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U.S. Department of Agriculture: Animal and Plant Health Inspection Service

2016

Chapter 3: One Health, One Medicine

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Published in *New Directions in Conservation Medicine: Applied Cases in Ecological Health,* edited by A. Alonso Aguirre, Richard S. Ostfield, and Peter Daszak (New York: Oxford University Press, 2012).

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ONE HEALTH, ONE MEDICINE

Laura H. Kahn, Thomas P. Monath, Bob H. Bokma, E. Paul Gibbs, and A. Alonso Aguirre

In recognition that the health of humans, animals, and the environment is linked, One Health seeks to increase communication and collaboration across the disciplines in order to promote, improve, and defend the health of all species on the planet. This strategy may seem simple, but unfortunately it will not be easy to implement. The explosion of medical knowledge in the 20th century led to academic, governmental, and industrial silos of specialization; these silos fostered a compartmentalized approach to health and disease. Building bridges across these silos will require leadership, joint educational programs, financial support, and other strategies that promote transdisciplinary efforts.

Before the 20th century, physicians typically worked with veterinary medical colleagues and others to improve the health of humans and animals. This chapter will describe the historical developments in medicine and veterinary medicine leading to the current status quo. It will provide examples of why the status quo is problematic and will highlight the challenges in changing the present paradigm. It will conclude with recommendations on how to implement a One Health approach in the future.

HISTORICAL BACKGROUND

Humans have been domesticating wild animals beginning with dogs since 14,000 years BC (Trut 1999), developing agriculture, and altering the environment. In contrast to the harsh nomadic hunter-gatherer lifestyle, most humans preferred the secure and productive lifestyle that agriculture allowed. However, this novel lifestyle introduced unanticipated health risks since aggregated crops and concentrated livestock altered the interactions of humans, domestic animals, wildlife, and ecosystems. Moreover, humans lived in close proximity to animals and sometimes shared living quarters (McNeill 1977).

Small farming communities eventually grew into villages, towns, and cities, which concentrated humans into dense living conditions that facilitated the spread of microorganisms from individual to individual, allowing infectious disease epidemics to develop and propagate. As a result, infectious diseases, such as sylvatic plague, smallpox, cholera, and malaria, began to afflict humans, leading to epidemic morbidity and mortality (McNeill 1977).

Some of the diseases affecting agricultural and urbanized societies came from humans or livestock after domestication, such as bovine tuberculosis, rabies, and a wide array of food-borne bacterial and protozoan infections as transmissible zoonoses (Diamond 1999). In addition, wildlife served as reservoirs of innumerable diseases that could be transmitted back to humans and domestic animals. For example, nearly one quarter to one third of the population of Europe was decimated by plague, also called "the Black Death" during the mid-14th century (Wheelis 2002).

To complicate matters, people thought epidemics were caused by divine retribution for lapsed moral behavior, bad air "miasmas," and demons and other spirit beings, among other etiologies (Conrad 1992; De Paolo 2006). These beliefs lasted for centuries, hindering effective preventive and control efforts. However, despite a lack of understanding of infectious diseases, some individuals developed effective control measures.

For example, during the 18th century, rinderpest, a deadly viral disease of cattle, was devastating the human food supply. Pope Clement XI asked Dr. Giovanni Maria Lancisi, his personal physician, to combat the problem. Lancisi recommended that all of the ill and suspect animals be killed and buried in lime, since he suspected that the disease was communicable. His concept proved effective, and in 1762, the first school of veterinary (from the Latin "beast of burden") medicine was established in Lyon, France, to educate the next generation about the management of diseases in livestock (Palmarini 2007).

BEGINNINGS OF SCIENTIFIC BREAKTHROUGHS AND ONE HEALTH, ONE MEDICINE

In 1827, Charles Darwin decided to leave medical school at the University of Edinburgh to pursue studies in religion and natural history at Cambridge University. Health practitioners in Darwin's time were routinely trained in natural history and zoology since these disciplines were closely aligned and were considered integral subjects in medical training. Darwin never completed medical school, but his experience aboard the *HMS Beagle*, and most likely his exposure to multiple disciplines, led to his publishing his monumental book in 1859, *On the Origin of Species* (Leff 2000).

Rudolf Virchow (1821–1902), the German physician and pathologist, coined the term "zoonosis" and said, "between animal and human medicine there are no dividing lines—nor should there be." He strongly supported veterinary medicine and advocated for public health meat inspections throughout Europe. The United States eventually adopted meat inspections as well. This novel practice served as the basis for modern-day public health meat and poultry inspections by veterinarians (Kahn et al. 2007).

Sir William Osler (1849–1919), first Professor of Medicine at Johns Hopkins Hospital and considered the "father of modern medicine," had traveled from Canada to Germany to study with Virchow. Virchow impressed upon his student the importance of autopsies, pathology, and scientific methodologies. Osler returned to Canada to teach parasitology, physiology, and pathology at the Montreal Veterinary College, which eventually became affiliated with the medical school at McGill University. At the veterinary college, Osler researched hog cholera (classical swine fever), Pictou cattle disease caused by tansy ragwort (*Senecio jacobaea*) intoxication, which was believed to be a microbial infection at that time, and verminous bronchitis of dogs, among others. He worked closely with veterinarians such as Albert W. Clement, who became the President of the United States Veterinary Medical Association (USVMA; Kahn et al. 2007).

Louis Pasteur (1822–1895) and Robert Koch (1843–1910) changed the course of history by discovering that microscopic organisms caused disease. This knowledge allowed the development of effective preventive and control measures against pathogens. Pasteur developed a vaccine against rabies, and Koch discovered that *Clostridium tetani* caused tetanus, *Streptococcus pneumoniae* caused pneumonia, and *Vibrio cholerae* caused cholera (Munch 2003).

The advances in scientific knowledge spurred efforts to improve medical education. The American Medical Association (AMA) invited the Carnegie Foundation for the Advancement of Teaching to conduct a study on the status of medical education in the United States. In 1910, Abraham Flexner published the report that recommended that medical education be modeled after that at Johns Hopkins University, which emphasized a scientific approach to medical education and patient care. The ultimate effect of incorporating medical schools into universities was the emphasis on training medical specialists rather than general practitioners (Starr 1982).

The idea of an American veterinary profession was supported by agricultural societies and by physicians such as Benjamin Rush and Andrew Stone. Before the 1880s, most school-trained veterinarians were trained in Europe. The development of veterinary schools in the United States arose from concerns over animal disease epidemics following the Civil War and the interest in scientific agriculture signaled by the Morrill Land Grant Act of 1862, which provided federal funding to establish the first college-affiliated veterinary school at Iowa State University in 1879. The curriculum derived from agriculture and veterinary medicine. The University of Pennsylvania's School of Veterinary Medicine opened in 1884 and was the first accredited veterinary medical college in the United States whose origin was in medicine rather than agriculture.

By the late 19th century, a web of veterinary institutions, organizations, and periodicals were established, including the USVMA, founded in 1863 and renamed the American Veterinary Medical Association (AVMA) in 1898; the Bureau of Animal Industry (BAI), created in 1884 in the U.S. Department of Agriculture (USDA) and headed until 1905 by veterinarian Daniel E. Salmon; and the *American Veterinary Review*, begun in 1877 and renamed the *Journal of the American Veterinary Medical Association* in 1914–1915.

BAI veterinarians Fred L. Kilbourne and Cooper Curtice and physician Theobald Smith first demonstrated the role of vectors in the transmission of animal diseases. The BAI also certified and employed veterinarians in food inspection and influenced veterinary medical school curricula. Between the 1880s and 1925, graduate veterinarians sponsored state laws creating examining boards and setting graduation and licensing requirements. In late 19th and early 20th centuries, Leonard Pearson, a bovine tuberculosis expert, directed attention to the relationship between animal and human health (Palmer and Waters 2011).

As the 20th century progressed, physicians became increasingly specialized and collaborative efforts with veterinarians waned. Human and animal diseases were largely treated as separate entities. However, a few veterinarians, such as Calvin W. Schwabe (1927–2006), the renowned veterinary epidemiologist and parasitologist, continued to promote a unified human and veterinary approach to zoonotic diseases by publishing his book *Veterinary Medicine and Human Health* (Schwabe 1984).

This need to work together has not diminished despite the professions drifting apart. Since 1940, over 330 infectious diseases have emerged from animals into human populations (Taylor et al. 2001). The threat to global health is increasing since human population density, the most significant independent predictor of disease emergence, continues to increase (Jones et al. 2008). Indeed, it is estimated that by 2050, the human population will reach 9 billion (United Nations 2007).

Human activities such as deforestation, intensive agriculture, bushmeat consumption, waste production, and greenhouse gas emissions will only intensify as growing populations demand more food, water, clothing, shelter, and energy. For example, surveillance of fruit bat health and behavior in Malaysia might have helped prevent the disaster that developed in 1998–99 after extensive deforestation destroyed the fruit bat's habitat. Millions of hectares of tropical rain forest were slashed and burned to make way for pig farms. Fruit bats (the natural reservoir of the virus), whose habitat was largely destroyed by deforestation, sought nourishment from fruit trees near the pig farms and subsequently spread the virus to livestock. The subsequent Nipah virus outbreak demonstrates that destruction of wildlife habitats has an adverse impact on livestock and human health. In this case, the flowering and fruiting trees that the fruit bats relied on for their survival were destroyed to make room for pig farms. The bats resorted to consuming fruit located next to the farms. Pigs ate the partially eaten fruit that had been contaminated by bat saliva and urine. The bats harbored the Nipah virus, a previously unknown pathogen. The economic and human health impact of the outbreak was severe: the pig farmers lost millions, and pig farming in the country largely collapsed and is now allowed in only approved areas. This set off a chain reaction that ultimately led to the development of encephalitis in hundreds of humans and over 100 fatalities (Kahn 2011).

The magnitude of the problem illustrates why human medicine, veterinary medicine, and ecology need to rejoin forces. Taylor et al. (2001) identified 1,415 infectious agents and determined that 868 (61%) were zoonotic. They found that zoonotic diseases were twice as likely to be newly emerged infections compared to other diseases. RNA viruses, in particular, are highly likely to emerge from animals and cross species barriers because they are subject to rapid mutagenesis and can readily adapt to new hosts and vectors. Examples include West Nile virus (WNV), avian influenza virus, SARS coronavirus, arenaviruses, and hantaviruses (Cleaveland et al. 2001).

CHALLENGES AND OPPORTUNITIES OF IMPLEMENTING A NEW PARADIGM

A new paradigm requires that human, animal, and ecosystem health be addressed equally, equitably, and expeditiously. Ironically, to address future threats, we need look no further than what the medical and scientific luminaries of the 19th century developed: the One Health concept. The One Health concept seeks to integrate human, animal, and ecological health in clinical practice, public health, scientific research, and policy. Some professional organizations have recognized the importance of this paradigm. In September 2004, experts at the Wildlife Conservation Society held a "One World, One Health" conference in New York City that led to the "Manhattan Principles" calling for an international, interdisciplinary approach to protect life on the planet (Cook et al. 2004). In June 2007, the AMA House of Delegates unanimously approved a "One Health" resolution following AVMA input endorsing interdisciplinary collaboration with AVMA (Kahn et al. 2008). Then AVMA approved a similar "One Health" resolution (*JAVMA*, 2009). Other organizations that have endorsed the One Health concept include the American Society of Tropical Medicine and Hygiene, the Society for Tropical Veterinary Medicine, the American Society for Microbiology, and the Council of State and Territorial Epidemiologists.

The mission statement for the "One Health" initiative states: "Recognizing that human and animal health are inextricably linked, 'One Health' seeks to promote, improve, and protect the health and well-being of all species by enhancing cooperation and collaboration between physicians, veterinarians, epidemiologists, public health professionals and allied health scientists by promoting strengths in leadership and management to achieve these goals." Three overarching goals are enhancing public health effectiveness, understanding anthropogenic changes and the emergence of new pathogens of animal and human origin, and accelerating biomedical research discoveries, including advances in clinical medical and surgical approaches. In June 2009, the AVMA's One Health Commission was incorporated with the mission of developing strategies to put the One Health concept into practice. The challenges are many, but the rewards would be a healthier future for humans, animals, and the Earth's ecosystems.

A similar approach was expounded by Aguirre et al. (2002), who emphasized the need to bridge disciplines, thereby linking human health, animal health, and ecosystem health under the paradigm that "health connects all species on the planet." Conservation medicine embraces the One Health concept by applying a transdisciplinary approach to the study of the health relationships between humans, animals, and ecosystems. Conservation medicine is closely allied with and primarily concentrates on the values of conservation biology by recognizing that health and disease are fundamentally related to the integrity of ecosystems. Therefore, it draws on the principles of both ecology and applied medicine in its approach to health and disease. The international peer-reviewed journal *EcoHealth* was launched in 2004 and focuses on the integration of knowledge at the interface between ecological, human, and veterinary health sciences and ecosystem sustainability. This publication, among others, links disciplines and focuses attention toward "One Health, One Medicine" (Bokma et al. 2008; Mackenzie and Jeggo 2011).

CHALLENGES AND OPPORTUNITIES IN MEDICINE AND VETERINARY MEDICINE

There are a number of challenges in implementing the One Health concept in human and veterinary medical education and practice. First, worldwide there are a disproportionate number of accredited medical schools compared to veterinary medical schools. There are 125 accredited medical schools compared to only 29 veterinary medical schools in the United States, and only a handful of them share campuses.

Globally, there are approximately 2,161 medical schools operating in 172 countries as of 2009. These international medical schools, recognized by their respective governments, might not necessarily meet each other's standards (Bokma et al. 2008; Foundation for Advancement of International Medical Education and Research 2009).

There are five colleges of veterinary medicine in Canada (four fully accredited and one with limited accreditation) and 29 in the United States (25 fully accredited and four with limited accreditation) fulfilling AVMA standards. In addition, the AVMA Educational Commission for Foreign Veterinary Graduates (ECFVG) Veterinary Schools of the World lists 471 colleges of veterinary medicine and animal sciences in 109 countries. The majority have either not been evaluated by the AVMA or do not have comparable standards to meet AVMA accreditation, and only nine (Australia [three], Scotland [two], and England, Ireland, Netherlands, and New Zealand) fulfill AVMA standards.

The ECFVG does not represent this as a comprehensive list of all veterinary schools in the world. For example, Brazil has 46 veterinary colleges listed, but as of September 2009 there are more than 108 schools, and this may be the case for other countries. The AVMA list includes all schools listed by the World Health Organization in its 1991 *World Veterinary Directory* and in the 1983 Pan American Health Organization publication *Diagnosis of Animal Health in the Americas*. The list includes additional schools that have come to the attention of the ECFVG for reasons related to certification.

Why would foreign medical and veterinary medical colleges want to comply with AMA or AVMA standards? Global needs differ. For example, cattle production and intensification have been major concerns in developing countries. In contrast, in the developed world, canine medicine and exotic medicine have been of primary interest. Unless international educational standards are developed, it might be hard to convince many countries to accept U.S. standards as a baseline.

From a purely logistical standpoint, increasing communication and collaboration between students of these professions would be difficult since there are not as many schools of veterinary medicine, and of those that exist, relatively few are close enough to medical schools to facilitate meaningful educational and collaborative efforts. During 2009, the World Animal Health Organization (OIE) released *Veterinary Education for Global Animal and Public Health* (Walsh 2009), which is devoted to the improvement of student education in global animal and public health. The main concern expressed by this and other publications is to determine how this education can be achieved within an already packed curriculum.

One solution might be to establish One Health Institutes in various geographic locations globally that would bring together medical and veterinary medical students for cross-species disease teaching, information-sharing, and problem-solving. For example, the Centers for Disease Control and Prevention (CDC) established a One Health program, and two veterinary colleges (UC-Davis and UM-Minneapolis) have established One Health programs within their curriculum. The trend continues to grow, and these partnerships may encourage medical and veterinary medical schools to establish "sister" institutional ties and allow their students to spend elective time at the designated sister school for courses not available at their home institution.

This arrangement could facilitate building bridges and filling gaps in areas that medical and veterinary medical schools might not emphasize. For example, medical schools do not emphasize public and environmental health, exotic pathogens, or the ecology of zoonotic diseases. In contrast, veterinary medical teaching is much more concerned with exotic pathogens (which threaten livestock if introduced), diseases affecting multiple species, and the effects of environmental health on livestock production. The lack of teaching of zoonoses in medical schools might explain why physicians are generally not comfortable discussing zoonotic disease risks with their patients (Grant and Olsen 1999).

Evidence suggests that infectious agents can jump from animals to humans and vice versa (Childs et al. 2007; CDC 2008). One bacterium of particular concern is methicillin-resistant *Staphylococcus aureus* (MRSA), which causes serious community-acquired soft-tissue and skin infections (Fridkin et al. 2005), as well as hospital-acquired infections and deaths (Klein et al. 2007). Scott et al. (2009) found that households with cats were almost eight times more likely to have MRSA on one or more household surfaces than those without cats. Members of the households in the study did not have a history of infections or antibiotic use.

The authors recommended that further study was needed to determine if MRSA cross-contamination was occurring between humans, pets, and household surfaces. Studies assessing pathogen transmission in home settings are critical for furthering our understanding of microbial dynamics and would help in developing strategies to reduce disease. Since millions of families own pets or share their homes with animals, research to prevent the spread of pathogens in homes should be given priority, especially since many pathogens are developing antibiotic resistance.

CHALLENGES AND OPPORTUNITIES IN PUBLIC HEALTH

The WNV outbreak in New York City highlights why disease surveillance of animals is as important as disease surveillance in humans in protecting public health. This outbreak illustrates that government agencies must seamlessly integrate human and animal disease surveillance efforts. In late May 1999, residents in Queens, New York, noticed dead and dying birds, and some were brought to the local veterinary clinic. The veterinarians noted that the birds had unusual neurological signs; unfortunately, no local or state agency took responsibility for the large wildlife die-off, so nothing was done to determine why these animals were dying (U.S. General Accounting Office 2000). A month later, an infectious disease specialist at Flushing Hospital admitted eight patients with encephalitis. Three patients died and CDC found that their brain tissue contained flavivirus antigen. These were later confirmed as the first human cases of WNV in the Western Hemisphere (Asnis et al. 2000).

Before and concurrent with the human disease outbreak, exotic birds at the Bronx Zoo were noted to have died. The veterinary pathologist noted that the birds exhibited tremors, loss of coordination, and convulsions. Upon necropsy most birds had brain hemorrhages and/or meningitis similar to the human cases. Tissues from these birds were sent to the USAMRIID laboratories, where isolated viruses were sent to CDC, and WNV was diagnosed by PCR and DNA sequencing (CDC 1999). Concurrently, a group of investigators at the University of California at Irvine also used molecular techniques to show that the offending agent was WNV (Briese et al. 1999). This was the first time that the virus had appeared in the Western Hemisphere (Mahon 2003).

In response to WNV emergence, CDC established ArboNET, a cooperative surveillance system that monitors the geographic spread of WNV in mosquitoes, birds, other animals, and humans (Marfin et al. 2001). ArboNET has provided an invaluable system for tracking the spread of WNV across the United States and identifying early activity in mosquitoes and birds (CDC 2008). This surveillance system demonstrates that monitoring disease activity in arthropod vectors, animals, and humans is invaluable in tracking zoonotic disease spread and in developing successful containment and preventive strategies.

Unfortunately, surveillance of zoonotic diseases on a wider scale might be more difficult to implement. In the United States, reporting of animal diseases varies from state to state. Some states have one agency, typically departments of agriculture, responsible for domestic animal disease surveillance, while others split reporting of animal diseases between different agencies. Wildlife on non-federal lands in the United States is generally owned by the states. In some states, local public health agencies are supposed to receive reports of zoonotic diseases, primarily rabies, from veterinarians (Kahn 2006).

At the national level, surveillance of animal health is hindered because responsibility is split between many different government agencies: USDA, U.S. Department of Health and Senior Services, U.S. Department of Interior, U.S. Department of Homeland Security (USDHS), and U.S. Department of Commerce (National Academy of Sciences 2005). The USDA's Animal and Plant Health Inspection Service (APHIS) is the lead agency for livestock health and compiles disease surveillance data that are reportable to Food and Agriculture Organization (FAO) and OIE. However, there is no comparable CDC for all animals, including pets, wildlife, and zoo animals, so there are no comprehensive data available like in human disease surveillance.

At the federal level, one agency is primarily responsible for human health: the U.S. Department of Health and Human Services (USDHS). The USDHS has a subsidiary role in human health, and the U.S.

Department of Defense provides support in times of crisis, such as USAMRIID laboratory expertise during the WNV crisis. State and local governments have primary responsibility for disease surveillance in humans, and they vary in infrastructures and capabilities (Institute of Medicine 2003). They provide data to the CDC, which compiles the information on a regular basis. The CDC serves primarily as a resource for state and local health departments. The USDA is in charge of domestic animal and captive wildlife health; however, several agencies are responsible for wildlife, depending on the animal's status as a migratory or non-migratory species.

Animal health and disease surveillance are also fragmented at the international level. WHO has primary responsibility for human health and has a significant presence in UN member countries. The mission of FAO is to promote agriculture and alleviate hunger and offers limited animal health expertise to member countries. The OIE has animal health expertise, but has only a 40-person staff and no specific country presence (Institute of Medicine 2009). The OIE's primary role is in the coordination of information, and it has an early warning system for member countries. It does not have the mandate to be physically present in countries or supportive in terms of funding. These three entities are the primary players in global domestic animal health. Although they work together, their different missions, functions, and levels of support limit collaborative efforts. For example, since the OIE is not part of the UN and has a small staff and budget, it does not have the capacity to assume a role analogous to WHO's role for human health. Furthermore, none of the three has significant staff or resources focused on wildlife or ecosystem health.

The Institute of Medicine (2009) recognized that a lack of comprehensive, integrated human and animal disease surveillance systems, both in the United States and internationally, impedes an early warning system of emerging zoonotic diseases. International systems need surveillance programs and diagnostic laboratory capacities, but these are limited in developing countries, where most of the zoonotic diseases have emerged. A centralized coordinating body would be important in developing, harmonizing, and implementing integrated international human and animal health surveillance activities.

CHALLENGES AND OPPORTUNITIES IN ECOLOGICAL HEALTH

The importance of ecological health was illustrated by the highly pathogenic avian influenza (HPAI) H5N1 outbreak in Hong Kong in 1997. Surveillance of wild waterfowl and domestic poultry in southern China during the preceding decades facilitated the early recognition of the virus in humans (Shortridge et al. 2003). In May 1997, H5N1 was isolated in a three-year-old boy who died of acute pneumonia respiratory distress syndrome (ARDS) and Reye syndrome. The isolation of this distinct avian virus subtype from a human signaled the beginning of a potentially deadly pandemic (deJong et al. 1997). By December 1997, the outbreak prompted slaughtering of all poultry in Hong Kong and introducing import control of poultry from mainland China, supervised cleaning of poultry farms, and increased surveillance of disease spread in humans and birds (Tam 2002).

These actions halted the outbreak. Unfortunately, six years later, the virus reappeared in humans in the Fujian province of China (Writing Committee of the WHO Consultation on Human Influenza 2005). In Southeast Asia, H5N1 outbreaks began in December 2003, devastating the poultry industries in the affected countries (Kuiken et al. 2005; see Chapter 16 in this volume). From 2003 to September 2009, a total of 442 laboratory-confirmed human cases were reported from 15 countries, with 262 (60%) fatalities (WHO 2009). Pathogen surveillance in wildlife was minimal to non-existent. Kuiken et al. (2005) recommended a joint expert working group to design and implement a global animal surveillance system for zoonotic pathogens. In November 2005, FAO, OIE, WHO, and World Bank officials met to discuss the worsening H5N1 HPAI crisis and agreed that surveillance systems for human and animal influenza were critical for effective responses. Veterinary infrastructures in many countries needed to be assessed and strengthened to meet OIE standards, countries needed to improve their laboratory and rapid response capabilities, and funding and investments in these efforts were urgently needed (Jong-Wook 2005).

In 2006, two animal surveillance systems were launched: the Global Early Warning and Response

System for Major Animal Diseases including Zoonoses (GLEWS) and Global Avian Influenza Network for Surveillance (GAINS). The revised 2005 International Health Regulations (IHR) require nations to notify WHO, within 48 hours, of all events that might constitute a public health emergency of international concern. WHO also has a Global Outbreak Alert and Response Network (GOARN) that shares technical expertise, supplies, and support to help coordinate outbreak response investigations. Similar to the IHR legal framework supporting WHO's central role in collecting global public health information, the OIE's Terrestrial Animal Health Code requires that member countries notify OIE within 24 hours of an animal disease event of international concern. FAO has an early warning system, Emergency Prevention System for Transboundary Animal Diseases (EMPRES), established in 1994, that collects data from a variety of sources, including from OIE, to monitor for events of concern. The goal of GLEWS is to combine the WHO, OIE, and FAO data collection systems into a joint effort to facilitate communication and collaboration between human and animal health.

Unlike GLEWS, GAINS conducts active surveillance of all strains of avian influenza in wild bird populations. Sponsored by the U.S. Agency for International Development (USAID) and the CDC, GAINS started in 2006 and is administered by the Wildlife Conservation Society. Dozens of partner institutions collaborate in the GAINS network to survey wild bird populations and collect and analyze samples from wild birds either non-invasively or from capture and release. All data, including denominator data, species and sample ownership, are publicly available via a shared, open database. This early warning system allows health officials to understand the distribution of influenza viruses as well as wild birds in country and in neighboring countries.

Much more should be done to monitor diseases in wildlife and domestic animals. There is no one international governmental agency that conducts comprehensive ecological surveillance and monitoring of diseases in animals (Karesh and Cook 2005). Even worse, many wild animals are exported from countries that conduct little or no surveillance of the pathogens they might harbor (Marano et al. 2007).

In response to a monkey pox outbreak introduced in the United States by importation of Giant Gambian rats (*Cricetomys* sp.), the CDC and the U.S. Food and Drug Administration (FDA) jointly issued an order prohibiting the importation of African rodents and banned the sale, transport, or release of prairie dogs or six specific genera of African rodents in the United States. The joint order was subsequently replaced by an interim final rule, which maintains the restrictions on African rodents, prairie dogs, and other animals. Unfortunately, the global trade in wildlife continues and poses serious threats to infectious disease ecology (GLEWS 2006; Smith et al. 2009; see Chapter 11 in this volume). There are many challenges of improving ecological health through disease surveillance of wildlife. A One Health approach involving many parties, including human and animal health professionals, modelers, ecologists, sociologists, anthropologists, and others, would help provide comprehensive, coordinated, and cohesive strategies in addressing this immense problem.

CHALLENGES AND OPPORTUNITIES IN BIOMEDICAL RESEARCH

Society would benefit if more biomedical research was done in comparative medicine. Comparative medicine is not a new academic discipline: the first chair was established in 1862 in France (Wilkinson 1992). Comparative medicine is the study of the anatomical, physiological, pharmacological, microbiological, and pathological processes across species. A long history of collaborations between veterinarians and physicians has been documented. For example, in the 20th century, Dr. Rolf Zinkernagel, a physician, and Dr. Peter Doherty, a veterinarian, won the 1996 Nobel Prize in physiology or medicine for their discovery of how normal cells are distinguished from virus-infected cells by a body's immune system (Zinkernagel and Doherty 1974). These discoveries illustrate that cross-disciplinary collaborations help generate new scientific insights in disease.

Unfortunately, evidence suggests that the next generations of physicians and veterinarians are not collaborating with each other, and they are losing interest in pursuing careers in research. From 1970 to 1997, the number of physician-scientists receiving National Institutes of Health (NIH) grants diminished in proportion to doctoral recipients who seek and obtain funding (Rosenberg 1999). Compared to the 1980s, there are now 25% fewer physician-scientists in medical school faculties (Varki and Rosenberg 2002). To counter these trends, the NIH in 2002 established a series of competitive loan repayment programs that provide at least two years of tax-free debt relief for young physician-scientists committed to clinically oriented research training. Private foundations, such as Burroughs-Wellcome and the Howard Hughes Medical Institute, have created awards for new physician-scientists engaged in patient-oriented research. Some hospitals and medical schools are creating programs to encourage medical students to pursue research before and after receiving their medical degrees (Ley and Rosenberg 2005).

The situation is dire for veterinarian-scientists. A 2004 National Academy of Sciences (NAS) report found that the total number of veterinarians who received NIH grant support is small. In 2001, veterinarian principal investigators received only 4.7% of all NIH grants for animal research, since the NIH does not fund veterinary research, only research that is of benefit to humans. An apparent consequence of the lack of research funding available to veterinarians is that less than 1% of AVMA members are board-certified in laboratory animal medicine and less than 2% are board-certified in pathology (National Research Council 2004). Much could be done to reverse these trends. First, NIH and private foundation support for young physicians and veterinarians interested in pursuing research careers must be strengthened. Nowhere in the NIH's plans to improve biomedical research in the 21st century are comparative medicine and the importance of veterinarians mentioned, even though one of its primary goals is to foster interdisciplinary research, encouraging new pathways to discovery (Zerhouni 2003). The NIH must recognize that animal health influences human health and must be supported accordingly. Jointly sponsored comparative medicine research grants from the National Center for Research Resources (NCRR) and other institutes, such as the National Institute of Allergy and Infectious Diseases (NIAID) and the National Cancer Institute, should be offered to medical and veterinary medical research teams to promote collaborative efforts (National Research Council 2005a,b). Further, some veterinary education reimbursement funding has recently been made available by the U.S. government in the National Veterinary Medical Service Act for veterinarians who decide to go into government positions (http://www.avma.org/advocacy/avma_advocate/jan09/aa_jan09b.asp andhttp://www.avma.org/fsvm/AnimalHealthcare%20(2).pdf). Also some states have begun offering veterinary student loan repayment programs (notably Ohio; http://ovmlb.ohio.gov/sl.stm). A new National Veterinary Medical Service Act will improve loan repayment options for graduating veterinarians who choose to work in certain areas that affect animal or public health (http://www.avma.org/press/releases/100420_VMLRP.asp)

DEVELOPMENT OF NEW DRUGS AND VACCINES BY INDUSTRY

The pharmaceutical industry provides many examples of unnecessary separation of human and veterinary medicine that provide impediments to progress. Typically the animal and human health divisions of pharmaceutical companies are physically and operationally divided. The regulatory requirements and review of products for human and veterinary health also lie in separate divisions of the FDA and USDA. Since physiological and pathological underpinnings of product development are generally shared across species, there would be much to gain from a close interaction between those engaged in research and development of animal and human health products.

On the positive side, a few enlightened programs have reached in this direction. For example, when Akso Nobel created a new division devoted to development of human vaccines, it integrated scientists from its veterinary health division (Intervet). Intervet and a human vaccines biotechnology company (Acambis) collaborated on the development of vaccines against WNV. The veterinary vaccine is now commercially available (Prevenile®) and the human vaccine is in late stages of clinical testing. The development of these products required a close working relationship between scientists at both companies.

THE FUTURE

The One Health concept has languished too long in the 20th and 21st centuries in clinical care, public and ecological health, and biomedical research. Civilization is facing many threats, including human overpopulation, the destruction of ecosystems, climate change, and emerging zoonotic pathogens. The combined, synergistic creativity and insights of transdisciplinary teams comprising physicians, veterinarians, ecologists, public health professionals, and others are needed to address these challenges.

The organizational, institutional, and financial obstacles to implementing a global One Health approach to disease threats must not be ignored. It is incumbent upon the leaders in medicine, veterinary medicine, science, ecology, and public health to alert and educate political leaders, policymakers, the media, and the public about this critical approach in global health. Implementing a One Health approach globally would significantly mitigate or possibly avert future health crises.

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