Chiroptera: A Public Health Perspective

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Since researchers identified Horseshoe Bats as a likely reservoir for the Severe Acute Respiratory Syndrome (SARS) coronavirus, research on the connection between bats and emerging infectious diseases (EIDs) has increased[1 2 3 4 5 6 7]. Bats have been known reservoirs for the rabies virus since the early 1900s when vampire bats caused a pandemic of rabies in South American cattle. The enormous health and economic costs of disease outbreaks such as SARS make identifying the sources of disease and developing policies to prevent outbreaks imperative. Beginning in April 2012, another coronavirus, Middle East Respiratory Syndrome (MERS) began affecting humans in Saudi Arabia. Like SARS, bats are again implicated as possible reservoirs for this new disease[8].

Using MERS and other viral agents as examples, this paper explores connections between the public health risks of EIDs and bats. To provide background, I briefly describe basic bat biology, evolutionary history, and social dynamics. I describe viral outbreaks linked to bats, explain the scope of the human populations affected, and explore the possible social and environmental drivers of outbreaks. Next, I compare how two health paradigms might deal with bats in terms of public health. I begin with a purely anthropocentric, biomedical concept of public health that focuses exclusively on human health outcomes. While I surely fail to characterize current public health completely in this way, I don't think I caricature public health to represent it as focused on human needs first. I contrast the think-of-humans-first perspective with One Health, an interdisciplinary medical paradigm that "seeks to promote, improve, and defend the health and well-being of all species"[9]. Lastly, I give an example of bat-related public health research and an intervention that exemplifies One Health.

1 The Basics of Bats

Bats are the only flying mammals. After rodents, Chiroptera is most diverse order of mammals. Bats range in size from the one inch in length Kitti's hog-nosed bats of Burma to the flying foxes of Australia and South Asia with wingspans over five feet. Bats are found on every continent except Antarctica and occupy a variety of ecological and trophic niches. Most of the world's bat species are insectivores or frugivores. Some bat species live alone, while others live in roosts with millions of individuals.[10]

With the growing interest in bats as reservoirs of disease, a number of papers from the past ten years examine if and how bats might be exceptional in the world's biota as harbors of pathogens[11 1 3 4 5 6]. I summarize bat's unique features discussed in the papers here:

- Bat's wide geographic distribution and the sympatry among species may favor the development of viruses.
- Chiroptera is one of the oldest orders of mammals, so bats and viruses have had millions of years to co-evolve.
- As mammalian flyers, bats have more direct and indirect contact with other animals at a variety of locations. This may increase interspecies virus transmission.
- In order to fly, bats have evolved a unique anatomy. Unlike other mammals, bats do not have bone marrow and produce lymphocytes in other locations.
- Bats live for 25 to 35 years, so in the dense structure of many bat colonies, older bats with persistent viral infections may transmit the virus to the juveniles with developing immune systems.
- Some bats hibernate and some go into a daily torpor, which may suppress immune functions.

To date, relatively little is known about bat immunology, and study of bat's immune systems could provide useful information in the prevention and treatment of pathogens in humans. Bats do succumb to viral infections, but in some cases bats seem to be resistant to overt signs of disease and may be carriers for long periods. In one small study, bats were infected with Ebola virus. After several days, the animals were killed and analyzed[12]. Though the Ebola virus was detected, none of the bats showed histopathologic evidence of infection.

While bats are obviously unique in the animal world, there is no conclusive evidence that bats are "ground zero" for EIDs. Still, we do know that bats host many emerging pathogens and this deserves further study. Wood et al. make the case:

> "...bats offer a critically important focus for study at the human-wildlife interface. ...These interactions are shaped by environmental, social and politico-economic drivers at multiple scales, yet these processes and interrelationships are poorly characterized and understood. Bats epitomize growing challenges associated with human-wildlife disease interactions, and thus offer a valuable model for building a new, holistic, policy-engaged paradigm to address these, now and in the future."[2]

2 Bats and Human Disease

At least 5 major EIDs from the past 20 years have been associated with bats. As already mentioned, bats are suspected reservoirs of coronaviruses SARS and MERS, but the Nipah, Hendra, and Ebola viruses have also been confirmed in bats. In most cases, bats do not not directly infect humans. A plant or animal spillover host serves as the intermediary[1]. For example, since 1999, four cases of Hendra virus have been linked to bats via the spillover host of horses in Australia[7].

In 1999, an outbreak of Nipah virus in Malaysia killed 105 people. Over one million pigs were killed and the Malaysia pork industry eviscerated after direct contact with pigs was identified as the mode of transmission. Researchers identified fruit bats as a natural reservoir for the virus[7]. Bat-associated EIDs tend to first affect people proximal to spillover hosts, such as pork farmers in Malaysia and horse trainers in Australia. Several mechanisms may explain the transmission from bats to domesticated animals. A shared water source, fecal contamination, pigs eating bats, for example, are hypothethical means. This is not always the case. Sometimes bats transmit the disease more directly.

An almost annual outbreak of Nipah virus has been linked to drinking raw date palm sap in Bangladesh[13 14]. The virus has been isolated in *Pteropus* bats who eat the date fruit. Bat guano and saliva from infected bats contaminate the sap drink leading to human infection. Later I discuss efforts to remediate this problem.

As of November 8, 2013, 150 cases of MERS, including 64 deaths, have been reported[15]. No certain animal-to-human transmission hosts have been identified to date. Recent research by Memish et al. showed the results of an initial survey of bats living near locations where human cases of MERS originated[16]. Of 29 specimens of the Egyptian Tomb Bats (*Taphozous perforatus*), one tested positive for MERS. A recent report found MERS in the infected person's pet camel[17]. Are camels the spillover host between bats and humans for MERS? The Memish paper proved bats do carry the pathogen, but whether and how MERS transmitted from bats to humans remains to be definitively answered.

These examples demonstrate the scope of EIDs related to bats, but nothing in modern history exemplifies the magnitude of bat-associated diseases like SARS. Lee and McKibben estimated the global cost of SARS in 2003 to be $US 40 billion, and over 700 people died from the disease[18]. These examples also manifest some of the social and environmental determinants of bat-related EIDs. Proximity to bats leading to direct or indirect interaction clearly increases risk for individuals. Often these individuals are of lower socio-economic classes, such as agricultural workers. Reporting on recent research on Straw Colored Fruit Bats in Africa, the International Business Times paraphrased researcher James Wood:

> "A lower-income African merchant might not ever eat a mouthful of bat meat, but he might live and work in areas near bat-roosting areas, where he might inadvertently come into contact with the bats' bodily floods. This constant, low-level exposure to bat-borne viruses might not even blossom into a serious

illness, but it might weaken his immune system and make him more vulnerable to other diseases and an early death."[19]

Wood's hypothetical situation is reasonable speculation and evidences that the drivers of bat-human (and wildlife-human, more generally) diseases deserve further research.

3 Anthropogenic Drivers of Disease

Several papers touch on the idea that human activities bring about much of zoonotic disease emergence[20 6 2]. Daszak et al. summarize this issue:

> "Emerging infectious diseases of humans, wildlife, and plants are linked by two common characteristics. First, by definition they are in a process of flux, either rising in incidence, expanding in host or geographic range, or changing in pathogenicity, virulence, or some other factor. Second, these changes are almost always driven by some type of large-scale anthropogenic environmental change (e.g., deforestation, agricultural encroachment, urban sprawl) or change in human population structure (e.g., increased density linked to urbanization) or behavior (e.g., increasing drug use, changes in medical practice, agricultural intensification, international trade)."[20]

In their paper, Kuzmin et al. present a hierarchal framework where EIDs are only the tip of the iceberg[6]. Environment destruction, socioeconomic forces, and human population growth and geographic expansion form the root causes of bat to human disease transmission. For example, the spread of pig farms into fruit bat habitat may have led to the spillover event between bats and pigs in the case of the Malaysian Nipah virus[21]. Another explanation could be that destruction of fruit bat habitat from forestry operations forced fruit bats closer to humans.

Kuzmin et al. make the case for integrating conservation ethics into public health: "Given the emerging evidence that environmental degradation leads to increased rates of disease emergence, it may be time for those in the public health field to also advocate environmental conservation." Before I argue for this approach and present a success story, I touch on an ethical concern unique to EIDs associated with bats and other wildlife.

4 Emerging Ethics of Emerging Infectious Disease

For decades, people thought Australia was free of rabies. Then in 1995, Australian Bat Lyssavirus was discovered. Lincoln Flynn was the third person to die from this disease since its discovery. Lincoln was only eight years old. Immediately after his death, his parents called for a culling of the fruit bat population[22]. One can empathize with their reaction. While population "culling" is sometimes used to deal with human/wildlife conflicts[23], this strategy begets obvious animal rights and environmental ethics concerns.

While much work has been done in bioethics in the past few decades, environmental public health ethics is still in its infancy. Writing in 2005, McCallum and Hocking point out:

> "One of the major general problems is that there is currently no general ethical basis on which to make decisions regarding environmental or ecological ethics. Over the last few decades, many ethicists have moved beyond an entirely anthropocentric view of environmental ethics. Nevertheless, the extent to which humans might have duties towards populations, species and ecosystems, and the extent to which these entities might have rights beyond those of the individual organisms within them is debatable."[24]

Without dwelling on the ethical intricacies, I submit that human health, wildlife conservation, and environmental goals are not necessarily in conflict, and more and more public health leaders are pushing an agenda to align these aims.

5 From Public Health to One Health

To frame the discussion of public health perspectives on EIDs, it is instructive to consider the history of infectious disease policy. In 1999, Porter et al. wrote:

> “Those working in infectious disease research tend to see ‘the control programmes’ as the policy: they concentrate on developing guidelines for managing a specific disease in a population (or micro-policy) with an emphasis on treatment and cure. The exclusively biomedical orientation of programme structures are generally assumed to be appropriate and the development of policy focuses on the need to improve diagnosis and treatment (i.e. improve ‘the product’). The possibility of alternative structures, which include but move beyond the biomedical model to include social, economic, and environmental factors, is not generally perceived”[25].

In dealing with bat-associated EIDs, a purely biomedical approach might focus on surveillance of at-risk human populations and the development of treatments and/or prophylactics for the disease. In the case of a major zoonotic disease outbreak, surveillance is clearly justified, but neither treatment nor screening deal with the fundamental drivers of the disease outbreak. As demonstrated by SARS, the costs of this reactionary approach to virulent zoonotic diseases are huge, and other concerns such as social justice, conservation, and the environment are neglected in the rush to contain the disease.

Wood et al. call for a “new holistic paradigm integrating biological, social and environmental science approaches to explain the mechanisms and impacts of zoonotic emergence, particularly through intermediate hosts”[2]. The integrated framework they outline could be described as a One Health approach. In addition to basic biomedical concerns, their framework calls for understanding:

- how the environment influences viral pathogen dynamics;
- how land use and conservation practices affect bat populations;
- what human-bat interactions exist and why they exist;
- what are the environmental, social, and economic drivers of change (for example, are people pushing further into undeveloped habitat in search of economic gains?)

- and what are the political and cultural framings on a local, national, and international scale.

The knowledge from these concerns can then inform policies that aim for simultaneous goals of human, animal, and environmental health. Given the interdisciplinary nature of public health work, the integrative modus operandi of One Health should not be unfamiliar to public health leaders. One Health calls for involving animal health professionals and ecology specialists to broaden the public health perspective, especially relating to EIDs. Next, I provide an example of an intervention that demonstrates One Health principles and may solve a global health issue on a local scale.

6 No Animals Were Harmed in the Prevention of This Disease

In a case-control study, Rahman et al. linked date palm sap to Nipah virus in Bangladesh[14]. The Nipah virus outbreaks coincide with the harvest season when bats frequent the date palm orchards. With the bat-human transmission strongly linked to date palm sap, how can we solve this problem? We can imagine several solutions. Treatment and prophylactyic measures could be developed. This is costly and time-consuming. Bat populations could be culled. The effectiveness of this approach is questionable and may lead to other ecological effects. People could be discouraged from drinking date palm sap, depriving the farmers of a needed income source and communities of a rich food source.

Khan et al. proposed installing bamboo skirts to the date palm trees above the sap apparatus, thus preventing contamination of the sap drink[26]. Using a crossover study design, the researchers found that bats contacted the date palm sap less frequently on covered trees versus uncovered trees (2% versus 83%). They recommend community interventions to promote the use of the date palm skirts. More recent research suggests that after applying the skirts *gachhis* (sap harvesters) obtain cleaner sap for which they can charge more[27]. This is a case where, consciously or not, One Health principles led to a solution that wins for the local people, public health, and wildlife. Preventing other EIDs may not prove as tractable as applying a bamboo skirt to date palms, but in this paper I have shown some of the gaps of a biomedically-driven public health agenda and some of the benefits of a One Health approach.

7 Conclusion

Bat-associated EIDs are an important global public health concern. The SARS, MERS, and Nipah viruses are just a few examples of the magnitude of the risks. Mitigating and understanding the public health impacts of bat-associated EIDs requires an integrated approach. The One Health paradigm expands public health perspectives and pushes environmental justice and conservation issues to the fore. As demonstrated by the case of Nipah virus in Bangladesh, One Health solutions are not merely theoretical. Diverse organizations such as the American Medical Association, the Association of Schools of Public Health, and the American Association of Wildlife Veterinarians officially endorse the One Health Initiative [9]. Let's see what is possible when their members fully embrace a One Health ethos.

References

[1] Kim Halpin, Alexander D. Hyatt, Raina K. Plowright, Jonathan H. Epstein, Peter Daszak, Hume E. Field, Linfa Wang, Peter W. Daniels, and Henipavirus Ecology Research Group. Emerging viruses: coming in on a wrinkled wing and a prayer. *Clin Infect Dis*, 44(5):711–7, 3 2007.

[2] James L. N. Wood, Melissa Leach, Linda Waldman, Hayley Macgregor, Anthony R. Fooks, Kate E. Jones, Olivier Restif, Dina Dechmann, David T. S. Hayman, Kate S. Baker, Alison J. Peel, Alexandra O. Kamins, Jakob Fahr, Yaa Ntiamoa-Baidu, Richard Suu-Ire, Robert F. Breiman, Jonathan H. Epstein, Hume E. Field, and Andrew A. Cunningham. A framework for the study of zoonotic disease emergence and its drivers:

spillover of bat pathogens as a case study. *Philos Trans R Soc Lond B Biol Sci*, 367(1604):2881–92, 10 2012.

[3] Angela D. Luis, David T. S. Hayman, Thomas J. O'Shea, Paul M. Cryan, Amy T. Gilbert, Juliet R. C. Pulliam, James N. Mills, Mary E. Timonin, Craig K. R. Willis, Andrew A. Cunningham, Anthony R. Fooks, Charles E. Rupprecht, James L. N. Wood, and Colleen T. Webb. A comparison of bats and rodents as reservoirs of zoonotic viruses: are bats special? *Proc Biol Sci*, 280(1756):20122753, 4 2013.

[4] Tsutomu Omatsu, Shumpei Watanabe, Hiroomi Akashi, and Yasuhiro Yoshikawa. Biological characters of bats in relation to natural reservoir of emerging viruses. *Comp Immunol Microbiol Infect Dis*, 30(5-6):357–74, 9 2007.

[5] Lin-Fa F. Wang, Peter J. Walker, and Leo L. M. Poon. Mass extinctions, biodiversity and mitochondrial function: are bats 'special' as reservoirs for emerging viruses? *Curr Opin Virol*, 1(6):649–57, 12 2011.

[6] Ivan V. Kuzmin, Brooke Bozick, Sarah A. Guagliardo, Rebekah Kunkel, Joshua R. Shak, Suxiang Tong, and Charles E. Rupprecht. Bats, emerging infectious diseases, and the rabies paradigm revisited. *Emerging Health Threats Journal*, 4(0), 2011.

[7] Charles H. Calisher, James E. Childs, Hume E. Field, Kathryn V. Holmes, and Tony Schountz. Bats: important reservoir hosts of emerging viruses. *Clin Microbiol Rev*, 19(3):531–45, 7 2006.

[8] Denise Grady. Solving a viral mystery. *The New York Times*, 7 2013.

[9] One Health Initiative. http://www.onehealthinitiative.com/mission.php.

[10] John D. Altringham. *Bats: from evolution to conservation.* Oxford University Press, 2011.

[11] Amy S. Turmelle and Kevin J. Olival. Correlates of viral richness in bats (order chiroptera). *Ecohealth*, 6(4):522–39, 12 2009.

[12] Robert Swanepoel, Patricia A. Leman, Felicity J. Burt, Nicholas A. Zachariades, L. E. Braack, Thomas G. Ksiazek, Pierre E. Rollin, Sherif R. Zaki, and Clarence J. Peters. Experimental inoculation of plants and animals with Ebola virus. *Emerging infectious diseases*, 2(4):321, 1996.

[13] Stephen P. Luby, Mahmudur Rahman, M. Jahangir Hossain, Lauren S. Blum, M. Mushtaq Husain, Emily Gurley, Rasheda Khan, Be-Nazir . N. Ahmed, Shafiqur Rahman, and Nazmun Nahar. Foodborne transmission of Nipah virus, Bangladesh. *Emerging infectious diseases*, 12(12):1888, 2006.

[14] Muhammad Aziz Rahman, Mohammad Jahangir Hossain, Sharmin Sultana, Nusrat Homaira, Salah Uddin Khan, Mahmudur Rahman, Emily S. Gurley, Pierre E. Rollin, Michael K. Lo, James A. Comer, Luis Lowe, Paul A. Rota, Thomas G. Ksiazek, Eben Kenah, Yushuf Sharker, and Stephen P. Luby. Date palm sap linked to Nipah virus outbreak in Bangladesh, 2008. *Vector Borne Zoonotic Dis*, 12(1):65–72, 1 2012.

[15] CDC - Coronavirus - Middle East Respiratory Syndrome. http://www.cdc.gov/coronavirus/mers/.

[16] Ziad A. Memish, N. Mishra, K. J. Olival, S. F. Fagbo, V. Kapoor, and J. H. Epstein. Middle East respiratory syndrome coronavirus in bats, Saudi Arabia. *Emerg Infect Dis*, 19(11), 2013.

[17] Donald McNeil. Saudi Arabia: MERS virus found in patients pet camel. *The New York Times*, 11 2013.

[18] Stacey Knobler, Adel Mahmoud, Stanley Lemon, Alison Mack, Laura Sivitz, and Katherine Oberholtzer. *Learning from SARS: Preparing for the Next Disease Outbreak–Workshop Summary.* National Academies Press, 2004.

[19] Roxanne Palmer. African fruit bats carry deadly viruses: Study. *International Business Times*, 11 2013.

[20] Peter Daszak, Gary M. Tabor, A. Marm Kilpatrick, Jon Epstein, and Raina Plowright. Conservation medicine and a new agenda for emerging diseases. *Ann N Y Acad Sci*, 1026:1–11, 10 2004.

[21] P. Daszak, J. H. Epstein, A. M. Kilpatrick, A. A. Aguirre, W. B. Karesh, and A. A. Cunningham. Collaborative research approaches to the role of wildlife in zoonotic disease emergence. *Curr Top Microbiol Immunol*, 315:463–75, 2007.

[22] Bianca Keegan. Boy's death from bat virus sparks calls for action to reduce flying fox populations. *Courier Mail*, 2 2013.

[23] A. J. Dickman. Complexities of conflict: the importance of considering social factors for effectively resolving human-wildlife conflict. *Animal Conservation*, 13(5):458–466, 7 2010.

[24] Hamish McCallum and Barbara Ann Hocking. Reflecting on ethical and legal issues in wildlife disease. *Bioethics*, 19(4):336–347, 2005.

[25] John Porter, Jessica Ogden, and Paul Pronyk. Infectious disease policy: towards the production of health. *Health Policy and Planning*, 14(4):322–328, 1999.

[26] Salah Uddin Khan, Emily S. Gurley, M. Jahangir Hossain, Nazmun Nahar, M. A. Yushuf Sharker, and Stephen P. Luby. A randomized controlled trial of interventions to impede date palm sap contamination by bats to prevent Nipah virus transmission in bangladesh. *PLoS One*, 7(8):e42689, 2012.

[27] Nazmun Nahar, Utpal Kumar Mondal, Rebeca Sultana, M. Jahangir Hossain, M. Salah Uddin Khan, Emily S. Gurley, Elizabeth Oliveras, and Stephen P. Luby. Piloting the use of indigenous methods to prevent nipah virus infection by interrupting bats' access to date palm sap in Bangladesh. *Health Promot Int*, 28(3):378–86, 9 2013.