

VETERINARY VACCINES

PRINCIPLES AND APPLICATIONS

FIRST EDITION

EDITED BY

SAMIA METWALLY | GERRIT VILJOEN

AHMED EL IDRISSEI



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Edited by

Samia Metwally

Senior Animal Health Officer
Animal Production and Health Division
Food and Agriculture Organization of the United Nations

Gerrit Viljoen

Section Head, Animal Production and Health
Joint FAO/IAEA Center
International Atomic Energy Agency

Ahmed El Idrissi

Former, Senior Animal Health Officer
Animal Production and Health Division
Food and Agriculture Organization of the United Nations



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List of Contributors

Alexandra Adams BSc, PhD

Professor of Aquatic Immunology and Diagnostics
Institute of Aquaculture, School of Natural Sciences
University of Stirling
Stirling, Scotland, UK

William Amanfu DCM, MS

International Veterinary Consultant
Formerly Animal Health Officer
FAO/UN
Rome, Italy

John Atkinson BSc Hons

Technical Manager, Ruminants
MSD Animal Health
Milton Keynes
Buckinghamshire, UK

Paul Barnett CBiol MRSB PhD

Biologicals Assessor
Veterinary Medicines Directorate
Addlestone, Surrey, UK

Carrie Batten Dr PhD

Head of Vascular Research Laboratory
The Pirbright Institute
Woking, Surrey, UK

Imane Belkourati DVM

Head of Quality Assurance
MCI Santé Animale
Mohammedia, Morocco

Abdelali Benkirane DVM, PhD

Full Professor
Microbiology, Immunology and Contagious
Diseases Unit, Department of Pathology
and Veterinary Public Health
Institut Agronomique et Vétérinaire Hassan II
Rabat, Morocco

José Maria Blasco PhD

Ad Honorem Researcher
Animal Health Department IA2 CITA
Universidad de Zaragoza
Zaragoza, Spain

Michèle Bouloy

Head of Research Unit “Molecular Genetics of Bunyavirus”
Department of Virology
Institut Pasteur
Paris, France

Zineb Boumart PhD

Research and Development Coordinator
MCI Santé Animale
Mohammedia, Morocco

Ian Brown MIBiol PhD

Head of Virology Department
Director of OIE/FAO International Reference
Laboratory for Avian Influenza and Newcastle Disease
Animal and Plant Health Agency
Addlestone, Surrey, UK

Emanuele Campese MSc

Researcher
Italian Reference Centre for Anthrax
Istituto Zooprofilattico Sperimentale
della Puglia e della Basilicata
Foggia, Italy

Peter Cargill BVM, CertPMP, MRCVS

Director
Wyatt Poultry Veterinary Services
Hereford, UK

Bryan Charleston BVM, MSc, PhD, MRCVS

Director
The Pirbright Institute
Pirbright, Surrey, UK

Adela Chavez PhD

Postdoctoral Researcher
CIRAD, UMR ASTRE
Petit-Bourg
Guadeloupe, French West Indies
CIRAD INRA, ASTRE
University of Montpellier
Montpellier, France

Karin Darpel VetMed, MRCVS, PhD

Head of Orbivirus Research
The Pirbright Institute
Woking, Surrey, UK

Klaus Depner DVM

Senior Scientific Officer
FAO Reference Centre for Classical Swine Fever
Friedrich-Loeffler-Institut
Greifswald, Germany

Adama Diallo DVM, PhD

Adviser to the Director
ISRA/LNERV
Dakar Hann, Senegal
UMR CIRAD-INRA ASTRE
Montpellier
France

Klaas Dietze DVM

Senior Scientific Officer
FAO Reference Centre for Classical Swine Fever
Friedrich-Loeffler-Institut
Greifswald, Germany

Meritxell Donadeu DVM, MSc

Visiting Research Fellow
Faculty of Veterinary and Agricultural Sciences
Veterinary Clinical Centre
The University of Melbourne
Werribee, Australia

Adelia Donatiello MSc

Researcher
Italian Reference Centre for Anthrax
Istituto Zooprofilattico Sperimentale della Puglia e della
Basilicata
Foggia, Italy

Baptiste Dunga DVM, PhD

CEO
Onderstepoort Biological Products SOC Ltd
Onderstepoort, South Africa

Mehdi El Harrak DVM, PhD

R&D Director
MCI Santé Animale
Mohammedia, Morocco

Monique Eloit DVM

Director General
World Organization of Animal Health (OIE)
Paris, France

Lawrence Elskén BS, DVM

Vice President of Global Development
EDGE Veterinary Vaccines Consulting
Group, LLC
Ames, Iowa, USA

Fatima Fakri DVM, PhD

Head of In Vitro Quality Control
MCI Santé Animale
Mohammedia, Morocco

Marisa Farber PhD

Researcher
INTA, CONICET, Instituto de Biotecnología
Buenos Aires, Argentina

Antonio Fasanella DVM, PhD

Director of the National Reference
Center for Anthrax and General Director
Italian Reference Centre for Anthrax
Istituto Zooprofilattico Sperimentale
della Puglia e della Basilicata
Foggia, Italy

Patricia Foley DVM, PhD

Risk Manager
Policy, Evaluation, and Licensing
Center for Veterinary Biologics
USDA APHIS
Ames, Iowa, USA

Alf-Eckbert Füssel DVM

Deputy Head
Animal Health and Welfare Unit
European Commission
Brussels, Belgium

Antonio Garmendia MSc, PhD

Professor of the Department of Pathobiology
and Veterinary Science
University of Connecticut
Storrs, Connecticut, USA

Giuliano Garofolo DVM

Researcher
Reference Laboratory for Brucellosis
Istituto Zooprofilattico Sperimentale
dell'Abruzzo e del Molise
Teramo, Italy

Donna Gatewood DVM, MS

President and Chief Operating Officer
EDGE Veterinary Vaccines Consulting Group, LLC
Ames, Iowa, USA

Mohamed Gharbi DVM, MSc, PhD

Professor
Laboratoire de Parasitologie, Ecole
Nationale de Médecine Vétérinaire de Sidi Thabet
University of Manouba
Sidi Thabet, Tunisia

Carol Gibbs PhD

Senior Staff Microbiologist
Policy, Evaluation, and Licensing
Center for Veterinary Biologics
USDA APHIS
Ames, Iowa, USA

Amanda Gibson BSc(Hons), PhD

Immunologist
Department of Pathology and Pathogen Biology
The Royal Veterinary College
Hatfield, Hertfordshire, UK

Amy Gill DVM, PhD

Senior Staff Veterinarian
Policy, Evaluation, and Licensing
Center for Veterinary Biologics
USDA APHIS
Ames, Iowa, USA

Jihane Hamdi DVM, PhD Student

Vaccine Production Team
MCI Santé Animale
Mohammedia, Morocco

Ahmed El Idrissi DVM, PhD

Formerly Senior Animal Health Officer
Animal Production and Health Division
Food and Agriculture Organization of the United Nations
Rome, Italy

Richard Hill Jr DVM, MS

USDA – Retired

Philippe Holzmüller Eng. PhD, HDR

CIRAD INRA, ASTRE
University of Montpellier
Montpellier, France

Pascal Hudelet DVM

Head
Veterinary Public Health Technical Services
Merial, France

April Johnson DVM, MPH, PhD

Veterinary Medical Officer, USDA APHIS
Veterinary Services, Field Operations
Alabama, USA

Alasdair King BVMS

Director of Intergovernmental Veterinary Health
Merck Animal Health
Madison, New Jersey, USA

Babett Kobe

Scientific Assistant and Assessor
Veterinary Division
Paul Ehrlich Institut
Langen, Germany

Charles Lamien MSc, PhD

Technical Officer
Animal Health, Animal Production and
Health Laboratory, Joint FAO/IAEA
Division of Nuclear Techniques
in Food and Agriculture, Department of
Nuclear Sciences and Applications
International Atomic Energy Agency
Vienna, Austria

Marie-Frédérique Le Potier PhD

Head of the Swine Virology and Immunology Unit
ANSES – Laboratoire de Ploufragan/Plouzané
National Reference Laboratory
for Classical Swine Fever
Ploufragan, France

Alessio Lorusso DVM, PhD

Veterinary Medical Officer
Virology Unit
Istituto Zooprofilattico Sperimentale
Dell'Abruzzo E Molise
Teramo, Italy

Nicholas Lyons MA, VetMB, MSc, PhD, DipECBHM, MRCVS

Research Fellow
The Pirbright Institute
Pirbright, Surrey, UK

James MacLachlan BVSc, PhD

Distinguished Professor
School of Veterinary Medicine
University of California, Davis
Davis, California, USA

Isabel Marcelino PhD

CIRAD, UMR ASTRE
Petit-Bourg
Guadeloupe, French West Indies
CIRAD INRA, ASTRE
University of Montpellier
Montpellier, France

Dominique Martinez PhD

CIRAD, UMR ASTRE
Petit-Bourg
Guadeloupe, French West Indies

Samia Metwally DVM, PhD

Senior Animal Health Officer
Animal Production and Health Division
Food and Agriculture Organization of the United Nations
Rome, Italy

Maria Montoya PhD

Centro de Investigaciones Biológicas (CIB-CSIC)
Madrid, Spain

Edgardo Moreno PhD

Research Leader – Immunology Laboratory
Programa de Investigación en Enfermedades Tropicales
Escuela de Medicina Veterinaria
Universidad Nacional
Heredia
Instituto Clodomiro Picado
Universidad de Costa Rica
San José, Costa Rica

Ignacio Moriyón PhD

Professor
Instituto de Salud Tropical y Departamento de
Microbiología y Parasitología
Universidad de Navarra
Pamplona, Spain

Douglas Murtle BS

Senior Biologics Specialist
USDA-APHIS-VS-DB-Center for Veterinary Biologics
Ames, Iowa, USA

Waithaka Mwangi PhD

Associate Professor
Vaccine and Adjuvant Development Program
Department of Diagnostic Medicine/Pathobiology
(DMP)
College of Veterinary Medicine
Kansas State University
Manhattan, Kansas, USA

Ivancho Naletoski DVM, PhD

Animal Production and Health Section
Joint FAO/IAEA Division of Nuclear
Techniques in Food and Agriculture Department of
Nuclear Sciences and Applications
International Atomic Energy Agency
Vienna, Austria

Nick Nwankpa DVM, MSC, PhD

Director
African Union Pan African Veterinary Vaccine Centre
Debre-Zeit, Ethiopia

Mark Pagala BS

Assistant Director
Microbiology
USDA-APHIS-VS-DB-Center for
Veterinary Biologics
Ames, Iowa, USA

David Paton MA, VetMB, PhD

Veterinary Adviser
The Pirbright Institute
Woking, Surrey, UK

Anton Pernthaner DVM, Habil

Senior Scientist
Hopkirk Research Institute
Palmerston North, New Zealand

Rabindra Prasad Singh PhD

Head of the Division of Biological Products
ICAR – Indian Veterinary Research Institute
Bareilly
Uttar Pradesh, India

Monica Reising PhD

Senior Staff Statistician
USDA APHIS
Ames, Iowa, USA

Gourapura Renukaradhya DVM, MS, PhD

Associate Professor
Food Animal Health Research Program, OARDC
Veterinary Preventive Medicine
The Ohio State University
Wooster, Ohio, USA

James Roth DVM, PhD

Distinguished Professor
Director of the Center for Food Security and Public Health
Department of Veterinary Microbiology and
Preventive Medicine
College of Veterinary Medicine, Iowa State University
Ames, Iowa, USA

Charles Rupprecht VMD, MS, PhD

CEO
LYSSA LLC
Atlanta, Georgia, USA

Matthew Sandbulte PhD

Scientist
Center for Food Security and Public Health
Department of Veterinary Microbiology and
Preventive Medicine
Iowa State University
Ames, Iowa, USA

Giovanni Savini DVM, PhD

Scientific Director
Istituto Zooprofilattico Sperimentale
Dell'Abruzzo E Molise
Teramo, Italy

Melisse Schilling DVM

Senior Staff Veterinarian
Policy, Evaluation, and Licensing
Center for Veterinary Biologics
USDA APHIS
Ames, Iowa, USA

Renee Schnurr BSc

Section Leader
Inspection and Compliance
USDA-APHIS-VS-DB-Center for Veterinary Biologics
Ames, Iowa, USA

David Siev DVM, MS

Policy, Evaluation, and Licensing
Center for Veterinary Biologics
USDA APHIS
Ames, Iowa, USA

Heather Simpson PhD

Professor Emeritus
Institute of Veterinary, Animal and Biological Sciences
Massey University
Palmerston North, New Zealand

Leslie Sims BVSc(Hons), MANZCVS

Director
Asia Pacific Veterinary Information Services
Montmorency, Australia

Rohana Subasinghe BSc, MSc, PhD

Managing Director
FUTUREFISH Pvt. Ltd.
Rajagiriya, Sri Lanka

David Swayne DVM, MSc, PhD

Center Director
Southeast Poultry Research Laboratory
Agricultural Research Service
US Department of Agriculture
Athens, Georgia, USA

Elma Tchilian PhD

Group Leader
Swine Influenza Immunology, Livestock Viral Diseases
The Pirbright Institute
Pirbright, Surrey, UK

François Thiaucourt PhD

Head of Bacteriology Team
UMR, CIRAD-INRA, ASTRE
Montpellier, France

Karim Tounkara DVM, PhD

OIE Regional Representation for Africa
Bamako, Mali

Eeva Tuppurainen DVM, MSc, PhD, MRCVS

Senior Scientist
Friedrich-Loeffler-Institut
Greifswald, Germany

Saleh Umair DVM, M.Phil, PhD

Scientist
Hopkirk Research Institute
Palmerston North, New Zealand

Hermann Unger DVM

Animal Production and Health Section
Joint FAO/IAEA Division of Nuclear
Techniques in Food and Agriculture,
Department of Nuclear Sciences
and Applications
International Atomic Energy Agency
Vienna, Austria

Nathalie Vachiéry PhD

Unit Director
CIRAD, UMR ASTRE
Petit-Bourg
Guadeloupe, French West Indies
CIRAD INRA, ASTRE
University of Montpellier
Montpellier, France

Thierry van den Berg

Operational Director Viral Diseases
Veterinary and Agrochemical Research Centre
Brussels, Belgium

Piet van Rijn PhD

Professor
Department of Virology
Central Veterinary of Wageningen University
Research Center (CVI)
Lelystad, The Netherlands

Gerrit Viljoen DSc

Section Head
Animal Production and Health Section
Joint FAO/IAEA Division of Nuclear Techniques
in Food and Agriculture Department of Nuclear
Sciences and Applications
International Atomic Energy Agency
Vienna, Austria

Veronika von Messling DVM

Director
Veterinary Medicine Division
Paul Ehrlich Institut
Langen, Germany

Dirk Werling Dr, VetMed, PhD

Professor and Chair of Molecular Immunology
Department of Pathology and Pathogen Biology
The Royal Veterinary College
Hatfield, Hertfordshire, UK

Esther Werner

Deputy Head of Veterinary Division and Head
of Section “Assessment of Immunological
Veterinary Medicinal Products”
Paul Ehrlich Institut
Langen, Germany

Viskam Wijewardana BVSc, PhD

Animal Health Officer
Animal Production and Health Section
Joint FAO/IAEA Division of Nuclear Techniques
in Food and Agriculture Department of Nuclear
Sciences and Applications
International Atomic Energy Agency
Vienna, Austria

Ralph Woodland BSc, PhD

Retired (Previously Senior Biologicals Assessor)
Veterinary Medicines Directorate
Addlestone, Surrey, UK

Teresa Yeary PhD

Biologics Specialist
Inspection and Compliance
USDA-APHIS-VS-DB-Center for Veterinary Biologics
Ames, Iowa, USA

Stéphan Zientara DVM PhD HDR

Director
ANSES Laboratoire de Santé Animale
Maisons-Alfort, France

Foreword

For centuries, vaccinating animals has been the most cost-effective and sustainable measure to prevent and control infectious emerging and reemerging diseases. A prominent example of the merit of vaccination practices in eliminating major infectious animal epizootics is that of rinderpest, which was declared to have been eradicated in 2011. Veterinary vaccines can also help protect the health of people from zoonotic diseases.

The proper use of a quality and effective vaccine provides significant benefits to stakeholders and food security, from the reduction in livestock mortality, increased milk production, savings by reducing antibiotic and acaricide treatments, and alleviating the impact of antimicrobial resistance. The effects of livestock vaccination provide a positive impact on rural, livestock-dependent families, contributing to reducing poverty at the household level and in turn help us achieve the core mandate of the Food and Agriculture Organization of the United Nations and many of the Sustainable Development Goals.

The increase in global investment in livestock and its products signifies the demand for the development of new vaccines and vaccine production in accordance with international standards, effective vaccination strategies and their application. The need for advanced knowledge among vaccine producers, users and decision makers led to the publication of this comprehensive book addressing the principles and applications of veterinary vaccines for livestock.

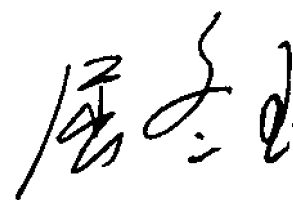
This is the first book that provides a thorough review on a wide variety of topics regarding the role of veterinary vaccines, vaccine international standards, immune response, current and novel vaccines, production and quality control

and more importantly a comprehensive review of vaccines for 13 high impact transboundary and zoonotic diseases. The book encompasses 29 chapters written by 97 leading experts, spanning 51 academic institutions, private and public sectors and regional and international organizations.

What I found impressive about this book is the high level of technical and practical information and guidelines it contains. I am confident that it will be valuable to a wide audience, including government authorities, decision makers, field veterinarians, livestock keepers, scientific community, vaccine producers and veterinary students.

I wish to thank the editors, authors, and their institutions for bringing together the first edition of this Veterinary Vaccines book in celebration of the 75th anniversary of the Food and Agriculture Organization of United Nations (FAO). A highly relevant publication that enhances the knowledge on vaccine principles and its applications to protect animal and public health and secure safe animal food for future generations.

Dr QU Dongyu



Director-General
Food and Agriculture Organization of
the United Nations (FAO)

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The Editors

Samia Metwally

Gerrit Viljoen

Ahmed El Idrissi

Introduction

First Edition

Over the past 200 years, following Louis Pasteur's first vaccine experiments, veterinary vaccines have played a central role in protecting animal and public health enabling efficient production of food animals, which is of significant importance to communities that rely on livestock to meet their nutritional and economic needs. Vaccines are now available for a range of important viral, bacterial, and parasitic diseases that have a major economic and public health impact.

Current veterinary vaccines based on inactivated and conventionally attenuated pathogens have illustrated good outcomes in the control of various types of animal diseases and therefore contribute significantly to animal welfare and safe food. However, vaccines also have their limitations, necessitating the application of different technologies to overcome the drawbacks and ensure the availability of safer and more efficacious vaccines. Improved understanding of the immunogenic and protective antigens of pathogens coupled with the advent in molecular genetics has opened the way for new generation vaccines. They afford numerous advantages over conventional vaccines, including ease of production, immunogenicity, and safety.

Manufacturing quality assured veterinary vaccines, whether conventional or new generation, and making them available on a large scale, requires the use of complex production methods, stringent quality control at every stage of the process, licensing regulations, and reliable distribution channels that ensure the products are potent and effective at their point of use. Reliable vaccine production and commercialization at affordable prices is the cornerstone of developing appropriate vaccination policies and strategies for prevalent animal diseases. This book primarily addresses the aforementioned aspects and provides vaccine users and stakeholders with concise, authoritative, and readily available information on vaccinology and vaccine immune response in animal populations.

Section I of this book is devoted to the importance of veterinary vaccines for animal health, animal welfare, and public health. Authors provide an overview of the benefits and challenges of vaccines for livestock species in the context of the growing human population, the global demand for meat, eggs, and dairy products, the rising standards of living in developing countries, and the changes in animal husbandry. This perspective is completed by a comprehensive technical review of the principles of vaccinology and immune response, vaccination strategies, implementation, and monitoring.

The following section provides an update on the current and future vaccines available for diseases caused by virus, bacteria, protozoans, rickettsia, and parasites in terrestrial and aquatic animals. The authors highlight the features of each vaccine category, challenges, research gaps, and technical options for the development of new generation vaccines and their possible impact on the design and modulation of novel vaccines or new approaches for their administration.

Section III of the book is dedicated to all aspects of vaccine production, quality control, licensing, and accessibility. It provides detailed schemes of in-process and final product quality control and testing to ensure the consistency of the vaccine quality. Aspects of external assessment, registration of veterinary vaccines, vaccine accessibility, and commercialization are also addressed. This section covers a comprehensive review of vaccine strategic reserves, or banks, as an adjunct to the control of important veterinary diseases.

The final section of the book provides a full review on vaccines and vaccination against selected high impact animal and zoonotic diseases. For each of the 13 diseases or group of pathogens addressed in this section, the book examines historical and current trends for immunization practices, the type of vaccines commercially available and those under development, practical recommendations and guidance on vaccination strategies, vaccine specifications,

factors affecting vaccine efficacy and safety, and monitoring vaccine effectiveness after vaccination campaigns.

We believe that this first edition will be invaluable and instrumental to the scientific community, vaccine producers, stakeholders, field veterinarians, veterinary authorities, and veterinary students.

Although every effort was made to complete this book in as short a time as possible, it proved to be a more formidable

and daunting task than anticipated, which took seven years from inception to publication. We sincerely hope that this book will help promote not only vaccine production and access to quality assured vaccines but also the control of infectious animal and zoonotic diseases so is the health of people and their livestock.

The Editors

Section I

Importance of Veterinary Vaccines

1

The Role of Veterinary Vaccines in Livestock Production, Animal Health, and Public Health

James Roth and Matthew Sandbulte

Department of Veterinary Microbiology and Preventive Medicine, Center for Food Security and Public Health, College of Veterinary Medicine, Iowa State University, Ames, Iowa, USA

1.1 Introduction: The Need for Veterinary Vaccines

The growing human population and rising standards of living in developing countries add to the global demand for meat, eggs, and dairy products. Changes in animal agriculture in recent decades include larger and denser populations of livestock species. Infectious diseases that degrade the health and productivity of livestock herds can be economically devastating and destabilize food supplies. Zoonotic transmission of infectious organisms from food-producing animals to humans is a significant threat to public health. There is an array of strategies used to control infectious diseases of livestock species, including facility sanitation, isolation or culling of infected animals, selection of disease-resistant genetic stock, treatment with antibiotics, and vaccination.

Vaccines are biological products designed to induce immune responses specific to pathogenic microorganisms, in order to prevent or reduce infectious diseases. Veterinary vaccines are a cost-effective method to prevent animal disease, enhance the efficiency of food production, and reduce or prevent transmission of zoonotic and food-borne infections to people. Safe and effective animal vaccines have become essential to modern society. The cost of producing enough animal protein to feed the 7 billion people on Earth would be dramatically higher without vaccines to prevent epizootics in food-producing animals. The lack of vaccines would leave farmers, communities, and countries more vulnerable to economically devastating livestock diseases. Zoonotic diseases such as brucellosis and leptospirosis would be much more prevalent in humans without effective vaccines for use in animals.

Rinderpest is a powerful example of how livestock vaccination, combined with other control measures, can dramatically improve animal health and human well-being. Rinderpest is an acute, highly contagious, viral disease of cattle, domesticated buffalo, and some species of wildlife. In 1889, cattle shipped from India carried the rinderpest virus to Africa, causing an epidemic that established the virus on the continent. Initially, approximately 90% of the cattle in sub-Saharan Africa died as well as many sheep and goats. The loss of draft animals, domestic livestock, and wildlife resulted in mass starvation, killing a third of the human population in Ethiopia and two-thirds of the Maasai people of Tanzania. The reduced number of grazing animals allowed thickets to form in grasslands. These thickets served as breeding grounds for tsetse flies, the vector for trypanosomes, resulting in an outbreak of trypanosomiasis (African sleeping sickness) in humans. This rinderpest epidemic is considered by some to have been the most catastrophic natural disaster ever to affect Africa. The Global Rinderpest Eradication Programme was a large-scale international collaboration involving vaccination, local and international trade restrictions, and surveillance. In 2011, rinderpest infection was declared to be eradicated from the world's livestock and wildlife, marking one of veterinary medicine's greatest achievements (OIE 2011).

Continuing improvement and increased use of livestock vaccines will promote the health and welfare of animals, promote efficient food production, reduce economic losses to producers, and reduce the dangers of zoonotic diseases. For animal vaccines to make a significant impact on animal and public health, they must be widely used, which means they must be affordable. This chapter provides an overview of the benefits and challenges of vaccines for livestock species.

1.2 Diversity of Veterinary Vaccines

Because a variety of livestock and poultry species are raised around the world and each species is susceptible to an array of bacterial, viral, and parasitic infectious agents, it is not surprising that many diverse vaccines are produced in the world. Livestock vaccines are developed and licensed for a variety of purposes, which are sometimes different from the purposes of human vaccines. Examples would be food safety vaccines to reduce the shedding of *Salmonella* by poultry and *Escherichia coli* 0157/H7 by cattle. Livestock vaccines are primarily used to improve the efficiency of production of food animals. The cost of the vaccine is an important consideration as to whether the vaccine will be used. It must contribute to profitability for the producer in the long run to be widely accepted. Vaccination against zoonotic diseases also can be used to reduce or eliminate the risk of human infection (e.g. rabies, brucellosis). Wildlife vaccines are generally used for zoonotic diseases (e.g. oral bait vaccines for rabies), or in some cases in conjunction with disease control programs in domestic species (e.g. brucellosis vaccine for bison and elk, oral bait vaccines for classic swine fever in feral swine).

Today, in the USA alone, there are about 1280 active licenses for nonautogenous veterinary vaccine products, including vaccines that consist of viruses, bacterins, bacterial extracts, toxoids, and many combinations (USDA-APHIS 2014). Licensed animal vaccines are available for some diseases where vaccines are not available for analogous human diseases, such as brucellosis and bovine respiratory syncytial virus in cattle, and *Mycoplasma hyopneumoniae* in swine. Veterinary vaccines have a distinct advantage in that they can be developed and licensed much more quickly and at much less cost than human vaccines. The ability to conduct safety and efficacy studies, including vaccination/challenge experiments, in the target species greatly facilitates licensing of veterinary vaccines. Liability issues associated with adverse reactions are much less restrictive for manufacturers of veterinary vaccines than for manufacturers of human vaccines. In addition, veterinary vaccines produced in developing countries may undergo less rigorous approval processes than in developed countries.

The equine West Nile virus vaccine is an example of how an animal vaccine can be developed and licensed quickly to meet an emergency situation (Brown et al. 2016). The West Nile virus was discovered in the USA in August 1999. The veterinary vaccine industry, working in cooperation with the US Department of Agriculture (USDA) Center for Veterinary Biologics, quickly developed an effective vaccine to prevent the disease in horses. By August 2001, an equine

vaccine for West Nile virus was conditionally licensed by the USDA. West Nile virus vaccine is now considered one of the core equine vaccines in the USA (American Association of Equine Practitioners – Vaccination guidelines). The vaccine has also been used off label to protect some endangered birds, such as California condors (Chang et al. 2007). Porcine circovirus 2 vaccines (Chae 2012) and influenza pandemic H1N1 vaccines (AVMA 2010) for swine are additional examples of newly emerging diseases for which veterinary vaccines were developed and licensed quickly.

1.3 Vaccines and Food Production

Veterinary vaccines are used in livestock to maintain animal health and improve overall production. More efficient animal production and better access to high-quality protein are essential to feed the growing population. According to the United Nations Department of Economic and Social Affairs Population Division, the world population was approximately 7 billion in 2014, and is estimated to increase to just over 8 billion in 2025 and to reach 9.1 billion people in 2050 (Figure 1.1). The United Nations Food and Agriculture Organization (FAO) estimates that 805 million people were undernourished in 2014 (FAO, IFAD, and WFP 2014). There were dramatic increases in world meat and egg production between 1962 and 2006 (Figure 1.2). The FAO projected that feeding a world population of 9.1 billion people will require overall food production to increase by 60% between 2007 and 2050 (FAO 2009; Alexandratos and Bruinsma 2012). The global demand for beef, pork, poultry, and other animal protein sources will increase sharply by the year 2050 (Figure 1.2). Vaccines that preserve animal health and improve production will be important components in meeting this need.

The economic structures of livestock husbandry are unique in the developing world, where many livestock and poultry are raised in small household settings. Even when licensed vaccines are commercially available for livestock pathogens of concern in a region or country, many producers cannot afford to use them. Reliable statistics on the use of livestock vaccines across the developing world are very scarce. A survey performed in Tanzania in 2008–2009 provided useful socioeconomic data on household livestock keeping in a sub-Saharan African context. A majority of rural households in Tanzania reported livestock-related income. Approximately 60% of households reported the presence of livestock disease in their herd/flock during the year of the survey. Only about 29% of households reported any use of vaccination in their animals. It could be inferred that the small livestock holders in Tanzania have

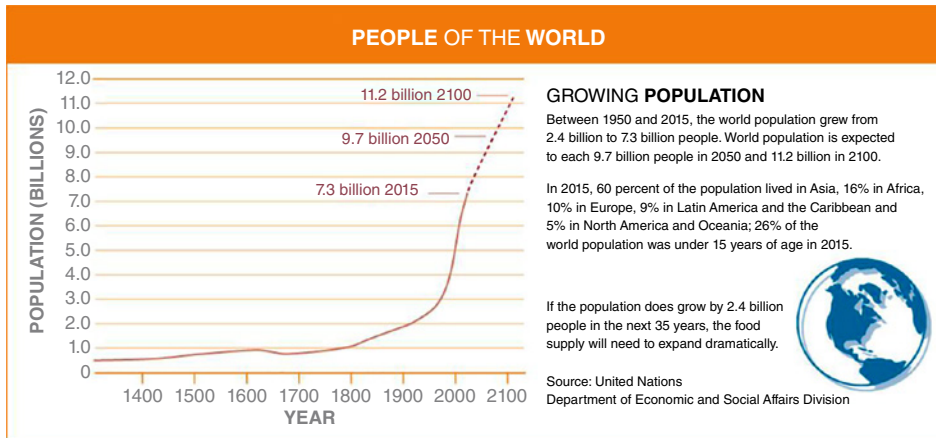


Figure 1.1 Global population growth in recent centuries, projected through 2100. Source: Reprinted with permission from Roth et al. (2016).

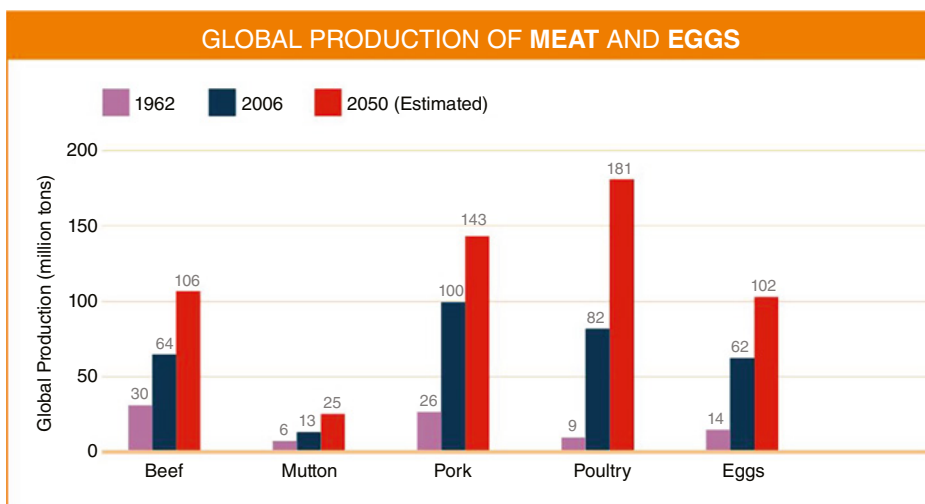


Figure 1.2 Global production of meat and eggs. Between 1962 and 2006 the production of major classes of animal-derived food increased by twofold or greater. Production of these food sources is projected to increase substantially again over the first half of the twenty-first century. Similar growth is reported for milk production, except on a larger scale: 344M tons in 1962, 664M tons in 2006, 1077M tons projected in 2050. Vaccines and other methods of controlling infectious diseases in livestock and poultry help to maximize food production. Source: Data from Table 4.18 of Alexandratos and Bruinsma (2012).

insufficient access to effective vaccines either due to cost or lack of availability, and the same is likely true in many other countries (Covarrubias et al. 2012).

Foot and mouth disease (FMD) virus is a tremendous burden to meat and dairy production in many parts of the world, especially developing countries. It is estimated that 2% of cattle in the world are infected with FMD virus in a year (Knight-Jones and Rushton 2013). The direct production losses from FMD – the majority of which are borne by China, India, and Africa – are estimated at roughly US\$ 7.6 billion per year (Knight-Jones and Rushton 2013). Losses include not only diminished animal weight gain and milk production, but also loss of traction power when draft

animals are infected. There are also indirect economic costs, such as restrictions to livestock export. In countries where FMD virus is endemic, vaccination has an important role in protecting cattle, pigs, and buffalo, thus reducing the economic impact of the disease. It is estimated that the world’s livestock are immunized with 2.35 billion doses of FMD vaccine annually (Knight-Jones and Rushton 2013). The positive impact of FMD vaccination in endemic countries would be greater if vaccine doses were less expensive and induced longer-lasting immunity (Kitching et al. 2007). Even countries recognized as FMD free, which often cease vaccination, have an economic burden from the virus. They must maintain costly preventive measures and

prepare resources to respond in the event of an outbreak emergency, such as vaccine banks (discussed in a section below).

Antibiotics are widely used to control bacterial pathogens of livestock and to promote efficient food production. However, there are increasing concerns related to antibiotic resistance associated with the extensive use of antibiotics in veterinary and human medicine (Dibner and Richards 2005). Producers may choose either vaccines or antibiotics to control some diseases based on cost, if both options are available. For example, swine ileitis caused by *Lawsonia intracellularis* can be controlled by either vaccination or antibiotics, along with good management practices. Swine producers will use the approved control method that is most cost effective. If regulatory requirements for a biologics company to obtain and maintain a license to produce the vaccine were to increase beyond what is essential, then the cost of the vaccine would increase and producers would opt to use less vaccine and more antibiotics. Affordable and available vaccines reduce reliance on antibiotics for animal health.

1.4 Vaccines for Control of Zoonotic Diseases

Vaccines to control zoonotic diseases in food animals, companion animals, and even wildlife have had a major impact on reducing the incidence of zoonotic diseases in people. Some examples of veterinary vaccines for zoonotic diseases that have been, or could be, used to control infections in animals, thereby reducing transmission of the infectious agent to people, include rabies, brucellosis, leptospirosis, influenza, Rift Valley fever, nipah, hendra, Japanese encephalitis, and Q fever. Without rabies vaccines, it is unlikely that families would be willing to keep cats and

dogs as pets. Recombinant vaccinia-vectored rabies vaccines have also been used successfully in baits for oral vaccination campaigns to reduce the incidence of rabies in wild animals (Pastoret and Brochier 1996). Vaccines for brucellosis were instrumental in the *Brucella abortus* eradication program in the USA. Many countries continue to have severe problems with brucellosis in cattle, small ruminants, and people due to a lack of available *Brucella* vaccines for animals (FAO 2010). An additional concern related to *Brucella* vaccines is that they are live vaccines which can infect and cause symptoms in people (Ashford et al. 2004). New-generation safer vaccines for brucellosis are needed.

Similarly, vaccinating livestock against various *Leptospira* serovars can reduce the incidence of human leptospirosis, which in severe cases can cause miscarriage or death. The tapeworm parasite *Taenia solium*, which is transmitted between pigs and humans, is a major cause of adult-onset epilepsy in developing countries (Spickler 2005). In recent field trials, an experimental *T. solium* vaccine administered to scavenging pigs protected them against transmission of the parasite (Jayashi et al. 2012). These promising results suggest that pig vaccination could become an effective way to break the cycle of *T. solium* transmission to people in the developing world.

Emerging and exotic animal diseases are a growing threat to human and animal health and jeopardize food security (Figure 1.3). Increases in human and animal populations, with accompanying environmental degradation, global warming, spread of arthropod vectors, and globalized trade and travel, enhance opportunities for transfer of pathogens within and between species. The resulting diseases pose enormous challenges now and for the future.

In most of the world, increased demand for animal protein has resulted in intensified commercial food animal production and/or expanded “backyard” production.

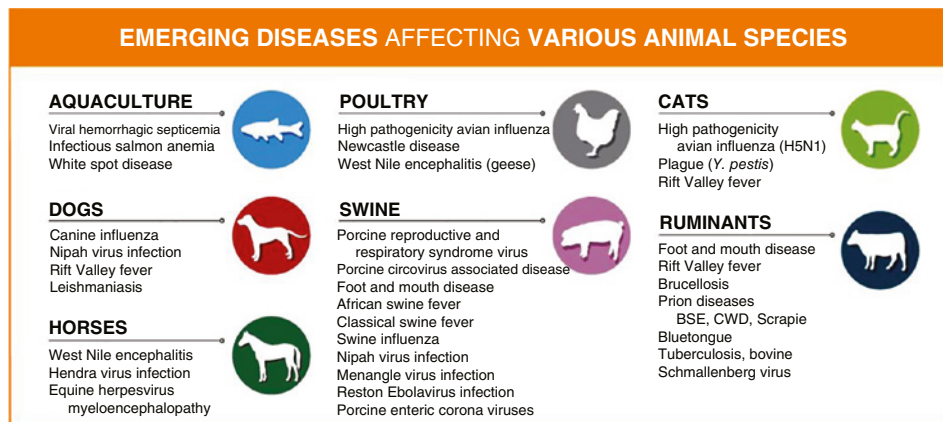


Figure 1.3 Emerging diseases affecting various animal species. Source: Reprinted with permission from Roth et al. (2016).

Both types of production present unique challenges for disease emergence and control. Large commercial operations with high concentrations of animals produce high-quality protein for human consumption at reduced costs. These operations typically have some degree of biosecurity, vaccination programs, and veterinary care. However, the high concentration of animals may facilitate the emergence of pathogens due to extensive replication in large numbers of animals, enhancing the potential for mutation and adaptation to the species. They also present concerns regarding animal welfare and environmental preservation. “Backyard” production of poultry, pigs, and small ruminants can efficiently use household waste for feed and can be an important supplement to dietary protein and income. However, the close interaction with humans, especially children, presents an increased risk of zoonotic disease transfer (e.g. avian influenza and *Brucella melitensis*). “Backyard” animal production rarely has biosecurity or adequate vaccination. Emerging zoonotic diseases of both food and companion animals are a major threat to public health. It is inevitable that the world will continue to experience emerging disease outbreaks in the coming decades. Rapid development of animal vaccines can play a key role in controlling emerging diseases.

There are several examples of vaccines successfully developed against emerging equine viruses, including Venezuelan equine encephalitis, West Nile, and hendra (Broder et al. 2013; Bowen et al. 2014). Vaccination against these agents lowers the risk of zoonotic infections. Several countries have used vaccines, together with other eradication measures, to control high pathogenicity avian influenza virus (H5N1) in poultry. From 2002 to 2010, it is reported that many billions of doses were administered to poultry, mostly in China (Chapter 18) (Swayne 2012). This practice is considered to have reduced disease and mortality in chicken flocks, while also reducing the number of human infections, which have very high fatality rates. Rift Valley fever virus, a devastating pathogen of ruminants and a virulent zoonotic agent, is seen as a prime target for animal vaccine development (Monath 2013). Continued development of more cost-efficient, safe, and effective vaccines against zoonotic agents will foster improvement of human health, animal health, and food security.

1.5 Vaccines to Improve Food Safety

Recently, vaccines have been developed to reduce the shedding of organisms that cause food-borne diseases in people. Vaccines are available for *E. coli* O157:H7 in cattle and *Salmonella enterica*, serovars *enteritidis* and *typhimurium*, in chickens. These vaccines typically do not improve the

health of the vaccinated animal, but reduce the intestinal colonization and shedding of pathogens that may contaminate animal products for human consumption (Thomson et al. 2009; Desin et al. 2013). The severity of the *S. enteritidis* outbreak in people in the USA in 2010 due to consumption of contaminated eggs (Cima 2010) could have been reduced or prevented if the associated chickens had received an *S. enteritidis* vaccine. Numerous other microorganisms, common in livestock, cause food-borne disease outbreaks in people, so there may be future opportunities to broaden the use of livestock vaccines for food safety purposes.

1.6 Vaccine Banks

In countries where a particular animal infectious disease does not exist – either due to eradication or because it was never endemic to the region – vaccination against the agent will usually not be practiced. When there is no market for vaccines, the biologics companies do not have an incentive to develop, license, and manufacture them. However, there is often a continuing risk that the agent will be (re)introduced. This requires readiness to respond quickly to control an outbreak, especially because herd immunity to the agent no longer exists.

In the USA, the Department of Agriculture and the Department of Homeland Security have recognized the need to have approved vaccines for important animal diseases that are not currently present within the country’s borders. US animal agriculture is highly vulnerable to the introduction of foreign diseases, most notably FMD. A Homeland Security Presidential Directive mandated the establishment of a National Veterinary Stockpile (NVS), a national repository that can deploy within 24 hours “sufficient amounts of animal vaccine, antiviral, or therapeutic products to appropriately respond to the most damaging animal diseases affecting human health and the economy” (Bush 2004). Although the USA is a partner in the North American FMD Vaccine Bank, the present supply is not sufficient to meet the needs of an FMD outbreak. European Union states, Japan, Australia, and New Zealand also maintain FMD vaccine banks (Hagerman et al. 2012). The World Organization for Animal Health has established vaccine banks for avian influenza, FMD, and peste des petits ruminants (PPR) and has shipped doses to many countries in the developing world.

Vaccine banks or stockpiles are expensive to establish and maintain, so robust funding is required. Also, establishing an emergency plan for vaccination against an emerging or foreign animal disease can be complicated from the regulatory standpoint. In some cases, a disease-free country does not issue a regular vaccine license, but

issues a conditional license for use in the event of an outbreak. Safety and efficacy criteria for conditional licensure may be different from criteria for a vaccine used against endemic diseases. A functional program of foreign animal disease preparedness requires cooperation among veterinary and public health agencies, regulators, and vaccine manufacturers.

1.7 Successes and Challenges

As discussed above, one of the greatest successes in the use of vaccination to control an animal disease was the global eradication of rinderpest virus. This was achieved using the Plowright vaccine, a conventional live attenuated virus that was generated by serial passages of a virulent rinderpest strain in primary calf kidney cells (Plowright 1984). Other striking examples of vaccine successes and challenges can be seen in some important swine viruses. Aujeszky's disease virus (also called pseudorabies virus) has been successfully eradicated from swine herds in numerous countries, including the USA. An important innovation aiding that success was vaccines with glycoprotein gene deletions (Mengeling et al. 1997; Pensaert et al. 2004). These deletions allow diagnostic tests that differentiate between infected and vaccinated animals (the DIVA strategy). With these tools, it is possible to conduct screening and selective culling in the eradication campaigns, without forgoing the use of immunization to protect herds.

After its discovery in the late 1990s, the porcine circovirus 2 (PCV2) was found to be widespread in major swine-producing countries. It was etiologically linked to postweaning multisystemic wasting syndrome and other clinical syndromes with great economic impact. Subunit and inactivated virus vaccines for PCV2 were developed commercially, became widely adopted, and led to significant improvements in swine health and productivity (Beach and Meng 2012).

On the other hand, efforts to produce effective vaccines against porcine reproductive and respiratory syndrome virus (PRRSV) and influenza A viruses of swine (IAV-S) have been less successful. These economically important viruses have been identified for many years, but current vaccines do not provide reliable control of infection and disease. A major hurdle in both cases is the antigenic variability of the viruses. One concept for improved vaccines against antigenically variable viruses like PRRSV and IAV-S is to identify epitopes that are highly conserved across the various strains. Vaccines that target the conserved epitopes would have the potential to supply broad cross-protection (Khanna et al. 2014). Utilizing new

adjuvants, vaccine vectors, delivery mechanisms, or rationally designed live attenuated viruses might also lead to more effective vaccines against these viruses.

Across the spectrum of livestock infectious diseases, there are many with no proven vaccines and others with inadequate vaccine options. Live and killed Newcastle disease virus vaccines are used extensively in some endemic countries, yet frequent outbreaks continue, possibly because genetic mutations in the pathogenic strains allow them to evade the immunity induced by the vaccines (Ashraf and Shah 2014). A live *Mycoplasma mycoides* subsp. *mycoides* vaccine against contagious bovine pleuropneumonia has existed in Africa for half a century, but problems with its efficacy and duration of immunity have been recognized (Jores et al. 2013). Improvements in vaccine technologies, such as adjuvants and recombinant vectors, can potentially aid the development of vaccines against many pathogens. However, one of the disadvantages faced in veterinary vaccine development is that the potential financial returns are much less than for human vaccines. Veterinary vaccines have lower sales prices and smaller potential market value. Consequently, there is a lower investment in research and development for animal vaccines compared to human vaccines, although the range of hosts and pathogens is greater.

1.8 Policies on Use of Vaccines in Disease Control Programs

In some situations, infectious disease agents pose a threat to animal health, human health, food security, or economic stability, but producers do not have the ability or strong incentive to pay for vaccination. Such situations may include endemic diseases in developing countries, zoonotic and food-borne diseases that do not cause serious sickness in livestock, and emerging or exotic diseases that have a small probability of spreading to the given region. For disease control and eradication programs, it is often necessary for governments or other entities to provide financial support. An example would be the current interest in eradication of PPR. Regardless of how the expense is met, a low cost per unit of vaccine is critical to achieving widespread vaccination of the susceptible livestock.

1.9 Summary

The consequences of livestock and poultry infectious diseases are felt throughout the world, regardless of wealth or veterinary medical infrastructure. When livestock diseases are not controlled effectively, global food production is