Semi-quantitative assessment of the risks of bi-directional transmission of influenza between pigs and workers on an indoor hog grower unit

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Background
Influenza A viruses (IAV) are distributed worldwide and infect humans and animals. Domestic pigs *(Sus domesticus*) help maintain IAV transmission globally (H1N1, H3N2, and H1N2 subtypes within the United States). In 2009 a novel subtype of H1N1 IAV (H1N1pdm09) emerged from swine populations and adapted to human-to-human transmission leading to a pandemic which was estimated to infect 15-45% of the world's population (1 – 3 billion individuals). Influenza viruses cause considerable economic burden to the pork industry due to their associated impact on growth rates and treatment costs, despite causing relatively mild disease in pigs. Influenza transmission between workers and pigs is known to occur but its relative contribution to the epidemiology of influenza in both species is poorly understood considering the potential public health and economic consequences of pandemic influenza. The purpose of our study was to assess the risks of interspecies transmission (pig-to-human or human-to-pig) of influenza within an indoor hog grower unit in the United States and to prioritize data gaps. We evaluated influenza transmission risk across two pathways common to the typical US Midwest Farm: 1. What is the likelihood that during a single production cycle on a single US indoor hog grower farm, at least one hog becomes infected with influenza virus (either H1N1pdm09, H1N1, H3N2, H3N2v, or H1N2) and that at least one worker becomes infected as a result and that the worker develops symptoms? 2. What is the likelihood that, during a single production cycle on a single US indoor hog grower farm, at least one worker becomes infected with influenza virus (either H1N1pdm09, H1N1, H3N2, H3N2v, or H1N2) and that at least one pig becomes infected as a result and at least one pig develops symptoms?

Materials and Methods
We adopted the World Organization for Animal Health (WOAH) risk assessment framework. This consists of defining a risk question and pathway, systematically evaluating the likelihood and uncertainty associated with each risk step in the pathway and combining these categories across the entire pathway. We conducted separate risk assessments for H1N1pdm09, H1N1, H3N2, H3N2v, and H1N2 subtypes. Likelihood and uncertainty assessments were based on literature review including official influenza surveillance data. At baseline, we assumed a typical Midwest indoor hog grower farm has capacity for 4,000 pigs, and two workers, with minimal influenza control measures (i.e. no vaccination but restricting personnel in contact with the pigs). Our likelihood estimations were based on a single production cycle (approximately 26 weeks). There were seven probability categories (Negligible [$0:10^{-9}$; event is so rate that its probability cannot be differentiated from zero, and in practical terms can be ignored], Extremely Low [$10^{-9}:10^{-4}$; event is extremely rare but cannot be excluded], Very Low [$10^{-4}:10^{-2}$; event is very rare], Low [$10^{-2}:10^{-1}$; event is rare], Moderate [0.1:0.5; event occurs sometimes], High [0.5:0.8; event occurs often], and Very High [0.8:1; event occurs almost always]). Uncertainty was broken into three categories (Low, Medium, and High) based on qualitative definitions e.g., data availability and agreement between sources. The following conditional risk steps were assessed: What is the likelihood that…1a) at least one piglet brought onto the farm is infected with influenza?; 1b) at least one worker is infected with influenza from an infected pig on the farm;1c) an infected worker develops influenza symptoms?; 2a) at least one swine worker is infected with influenza outside of swine farm?; 2b) at least one pig is infected by a worker; 2c) the newly infected pig will develop symptoms of influenza?

Results
Based on literature review we estimated the probability that at least one piglet being brought onto a hog farm during a single production cycle to vary from Low [$10^{-2}:10^{-1}$] to Very

high [0.8:1] for most subtypes. We estimated the probability that at least one piglet being brought onto the farm during a single production cycle being infected with a virus associated with H3N2v in people to range from Low [10^{-2}:10^{-1}] to Moderate [0.1:0.5]. The probability of at least one worker being infected from a pig during a single production cycle was estimated Moderate [0.1:0.5] to High [0.8:1] for H1N1 and H1N1pdm09, Low [10^{-2}:10^{-1}] to Moderate [0.1:0.5] for H3N2 and H3N2v, and Moderate [0.1:0.5] for H1N2. Lastly, we estimated the probability of a worker developing symptoms after being infected with influenza from a pig to be Moderate [0.1:0.5] for H1N1 and H1N2. We could not assess the other subtypes due to lack of data.

We estimated the probability that at least one worker is infected with influenza during a single production cycle outside of the swine farm to be Low [10^{-2}:10^{-1}] for H1N1pdm09, H3N2, Very Low [10^{-4}:10^{-2}] for H3N2v, and Negligible [0:10^{-9}] to Very Low [10^{-4}:10^{-2}] for H1N1 (other than pdm09) and H1N2. We estimated the likelihood that a worker transmits influenza to at least one pig (out of 4,000) during a production cycle to be Low [10^{-2}:10^{-1}] to High [0.5:0.8] for H1N1pdm09 and H1N1. This probability was estimated to be Very Low [10^{-4}:10^{-2}] to High [0.5:0.8] for H3N2 and Low [10^{-2}:10^{-1}] to High [0.5:0.8] for H3N2v. The probability of a worker transmitting H1N2 to a pig was estimated to be Moderate [0.1:0.5]. Lastly, the probability that a pig develops symptoms after being infected from a worker was estimated to be Low [10^{-2}:10^{-1}] for H1N1pdm09, Very High [0.8:1] for H3N2, and Very High [0.8:1] for H3N2v. We could not find data to inform an estimation for H1N1 and H1N2.

Conclusions

These findings suggest the frequency of transmission events between workers and pigs during a production cycle on a farm could be relatively high depending on the influenza subtype but is associated with high uncertainty levels (often due to limited empirical data). Most notably, H1 subtypes of influenza (H1N1 including H1N1pdm09) were estimated to have the greatest probability of transmission between pigs and workers. Improved biosecurity for workers and PPE adherence could potentially mitigate future transmission from workers to pigs. There are approximately 67,000 pig farms at the US, suggesting a high frequency of transmission events between worker and pigs across all swine farms and production cycles.