell that I infect without a preliminary transcription. This is why it also is called infectious RNA.

I am a genetically thrifty virus. I synthesize my different functional proteins using the sole gene carried by my RNA molecule, in other words, with a minimal genetic configuration of regulatory elements.

The coding region of my gene is flanked by two non-coding regulatory regions that control my replication. The one situated on my 5'-end, with about 1 300 nucleotides, contains a secondary structure named the Internal Ribosomal Entry Site (IRES) which ends in a VPg (Viral genome linked Protein), a small viral protein of 24 amino acids.

In a first step, I requisition a cellular protease in order to have it separate the VPg protein from the 5'-end of my molecule. This condition allows the cellular ribosomes to bind onto the site dedicated to them (IRES) and start the translation of my genetic message into amino acids.

The decoding gives birth to a non-functional polyprotein, said to be immature, of 2 332 amino acids. Unstable, it rapidly fragments into 3 primary polypeptides, P1, P2 and P3, each of which will undergo cascading divisions that ultimately generate the 4 structural proteins of my capsid (derived from P1) and the 7 enzymatic proteins (derived from P2 and P3) which I need to reproduce myself.

In a second step, I orchestrate in parallel the replication of my genome and the construction of a capsid, the two elements of my future clones. To replicate my positive polarity RNA molecule, I first synthesize a negative polarity mirror molecule.

To do so, I call upon the regulatory region of about 90 nucleotides located on its 3’-end. I use it as a matrix to produce several thousand more or less perfect copies of the positive RNA molecules of my future clones.

Unlike the translation process, this duplication requires the presence of the VPg protein at the 5’-end of my molecule because it serves as a primer to the polymerase-replicase RNA.

The positive RNA that I produce has three roles to play:

- to serve as a matrix for the synthesis of negative polarity RNA strands that will become in turn matrixes for the synthesis of positive polarity RNA strands;

- to act like a RNA messenger for the production of new polyproteins and the initiation of a new replication cycle;

- to be encapsidated and to constitute the genome of future viruses.

The capsid proteins of my future clones are synthesized using the polypeptide P1. It first is divided into 3 proteins VP0, VP3 and VP1. They self-assemble into sub-units, gather together into pentamers, form an instable procapsid around one of the numerous strands of newly synthesized prositive RNA, and give birth to a provirion. This assembly marks the end of the eclipse phase. The VP0 protein divides itself into VP2 and VP4. The procapsid becomes a stable capsid and the provirion becomes a mature virion. My offspring accumulate in the cytoplasm of the infected cell, ready to emerge as soon as the cell dies, probably by apoptosis, a kind of cellular suicide induced by complex mechanisms to which I contribute.

After the cells burst, my liberated virions circulate in the blood and lymph of my host and go on to contaminate receptive organs such as the animal’s heart. This is how I reproduce myself, piece by piece and at the expense of metabolic machinery outside my body without which I cannot continue.

Mixed success

But the process is not perfect. I admit that errors take place with each intracellular replication. Evidence of these errors may be found when the walls of my host cells burst. Alongside complete viruses that are correctly shaped and infectious, one finds viral particules that appear complete but have no RNA in the center, immature virions, free capsomers, and unused viral proteins.

In practice, only 5% of the virions produced become infectious viruses matching my expectations. The rest are abandoned like production waste. As I play the high numbers card, enough offspring usually remain to ensure my continued existence. However, I must seize every possible opportunity to reproduce myself in very large numbers.

In the end, I am satisfied when I succeed in compelling a mammal’s cell to provide 200 to 300 reproductions of myself. Like all viruses, I of course depend on foreign organisms to survive, but my power to take them over and divert their metabolic commands to serve my own interests is excellent revenge.

Virus typing

I probably have been present on Earth since the emergence of Artiodactyla, the branch of mammals with two toes on each foot, between 5 and 25 million years ago. I lived at the expense of wild animals well before the invention of livestock husbandry by humans some 6 000 to 8 000 years ago.

The description of the clinical signs of my presence goes back to 1546 but it took another 300 years for me to be identified. In 1897, I was the first animal virus isolated in cattle by two German researchers, Friedrich Löffler and Paul Frosch, but for many years, I intrigued scientists by the inconstancy of the immunity acquired by animals that had hosted me. Some seemed to definitively resist my presence, others relapsed.

It was not until 1922 that two research scientists, Henri Vallée and Henri Carré, found the explanation and validated the principle of my antigenic and immunogenic diversity. They introduced the concept of viral type by studying animals infected with foot-and-mouth disease in France and separating what they called type O (because it was sampled in Oise) from type A (coming from Ardennes). Four years later, in 1926, a third type was recognized in Germany by D. Waldmann and K. Trautwein. As it was the third type to be discovered, it was given the third letter of the alphabet, C. Ten years later, in 1936, samples from South African territories required three new types of the virus to be recognized that were named after their geographic origin by the acronyms SAT1, SAT2 and SAT3 (SAT signifies South African Territories). The seventh type, found in Asia in 1956, is called Asia1.

At the dawn of the third millennium, I thus am known based on serological tests under 7 different types. The first three are found nearly everywhere in the world, the last four seem to limit themselves to tropical countries. Researchers now are comparing the exotic types with the ubiquitous types. All of my 7 serotypes display a relative antigenic stability despite my particularly high mutation rate.

After nearly 50 years of study, scientists have dismissed the idea that I could give birth to an eighth serotype. Their conviction rests on the fact that changes in the tertiary configuration of my structural proteins are restrained by the maintenance of their functions. In their view, I have reached the physical limits of deformations compatible with my molecular integrity. Any new major protein modifications would endanger the physical architecture of my capsid and that of my antigenic site located on VP1. But perhaps surprises await the scientists?

Nevertheless, they know that I can accommodate minor genetic reshuffling, which obliges them to invent the idea of subtypes to capture my antigenic diversity, even if they remain unaware of the interactions between my different strains within the same host population.

By 2010, over a century after we first met, scientists had inventoried 32 subtypes for type A, 11 subtypes for type O, 5 subtypes for type C, 6 subtypes for type SAT1, 3 subtypes for type SAT2, 4 subtypes for type SAT3 and 3 subtypes for type Asia1.

My tremendous genetic flexibility separates me into over 1 000 distinct variants, each with a unique immunogenic power and infectious character.

Who said that a small virus like me would be easy to describe?

A unique virus…

Schematic representation of the exterior and interior of the capsid of the foot-and-mouth disease virus: the three external structural proteins ■ VP1, ■ VP2 and ■ VP3 and the sole internal structural protein ■ VP4. – 2011. - *© Michel Launois, Cirad.*

…a diverse virus.

Serotype O	Serotype A	Serotype C
Serotype SAT1	Serotype SAT2	Serotype SAT3
Serotype Asia 1	○ Sub-types and topotypes	

A breakdown of the foot-and-mouth disease virus in multiple serotypes, subtypes and topotypes. - 2011. - *© Michel Launois, Cirad.*

Source of inspiration: « Knowles N. - Global diversity of foot and mouth disease virus. Symposium: « Tracking the Emergence and Global Spread of FMD, Royal Society of London, 13th may 2008 ».

Between comfort and discomfort

I like a neutral environment, one that is not too acidic, too alkaline, too dry, too hot or too exposed to ultraviolet light. In addition, I have the curious ability to stick to diverse inert elements such as aluminium hydroxide. This characteristic is used by humans who manufacture vaccines, the weapons they use against me.

I am fine with relatively cold environments even though I really only am active when inside the feverish body of my animal hosts.

However, when the surrounding temperature goes past 56°C, my chemical and physical integrity do not survive more than 30 minutes. I remain active 10 days at 37°C, 70 days at 22°C, and over a year at 4°C, especially if I am placed in a glycerol medium that stops the formation of ice crystals.

Fat and sugar solvents leave me indifferent for the simple reason that my capsid basically is made exclusively of protein.

In contrast, I do not like household bleach, N-acetyl-ethylene-imine, azaridine, glycidaldehyde, caustic soda, even when highly diluted with water, and formaldehyde. Scientists have used this last weakness to procure an inactivated vaccine from me.

I can withstand relative humidity above 55%, indirect daylight, darkeness and time passing. In this way, I remain potentially active for 3 days in the ground during the summer, 14 days in dry cattle manure, 28 days in the ground during the winter, 39 days in urine, and 180 days in slurry.

I am not interested in anything that falls outside a pH (hydrogen point) range of 7.2 to 7.6. The simple and natural acidification of muscles in an infected, deceased animal is enough to displease me, which is one way of saying that the meat no longer is a refuge for me, unless it is put somewhere cool for longer conservation.

The fact that I easily accommodate neutral environments, resist both dry and humid heat, and both the cold and heat tolerated by my hosts, means that overall, my requirements present more advantages than disadvantages.

Carried towards hosts

Livestock animals like cattle, sheep, goats, and pigs ensure my spread. Today, there are more opportunities for me to multiply and create epizootics than in centuries past. There are more animals, they travel extensively around the world, people selectively have bred livestock to perform well in terms of meat and milk production and growth, but the animals are more susceptible from a health perspective. This facilitates my activities, particularly because these new livestock breeds are raised intensively, and crowded conditions are ideal for me to spread from neighbour to neighbour.

Animal markets, fairs, rural competitions and even family reunions in the countryside are other opportunities that I exploit to spread.

Even if numerous countries have taken radical measures to make my life difficult, especially beginning in the second half of the 20th century, I persist in an enzootic form in more than half of the countries in the world. When people believe I have been eradicated, I can manifest myself in sometimes unexpected outbreaks of foot-and-mouth disease. It helps that numerous wild Artiodactyla species, such as the African buffalo, sometimes host me very discretely.

To boost my chances of coming into contact with a host, I follow a two-pronged strategy, direct transmission and indirect transmission.

By direct transmission, I mean passing from one animal to another through simple contact, which is not difficult in intensive livestock systems. I make the most of licking, skin contact with a fellow beast, and suckling offspring, to pass from one individual to another, particularly when viral excretion is abundant.

I also use a silent carriage technique of taking refuge in the sanctuary of the tonsils and pharynx of animals that appear absolutely healthy to both farmers and veterinarians. Not a single clinical sign betrays my presence. This silent spread often is overlooked.

My indirect transmission is ensured first by humans themselves. Veterinarians, inseminators, rural technicians, policemen, postmen, itinerant traders, and agricultural product suppliers all involuntarily have enabled my spread in the past. With only very rare exceptions, I have no effect on this five-toed mammal. To me, humans are merely mobile supports that harbor me in their nasal cavities, on their hands -- with or without gloves -- shoes, work and leisure clothes, and transmit me to all of the tools and equipment that they use.

Animals such as cats, dogs, and horses also can serve as passive transmission vectors.

Contaminated milk collection trucks once were excellent vectors for my dispersion between dairy farms because the overpressure in the tanks created very powerful aerosols. Sadly for me, humans now have equipped the trucks with special filters. A lost opportunity! Luckily, I still have many others.

I can survive in meat and in animal by-products such as offal, endocrine glands, bones and marrow. I sometimes can be found in uncooked cured products and in hams, even six months after they were made. This is how in 2001 I found myself in catering waste (swill) meant for pig feed and, as it had not undergone the officially required heat treatment that could have killed me, I contaminated the pigs.

Wind also contributes to my long-distance spread, especially with the right weather conditions: a relatively low speed, without gusts, in a constant direction, relative humidity over 60% but without heavy rain, and moderate sunlight.

In 1981, scientists established that I passively travelled 250 km over the Channel from contaminated pig farms in the French department of Côtes-d’Armor in Brittany to cattle farms on the Island of Wight.

I understand the fear inspired by my ability to create secondary and even tertiary outbreaks from a first outbreak that people thought had been contained, without anyone really understanding how! Experts have spoken about aberrant saltatory outbreaks. I savour the salt of the expression. However, my air travels are five times less efficient above land and less effective in tropical regions than in temperate areas. It is up to biometeorologists to confirm my other modes of circulation! They have not yet proven my capacity to cover several thousand kilometres, at several thousand feet in altitude, either alone as a viral particle mixed with sand or ionized clay, or by using carrier birds or migratory insects.

My infectious potential revealed

Sick animals exhale me in veritable aerosols. Cattle can excrete 10 000 viral particles per day. By breathing, pigs can eject me into the environment in amounts that are 1 000 to 10 000 times higher than cattle. When one knows that only 10 of my particles are enough to infect a susceptible bovine, it is easy to imagine my infectious potential. Some have calculated that in one minute, a sick pig is able to disseminate a sufficient quantity of me to contaminate 60 000 cattle.

I am happy in saliva, tears, urine and all leaking bodily fluids, as well as blood and lymph.

Lesions are a kind of incubator for me. After the vesicles burst, some of my fellow viral particles find themselves in the circulatory systems within the body and then in the excrement of mammals while conserving their infectious potential.

Slurry and manure therefore are major sources of contamination. In male hosts, I am present in the sperm, and in females, in milk and embryonic envelopes. I can even infiltrate the wool of sheep. In other words, I am everywhere.

I do not only infect healthy animals. Some already are carrying other pathogenic agents. Scientists still do not understand how we cohabitate.

The expression of my pathogenic power depends on numerous factors: my serotype and topotype, the environment in which I find myself, the receptivity of hosts that I encounter, their general condition before contamination, and the tissues that I infect, my preference being mouth epithelium and heart muscle.

Some of my strains cause gastrointestinal, respiratory, and eye lesions. Cattle and sheep are more susceptible than pigs to respiratory infections linked to my presence.

I often use sheep and goats, which are very good reservoirs, to discretely introduce myself into new areas. Pigs are marvellous hosts in terms of helping me to multiply and spread. And cattle on livestock farms are good at revealing my presence.

For a virus, living with others is not a weakness, it is a metabolic requirement.

An ambiguous status

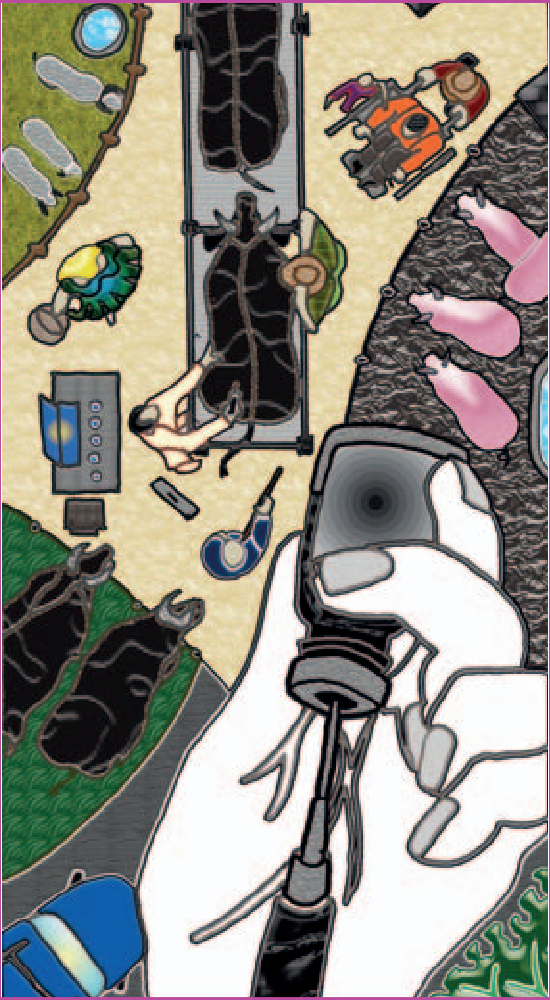
Am I living or dead? Virologists and philosophers are hotly debating this question. Some classify me as a structured biological entity, reactive but not alive, under the pretext that I am incapable of metabolic autonomy. It is true that I do not breathe, eat, excrete any waste, or have a personal energy system, and I can only reproduce myself by hijacking a receptive host cell. I therefore am not a cell according to the definition of biologists but an obligate parasite.

However, my virus status has been evolving ever since some of my cousins drew attention to themselves due to their huge size, with a genome two times larger than that of a bacterium, and their capacity to infect other members of our family. To be the virus of a virus is something even those who consider us to be merely primitive and harmful have to admire!

My evolution follows the law of natural selection discovered by Darwin. I adapt myself to new environments through mechanisms that are identical to those of other living beings. Furthermore, I only am active when my physical-chemical integrity is scrupulously respected.

When I consider my place and role in the history of evolution, my answer to the question, “living or dead?” leans towards “living”. I am made up of the same base protein molecules and I use the same genetic alphabet as living organisms. This probably allowed some of my ancestors to sustainably introduce themselves into the genome of other single and multi-celled organisms. A hypothesis that they were the origin of the nucleus of eukaryotic cells even has been advanced.

In addition, although I compensate for the absence of metabolic machinery by borrowing the enzymatic know-how of my hosts, some scientists think that I was an essential actor in the organization of the living world and its evolution by bringing about crucial gene transfers between ancestral animal and plant hosts. Up until recently, humans were interested in us in a limited manner, focussing only on how to fight us. In the future, they will have to accept us as key actors in the maintenance of the planet’s biological equilibrium.



The point of view of the vaccine

Before there was science, there were local customs

In the past, farmers understood the contagious character of the disease and knew by observing clinical signs that naturally infected animals could recover spontaneously and develop resistance to new infection.

Some were inspired to hasten the natural contamination of their cattle herds. They would introduce an animal infected with foot-and-mouth disease into a group of healthy animals gathered together in a stable and practice aphtisation by rubbing the muzzles or lips of healthy animals with virulent saliva taken from the lesions of the sick animal. A maximum number of animals consequently fell ill at the same time and the quarantine of the farm could be lifted more quickly. Farmers also knew that when triggered in this way, the disease was similar to spontaneous infection but it was expressed in a less severe form, leading to fewer losses.

Doctors recommended similar empirical processes to prevent certain highly contagious childhood diseases such as smallpox.

Prior to my birth

Around 1900, before I was invented, numerous researchers, including F. Löffler, the co-discoverer of the foot-and-mouth disease virus, tested different methods to immunize herds against foot-and-mouth disease by using the immunogenic power of viruses.

These methods were based on the principle that every host organism reacts to the presence of a pathogenic agent, which plays the role of an antigen, with the production of antibodies, large defensive proteins called immunoglobulins, which confer protection or immunity that lasts for a certain period of time depending on the quantity produced.

In theory, transferring antibodies produced by an animal that recovered naturally from a disease to a healthy animal renders the healthy animal more resistant to the disease. Serotherapy, otherwise know as seroprevention, confers a passive immunisation to the recipient. Practitioners took blood from convalescent animals that had contracted the disease some twenty days earlier. The blood then was treated and subcutaneous injections of the serum obtained were given to animals that were still disease free.

The immune serum was used widely in numerous European countries between 1920 and 1930 despite erratic results, a high cost price, and often imperfect and short-lived effectiveness.

In Denmark, 112 000 litres of immune serum from convalescent animals were used between 1925 and 1933. During the same period in France, up to 13 000 cattle were treated by serotherapy in one year. A combination of immune serum and virulent lymph even was marketed by a pharmaceutical laboratory under the name “seraphtine”.

A triple association

In 1926, I appear as a vaccine in the form of a formalin decoction developed by three French researchers, H. Vallée, H. Carré and P. Rinjard. The task of the formalin, also known as formaldehyde, is to inactivate the virus by chemically destroying its RNA molecule.

Stripped of its steering unit, the virus loses its infectious power and its capacity to reproduce. However, the virus retains its antigenic and immunogenic power, which is held by its capsid’s VP1 protein. The animal that receives me thus can produce antibodies specific to the viral type that I contain without the risk that the disease will be triggered. I was authorized by international authorities with this form of an inactivated virus.

However, until only recently, countries always manufactured me with attenuated viruses. These are living viruses whose virulence has been reduced by successive passages in hosts that are not very susceptible, such as rabbits. My immunogenic efficiency with an inactivated virus is less than what I can express with an attenuated virus; however, there is no risk of a reverse mutation that could return the infectious and pathogenic power to the virus. It would not be appropriate if I triggered or revived this disease instead of fighting it!

To compensate for the lesser immunogenic power of my viral component and to stimulate the production of specific antibodies in the animal to be protected, researchers added adjuvants.

Beginning in 1932, a Danish scientist, S. Schmidt, experimented with aluminium hydroxide and discovered that the foot-and-mouth disease virus fixes itself easily to this material through adsorption. This would be my only immunity adjuvant for over twenty years. In 1937 in Germany, Professor D. Waldmann's team demonstrated the determining role of certain physical-chemical parameters (pH, temperature, concentration of formaldehyde) in the inactivation of the foot-and-mouth disease virus. Their method was adopted and used with almost no modification until the 1970s.

These successive developments made me the first foot-and-mouth disease vaccine to be made with a formalin-treated virus, known in France as the VSW vaccine, short for "Vallée-Schmidt-Waldmann".

The multiplication of the virus

In order to be used to control foot-and-mouth disease, I had to be produced on an industrial scale. In the 1930s, the main difficulty was obtaining an abundant source of the virus. D. Waldmann developed a first method that was inspired by the aphtisation technique.

It consisted of inoculating the virus in the lingual epithelium of live cattle free of the disease to obtain lesions and then to harvest the infected epithelium and lymph to manufacture me.

After the animals were slaughtered, 40 to 50 doses containing about 60 ml of vaccine could be fabricated from each tongue. Of course, I was only monovalent because I was prepared from a single viral type, the one encountered most often in the field.

In parallel, during the 1930s a Dutch researcher named H.S. Frenckel developed a method to grow the virus on fragments of cattle tongue epithelia, the cells of which were kept alive in a nutrient medium.

This technique, which was presented in 1947, was revolutionary at the time. By 1950 it had replaced other methods thanks to: its independence from the immune status of the animal, regular production of the virus, and high yield that was 100 times greater than with Waldmann's method.

The manufacturing and bottling of the first foot-and-mouth disease vaccines - France, 1952 - *© Marc-Henri Cassagne, FNGDS.*

Begining in 1970, the multiplication of the virus on cell culture lines in suspension, such as the BHK 21 line, an acronym for Baby Hamster Kidney (meaning the kidney cells of a newborn hamster, clone 21), was carried out in contained environments inside veritable biological reactors.

This technique allows every step of my production process, from the growth of cells for my multiplication to my inactivation, formulation and packaging in ready-to-use doses, to be carried out under maximum biosecurity conditions. This has made undesirable virus escapes, which occurred up to the 1980s, to become extremely rare.

Over the course of discoveries

My formulation and design evolved with scientific and technological advances. In keeping with European safety rules regarding the manufacture of veterinary medecines, great care now is taken to ensure that I am harmless.

Formalin, the first generation inactivant which was known since the 1950s to have an incomplete neutralizing effect on targeted viruses, has been replaced by second generation inactivants such as Binary-Ethylene-Imine (BEI), whose chemical activity and manner of application guarantees a complete inactivation of the infectivity of my viral particles.

To avoid all risk, a large pharmaceutical laboratory even is going to double the dose of the inactivant and double its application time. In ten years, it has produced over 3.5 billion doses from inactivated viruses using this method without a single vaccine accident!

I have come a long way since my first semi-industrial production in 1937 as a monovalent vaccine, meaning a vaccine directed against only one virus serotype.

New adjuvants have been introduced into my preparation. They allow a concentration of my active material, in this instance my viral antigens, to stimulate a more powerful and precocious immunity in the recipient in order to reduce the volume of my dose.

Around 1955, thanks to saponin, a molecule of plant origin, the dose of my trivalent version, which allows cattle to be vaccinated against three viral serotypes with a single injection, was reduced from 45 to 15 ml. This helped to reduce nodules, edema, and difficult to absorb indurations at the site of the injection of the animal being vaccinated!

The use of oil adjuvants, first in a simple emulsion like oil-in-water or water-in-oil in the 1970s, then a double emulsion, such as water-in-oil-in-water, in the 1990s, brought my dose down to 10 ml, then 5 ml, and finally to 2 ml, much to the satisfaction of the vaccinated and the vaccinators, furthermore offering the advantage of a unique vaccine formula tolerated by both pigs and ruminants equally well.

When all is going well, I am injected in cattle at the age of 2 months and then at 6 months. The production of antibodies starts 4 days after I am injected and increases over 2 to 3 weeks to reach a plateau where it is maintained before gradually decreasing. A simple annual booster shot prolongs the protection for one year. However, I admit that I have been the cause of several vaccine-related accidents.

In the old days, when I contained attenuated viruses or viral particles that were not completely inactivated, my injection actually provoked infectious outbreaks of foot-and-mouth disease.

My adjuvants, such as aluminium hydroxide or saponin, and my imperfect purification also could trigger allergic reactions that could at times be as bad as mortal anaphylactic shocks.

Some cattle expressed an immediate hypersensitivity with fever, respiratory and cardiac problems and a drop in milk production. Others reacted many days later with eczema rashes and gestational disorders that could lead to abortion.

Allergic reactions linked to my preparation on cell cultures were reported in 1984-1985. This must have had a negative impact on farmers who had been encouraged to vaccinate their herds.

At the beginning of the 21st century, my industrial production is accompanied by very strict safety controls.

The careful purification of my antigens using ultrafiltration and chromatography methods enable all undesirable proteins to be eliminated with the exception of those of the virus' capsid in charge of immunity. The undesirable proteins in question are the allergenic cellular proteins produced by my culture medium and non-structural viral proteins (NSP) that are synthesized when the virus reproduces both in vivo during an infection and in vitro on cell cultures.

When these are removed from my composition, vaccinated animals no longer develop antibodies against the virus' NSPs. Consequently, one now can serologically distinguish a vaccinated animal that does not develop anti-NSP antibodies from an infected animal that does develop them.

The necessary specificity

My goal is to allow animals susceptible to the foot-and-mouth disease virus, starting with the most valuable cattle, to safely acquire strong and lasting immunity by powerfully stimulating their immune systems to increase the production of neutralizing anti-bodies circulating in their blood.

My first monovalent preparations were targeted against serotype O of the foot-and-mouth disease virus. I then became bivalent against the two most common virus types, O and A, before becoming trivalent against O, A and C. Today, type C is no longer included in my preparation because it is on its way to being eradicated in the world. Each country can obtain a personalized vaccine cocktail depending on the strains circulating. When I am used in Turkey, Iran, and the Caucases, I am multivalent with at least 4 valences (type O, 2 sub-types A, and type Asia1). In Africa and the Middle East, type SAT2 often is introduced into my composition. Since 1966, my foot-and-mouth disease antigens have been associated with a rabies vaccine to produce a combined vaccine able to protect cattle from these two diseases with just one injection.

I realized early on that there were limits to my impact and I fascinated scientists by my drops in efficacy, which they refer to as “immunity breaks”, where an animal that is vaccinated nonetheless manifests signs of the disease. They discovered that the genetic instability of the foot-and-mouth disease virus and the antigenic variability of its VP1 protein produced within the same serotype numerous variants (subtypes and topotypes) with different immunogenic and antigenic powers.

No viral strain therefore is exactly identical to another. This plurality complicates both their job and mine. In addition, a new variant can appear from one year to the next. The problem is that I only am effective when my antigens are closely related to the infectious strain that is circulating.

If my index of similarity with the field strain is less than 0.6, scientists consider that I offer imperfect protection. Like all human influenza vaccines, I must be updated periodically through the preparation of a new vaccine cocktail that is adjusted to the viral strains circulating.

Legal obligations

The history of my adoption in the fight to control foot-and-mouth disease is linked closely to the evolution of biological and virological technologies and the creation in many countries of industrial vaccine production laboratories.

After the important foot-and-mouth disease panzootics of 1937 in Germany and 1952 in France, where over 350 000 outbreaks were declared, health officials made stopping the spread and the eradiction of the disease a priority, with plans to implement preventive medical measures.

In Lyon, the work of the *Institut Français de la Fièvre Aphteuse* (IFFA), created in 1947 by Dr. Charles Mérieux, enabled the mass production of vaccines. The voluntary vaccination approach, which had been necessary when I was not available in large quantities, was replaced by a collective vaccination strategy.

In most continental European countries, I became the key actor in the fight against foot-and-mouth disease starting in 1961 with obligatory mass vaccinations of all cattle over 4 months old on a yearly basis. In France, my preparation and inspections of my safety and effectiveness were regulated by a ministerial decree in 1965.

This was the beginning of a 30 years fight against the foot-and-mouth disease virus that coincided with a period known in France as the "*trente glorieuses*", or "thirty glorious years" because it was a period of economic prosperity which no doubt had little to do with my prophylactic contribution.

I am quite proud of my work because this strategy, associated with the systematic slaughter of susceptible cattle, sheep, goats, and pigs in contaminated outbreaks, allowed the number of foot-and-mouth disease cases to drop from several hundred thousand at the beginning of the 1950s to several thousand in the 1970s, and then to the disappearance of the disease from Europe at the end of the 1980s.

Sign used in the 1950s to restrict access to a vaccine production laboratory. To avoid leaks, the foot-and-mouth disease virus is handled only in confined, secured areas. - France. - *© Marc-Henri Cassagne, FNGDS.*

Forbidden to stay in Europe

Thrilled with my vaccinal success, I was amazed to learn that a European directive ordered me to the sidelines on January 1, 1992. In preparation for the single market of 1993, it became illegal to use my services throughout the European community.

Before presenting the argument that led from my being required to my being forbidden, I should acknowledge that occasional episodes of foot-and-mouth disease in France in 1981 and in Italy in 1984, as well as a few post-vaccination accidents and virus leaks between 1977 and 1987, had weakened my credibility in favour of some countries such as Great Britain, Ireland, and Denmark, which had never adopted vaccination.

After five years of discussions between representatives of European member countries, the decision to end the preventive vaccination policy was confirmed by the Commission and the Council on the basis of sanitary, commercial, and economic considerations. All the same, I doubt the good faith of certain arguments put forth by my opponents.

The special characteristics of the foot-and-mouth disease virus were played to my disadvantage. Its antigenic plurality, its absence of crossed immunity, the regular emergence of new strains and the possible introduction of the exotic SAT and Asia1 serotypes, associated with the fact that I was used in most countries only on cattle, called into question the point of pursuing my prophylactic use in Europe. When I do not correspond to the antigenic profile of an invading strain, I face a high risk of underachievement as a vaccine.

I also worried veterinarians when they discovered that vaccinated cattle carrying the virus could, without showing any revealing signs, replicate the virus deep in their throats with the risk of excreting the virus and contaminating susceptible species. Yet to date no case of foot-and-mouth disease has been reported that could be traced to vaccinated virus carriers.

However, in the 1990s, the decisive factor was the economic interests related to the establishment of the free circulation and trade of animals and animal products within the European Community. Three member countries did not vaccinate and nine others did. It was out of the question to engage in commercial trade while this difference remained. At the time, serological tests were unable to differentiate between antibodies caused by a vaccination and those caused by an infection in an animal. Only the cessation of vaccination could resolve this issue, and vaccination also was hindering exports and the conquest of new international markets.

To further complicate the situation, vaccinating European countries applied different vaccination strategies for susceptible animals other than cattle (pigs only were vaccinated in Spain and Portugal, sheep only in Spain, border areas of France and Italy) and some virus strains had shown a preference for unusual hosts (pigs rather than cattle).

The continuation of preventive vaccination therefore would have required choices to be made regarding the animals to vaccinate: cattle -- like prior to 1991 -- due to their market value? Pigs for their virus reproduction potential? Sheep and goats because they discretely introduce the virus without suffering much?

Today, the situation has evolved and laboratories produce me in a highly purified form that does not contain non-structural proteins (NSP). I no longer induce the production of anti-NSP antibodies in vaccinated animals. The presence of these antibodies in an animal therefore is evidence of a viral infection. In endemic areas, serological tests can be used to identify infected herds and verify the absence of virus circulation in a vaccinated herd.

In the future, these tests may enable some countries to pursue a foot-and-mouth disease control policy using vaccination without penalizing their commercial transactions and provide proof of the absence of infection, thereby justifying their status as countries "free of foot-and-mouth disease with vaccination”.

The non-vaccination policy allowed European countries to constitute livestock free of foot-and-mouth disease but vulnerable if the virus is reintroduced because the animals are not immunized. Heightened vigilance must be maintained. This is made possible by the coordinated implementation of epidemiological surveillance networks and the development of antigen and vaccine banks.

A protection mechanism

Foot-and-mouth disease free countries manage antigen banks that are strategic reserves for emergency vaccination situations. My antigens are stored most often in a form concentrated 80 to 1 000 times and frozen in nitrogen at very low temperatures, usually -130°C to guarantee a shelf-life of at least five years.

Upon demand of client countries, millions of monovalent or multivalent doses of vaccine are manufactured within a few days under strict quality controls, with a potency and range adapted to the situation on the ground. A 50 litre volume of concentrated antigen can produce 15 million doses of cattle vaccine. I also am stored in the form of ready-to-use vaccines but my shelf-life at 4°C is only 12 to 24 months.

I am housed in three international banks: the International Vaccine Bank (IVB) established in 1985 and based in Pirbright, United Kingdom on the site of the world FAO/OIE foot-and-mouth disease reference laboratory; the North American Vaccine Bank (NAVB) established in 1980 and based in the United States; the European Union Vaccine Bank (EUVB) established in 1991 with offices in Italy (Brescia), France (Lyon) and United Kingdom (Pirbright).

I also am held in national banks in numerous other countries.

To keep these antigen and vaccine banks up to date, field surveillance is carried out by regular sampling campaigns around the world. Samples are sent to national or international reference laboratories for characterization.

Molecular biology techniques enable scientists to establish the degree of their immunological relationship with vaccine strains already listed in order to detect the emergence of a new variant. Using this data, it is possible to construct a phylogenetic tree (a dendrogram) of strains of a same type and to monitor their evolution over time and space.

Since I was abandoned by European countries, the fight to prevent foot-and-mouth disease has become one of disease control. It relies on an epidemiological surveillance system that allows a rapid response to the introduction of the virus to limit the spread of the disease. It is based on:

- training and informing all actors involved (farmers, veterinarians, livestock professionals), development and establishment of a national emergency plan and carrying out simulation exercises;

- very strict surveillance of the movement of susceptible animal species within Europe and with countries outside of Europe thanks to individual identification marks (tatoos or ear tags) combined with identity documents that accompany animals over their entire lives (per animal for cattle, per animal batch for pigs, sheep and goats). Their movements are recorded in a data bank that allows them and their derived products to be traced;

- reinforced health controls on borders and good knowledge of trade flows to limit the risk of cross-border virus transmission linked to the importation of animals and animal products.

An under-estimation and misunderstanding of risks, and poorly applied surveillance measures are weaknesses which benefit the virus.

The most striking example is the 2001 epizootic in Great Britain, which experts had considered to be a country facing a very low risk of foot-and-mouth disease due to the protection provided by being an island. However, an inadequate supervision of farms and the feeding of pigs with insufficiently heated swill imported from Asia opened the door to the virus. The result was the massive slaughter of animals (over 6 million heads, including 4.9 million sheep, 0.7 million cattle, and 0.4 million pigs) and economic losses estimated at nearly 13 billion euros.

Authorized elsewhere in different forms

Despite endemic outbreaks of foot-and-mouth disease in countries bordering on the European Union, themselves faced with a permanent threat from their own neighbours more to the east (Turkey) and south, and despite the risks linked to the intensification of trade and the movement of people, annual preventive vaccination has become an outdated concept in Europe, one that has been replaced by prophylaxis based on health measures.

If it was still followed, each year at least 80% of the 300 million animals concerned, of which 40 million are in France, would have to be vaccinated at great expense for me to ensure effective immunization coverage against the progression of the virus and the spread of the disease.

In epizootic outbreak situations, the recommended control strategy is slaughter in the infected zone, accompanied or not by emergency vaccination. That choice is heavily regulated and is only applied following authorization by the European Commission.

When the infected zone has a high density of animals and/or the slaughtering capacities are insufficient, I am used as an emergency or suppressive vaccine. I am called that because the animals subsequently are slaughtered.

If the epizootic is difficult to control through stamping out alone, I am used as an emergency protection vaccine to create a belt of vaccinated animals around the infected outbreak.

The choice to use slaughter alone or slaughter combined with emergency vaccination is assessed in terms of the economic impact on export markets. To date, European countries always have favoured the first option (slaughter alone) with the exception of the Netherlands, which resorted to suppressive vaccination during the 2001 epizootic.

In 1994, OIE (World Organization for Animal Health) set up a procedure to recognize the foot-and-mouth disease sanitary status of its members (178 countries and territories in 2010).

In 2010, 65 member countries were recognized as being “free of foot-and-mouth disease, without vaccination”. Australia, New Zealand, Indonesia, USA, Canada, Chili, and countries of Central America and the European Union are on the list.

To avoid any introduction of the virus and retain their status, these countries must respect very strict sanitary standards covering their trade in animals and animal products. They therefore cannot import vaccinated animals. If an infection occurs, a country loses its status and consequently its export markets. These only may be retrieved after a period of between 3 months to 2 years when the country has demonstrated, through clinical surveillance and serological tests, the absence of viral circulation.

In countries where foot-and-mouth disease is endemic, the priorities are different and I still provide highly appreciated services to rectify the sanitary situation in livestock areas and keep the disease under control, particularly when socio-economic and cultural factors exclude stamping out options.

Only one South American country, Uruguay, is recognized as being “free of foot-and-mouth disease, with vaccination”. In countries where the disease is endemic, OIE authorizes the application of zoning measures and the maintenance of disease-free zones from which animal products may be exported towards disease-free countries of Europe and the USA. This is the case for the majority of South American countries (Argentina, Bolivia, Brazil, Colombia, Paraguay, Peru), and some African (South Africa, Botswana, Namibia) and Asian countries (Malaysia, Philippines).

But for some one hundred other developing and emerging countries, the disease is a real scourge and is a major preoccupation for veterinarian authorities and farmers who are increasingly well informed, but uncontrolled animal movements and porous borders remain a reality.

My future in question

Today, the elimination of viral infection markers (NSP) in my highly purified vaccine composition renders it possible to rule out the circulation of the virus in animals that have received an emergency vaccination. This means there is now an alternative to slaughtering healthy animals simply because they have received a vaccine injection.

When slaughter must be carried out, the ordeal for farmers and veterinarians thus should be less traumatic than in the past and the practice better accepted by public opinion.

Although molecular biology experts envision me as a synthetic peptide-based vaccine or as a recombinant vaccine, I continue to be obtained through biological methods. Research -- already dated -- into producing me through genetic engineering has not yet found practical applications. I do not know what the virus thinks of that!

The point of view of the journalist

My first professional internship

I am completing the last year of journalism school and I am about to have a two-month taste of work at a regional daily paper whose director I know, which helped in getting me this placement.

At the heart of the craft

Today, I meet the chief-editor for the first time. The meeting takes place just before the editorial conference: "As you know, this paper places a lot of importance on covering local news. In a few months, the International Livestock Show will take place. We are going to use this event to introduce the general public to the daily reality of livestock farmers in the region. You must be aware that the profession has become hostage to recurrent health crisises: mad cow, foot-and-mouth, bluetongue, which is putting the sector into a difficult economic situation. Since the end of 2010, foot-and-mouth disease is again in the news. Epizootic outbreaks are spreading through Asia, the disease is at our door in Bulgaria after a 12 year absence, and the latest AFP (*Agence France Presse*) dispatches report that South Africa just suspended meat exports after discovering cattle and sheep carrying the virus. I read in your curriculum vitae that you studied science at your university. You will be able to make the most of that training because I am expecting you to prepare a dossier on this disease. We will publish it when the International Livestock Show takes place. Remember that our readers are not scientists. You should present us with some proposals next week during the editorial meeting. Give you imagination free rein!"

The moment has come for me to put into practice what I have learned and to show what I am capable of doing.

First step: Research the topic.
My first objective is to understand the basics of foot-and-mouth disease. Like many journalists, I use the Internet to better understand the topic. I rapidly identify a publication in French and a vade mecum illustrated with striking photos of the clinical signs of the disease. Jumping from link to link, I gather together scientific articles, a Senate report, and presentations made for livestock farmers by health protection groups. I am impressed by the number of works that have been written following the 2001 epizootic in Great Britain: first person accounts and on-the-spot interviews, press releases, contradictory debates over the non-vaccination and stamping out policy, and even articles for the general public intended to be reassuring but whose titles alone were enough to make one nervous.

I become aware of the global character of this contagious animal disease by consulting the epizootic outbreak mapping system put in place by the OIE, and by discovering that the FAO devotes a large section of its EMPRES (Emerging Prevention System) bulletin, which focuses on monitoring transboundary animal diseases, to foot-and-mouth disease.

After spending two days navigating the web, I know enough about foot-and-mouth disease to outline a draft paper organized around five questions: what? (the virus and the disease), who? (the susceptible animals), where? (worldwide), how? (the spread), why? (deficient health controls, illegal movements, non-vaccination).

Before proceding to the second step of my work, I set up a web tracking system to follow foot-and-mouth disease news on the Internet and I subscribe to the ProMED system for monitoring emerging infectious diseases managed by ISID (International Society for Infectious Diseases). It would not make a good impression to be caught by surprise by a news release from a fellow journalist.

Second step: Identify resource persons and conduct interviews.
Through my reading, I discovered the magnitude of the economic consequences of an epizootic of foot-and-mouth disease for an entire range of actors who often are quite removed from the world of agriculture and the agro-food industry. I also know that when there is a sanitary crisis, the media do not play a neutral role and can have a strong impact on consumers with negative repercussions on the meat sector.

To limit this risk, I put together a regional directory of organisations and people to contact if needed. It includes representatives of the livestock, animal health, and meat industry sectors: Chamber of Agriculture, health protection groups, veterinarian technical groups, public health veterinarians, departmental veterinarian services, renderers, slaughterhouses, cattle trading companies, and cattle, sheep, and pig farmers.

I then prepare scenarios for a few mini-documentaries to film in the field to capture the daily reality of farmers and public health veterinarians. I will propose to the chief-editor to post these videos on the newspaper's website accompanied by my Q&A presentation on foot-and-mouth disease. Internet readers will be able to respond directly with their opinions.

Third step: Vocation confirmed
At the end of two months working on foot-and-mouth disease, I sincerely wish to pursue a career in scientific journalism writing for the general public. I would like to be a mediator who provides information in a form that can be understood by a broad audience, allowing people to form their own opinions about current scientific issues, particular emerging and re-emerging zoonotic diseases coming from developing countries that regularly feature on the front page of the news.

The point of view of the economist

By way of introduction

As a senior researcher, a position which reflects my long professional career in sociology and rural economics in the service of animal production, I am a consultant advising working groups on health risks related to emerging and re-emerging animal diseases and their economic and social consequences for developed and developing countries.

In 2001, while the mad cow crisis was still making headlines, foot-and-mouth disease re-emerged in the United Kingdom, with two secondary outbreaks in France. The event threw me several decades back to when, as a child in the Vendée countryside, I heard people discussing the disease, which featured regularly in the local newspapers.

After the last epizootic in 1957 and the implementation of the obligatory cattle vaccination program in Europe in 1961, the disease was largely forgotten even though it was endemic in many developing countries.

However, in 1967-1968, when I was a young student finishing my studies, it re-emerged in the United Kingdom, a country which never had accepted vaccination. To contain the epizootic and save the cattle sector, 430 000 cattle were slaughtered in the space of six months. That was when I really became aware of the economic stakes involved in a sanitary situation and decided to pursue research in the economics of epizootic animal diseases.

My reason was that the gravity of an illness like foot-and-mouth disease is not assessed in terms of animal health alone, but also in terms of economic and social impacts and barriers to international trade in animals and their products.

An economic disease

Today, in European countries where foot-and-mouth disease control strategies favour the stamping-out of herds, the direct economic and social consequences of an epizootic for livestock farmers are dramatic despite legal compensations: loss of income, farms on the brink of failure, cessation of activities, change of professional occupation, psychological shock.

For farms untouched by the disease but placed under quarantine, restrictions on animal movements incur extra costs and shortfalls.

When infectious outbreaks are detected and rapidly controlled, the economic impact is limited in time and space. In contrast, a lack of vigilance and late disease detection in a country without vaccination can lead to a major epizootic such as that which took place in 2001 in Great Britain, where the effects were devastating.

Every single component of agricultural, economic, social, industrial and political systems were affected, farmers and animal production sector stakeholders first, some to the point of bankruptcy: suppliers of cattle feed and medicine, butchering and meat processing companies down to retail butchers, cattle trading companies whose trucks remained in the parking lots.

The domino effect did not spare other sectors: tourism, leisure, sports, labor, distribution, food, security. Daily life was disrupted at local, regional, and national levels: closing of roads, restrictions on movement, prohibition of large gatherings and sports and cultural events. Companies were closed. Thousands of jobs were lost. Considerable technical and human resources were diverted from their usual tasks to be mobilized by the control plan: police, soldiers, veterinarians, government employees, logistic personnel.

And on top of all that you must add: the nation-wide trade embargo on all susceptible species -- cattle, pigs, sheep, goats, whether live animals or animal products (meat, milk, sperm, embryos, hides) -- which destabilized international cattle markets and the meat sector; loss of confidence on the part of importing countries and consumers, even in the absence of documented risk for their health; and the negative media images of mounds of sheep and cattle burning all over the English countryside that were projected around the world.

The epizootic lasted 221 days between the first and last confirmed case. According to the World Bank, the financial repercussions amounted to 100 billion US dollars, half of which was in the tourism and leisure industries.

It is an excellent case study for university research students working in laboratories because this British episode had not been predicted by any simulation exercise. Experts considered the risk factor to be close to zero. And yet!

A cross-border disease

Like people, animals, their products and their viruses are travelling around the world more and more. Producing countries often are geographically quite distant from consuming countries. For economic reasons, livestock animals may be transported from the country where they are born to a country where they are fattened and finally to a country where they are slaughtered.

All of these animal movements, legal and illegal, are increasing in volume and intensity in response to the growing global demand for meat. They also are drastically increasing the probability of an accidental introduction of the foot-and-mouth disease virus despite very strict sanitary controls in countries recognized by the OIE as being “free of foot-and-mouth disease, without vaccination.”

The path of the virus is charted by their movements, which are pointed in the direction of increasing beef prices, from countries where foot-and-mouth disease is endemic such as India and Pakistan, towards Iran, Turkey, and the borders of Europe. This explains how new viral strains from the East emerge in the West.

In Turkish Thrace, bordering Greece and Bulgaria, European authorities have designated a buffer zone under strict surveillance, with prophylactic vaccination. Another sanitary cordon was established on the borders of Turkey and Iran by the Transcaucasian countries.

However, conflicts and political instability in countries are likely to modify the traditional direction of trade and requires constant vigilance.

Other risk factors also render foot-and-mouth disease a threat that is difficult to control with regard to European livestock. For example, economic difficulties in a country may lead to inexpensive meat being imported from an infected country, or to cross-border exchanges within a single ethnic group.

Certain events, such as the Eid-el-Kebir Islamic religious festival, during which large groups of sheep from different areas are gathered together, render it difficult to trace the origins of animals, and favour the introduction of the virus.

The most unusual entry point for foot-and-mouth disease may be the one discovered by a study commissioned by AESA (European Food Safety Authority based in Parme, Italy). In 2006, 2 000 tons of meat arrived on the ground at international airports of 25 European Union member countries in carry-on luggage. This is food for thought regarding the opportunities available to the virus to introduce itself in completely unexpected ways!

The fragile equilibrium of markets

When giving a public speech, I often am asked about the non-vaccination policy adopted by European countries.

When there is an epizootic, how do authorities decide whether or not to accompany stamping out (also refered to as slaughter) -- with emergency vaccination?

I must explain that the sanitary status, “free of foot-and-mouth disease, without vaccination”, gives a country access to top notch international markets where animals and animal products fetch the highest prices.

An epizootic outbreak in such a country would lead to the immediate closure of its borders to exports for several months and the loss of markets. Given the complex game of economic actors, this could result in:

- a disturbance in the global balance of supply and demand with instability in prices that can rise sharply or collapse;

- a risk of oversupply on the domestic market of the country under embargo resulting in a drop in prices, which is negative for producers but positive for consumers;

- a collapse in demand if consumer confidence is lost and consumers turn to another animal sector.

Some countries may be able to take advantage of the sanitary embargo of the infected country if they have export capacities. Other importing countries, having become wary of the country affected, may continue to maintain an embargo even when the required waiting period for a return to normal has ended.

Following two epizootic outbreaks in 2001, it took France two years to recover markets in a number of countries in the Pacific region even though France was recognized as being free of foot-and-mouth disease three months after the end of the second outbreak.

In such a globalized trade environment, all economic simulations demonstrate that for an exporting country, eradication by stamping out, without the use of vaccination, remains the least expensive policy option. If a decision is taken to vaccinate, the embargo on exports is prolonged and the resumption of commercial activities consequently is delayed.

From my perspective as an economist, my analysis of the situation is that for a European country, production losses have less economic and social consequences than the loss of certain export markets and it is this point which is the decisive factor.

This is why European countries will not use vaccination except when confronted with an extreme situation such as the need to defend against a biological attack. Due to its highly contagious nature and economic impact, the foot-and-mouth disease virus effectively could be used as a biological weapon by terrorists or armies in order to weaken a country by ruining its livestock.

This is not just a hypothesis! Recently, an individual claimed he would spread the foot-and-mouth disease virus over the British countryside if the British government did not give him a ransom of several million US dollars. The case was taken very seriously by the South African police, the British secret service, and the American FBI. A suspect was arrested after several months of investigations.

A highly contagious, global disease

Foot-and-mouth disease is a disease that might have been described by Aristotle in the 3rd century BC. However, it was in 1546 that a trustworthy description was made by an Italian doctor, Girolamo Frascatoro. In France, the disease is first mentioned in archived documents starting in 1776, but it probably was present well before. Since that time, foot-and-mouth disease epizootics, some devastating, such as those of 1812, 1920, 1938, 1952, 1957, have alternated with periods of respite that lull people into believing that the disease has disappeared.

From 1961, the required preventive vaccination of cattle in Europe interrupted this cycle. In my view, it allowed at least three major crises to be avoided.

Some countries and regions continue to be deemed free of foot-and-mouth disease: Canada, USA, Central America, Australia, New Zealand and Pacific Ocean islands. Outside Europe, foot-and-mouth disease is endemic in numerous countries of Africa, Asia, and South America.

Since the start of 2010, the type O foot-and-mouth disease virus has been spreading in numerous Asian countries. Outbreaks of foot-and-mouth disease have been recorded for the first time in eastern regions of Russia and Mongolia. Others have been reported in China, Taiwan, Japan, South Korea and in 2011 in Vietnam, with at times unexpected impacts.

In Japan, the presence of the virus is threatening the existence of the Miyazaki cattle breed raised on the island of Kyushu in the south of the country. These cattle, a source of pride in Japan, are well known for the gastronomic quality of their meat, which is the most expensive in the world. The animals are pampered by their farmers, who massage them with sake, give them beer to drink, and provide a relaxing environment with classical music.

In South Korea, the virus led to the resignation of the Minister of Agriculture following the magnitude of the epizootic and its impacts.

Africa

Foot-and-mouth disease is endemic in Africa and six of seven serotypes circulate on the continent either permantly or periodically.

The types circulating in each region varies: East Africa (A, C, O, SAT1, SAT2, SAT3), Southern Africa (SAT2, SAT1, SAT3), Central Africa (O, A, SAT1, SAT2), West Africa (SAT2, O, A, SAT1), North Africa (A, O, SAT2).

On the level of the continent, my economics approach to analysing and understanding the disease takes into account three situations on the ground.

In North Africa, three countries of the Arab Maghreb Union (AMU), Morocco, Tunisia, and Algeria, successfully carried out a campaign to prevent and control foot-and-mouth disease, which led to its eradication. The last epizootic outbreaks date back to 1999. In 2011, they were recognized by the OIE as “countries free of foot-and-mouth disease with or without vaccination”. This status opens the door to international markets, notably for sheep exports to European Union countries.

In West and Central Africa, pastoralism, transhumance, and markets facilitate the circulation of the foot-and-mouth disease virus in livestock. This is true of large seasonal gatherings, such as the salt cure festival held in Ingall in Niger, a meeting point of goat, sheep, cattle, and camel herds of Fulani and Touareg livestock farmers, who travel through the Sahelian countries in the direction of countries on the coast or towards the outskirts of Mopti in Mali.

Epidemiological data on the disease remains difficult to obtain in the countries of West and Central Africa and generally are underestimated. When the livestock affected are rustic breeds, foot-and-mouth disease often is perceived as being a disease with limited impacts, one that returns regularly and that can be lived with. Reporting it risks penalties: being barred from pasture lands, water points, access to markets.

Nonetheless, there is an economic impact for these small livestock farmers. In pastoral systems, it can affect the mobility of animals. On dairy farms, abortions in females result in reductions of up to 50% in milk production during the year following the epizootic. There also are negative impacts when animals are used for draught power.

In this context, there are numerous obstacles to implementing epidemiological surveillance and a control strategy despite the support of international agencies:

- insufficient funding for organizing public and private veterinarian services, which results in a lack of veterinarians, who often have little or poor training and limited resources to visit herds in the field;

- lack of schooling for most livestock farmers, which complicates their perception of the purpose of fighting the disease, although this situation has been improving over the past few years;

- absence of a compensation policy for farmers when their animals must be slaughtered;

- weak diagnostic capacity in national laboratories, a multiplicity of serotypes circulating, communication difficulties between countries, unavailability of vaccines when they exist and difficulty keeping them at correct temperatures while transporting them to where they need to be used;

- sometimes it is impossible to slaughter herds during an epidemic due to religious or cultural taboos.

In Southern Africa and East Africa, the situation is a little different. It is wildlife, which are a reservoir for the foot-and-mouth disease virus, particularly African buffalo, which have a major impact on cattle farming. Despite considerable investments:

- construction of sanitary cordons allowing wildlife to be maintained in conservation areas far from livestock;

- vaccination of herds and sanitary controls;

- implementation of an animal tracability system and a meat production chain that respects international standards and requirements regarding food safety;

international export markets remain closed to small farmers in Southern African countries (Botswana, Zimbabwe, Namibia, South Africa) who live in areas where foot-and-mouth disease is rife.

I read that sustainable development associations would like to change the current international standards and establish new standards that take into account the product itself, in other words, the meat production and processing sector rather than a product's region of provenance. This product approach could offer livestock farmers access to new markets and better prices for their products than those currently available on local markets.

Brazil

I often cite Brazil as an example to my students when discussing the fight to control foot-and-mouth disease. This immense country has the largest commercial cattle herd in the world with 190 million animals raised on over 2 million farms.

Thanks to a half century spent fighting the disease, Brazil has become the leading beef exporting country for 170 countries in the world with over 2.2 million tons exported annually. The country alone accounts for 30% of the international trade in meat.

The first cases of foot-and-mouth disease appeared in the country in 1870 and originated from Europe. Starting in 1926-1927, the State of São Paulo launched a regional disease control programme. With the creation of the Pan-American Foot and Mouth Disease Center (PANAFTOSA) in 1951, other federal states launched preventive vaccination programmes. These encountered some resistance from farmers owning cattle herds of several hundred thousand heads raised in extensive systems whose production losses caused by foot-and-mouth disease were insignificant compared to the constraints of vaccination.

Starting in 1971, the federal government of Brazil re-launched a national foot-and-mouth disease control programme (PNCFA) that today has become the National Programme for the Eradication of Foot and Mouth Disease (PNEFA).

Under the coordination of the Ministry of Agriculture, all public and private stakeholders in each Brazilian federal state contribute to an action plan to eradicate foot-and-mouth disease through on-going surveillance, vaccination, and training. Included are agricultural federations, Brazilian farmers' associations such as the National Agriculture Confederation (CNA), the National Animal Health Product Industry Syndicate (SINDAN), and the National Beef Farming Council (CNPC), an association of beef exporting industries.

Over 500 million doses of vaccine are manufactured each year and the Ministry of Agriculture requires the maintenance of a strategic reserve of 50 million doses for emergency situations.

The cattle sector was reorganized completely through considerable technological and financial investments. In 2002, in order to meet the requirements of the international market, a traceability system known as SISBOV was implemented to cover the entire production chain, from the farmer up to the shipper. It certifies the origins and quality of animal products.

Since 1999, Brazil has applied the concept of zoning with recognition from the OIE of zones "free of foot-and-mouth disease, without vaccination" and zones "free of foot-and-mouth disease, with vaccination". Today, the latter cover half of the country and hold 75% of the cattle population.

Brazil owes the excellent health status of its cattle herds to foot-and-mouth disease, which allowed it to increase its beef exports. However, the maintenance of export levels and access to new markets remain an on-going challenge.

Epizootic outbreaks of foot-and-mouth disease occur regularly in border areas. There was an epizootic outbreak in 2005 in Mato Grosso do Sul and Paraná states that spread to other states. They lost their “free of foot-and-mouth disease, with vaccination” zone status and their license to export. It was not until 2008 that Mato Grosso do Sul regained its sanitary status.

To help control these high surveillance border areas, a European research programme is underway. It will allow the risks of foot-and-mouth disease spread to be analysed by using the data of geographic information systems.

Southeast Asia

Foot-and-mouth disease emerged in an endemic manner in Southeast Asia in 1976. However, for many years the political situation and armed conflict did not permit disease prevention and control programmes to be implemented.

Three virus serotypes circulate in the region: type O, the most common, and which includes the Pan-Asia topotype that was at the origin of the 2001 epizootic in the United Kingdom, type A, and type Asia1.

Indonesia succeeded in eradicating the foot-and-mouth disease virus by 1986. In 1997, a coordinated prevention and control campaign against the disease was implemented in seven countries: Cambodia, Laos, Malaysia, Myanmar, Philippines, Thailand and Vietnam, with the participation of Indonesia under the regional SEAFMD (South-East Asia Foot and Mouth Disease) programme.

In 2010, this allowed parts of Malaysia and the Philippines to achieve the OIE status of zones “free of foot-and-mouth disease, without vaccination”.

With this same progressive zoning approach, epidemiological surveillance, control of animal movements, awareness raising campaigns and strategic vaccination, governments of other ASEAN (Association of Southeast Asian Nations) countries aim to move from an endemic situation to the eradication of foot-and-mouth disease by 2020 with the objective of gaining access to high value-added Asian markets and international markets.

In 2007, during surveys on the Mekong river basin in Laos, Cambodia, and Vietnam on cross-border livestock trade involving mainly cattle, buffalo and pigs, I assessed how much work remains to be done.

The spread of the foot-and-mouth disease virus over long distances is linked to the illegal movement of animals which is done to avoid complex border controls and dissuasively high taxes.

The majority of imports and exports of cattle and buffalo follow underground routes, often in several stages, with collection points where the animals remain while in transit, sometimes serving as sorting stations for future buyers from destination countries. Herds also are confided to villagers who take them across the border on foot. Every month, approximately 15 000 buffalo and cattle cross the border in this way from Thailand into Cambodia.

These cross-border exchanges are dictated by rising prices and contribute to the upsurge of foot-and-mouth disease outbreaks in areas where prices are high. This is how serotype A of the foot-and-mouth disease virus was introduced into Vietnam from Cambodia for the first time in 2004.

Foot-and-mouth disease does not only have an economic impact at the level of the country; it also has a direct impact on village communities. The consequences can be dramatic for impoverished families if the disease occurs in buffalo during peak agricultural periods, or if cows and pigs, raised as a source of income, lose their market value.

A villager told me that one year, following an attack of foot-and-mouth disease, he could not pay his children's school fees. In addition, he was forced into debt to buy medecines. And yet he had followed the advice of the village veterinary nurse to clean the sores on the tongues and feet of his two infected cattle with a concoction of boiled tamarind leaves to hasten healing and he had made offerings to Buddha. But after having been sick with foot-and-mouth disease, his animals were thin and lacked the strength to pull a cart. No one wanted to buy from him. It was a bad year!

To conclude

In some regions of the world, notably Asia, epizootics of foot-and-mouth disease co-exist with outbreaks of avian influenza. In these countries, it often is financially impossible for the veterinarian services to combat the combination of these two contagious animal diseases. Inevitably, choices are made based not on market values, but the zoonotic character of the two diseases, meaning their capacity to be transmitted to people. This is why avian influenza is the sanitary priority.

Despite its small size and discretion, the very aggressive foot-and-mouth disease regulates international trade in animals and animal products on a global scale through the constraints that it imposes. This is yet another example of how we are ruled by an infinitely small, invisible world.

Use of cattle to pull people and cargo in a village in the highlands of Vietnam. - Vietnam, Kontum, April 2003. - *© Georgette Charbonnier, Cirad.*

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Foot-and-mouth disease

Following the well-received French edition, which was supported by thirteen partner institutions, this educational handbook is now being offered in English in order to communicate to a wider audience knowledge about this very contagious viral disease that re-emerged in numerous countries in 2011.

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