Human to animal transmission of influenza A(H1N1)pdm09 in a turkey breeder flock in Norway

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ABSTRACT

Introduction: Routine surveillance samples disclosed seropositivity to influenza A virus (IAV) in a Norwegian turkey breeder flock. Simultaneous reports of influenza-like symptoms in farm workers and a laboratory confirmed influenza A(H1N1)pdm09 (H1N1pdm09) infection in one person led to the suspicion of a H1N1pdm09 infection in the turkeys. Animals and methods: H1N1pdm09 infection was confirmed by a positive haemagglutinin inhibition test using H1N1pdm09 antigens, and detection of H1N1pdm09 nucleic acid in reproductive organs of turkey hens. The flock showed no clinical signs except for a temporary drop in egg production. Previous reports of H1N1pdm09 infection in turkeys suggested human-to-turkey transmission (anthroponosis) during artificial insemination. Results and discussion: The flock remained seropositive to IAV and the homologous H1N1pdm09 antigen throughout the following 106 days, with decreasing seroprevalence over time. IAV was not detected in fertilised eggs or in turkey poults from the farm, however, maternally derived antibodies against H1N1pdm09 were found in egg yolks and in day-old poults. Genetic analyses of haemagglutinin gene sequences from one of the infected farm workers and turkeys revealed a close phylogenetic relationship, and confirmed human-to-turkey virus transmission.

Introduction

Wild birds are the natural reservoir for all subtypes of influenza A viruses (IAVs), and thought to be the primary source of influenza A in other animals and humans [1]. Circulating avian influenza viruses (AIVs) evolve continuously due to antigenic drift and shift. Examples of human infections with avian and zoonotic influenza viruses include H5N1 and H7N9, which are causing sporadic infections with high mortality in Asia and Egypt [2].

Although anthroponoses are less debated and documented, IAVs may also be transmitted from humans to animals. Suspected cases of human to animal transmission of influenza A(H1N1)pdm09 (H1N1pdm09) virus have been reported in several mammalian species, including pigs, dogs, cats, and ferrets [3]. Although poultry has been regarded as less susceptible to the H1N1pdm09 virus [4], several international case reports have described H1N1pdm09 infection of suspected human origin in turkeys in the wake of the 2009 pandemic [5–8]. The transmission has occurred solely in turkey breeders, most likely during artificial insemination [9]. This paper describes an outbreak of H1N1pdm09 virus infection in a turkey breeder flock in Norway due to suspected human-to-turkey transmission.

Materials and methods

All turkey samples were analysed at the Norwegian Veterinary Institute. Blood samples were tested for antibodies against IAV using a blocking ELISA from IDvet (ID Screen influenza A antibody competition multi-species), and an indirect ELISA from IDEXX (IDEXX AI Ab test). For confirmation, positive samples were followed up with subtype specific haemagglutination inhibition (HI) tests [10]. Inactivated virus antigens and positive control sera for AI subtypes were obtained from the EU Reference Laboratory for Avian Influenza, Animal and Plant Health Agency, UK, and were as follows: H5N1 A/chicken/Scotland/59; H5N2 A/Ostrich/Denmark/72420/96; H5N3 A/teal/England/7394-2805/06; H5N7A/Mallard/Denmark/64650/03; H7N1 A/African starling/England/983/79; H7N7 A/turkey/England/647/77 [11]. Inactivated virus antigens and positive control sera for H1N1pdm09 were purchased from the University of Gent, Belgium (H1N1 A/Swine/California/07/09). Antibodies from egg yolk were extracted with chloroform, as described by Mohammed [12]. Turkey cloacal and oropharyngeal swabs and tissue samples were tested with a pan-influenza A real-time RT-PCR (rRT-PCR) [13], and subtype specific rRT-PCRs for H5, H7 and...
H1N1pdm09 [14–16]. HA gene sequences from positive samples were based on PCR fragments generated as previously described [17]. Human samples were tested at the Norwegian Institute for Public Health. Nucleic acid from human nasopharyngeal swabs were typed [18] and H1 subtyped [14] by rRT-PCR. The HA gene was sequenced by dye-terminator Sanger sequencing (PCR and sequencing primers available upon request). Nucleotide sequences were further analysed by BioNumerics (AppliedMaths, Belgium), BioEdit [19], and MEGA 6 software [20]. Phylogenetic trees were constructed with the neighbour-joining method, using Kimura2-parametre pairwise distances. Viral nucleotide sequences from the turkey sample (A/Turkey/Norway/1051/2016) and the human sample (A/Norway/1728/2016) were submitted to GISAID with the accession numbers: 11,046,376 and 1,046,371, respectively.

**Outbreak history**

Sera were collected on the 3rd of March 2016 at a turkey breeder farm as part of the national surveillance program for notifiable avian influenza (AI) in poultry, which investigates serological evidence for infection due to the H5 and H7 AIV subtypes [11]. Initially, antibodies against a highly conserved epitope of the IAV nucleoprotein was detected in 10 out of 10 sera using a blocking ELISA. Further analysis for H5/H7 subtype-specific antibodies using the HI test showed a low-titre reaction against H5 in 12 out of 16 sera (titres of 1:8 or 1:16), which prompted immediate infection control measures to be taken at the farm [21].

With the exception of a transient decrease in egg production in February (Figure 1) the flock showed no clinical signs. House 1 and 3 at the farm contained 1000 turkey hens each, while 200 stags were kept in house 2. The entrances to all houses had contaminated and clean zones separated by step-over barriers. All surveillance sera were taken from house 3.

Further testing showed that animals in house 1 and 2 were negative for antibodies against IAV. Also, 20 + 20 (cloacal and oropharyngeal) swabs taken from each of the three houses and cloacal and oropharyngeal swabs and tissue samples from 13 recently dead birds recovered from a freezer at the farm were negative for IAV by rRT-PCR. The absence of clinical signs and pathological changes except for the drop in egg production, which was noted retrospectively, led to the suspicion of a past infection with a low pathogenicity (LP) AIV virus H5 strain.

Concurrent epidemiological investigations revealed that six out of nine (67%) workers at the farm had been sick with flu-like symptoms during the period from 24/12/2015 to late February 2016. Artificial insemination of turkey hens had been performed on a weekly basis since start of lay in January, but on different weekdays in the two hen houses. Antibodies against H1N1pdm09 virus were only confirmed in two of the workers, reporting respiratory illness from early January and February, respectively; H1N1pdm09 infection had been laboratory-confirmed on the 11th of February in one of these, raising suspicion of a human-to-turkey transmission of H1N1pdm09. An HI test using H1N1pdm09 antigen was performed on IAV positive turkey sera, and

![Figure 1. The solid line displays average egg production in the influenza A(H1N1)pdm09 infected turkey flock from start of lay (A) until blood samples seropositive for influenza A were detected in the flock (B). The dotted line shows average egg production in a previous turkey flock at the same farm. Average egg production was calculated as total daily egg-laying rate (%) for both houses at the farm, indicating that the actual reduction in the infected house was greater.](image-url)

revealed that 95% of the sera were seropositive to H1N1pdm09, and that the majority (>70%) of positive sera had a titre of 1:1024 or higher. Subsequent rRT-PCR analyses showed that two dead turkey hens that had previously tested negative for IAV in cloacal and oropharyngeal swabs and other tissue samples tested positive for H1N1pdm09 in reproductive tissue (ovary and oviduct). Phylogenetic analysis of the human and turkey (partial) H1N1pdm09 sequences provided further evidence for a human-to-turkey transmission (Figure 2) as the virus sequence from one of the farmers and the virus sample from the turkey grouped together phylogenetically. Still, these two samples were not more similar to each other than many other H1N1pdm09 samples from Norway in the influenza season 2015/2016. The turkey sample did possess one unique amino acid substitution in the HA1 gene: N129S, not seen in any other Norwegian samples. This genetic polymorphism does not appear to be associated with any known phenotypic change.

Since infection with an AIV H1 strain is not a reportable disease in poultry, all governmental infection control measures were lifted, and the animals were released for continued egg production.

Results from subsequent testing in the flock

Affected turkey hens

The infected flock was monitored over the next few months with serology, rRT-PCR analyses and post mortem examinations. New blood samples were taken 45, 80 and 106 days post detection (dpd) and analysed with ELISA and HI test. Turkey hens in house 3 remained seropositive throughout the sampling period, but showed a statistically significant decline (p ≤ 0.05) in seroprevalence for all tests between initial detection and 106 dpd (Figure 3). The homologous H1 antigen seems to be more sensitive in detecting the humoral response for longer time intervals than the generic IAV ELISAs.

Post mortem examination of ten euthanized, non-productive hens at 45 and 80 dpd showed no pathological changes. H1N1pdm09 virus was detected in reproductive tissue of 3 out of 10 hens at 45 dpd, but not at 80 dpd. Post mortem examination and rRT-PCR was not performed on day 106.

Poults and hatching eggs

Eggs from the affected farm were collected at the hatchery at different time points in the hatching process. Egg white and embryo tissue from 20 eggs collected at the time of candling, 20 eggs with dead embryos collected at the time of transfer from the setter to the hatcher, and 20 non-hatched eggs tested negative for H1N1pdm09 virus by rRT-PCR. Yolks from 4 out of 10 eggs from house 3 collected at candling were positive for antibodies against H1N1pdm09, whereas eggs from house 1 were negative.

IAV was not detected in turkey poults from the affected farm at any age. In day-old poults, maternally derived antibodies against H1N1pdm09 were detected in 8 out of 10 poults from house 3, whereas poults from house 1 were negative. Blood samples taken from 8 weeks old turkey poults were all negative for antibodies against H1N1pdm09.

Discussion

The H1N1pdm09 virus infection in the Norwegian turkey flock was caused by a human-to-animal transmission of IAV. The virus was only found in the reproductive organs of turkey hens, which has previously been suggested to be a likely route of infection with H1N1pdm09 in turkeys in experimental settings [9]. The absence of virus in other tissue, including cloacal and oropharyngeal swabs, supports clinically that turkeys are refractory to H1N1pdm09 infection through aerosol and oral transmission routes. The biosecurity measures on the farm can be characterized as good, but the farm with its three houses should be considered as one epizootological unit. Given this, house-to-house contamination by fomites, faecal-oral transmission and aerosol transmission would be difficult to prevent since workers with influenza-like illness had access to all houses. The findings that only a single house was infected indicate that the aerosol and faecal-oral routes were not important for transmission. It is therefore likely that the process of artificial insemination is the mode of viral transfer and subsequent infection.

Although flu-like symptoms were reported in several farm workers, H1N1pdm09 infection was confirmed in only one case. Genetic analysis revealed that the turkeys were infected by human H1N1pdm09 virus. The sample from the infected farm worker was not more similar to the turkey sample than other human samples from the same region or other parts of Norway. Thus, the virus transmitter was not identified. Unfortunately, detailed work lists for each of the houses during the insemination process were not available. However, since turkey hens in different houses are inseminated at different weekdays, it is possible that a farm worker shedding virus worked only in one house, but not the other. The absence of systemic and respiratory disease in the flock and the drop in egg production during the period of suspected infection also support a virus transmission during the process of artificial insemination.

While sera from the affected turkey hens were negative for antibodies against the primary H5 antigen recommended by the EURL for the AI H1 test (H5N3 A/teal/England/7394-2805/06), other H5 antigens showed a low-grade cross-reactivity against
Figure 2. Phylogenetic reconstruction of Norwegian A/H1N1 genetic clade 6B.1 HA genes. (Subtree of all H1N1 viruses from Norway season 2015–16 with different clades representing reference viruses). Clade 6B.1 reference virus is in italic bold font. Aligned partial HA1 gene sequences (856 bases) were subjected to phylogenetic analysis using neighbour-joining of Kimura-corrected genetic distances. The genetic distance between two strains is represented as the sum of the length of horizontal branches connecting them. Bootstrap values above 70% out of 500 resamplings are shown. Norwegian viruses from this season are named as ‘GISAID accession number |Isolate ID |week’. The two virus sequences from this study are marked in red bold font.
H1N1pdm09. Although for H5N1 a cross-reactivity towards the neuraminidase of H1N1pdm09 was expected, the cross reactivity towards subtypes with different H- and N-antigens (H5N2 and H5N7) was surprising. The same observations have been made in the USA during H1N1pdm09 infection in turkeys (Mia Kim Torchetti, David L Suarez, personal communications). Cross-reactivity was no longer observed in blood samples taken 45, 80 and 106 dpd, and in blood samples that had been frozen for some time. This might indicate that cross-reactive antibodies are not sustained in the same way as specific antibodies; however, further investigations into this matter were beyond the scope of this study.

Our work indicates that the H1N1pdm09 virus is not transferred vertically from parent stock to offspring. On seroconversion, antibodies are present for at least 15 weeks, with a declining prevalence, as expected. Antibodies detected in hatching eggs and day-old poults illustrate transmission of maternally derived antibodies, although their protective capacity in poults has not been investigated.

Although turkeys are not normally regarded as potential ‘mixing vessels’ for influenza viruses, they are susceptible to a wide variety of IAVs, including those from wild birds, swine and humans, providing the opportunity for influenza virus reassortants [22,23]. In that context, this paper adds to the discussions regarding the usefulness of vaccination in poultry farm workers.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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References

[1] Webster RG, Bean WJ, Gorman OT, et al. Evolution and ecology of influenza A viruses. Microbiol Rev. 1992 Mar;56(1):152–179. PubMed PMID: 1579108; PubMed Central PMCID: PMC2378589. eng.
[2] Bui CM, Chuaghui AA, Adam DC, et al. An overview of the epidemiology and emergence of influenza A infection in humans over time. Arch Public Health. 2017 Mar;75(15). eCollection 2017. DOI: 10.1186/s13690-017-0182-z.
[3] Keenliside J. Pandemic influenza A H1N1 in Swine and other animals [Review]. Curr Top Microbiol Immunol. 2013;370:259–271.
[4] Swayne DE, Pantin-Jackwood M, Kapczynski D, et al. Susceptibility of poultry to pandemic (H1N1) 2009 virus [Letter Research Support, U.S. Gov’t, Non-P.H.S.]. Emerg Infect Dis. 2009 Dec;15(12):2061–2063. DOI: 10.3201/eid1512.091060.
[5] Berhane Y, Ojikj D, Neufeld J, et al. Molecular characterization of pandemic H1N1 influenza viruses isolated from turkeys and pathogenicity of a human pH1N1 isolate in turkeys. Avian Dis. 2010 Dec;54(4):1275–1285.
[6] Mathieu C, Moreno V, Retamal P, et al. Pandemic (H1N1) 2009 in breeding turkeys, Valparaíso, Chile. Emerg Infect Dis. 2010 Apr;16(4):709–711. DOI: 10.3201/eid1604.091402.
[7] Pasick J, Pedersen J, Hernandez MS. Avian influenza in North America, 2009-2011. Avian Dis. 2012 Dec;56(4 Suppl):845–848.
[8] Reid SM, Cox WJ, Ceeraz V, et al. First reported detection of influenza A (H1N1)pdm09 in turkeys in the UK [Research Support, Non-U.S. Gov’t]. Avian Dis. 2012 Dec;56(4 Suppl):1062–1067.
[9] Pantin-Jackwood M, Wasielenko JL, Spackman E, et al. Susceptibility of turkeys to pandemic-H1N1 virus by reproductive tract insemination [Research Support, U. S. Gov’t, Non-P.H.S.]. Virol J. 2010;7:27. DOI: 10.1186/1743-422X-7-27.
[10] OIE. Chapter 2.3.4. Avian influenza. In: Manual of diagnostic tests and vaccines for terrestrial animals. 7th ed. Paris (France): World Organisation for Animal Health; 2012.
[11] EC. Commission Decision 2010/367/EU of 25.06.2010 on the implementation by member states of surveillance programmes for avian influenza in poultry and wild birds. Brussels: European Commission; 2010. Available from: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1505909783868&uri=CELEX:32010D0367.
[12] Mohammed HO, Yamamoto R, Carpenter TE, et al. Comparison of egg yolk and serum for the detection of Mycoplasma gallisepticum and M. synoviae antibodies by enzyme-linked immunosorbent assay [Comparative Study Research Support, Non-U.S. Gov’t Research Support, U.S. Gov’t, Non-P.H.S.]. Avian Dis. 1986 Apr-Jun;30(2):398–408.
[13] Spackman E, Senne DA, Myers TJ, et al. Development of a real-time reverse transcriptase PCR assay for type A influenza virus and the avian H5 and H7 hemagglutinin subtypes [Evaluation Studies Research
[14] Schulze M, Nitsche A, Schweiger B, et al. Diagnostic approach for the differentiation of the pandemic influenza A(H1N1)v virus from recent human influenza viruses by real-time PCR [Research Support, Non-U.S. Gov’t Validation Studies]. PLoS One. 2010 Apr 1;5(4):e9966. DOI:10.1371/journal.pone.0009966.

[15] Slomka MJ, Pavlidis T, Banks J, et al. Validated H5 Eurasian real-time reverse transcriptase-polymerase chain reaction and its application in H5N1 outbreaks in 2005-2006 [Research Support, Non-U.S. Gov’t]. Avian Dis. 2007 Mar;51(1 Suppl):373–377.

[16] Slomka MJ, Pavlidis T, Coward VJ, et al. Validated RealTime reverse transcriptase PCR methods for the diagnosis and pathotyping of Eurasian H7 avian influenza viruses [Comparative Study Evaluation Studies Research Support, Non-U.S. Gov’t]. Influenza Other Respir Viruses. 2009 Jul;3(4):151–164. DOI:10.1111/j.1750-2659.2009.00083.x.

[17] Forberg H, Hauge AG, Gjerset B, et al. Swine influenza in Norway: a distinct lineage of influenza A (H1N1)pdm09 virus [Research Support, Non-U.S. Gov’t]. Influenza Other Respir Viruses. 2013 Dec;7 Suppl 4(Suppl 4):21–26. DOI:10.1111/irv.12194.

[18] Hauge SH, Dudman S, Borgen K, et al. Oseltamivir-resistant influenza viruses A (H1N1), Norway, 2007–08. Emerg Infect Dis. 2009 Feb;15 (2):155–162.

[19] Hall TA. BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. Nucl Acids Symp Ser. 1999;41:4.

[20] Tamura K, Stecher G, Peterson D, et al. MEGA6: molecular evolutionary genetics analysis version 6.0 [Research Support, N.I.H., Extramural Research Support, Non-U.S. Gov’t]. Mol Biol Evol. 2013 Dec;30(12):2725–2729. Epub 2013 Oct 16. DOI:10.1093/molbev/mst197.

[21] EC. Council Directive 2005/94/EC of 20.12.2005 on Community measures for the control of avian influenza. Brussels: European Commission; 2005. Available from: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1506072986761&uri=CELEX:32005L0094:

[22] Kapczynski DR, Gonder E, Liljebjelke K, et al. Vaccine-induced protection from egg production losses in commercial turkey breeder hens following experimental challenge with a triple-reassortant H3N2 avian influenza virus [Controlled Clinical Trial Research Support, Non-U.S. Gov’t Research Support, U.S. Gov’t, Non-P. H.S.]. Avian Dis. 2009 Mar;53(1):7–15.

[23] Sun H, Kong W, Liu L, et al. The infection of turkeys and chickens by reassortants derived from pandemic H1N1 2009 and avian H9N2 influenza viruses [Research Support, Non-U.S. Gov’t]. Sci Rep. 2015;5:10130. DOI:10.1038/srep10130.