

Emerging and re-emerging infectious diseases in the Sahel: a One Health investigation of an influenza A(H1N1)pdm09 outbreak in the Abéché Health District, Chad, 2021

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Abstract

Emerging infectious diseases threaten global health security, particularly where integrated human-animal-environment surveillance is limited. In May 2021, Chad reported an influenza-like illness (ILI) outbreak in the Abéché Health District (Ouaddaï Province) following unusual avian mortality. We conducted a One Health investigation from May 1 to June 24, 2021, combining active case finding, a neighborhood-matched case-control study (58 cases, 58 controls) of warthog- and poultry-related exposures, an animal/environmental investigation, and virological testing (quantitative reverse transcription polymerase chain reaction [RT-qPCR] in humans; hemagglutination inhibition in poultry). We identified 210 ILI cases, 77.6% in the Amtiab villages (Abéché Health District); children under 10 were the most affected, with one death (probable encephalitis, age 13). Age under 15 years (odds ratio [OR]=4.49, 95% confidence interval [CI]: 1.61-12.55) and contact with a case (OR=4.39, 95% CI: 1.89-10.21) were significantly associated with ILI. RT-qPCR confirmed A(H1N1)pdm09 in humans; poultry showed prior mortality and anti-H9N2 antibodies, without an established causal link. This investigation rapidly identified an A(H1N1)pdm09 outbreak in a rural Sahelian setting where human-wildlife-poultry cohabitation and poor sanitation favor zoonotic pathogens. Young age and close contact drove the transmission. Strengthened integrated influenza surveillance and diagnostic capacity are needed in sub-Saharan Africa.

Key words: influenza A(H1N1)pdm09; emerging disease; One Health; case-control study; epidemiological surveillance; Chad; Sahel; zoonosis.

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Introduction

An emerging disease is defined as a disease whose true incidence increases significantly in a given population and region, relative to the usual epidemiological situation.¹ Emerging diseases in humans are zoonoses in 60 to 70% of cases:^{2,3} a considerable number of wild or domestic animal species, harboring pathogens that are increasingly well characterized, participate in the ecology of diseases transmissible to humans, with humans being inseparable from their ecosystem.⁴ Around 1,500 pathogens are currently known in humans, of which more than 170 are considered emerging or re-emerging.⁵

Influenza A(H1N1) is among these diseases. In 1918, the Spanish flu pandemic remains the most devastating infectious event of modern history. Since then, three further pandemics have occurred – in 1957, 1968, and 2009.⁶ The 2009 pandemic virus, A(H1N1)pdm09, arose from a complex reassortment combining genomic segments from swine, avian, and human viruses, making

it a reassortant virus with efficient human-to-human transmission.⁷⁻⁹ Like other influenza viruses, it is transmitted by the airborne route (respiratory droplets) or through contact with contaminated surfaces.⁶

These emerging or re-emerging infectious diseases remain a permanent threat to global health security, a threat that is all the more concerning in resource-limited countries where diagnostic and surveillance capacities remain restricted.^{10,11} In sub-Saharan Africa, malaria remains the default diagnosis for any fever, leading to chronic under-detection of other febrile etiologies, particularly viral ones.¹¹⁻¹³ Influenza surveillance there remains fragmentary: few countries have a sustained sentinel surveillance system, and data on the circulation of avian influenza viruses (notably H9N2, widespread in domestic poultry in West and North Africa) and swine influenza viruses remain limited.¹⁴⁻¹⁷

As part of active influenza surveillance, Chad reported an outbreak of influenza-like illness (ILI) in May 2021 in the eastern region of the country, in the Abéché Health District, preceded by

unusual avian mortality in several villages. In line with the One Health approach, a multidisciplinary team including infectious disease specialists, epidemiologists, veterinarians and environmental health officers traveled to the site to investigate its origin. We report here the results of this investigation, which aimed to describe the epidemiological characteristics of the outbreak, identify the causative agent(s), and explore the risk factors associated with transmission, with a view to strengthening integrated surveillance of diseases with epidemic potential in the Sahel.

Materials and Methods

Setting and study area

The Krey Health Center (GPS coordinates: 13.9584° N, 20.4498° E) is located 55 km from Abéché, the main town of the Abéché Health District in Ouaddaï Province, Chad (Figure 1). Its catchment area, home to approximately 9,170 inhabitants, encompasses 32 villages, ferricks (Fulani encampments), and damrés (encampments of nomadic Arab communities). It is an area cut off by large wadis during the rainy season, where the population is mainly engaged in agriculture, livestock farming, and small-scale trade. The villages of Amtiab I and III (Abéché Health District), located 7 km from the health center and about 3 km apart from each other, have no improved drinking water point; the population, which is sedentary and agropastoral, draws water directly from the wadis. Housing there is traditionally built from straw.

Descriptive epidemiological investigation

An active case count was conducted throughout the Krey catchment area, based on the ILI case definition from the Integrated Disease Surveillance and Response (IDSR) guide, combining cough, headache, and fever. For each case identified, socio-demographic characteristics (age, sex, village of residence) and clinical signs were collected using a linear case-recording form (line list).

Case-control study

An analytical causal investigation was conducted in the form of a neighborhood-matched case-control study, in order to test two competing etiological hypotheses: i) indirect transmission from warthogs (*Phacochoerus africanus*) to humans *via* shared water points; and ii) direct transmission from domestic poultry to humans.

Cases were defined as residents of the villages of Amtiab I, II, and III who developed ILI (cough, headache, and fever according to the IDSR definition) during epidemiological week 18 of 2021. Controls were defined as residents of the same villages who had presented no influenza symptoms between May 1 and June 24, 2021, recruited from the immediate neighborhood of each case.

Sample size was calculated using StatCalc software (Epi Info™), based on the following parameters: 95% confidence interval (CI), 80% statistical power, control-to-case ratio of 1:1, expected odds ratio (OR) of 3, and expected exposure prevalence among controls of 50%. This calculation determined a minimum size of 58 cases and 58 controls, which was the number actually included in the analysis. Cases were selected from the line list in chronological order of symptom onset (the first 58 recorded cases); controls were recruited from the neighborhood of each corresponding case. Data were collected using a standardized questionnaire administered face-to-face to cases and controls, covering risk factors for exposure to avian or swine influenza (contact with sick or dead

poultry, contact with warthogs or their water points, contact with a human case, presence of migratory birds at home). This study is subject to potential exposure and outcome misclassification bias, as not all cases underwent individual biological confirmation. Accordingly, the analysis examines risk factors associated with the occurrence of ILI observed in the Amtiab villages, rather than specifically with laboratory-confirmed A(H1N1)pdm09 infection. This limitation is discussed in greater detail below.

Animal investigation

An animal investigation was carried out in the locality to look for a possible zoonotic source of the event. It consisted of enumerating the presence of domestic animals as well as wild animal populations, notably warthogs, sharing the same water points as the human population. A survey was conducted among residents to document any unusual mortality or morbidity among warthogs and other wild animals, as well as among domestic animals. A retrospective search for avian mortality was also carried out among households, covering the period preceding the notification of the first human cases. Poultry carcasses reported by residents were sought out and examined. A live chicken showing clinical signs (sneezing, whitish diarrhea, coughing, lethargy) was identified and sampled: a tracheal swab was taken (Figure 2).

Assessment of hygiene and sanitation conditions

An assessment of hygiene and sanitation conditions was carried out in the villages visited, covering defecation practices, water supply sources, the availability of drinking water points and latrines, as well as the community's basic hygiene practices (hand-washing, latrine use). For each village, the drinking water source(s) were identified and visually inspected (appearance, level of protection, presence of treatment), with particular attention paid to the village of Amtiab (Figure 3).

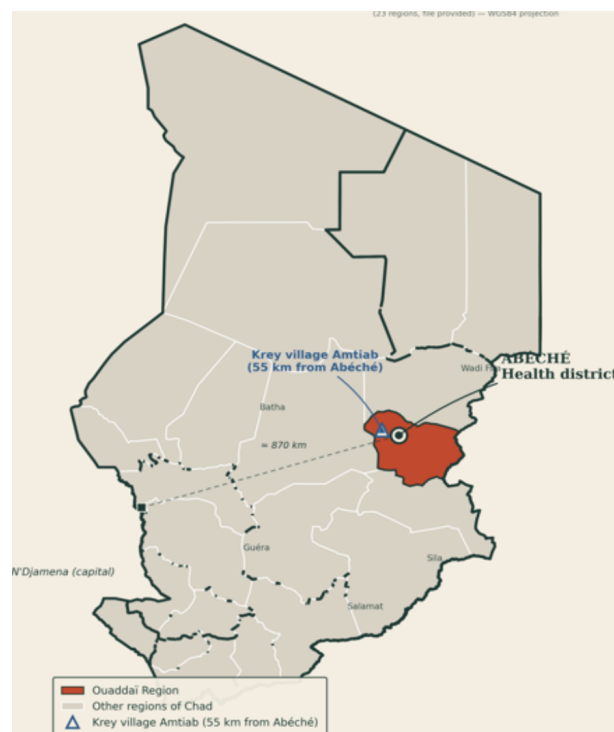


Figure 1. Map showing the location of the Krey Health Center in the Abéché Health District, Chad.

Virological investigation

In the sampled poultry, two types of direct samples were taken: a tracheal swab and a cloacal swab. This dual sampling site is recommended by the World Organisation for Animal Health (WOAH) *Terrestrial Manual* for the detection of avian influenza viruses, as viral shedding may be predominantly respiratory or digestive depending on the viral subtype involved.¹⁸ These swabs were intended for direct detection of the viral genome by quantitative reverse transcription polymerase chain reaction (RT-qPCR).

An additional blood sample was taken for serological testing for anti-H9N2 antibodies by hemagglutination inhibition assay, the reference method for detecting prior exposure to avian influenza viruses with functional hemagglutinin.¹⁸

A sample from the warthog had been planned as part of the broader animal investigation but could not be carried out.



Figure 2. Tracheal swabbing of a hen by the veterinary team.

Statistical analysis

Data were entered and analyzed using Epi Info™ software (Centers for Disease Control and Prevention, Atlanta, USA). Qualitative variables were described as counts and percentages, and quantitative variables as means or medians depending on their distribution. Associations between risk factors and the occurrence of ILI were estimated using crude OR and 95% CI, by means of univariate followed by stepwise multivariate logistic regression, adjusted for demographic variables (age, sex) and other risk factors. The statistical significance threshold was set at $p < 0.05$.

Results

Descriptive characteristics of the outbreak

In total, 210 cases of ILI meeting the IDSR definition were recorded in the Krey catchment area between May 1 and June 24, 2021. All age groups were represented, with a marked predominance among children under 10 years of age, who accounted for more than half of the cases (Table 1). The sex ratio was 1.12 in favor of males (111 males to 99 females). One death was recorded, involving a 13-year-old girl who presented a clinical picture of probable encephalitis. Among the 23 cases for which clinical signs were documented in detail, the most frequent manifestations were cough (95.7%), headache (87.0%), and fever (78.3%), followed by anorexia and physical asthenia (60.9% each) (Table 1).

Results of the animal and environmental investigation

The presence of a large warthog population sharing water points with the community was confirmed, with no unusual mortality or morbidity reported among these animals. In contrast, notable domestic avian mortality preceded the notification of the first human cases by about a week, with several households reporting the death of local chickens and the discovery of carcasses; a symptomatic chicken (sneezing, whitish diarrhea, coughing,



Figure 3. View of Amtiab village I showing a dwelling, an open-defecation site, and a well.

lethargy) was identified and sampled. From an environmental standpoint, the absence of improved drinking water points and latrines in the villages investigated, the use of unprotected well water (notably stagnant, turbid water in Amtiab III), widespread open defecation, and a low level of awareness of basic hygiene practices constituted conditions favorable to the transmission of waterborne and zoonotic pathogens.

Results of the case-control study

Univariate analysis showed a statistically significant association between the occurrence of ILI and two factors: age under 15 years (OR=4.49; 95% CI: 1.61-12.55; $p=0.003$) and contact with a sick case (OR=4.39; 95% CI: 1.89-10.21; $p<0.001$) (Table 2). The presence of poultry mortality in the immediate vicinity of the home was associated with an increased risk at the borderline of statistical significance (OR=3.24; 95% CI: 0.96-11.00; $p=0.050$). In contrast, neither consumption of water frequented by warthogs (OR=0.73; $p=0.488$), nor bathing in ponds shared with these animals (OR=1.36; $p=0.499$), nor keeping poultry at home (OR=0.76; $p=0.603$), nor handling dead poultry (OR=2.67; $p=0.240$) reached the threshold of statistical significance, although these last two associations suggest a trend toward increased risk whose significance may have been limited by the study's statistical power.

Virological results

In humans, RT-qPCR analysis targeting the matrix gene of influenza A revealed influenza A(H1N1)pdm09 virus in 3 of the 18 samples tested, a result confirmed by the Institut Pasteur de Yaoundé, Cameroon. RT-qPCR testing for SARS-CoV-2, targeting the *ORF1ab* gene, yielded negative results for all samples tested.

In poultry, serological testing by hemagglutination inhibition assay revealed the presence of anti-H9N2 antibodies in the two birds from which blood samples were taken, reflecting prior circulation of a low-pathogenicity avian influenza virus in the local poultry population. Sampling of the warthog, initially planned as part of the broader animal investigation, could not be carried out.

Discussion

This field investigation, conducted using a One Health approach, made it possible to document, in a resource-limited rural Sahelian setting, an outbreak of ILI associated with confirmed circulation of influenza A(H1N1)pdm09 virus in humans, in an environment marked by close cohabitation with wildlife and domestic

poultry. The age distribution observed, with a marked predominance among children under 10 years of age, is consistent with data available since the 2009 pandemic, which had already highlighted disproportionate involvement of children and young adults compared with the elderly, in contrast to the usual profile of seasonal influenza.¹⁹ In our case-control study, age under 15 years was precisely one of the two factors significantly associated with the occurrence of ILI, which could be explained by lower pre-existing immunity among younger individuals and by behaviors that promote exposure (crowding, close contact, limited hand hygiene).

The second significantly associated factor, contact with a sick case, argues in favor of active human-to-human transmission within the Amtiab villages, *via* respiratory droplets or contact with contaminated surfaces, consistent with the mode of transmission classically described for influenza viruses.⁶ The concentration of 77.6% of cases in the three contiguous Amtiab villages, linked by

Table 1. Distribution of ILI cases by socio-demographic characteristics and clinical signs (Abéché Health District, Chad, May-June 2021).

Variable	n	%
Sex (n=210)		
Female	99	47.1
Male	111	52.9
Age, years (n=210)		
0-5	75	35.7
6-10	45	21.4
11-20	26	12.4
21-30	16	7.6
31-40	23	11.0
41-50	7	3.3
51-60	5	2.4
>60	13	6.2
Signs and symptoms		
Cough	22	95.7
Headache	20	87.0
Fever	18	78.3
Anorexia	14	60.9
Physical asthenia	14	60.9
Altered general condition	13	56.5
Dyspnea	5	21.7
Myalgia	5	21.7
Chest pain	4	17.4
Vomiting	3	13.0
Epistaxis	3	13.0

Table 2. Factors associated with the occurrence of ILI: results of the case-control study (58 cases, 58 controls; Amtiab villages, Abéché Health District, Chad, 2021).

Variable (exposure)	OR	95% CI	p
Age under 15 years	4.49	1.61-12.55	0.003
Sex (male vs female)	1.33	0.60-2.92	0.482
Contact with a sick case	4.39	1.89-10.21	0.001
Consumption of water frequented by warthogs	0.73	0.29-1.80	0.488
Poultry mortality near the home	3.24	0.96-11.00	0.050
Keeping poultry at home	0.76	0.27-2.12	0.603
Presence of migratory birds near the home	0.65	0.27-1.57	0.339
Bathing in ponds frequented by warthogs	1.36	0.56-3.30	0.499
Handling dead poultry	2.67	0.49-14.45	0.240

OR, odds ratio; CI, confidence interval. Bold values indicate a statistically significant association ($p<0.05$).

frequent social and economic exchange, is consistent with community-level local spread rather than a one-off, diffuse exposure to a common environmental source.

The hypothesis of indirect transmission from warthogs *via* shared water points was not confirmed by our analytical study: neither consumption of water frequented by these animals nor bathing in the same ponds showed a significant association with the occurrence of ILI. This finding does not, however, entirely rule out a role for warthogs in the local viral ecology, since the planned sampling of these animals could not be carried out; it calls for caution in interpretation and highlights the value of complementing this investigation with virological data from local wildlife.

The unusual avian mortality preceding the appearance of human cases by about a week, together with the detection of anti-H9N2 antibodies in poultry, is a signal that warrants cautious interpretation. The H9N2 avian virus is widespread and of low pathogenicity in birds in several regions of Africa, where its circulation in backyard poultry is regularly documented.^{20–23} H9N2 seropositivity in local poultry does not, in itself, establish a causal link with the human cases of ILI in this district, particularly since the human virological analyses confirmed the circulation of the A(H1N1)pdm09 virus and not an avian virus. It nonetheless illustrates the possible co-circulation of several distinct influenza viruses within the same human-animal ecosystem, justifying joint and sustained surveillance of the avian-human interface in this region, as recommended by integrated influenza surveillance approaches in Africa.^{16,17,23}

The clinical picture of probable encephalitis that led to the death of a 13-year-old girl serves as a reminder that, although A(H1N1)pdm09 influenza was generally associated with mild clinical forms comparable to seasonal influenza during the 2009 pandemic, severe complications – including neurological involvement – have been reported in certain subgroups, particularly children.¹⁹ This case underscores the importance of vigilant clinical management of ILI in an epidemic context, even in areas where access to specialized care is limited.

The environmental determinants identified – absence of drinking water points, open defecation, limited awareness of basic hygiene practices – do not directly explain the transmission of a respiratory virus such as A(H1N1)pdm09 influenza, but reflect precarious living conditions that, more broadly, favor the emergence and circulation of multiple pathogens in this area, whether waterborne, vector-borne, or respiratory. These findings echo observations made in other Sahelian and, more broadly, sub-Saharan contexts, where fragile health infrastructure and close human-animal proximity are identified as structural factors in the emergence of infectious diseases.^{10,11}

Study limitations

This investigation has several limitations that should be noted. First, the case definition used in the case-control study was based on syndromic clinical criteria (cough, headache, fever) rather than individual virological confirmation; the risk factors identified should therefore be interpreted as associated with the occurrence of ILI in the Amtiab villages, and not specifically with A(H1N1)pdm09 infection, exposing the study to outcome classification bias. Second, the number of human samples that underwent RT-qPCR confirmation remained limited relative to the total number of cases recorded, which restricts the generalizability of the virological diagnosis to the outbreak as a whole. Third, the planned warthog sampling could not be carried out, which limits the assessment of the hypothesis of indirect transmission from wildlife.

Finally, certain associations close to the statistical significance threshold (poultry mortality near the home, handling of dead poultry) may reflect a lack of statistical power related to sample size rather than a true absence of association, and would warrant re-examination in larger studies.

Conclusions

This One Health investigation of an influenza A(H1N1)pdm09 outbreak in the Abéché Health District illustrates the value of a multidisciplinary approach combining human medicine, veterinary medicine, and environmental health for the rapid detection and characterization of epidemic events in a rural Sahelian setting. Young age and close contact with a sick case emerge as the main determinants of human-to-human transmission identified in this context, while the role of wildlife and domestic poultry in the origin of the outbreak remains incompletely elucidated and justifies continuing the virological investigations under way. These findings call for strengthened integrated surveillance of influenza and other respiratory pathogens at the human-animal interface in sub-Saharan Africa, as well as sustained investment in local diagnostic capacity, in order to reduce the underreporting of emerging infectious diseases and better protect the most exposed rural populations.

References

1. Morse SS. Factors in the emergence of infectious diseases. *Emerg Infect Dis* 1995;1:7-15.
2. Taylor LH, Latham SM, Woolhouse MEJ. Risk factors for human disease emergence. *Philos Trans R Soc Lond B Biol Sci* 2001;356:983-9.
3. Jones KE, Patel NG, Levy MA, et al. Global trends in emerging infectious diseases. *Nature* 2008;451:990-3.
4. Woolhouse MEJ, Gowtage-Sequeria S. Host range and emerging and reemerging pathogens. *Emerg Infect Dis* 2005;11:1842-7.
5. Wolfe ND, Dunavan CP, Diamond J. Origins of major human infectious diseases. *Nature* 2007;447:279-83.
6. Taubenberger JK, Morens DM. 1918 Influenza: the mother of all pandemics. *Emerg Infect Dis* 2006;12:15-22.
7. Smith GJD, Vijaykrishna D, Bahl J, et al. Origins and evolutionary genomics of the 2009 swine-origin H1N1 influenza A epidemic. *Nature* 2009;459:1122-5.
8. Garten RJ, Davis CT, Russell CA, et al. Antigenic and genetic characteristics of swine-origin 2009 A(H1N1) influenza viruses circulating in humans. *Science* 2009;325:197-201.
9. Trifonov V, Khiabani H, Rabadan R. Geographic dependence, surveillance, and origins of the 2009 influenza A (H1N1) virus. *N Engl J Med* 2009;361:115-9.
10. World Health Organization. *International Health Regulations* (2005). 3rd ed. WHO; 2016.
11. Achonduh-Atijegbe OA, Mfuh KO, Mbange OS, et al. Prevalence of malaria, typhoid, toxoplasmosis and rubella among febrile children in Cameroon. *BMC Infect Dis* 2016;16:658.
12. Ali IM, Tchuente VPK, Colton M, et al. Arboviruses as an unappreciated cause of non-malarial acute febrile illness in the Dschang Health District of western Cameroon. *PLoS Negl Trop Dis* 2022;16:e0010790.

13. Bangoura ST, Keita AK, Diaby M, et al. Arbovirus Epidemics as Global Health Imperative, Africa, 2023. *Emerg Infect Dis* 2025;31:1-8.
14. Ortiz JR, Sotomayor V, Uez OC, et al. Strategy to enhance influenza surveillance worldwide. *Emerg Infect Dis* 2009;15:1271-8.
15. Tarnagda Z, Yougbaré I, Ilboudo AK, et al. Sentinel surveillance of influenza in Burkina Faso: identification of circulating strains during 2010-2012. *Influenza Other Respir Viruses* 2014;8:524-9.
16. El Sayes M, Kandeil A, Moatasim Y, et al. Insights into Genetic Characteristics and Virological Features of Endemic Avian Influenza A (H9N2) Viruses in Egypt from 2017-2021. *Viruses* 2022;14:1484.
17. Ahmed NI, Abdullahi YB, Bashir SG, et al. Epidemiological surveillance of emerging infectious diseases in sub-Saharan Africa and priorities for strengthening. *Discov Public Health* 2026;23.
18. World Organisation for Animal Health (WOAH). Manual of diagnostic tests and vaccines for terrestrial animals. 6th ed. WOAH; 2021. Chapter 3.3.4, Avian influenza (including infection with high pathogenicity avian influenza viruses).
19. Writing Committee of the WHO Consultation on Clinical Aspects of Pandemic (H1N1) 2009 Influenza. Clinical aspects of pandemic 2009 influenza A (H1N1) virus infection. *N Engl J Med* 2010;362:1708-19.
20. El-Sayed MM, Arafa AS, Abdelmagid M, Youssef AI. Epidemiological surveillance of H9N2 avian influenza virus infection among chickens in farms and backyards in Egypt 2015-2016. *Vet World* 2021;14:949-55.
21. Kotey EN, Asante IA, Adusei-Poku M, et al. Phylogenetic and genetic characterization of influenza A H9N2 viruses isolated from backyard poultry in selected farms in Ghana. *Vet Med Sci* 2022;8:1570-7.
22. Abdelwhab EM, Hassan MK, Abdel-Moneim AS, et al. Introduction and enzootic of A/H5N1 in Egypt: virus evolution, epidemiology, vaccination, control efforts, and emergence of A/H5N8. *Infect Genet Evol* 2016;40:80-90.
23. Jallow MM, Diagne MM, Ndione MHD, et al. Genetic and Molecular Characterization of Avian Influenza A(H9N2) Viruses from Live Bird Markets (LBM) in Senegal. *Viruses* 2025;17:73.

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Conflict of interest: the authors declare that they have no conflict of interest related to this work.

Ethics approval and consent to participate: this investigation was conducted under the legal mandate for epidemiological surveillance of Chad's Ministry of Public Health and Prevention, in response to a public health alert. It received authorization from the Provincial Health Delegation of Ouaddaï and the Abéché Health District, Chad. Informed oral consent was obtained from each participant (or their legal representative for minors) prior to administration of the questionnaire and biological sampling, in accordance with national outbreak response procedures. Data were anonymized prior to analysis. Field photographs illustrating sampling procedures in poultry and in humans were taken with the explicit written consent of the identifiable individuals shown, for use in scientific publication; the signed consent forms are kept by the authors and can be made available to the editorial team upon request.

Availability of data and materials: all relevant data underlying the results presented in this article are available in the manuscript. Anonymized individual data from the case-control study can be made available by the authors upon reasonable request, subject to the agreement of the Provincial Health Delegation of Ouaddaï, Chad.

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