HHS Public Access

Author manuscript

J Infect Dis. Author manuscript; available in PMC 2019 May 09.

Published in final edited form as:

J Infect Dis. 2018 July 24; 218(5): 757–767. doi:10.1093/infdis/jiy204.

Household Transmission of Ebola Virus: Risks and Preventive Factors, Freetown, Sierra Leone, 2015

Mary R. Reichler[1], **James Bangura**[2], **Dana Bruden**[3], **Charles Keimbe**[2], **Nadia Duffy**[4], **Harold Thomas**[2], **Barbara Knust**[5], **Ishmail Farmar**[2], **Erin Nichols**[6], **Amara Jambai**[2], **Oliver Morgan**[7], **Thomas Hennessy**[3], and **the Household Transmission Investigative Team**

[1]Division of Tuberculosis Elimination, National Center for HIV/AIDS, STD, and TB Prevention, Centers for Disease Control and Prevention, Atlanta, Georgia [2]Directorate of Disease Prevention and Control, Ministry of Health and Sanitation, Freetown, Sierra Leone [3]Division of Preparedness and Emerging Infections, National Center for Emerging and Zoonotic Diseases, Centers for Disease Control and Prevention, Anchorage, Alaska [4]Division of Healthcare Quality Promotion, National Center for Emerging and Zoonotic Diseases, Centers for Disease Control and Prevention, Atlanta, Georgia [5]Division of High-Consequence Pathogens and Pathology, National Center for Emerging and Zoonotic Diseases, Centers for Disease Control and Prevention, Atlanta, Georgia [6]National Center for Health Statistics, Centers for Disease Control and Prevention, Hyattsville, Maryland [7]Health Emergencies Program, World Health Organization, Geneva, Switzerland

Abstract

Background.—Knowing risk factors for household transmission of Ebola virus is important to guide preventive measures during Ebola outbreaks.

Methods.—We enrolled all confirmed persons with Ebola who were the first case in a household, December 2014-April 2015, in Freetown, Sierra Leone, and their household contacts. Cases and contacts were interviewed, contacts followed prospectively through the 21-day incubation period, and secondary cases confirmed by laboratory testing.

Results.—We enrolled 150 index Ebola cases and 838 contacts; 83 (9.9%) contacts developed Ebola during 21-day follow-up. In multivariable analysis, risk factors for transmission included index case death in the household, Ebola symptoms but no reported fever, age <20 years, more

Correspondence: M. R. Reichler, MD, Division of Tuberculosis Elimination, Centers for Disease Control and Prevention, 1600 Clifton Road, MS E-10, Atlanta, Georgia 30333 (mrr3@cdc.gov).

Household Transmission (HHT) Investigative Team. HHT supervisors: Francis Davies, Mohamed Sima Dumbuya, Hannah Kamara, Mohamed Yayah Kallon, Joseph Kpukumu; HHT District Surveillance Officers: Sheku Abu, Fatmata Bangura, Saidu Rahim Bangura, Tomeh Bangura, Hassan Benya, Sandi Blango, Imurana Conteh, Peter Conteh, Bintu Jabbie, Sheku Jabbie, Luseni Kamara, Francis Lansana, Maada Rogers, Sahr Brima Sewa, Matthew Yamba; Holding Center District Surveillance Officers; US Centers for Disease Control and Prevention: P. Bessler, S. Campbell, W Chung, E. Ervin, S. Hersey.

Disclaimer. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Potential conflicts of interest. All authors report no potential conflicts of interest. All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

days with wet symptoms; and providing care to the index case ($P < .01$ for each). Protective factors included avoiding the index case after illness onset and a piped household drinking water source ($P < .01$ for each).

Conclusions.—To reduce Ebola transmission, communities should rapidly identify and follow-up all household contacts; isolate those with Ebola symptoms, including those without reported fever; and consider closer monitoring of contacts who provided care to cases. Households could consider efforts to minimize risk by designating one care provider for ill persons with all others avoiding the suspected case.

Keywords

Ebola; Ebola virus; transmission; household contact; epidemiology; risk factors; preventive factors; Sierra Leone

The 2014–2016 Ebola outbreak in West Africa was unprecedented in size and duration, lasting over 2 years and resulting in 28 646 cases in Guinea, Sierra Leone, and Liberia [1]. Widespread transmission within the cities of Freetown and Monrovia was an extraordinary feature of this outbreak.

Ebola virus disease (EVD) epidemic control relies on interrupting person-to-person transmission through rapid isolation and diagnosis of patients in Ebola treatment facilities, using special precautions to manage corpses [2], and use of personal protective equipment by health care workers, burial, and environmental decontamination teams [3]. However, previous outbreaks show that many secondary cases were household members of confirmed cases [4–7]. Despite this, we have limited understanding about risk or protective factors for disease transmission to household contacts. Evidence-based guidance for households could reduce secondary cases when used along with existing recommendations for occupationally exposed persons.

From this prospective investigation of households with a first case of EVD in Freetown, Sierra Leone, we present the rates and risk factors associated with transmission to household contacts.

METHODS

We enrolled all EVD cases in greater Freetown and surrounding rural areas in Western District who were the first reported case in their household and their household contacts from 15 December 2014 through 30 April 2015. We identified confirmed EVD cases or deaths through routine EVD surveillance conducted by District Surveillance Officers, who investigated potential cases within 24 hours after notification and moved suspect cases to an isolation facility. If a death was reported, the body was removed from the house. Cases and deaths were laboratory confirmed by polymerase chain reaction detecting Ebola virus (EBOV) RNA. Sierra Leone authorities quarantined all household members for 21 days after last exposure to a confirmed case.

We defined household contacts as persons who spent at least night sharing the same residential unit/indoor living space as the index case after onset of symptoms.

Project staff interviewed all household contacts and the index case (or head of household as proxy) about the period from symptom onset to removal of the index case. Households of index cases confirmed before 1 February 2015 were enrolled in early February and those confirmed after 1 February were enrolled upon identification of a suspect case.

Wet symptoms were defined as vomiting, diarrhea, or bleeding. All symptoms were self-reported, including fever, and thermometers for measuring temperature were not commonly available in the community.

Study assistants visited households throughout the 21-day follow-up period (or directly following enrollment for retrospectively enrolled cases) to determine whether enrolled contacts developed EVD symptoms or died. For contacts who developed symptoms, we queried the national laboratory database for confirmation of EVD status, matching on name, age, gender, address, and EBV onset date; those with positive laboratory results were considered confirmed secondary cases, those with no laboratory results were probable secondary cases, and those with negative laboratory results were excluded because EVD status could not be determined with certainty.

All study activities were coordinated closely with the EVD program but were performed independent of program activities. Data completeness for all key variables was >99%. This investigation was determined to be a public health response activity by the Sierra Leone Ministry of Health and United States Centers for Disease Control and Prevention Ethical Review Boards.

We defined the individual secondary attack rate (SAR) as the number of confirmed or probable secondary cases of EVD among contacts occurring within 21 days after index case isolation divided by the total number of contacts. We defined household transmission rate (HTR) as the number of households with ≥ 1 secondary case of EVD among contacts divided by the total number of households.

We used logistic regression to examine index case, household, and individual contact factors associated with secondary transmission. For univariate analyses of case and household factors, we calculated both HTR and individual SAR to examine transmission risk. For univariate analyses of contact factors, we used individual SAR as the outcome. We used a logistic regression model for HTR and generalized estimating equations to account for household clustering for individual SAR analyses.

We developed multivariable models using an analyst-driven forward selection. We used the Akaike information criterion and Wald χ^2 to determine the most parsimonious model and the Quasi-likelihood information criterion and z statistic in the general estimating equation (empirical standard errors). We considered variables for the multivariable models if their univariate *P* value was < .25. We developed multivariable models that looked first at HTR for case factors and second at HTR for case and household factors together. We then developed an integrated multivariable model including individual SAR for case, household, and contact factors. We assessed colinearity by examining the variance inflation factor and calculating pairwise Kappa statistics. We kept variables if they had a 2-sided statistical significance level ≤0.05. We ran sensitivity analyses removing probable secondary cases;

results were similar and are not reported. No statistically significant interaction terms were identified. We performed all analyses using SAS software [8].

RESULTS

One-hundred and fifty households were enrolled. The date the index case was isolated from the household ranged from 15 December 2014 to 19 April 19 2015; 104 (69%) index cases were enrolled prospectively. Among cases, 129 (86%) were alive and 21 (14%) dead at the time of removal; 122 (81%) index cases were interviewed by proxy. The Freetown epidemic peaked from 20 October to 30 November 2014 with over 200 confirmed cases per week (Figure 1). The epidemic waned during this investigation; confirmed EVD cases declined from approximately 25 per week to fewer than 5 per week during the study period.

The 150 index cases ranged from 2 months to 90 years old; 54% were between 20 and 40 years old (Table 1). Clinical sign and symptom frequencies ranged from 1% for bruising to 81% for weakness or fatigue. Although fever was the second most frequent symptom, only 75% of index cases reported fever. All index cases without reported fever had other EVD symptoms (median, 4 symptoms), including 46% with wet symptoms. A majority of index cases resided in urban areas (71%) and in apartments (60%); few had flush toilets (13%).

A secondary case of EVD occurred in 40 (27%) of 147 households with contacts. Among these, 17 (42%) had more than 1 secondary case; 2 households had 2 cases, 7 had 3 cases, 5 had 4 cases, and 3 had 5 cases.

We enrolled 845 household contacts; 7 contacts with EVD symptoms but negative laboratory results were excluded. Of the remaining 838, 83 (9.9%) developed EVD (74 confirmed and 9 probable cases) within 21 days of index case isolation. The median number of contacts per index case was 5. Very few contacts (0.7%) reported touching the body of an index case after their death and only 3% reported known medical conditions.

The HTR was higher when the index case died in the house, had EVD symptoms but no reported fever, was <20 years old, had jaundice, or spent more days in the house with wet symptoms; the last association was of borderline statistical significance (Table 2). The individual SAR was higher when the index case died in the house, did not have headache, and did not have reported fever; the last association was of borderline statistical significance. Among the index case factors, patients that had no reported fever and death in the household were associated with the largest proportions of secondary cases (34 [41%] and 28 [34%] of 83, respectively). Index cases with no reported fever were more likely to die in the house than those with fever (27% vs 9%, $P < .01$), and among index cases who died in the house, there was a significantly higher attack rate among contacts for those with no reported fever versus for those with fever (37% vs 12%, $P = .02$).

During the 5-month enrollment, there was no difference in HTR or individual SARs by month of index case symptom onset (Table 2). The average interval from index case symptom onset to removal from the household had a decreasing trend from 4 days to 3.5 days over the enrollment period ($P = .07$; data not shown).

The HTR and individual SARs were lower for houses with a piped drinking water source. The individual SAR was decreased for contacts in households where there were 6 or more persons.

Individual SARs based on household contact characteristics are given in Table 3. Higher SARs were seen among contacts who provided care to the index case, had physical contact with the case or case's body fluids, had contact with the case's clothing or bed linens, slept in the same room with the case, or were a case's first-degree relatives. Higher SARs were also seen among contacts who shared a blanket or bed, meals, or a toilet with the case but these associations were of borderline significance. SARs were lower for contacts who reported having reduced contact with the case after illness onset by staying at least 1 meter away, stopping eating meals together, or avoiding touching the case. Among persons who provided care to the case, use of improvised barrier protection was not common (14%).

In a multivariable model, index case factors independently associated with increased household transmission included being less than 20 years old, no reported fever, more days in the house with wet symptoms, and death in the house (Table 4). In a multivariable model of index case and household factors, the same index case factors were independent risk factors for house-hold transmission, and having a piped drinking water source was protective. In the model integrating index case, household, and contact factors, independent risk factors for transmission included providing care to the index case, index case death in the house, no reported index case fever, and being a first-degree relative of the case; behaviors adopted by the contact to avoid the index case and piped drinking water were protective.

DISCUSSION

We conducted a prospective evaluation of risk factors for household transmission during the 2014–2016 Ebola outbreak in West Africa. When taking index case, household, and contact factors into account, independent risk factors for increased transmission included providing care to the index case, being a first-degree relative of the case, death of the index case in the house, and EVD symptoms but no reported fever in the case. Behaviors adopted to avoid contact with the index case and a piped drinking water source for the household were associated with lower transmission rates.

Within the 21-day follow-up period, 27% of households had a secondary EVD case and 9.9% of all contacts developed EVD. Individual SARs for household contacts in outbreaks have varied widely between reports [4–7, 9–16]. The lowest individual SARs reported (2.5% [Uganda 2000], 3.0% [Liberia 2017], and 5.6% [Zaire 1975]) all included nonhousehold contacts [7, 11, 14]. Thus, these reports likely underestimated the individual SAR associated with household transmission. The highest individual SARs reported were for outbreaks in Zaire in 1995 (16%), Sudan in 1979 (22%), Sierra Leone in 2018 (18%), and Uganda in 2000 (26% and 27%). However, all were retrospective studies, 4 included multiple transmission chains [4, 5, 10, 15], 2 included exposures to the index case after hospitalization [4, 5], 2 included nonhousehold community [9, 10], and all identified secondary cases based on symptoms without laboratory confirmation. Thus, these SARs

likely overestimated the individual risk associated with household transmission. A further report from this Sierra Leone epidemic calculated an SAR of 5.9% by retrospectively linking cases using names and addresses on report forms [16]. In our experience, these were frequently missing or inaccurate and likely would systematically undercount household relationships and lower the SAR. These differing methodologies preclude making a direct comparison with our study findings, which are based predominantly on prospective data collection, laboratory confirmation of EVD, enrollment restricted to index cases who were the first case in a household, and a strict definition for household contacts.

Death of the index case in the household was a strong risk factor for transmission in our study, with a 3.5-fold increase in EVD risk. Most EVD cases die at peak viremia [17, 18] and most deaths occur after 5–7 days of illness [18]. Thus, exposure to cases with high viral loads and for a longer time may explain the high risk associated with death in the household. Unsafe corpse preparation for burial is known to have contributed to EBOV transmission in West Africa [19, 20], but was not a source of exposure in our study, because all enrolled EVD cases were removed from the house by health authorities for safe and dignified burial. All contacts were quarantined and unable to participate in corpse preparation for burial. Dying in the house was associated with secondary infection in rural Liberia and Guinea, and it was postulated that traditional practices of touching the body after death may have contributed to transmission [21]. Very few contacts in our study reported touching a deceased patient and none helped to prepare the corpse for burial; thus, in our primarily urban setting in Sierra Leone this factor appears unlikely to have played a major role in transmission.

In our study, EVD symptoms but no reported fever in the index case was a risk factor for transmission; 41% of secondary cases were associated with a case with no reported fever. Fever is part of the EVD surveillance case definition [22] and was emphasized as a key symptom in public communications during the epidemic. The practices of setting roadblocks to check travelers for fever and fever screenings at public building entrances are likely to have focused public attention on fever. However, fever is difficult to reliably measure without an accurate thermometer, and some people may not realize that they have a fever. Additionally,we assessed the symptoms of most index patients through proxy interviews, which may have contributed to incomplete assessment of fever. Therefore, we think that no reported fever in 25% of index cases may be a combination of cases who truly did not have fever, did not realize they had fever, or did not complain of fever to other household members. The absence of recognized fever may have delayed EVD recognition by household members,resulting in contacts taking fewer precautions and leading to more exposure and higher rates of transmission. We recommend that during future outbreaks, public messages should emphasize heightened vigilance for illness, and household members with any EVD symptoms should be separated and referred for evaluation early, even in the absence of reported fever.

Index cases without reported fever were also more likely to die in the household, and viral loads are known to be highest near the time of death [17, 18]; thus, increased transmission rates are plausible. However, in multivariable analysis, index case death in the household and no reported fever were independent risk factors for transmission. Further, among all

deaths in the household, transmission rates were significantly higher for index cases with no reported fever. Thus, the increased risk of death in the household and likelihood of higher associated viral loads does not completely explain the higher attack rate among contacts of index cases with no reported fever that we observed. Further studies are needed to evaluate potential mechanisms for higher transmission rates to contacts from EVD patients without reported fever.

The length of time an index case was in the house with wet symptoms was another transmission risk factor. Cases are most infectious when wet symptoms are present [4, 13]. Such patients likely require more care and increase household environmental contamination with virus-containing body fluids; thus, increasing the transmission risk to care providers and other household members. Therefore, persons with EVD symptoms should be isolated early and community messages should promote steps within households to separate ill persons and avoid contact with their body fluids.

Twenty-four percent of household care providers developed EVD, more than 3 times the rate among contacts not providing care. Despite the risk, few care providers reported using any form of barrier protection such as gloves or plastic bags over the hands. This is noteworthy because enrollment started 6 months after the outbreak began, when there was heightened awareness about Ebola from educational campaigns that emphasized avoiding direct contact with EVD cases. Further, providing nursing care to EVD cases early in the illness [9], during the hospital phase [5], and near death [9, 13] have all been associated with increased transmission risk. Further evaluation of communication strategies to reduce exposure among care providers is needed. Limiting the number of care providers in a household to minimize the number of persons exposed is worth consideration, as was recommended in Sierra Leone late in the outbreak [23].

Because few care providers used any form of improvised protection, we cannot draw conclusions about the utility of specific protective barriers for this high-risk group. However, we did identify avoidance behaviors that were associated with decreased transmission risk. Household members were at decreased risk for EVD if they stayed at least 1 meter away, avoided eating with or touching, or stopped sleeping with or near an ill index case. This establishes the protective benefit of a set of behaviors that can be adopted by household contacts. Several of these behaviors were recommended through the “Stay Safe While You Wait” intervention [23]. This evidence for protective benefit has implications for education messaging and could be an important tool for future outbreaks.

Two exposures linked with transmission in previous out-breaks, physical contact with the index case and contact with body fluids [4, 5, 9, 12, 13], were associated with increased risk in our study. Risk of household spread could be reduced by placing a suspected case in a separate room or part of a room, having them sleep on a separate bed or mat, and advising household members to avoid physical contact with the persons, their body fluids, bed linens, or clothes until EVD is excluded.

EBOV transmission was also more likely in households with younger index cases. It is suspected that this observation may be due to children requiring more care, having more

interactions at home with other people, and being more active compared to older individuals, thus exposing more household members. The small number of index cases who were children and the strength of the association between being a care provider and risk of EBV limited our ability to confirm these hypotheses.

Piped water as the source of drinking water was the only household factor independently associated with decreased transmission risk. Because Ebola is not a water-borne disease, this finding is not related to water quality. In Freetown, having piped water generally meant having access to a community tap and rarely meant having pipes leading to the home. We think having piped water could mean increased access to water that is closer, more consistent, or available in greater volume, resulting in more water for hygiene purposes that could reduce transmission risk. Unfortunately, data were not obtained on distance to water source, consistency of access to water, source of washing water, or household socioeconomic status. Our study was done in the dry season when some water sources are known to run dry, highlighting the importance of consistent access to sufficient quantities of water. Water is rationed in Freetown, with few households receiving a 24-hour supply; residents of periurban and densely populated poor areas only receive water supplies once a month or not at all [24]. Further studies are needed to explore the piped drinking water association.

Our findings have implications for public health strategies to control future Ebola outbreaks. In settings where a 2-tiered system of risk stratification is feasible and prioritization is needed, index case death in the household, wet symptoms for more than 3 days, and EVD symptoms but no reported fever should be considered to identify higher-risk households. Within households, contacts who provided care to the index case, had contact with body fluids, or had physical contact with the case, and those who slept in the same room, touched or washed bed linens, or washed or wore clothes belonging to the case should be considered high risk. Consideration should be given to more intensive monitoring of high-risk contacts to promote rapid diagnosis of secondary cases and to minimize further transmission within the household.

We could not assess corpse preparation for burial as a risk because this study was done after these practices had largely been eliminated. Further, compared to earlier in the outbreak, suspect cases were isolated from the household more promptly and extensive community education efforts were underway. These factors could have altered the risk factors for transmission but strengthened our study by reducing the likelihood of exposures outside the household. In households with more than 1 contact with EVD, we could not be certain that each secondary EVD case was the result of transmission from the index case. Another study limitation was potential information bias due to proxy interviews of many index cases and no direct observation of behaviors or clinical illness.

Our study established the EBOV transmission rate from new EVD cases to household contacts in Freetown, Sierra Leone and identified modifiable risk and protective factors for transmission. These findings could be used to develop more effective practices to reduce household secondary transmission. These could include optimizing community educational messaging about risk factors and protective measures, increasing suspicion of EVD based on

the presence of symptoms with or without fever, and developing approaches to prioritize identifying and managing high-risk contacts.

Acknowledgments.

Household Transmission Project assistants: Mustapha Biro, Mohamed Dumbuya, Lucinda Johnson, Solomon Kargbo, Sylvester Tamba Kanessie, Ibrahim Sulaiman Kamara, Elizabeth Kanawa, Abdul Karim Koroma, Bushrah Lewally, Issa Mansaray, Yusuf Mansaray, Shangbe Momoh, Mariatu Ndhamina, Kai Sesay, Ibrahim Sawaneh; Western Area DERC: Andrea Kamara, Joann; Sierra Leone MOH: Dr Dafae; Helen Keller: Mohamed Turay; US Centers for Disease Control and Prevention: P. Bimba, J. Van den Eng, M. Foster, M. Fox, M. Glover, D. Jernigan, M. Marx, A. Mounts, J. Redd, J Sabatier, R. Swain, Faith Washburn, D. Williams.

Financial support. This work was supported by the Centers for Disease Control and Prevention and by the CDC Foundation.

References

1. World Health Organization (WHO). Situation report. Ebola virus disease 10 June 2016. http:/apps.who.int/iris/bitstream/10665/208883/1/ebolasitrep10Jun2016eng.pdf. Accessed 7 April 2018.
2. Kuhn JH. Filoviruses: a compendium of 40 years of epidemiological, clinical, and laboratory studies. New York: Springer, 2008.
3. World Health Organization (WHO). Personal protective equipment for use in a filovirus disease outbreak, rapid advice guideline. Geneva: WHO, 2016.
4. Dowell SF, Mukunu R, Ksiazek TG, Khan AS, Rollin PE, Peters CJ. Transmission of Ebola hemorrhagic fever: a study of risk factors in family members, Kikwit, Democratic Republic of the Congo, 1995. J Infect Dis 1999; 179:S87–91. [PubMed: 9988169]
5. Baron RC, McCormick JB, Zubeir OA. Ebola virus disease in southern Sudan: hospital dissemination and intrafamilial spread. Bull World Health Organ 1983; 61:997–1003. [PubMed: 6370486]
6. Francis D, Smith D, Highton R. Ebola fever in the Sudan, 1976: epidemiological aspects of the disease In: Pattyn S, ed. Ebola virus haemorrhagic fever. Amsterdam: Elsevier/ North Holland Biomedical Press, 1978:129–35.
7. Breman JG, Piot P, Johnson KM, et al. The epidemiology of Ebola haemorrhagic fever in Zaire, 1976 In: Pattyn S, ed. Ebola virus haemorrhagic fever. Amsterdam: Elsevier/ North Holland Biomedical Press, 1978:103–24.
8. SAS software, Cary, NC, version 9.3. https://www.sas.com. Accessed 7 April 2018.
9. Francesconi P, Yoti Z, Declich S, et al. Ebola hemorrhagic fever transmission and risk factors of contacts, Uganda. Emerg Infect Dis 2003; 9:1430–7. [PubMed: 14718087]
10. Borchert M, Mutyaba I, Van Kerkhove MD, et al. Ebola haemorrhagic fever outbreak in Masindi District, Uganda: outbreak description and lessons learned. BMC Infect Dis 2011; 11:357. [PubMed: 22204600]
11. Okware SI, Omaswa FG, Zaramba S, et al. An outbreak of Ebola in Uganda. Trop Med Int Health 2002; 7:1068–75. [PubMed: 12460399]
12. Dean NE, Halloran ME, Yang Y, Longini IM. Transmissibility and pathogenicity of Ebola virus: a systematic review and meta-analysis of household secondary attack rate and asymptomatic infection. Clin Infect Dis 2016; 62:1277–86. [PubMed: 26932131]
13. Brainard J, Hooper L, Pond K, Edmunds K, Hunter PR. Risk factors for transmission of Ebola or Marburg virus disease: a systematic review and meta-analysis. Int J Epidemiol 2016; 45:102–16. [PubMed: 26589246]
14. Skrip L, Fallah M, Gaffney S, et al. Characterizing risk of Ebola transmission based on frequency and type of case-contact exposures. Phil Trans R Soc 2018; 372: 20160301.
15. Glynn JR, Bower H, Johnson S, et al. Variability in intrahouse-hold transmission of Ebola virus, and estimation of the house-hold secondary attack rate. J Infect Dis 2018; 217:232–7. [PubMed: 29140442]

16. Fang LQ, Yang Y, Jiang JF, et al. Transmission dynamics of Ebola virus disease and intervention effectiveness in Sierra Leone. Proc Natl Acad Sci U S A 2016; 113:4488–93. [PubMed: 27035948]
17. Lanini S, Portella G, Vairo F, et al.; INMI-EMERGENCY EBOV Sierra Leone Study Group. Blood kinetics of Ebola virus in survivors and nonsurvivors. J Clin Invest 2015; 125:4692–8. [PubMed: 26551684]
18. Vetter P, Fischer WA 2nd, Schibler M, Jacobs M, Bausch DG, Kaiser L. Ebola virus shedding and transmission: review of current evidence. J Infect Dis 2016; 214:177–84.
19. International Ebola Response Team, et al. Exposure patterns driving Ebola transmission in West Africa: a retrospective observational study. PLoS Med 2016; 13:e1002170. [PubMed: 27846234]
20. Fairhead J The significance of death, funerals and the after-life in Ebola-hit Sierra Leone, Guinea and Liberia: anthropological insights into infection and social resistance. Sussex, UK: Institute of Development Studies, University of Sussex, 2014.
21. Lindblade KA, Nyenswah T, Keita S, et al. Secondary infections with Ebola virus in rural communities, Liberia and Guinea, 2014–2015. Emerg Infect Dis 2016; 22:1653–5. [PubMed: 27268508]
22. World Health Organization. Case definition recommendations for Ebola or Marburg virus diseases, 2014 http://www.who.int/csr/resources/publications/ebola/case-definition/en. Accessed 7 April 2018.
23. Sierra Leone Ministry of Health. Quarantine safety plan, rapid response plan. Sierra Leone: Sierra Leone Ministry of Health, 2016.
24. Ministry of Energy and Water Resources, Government of the Republic of Sierra Leone. National Water and Sanitation Policy, 7 2010 Sierra Leone: Sierra Leone Ministry of Health.

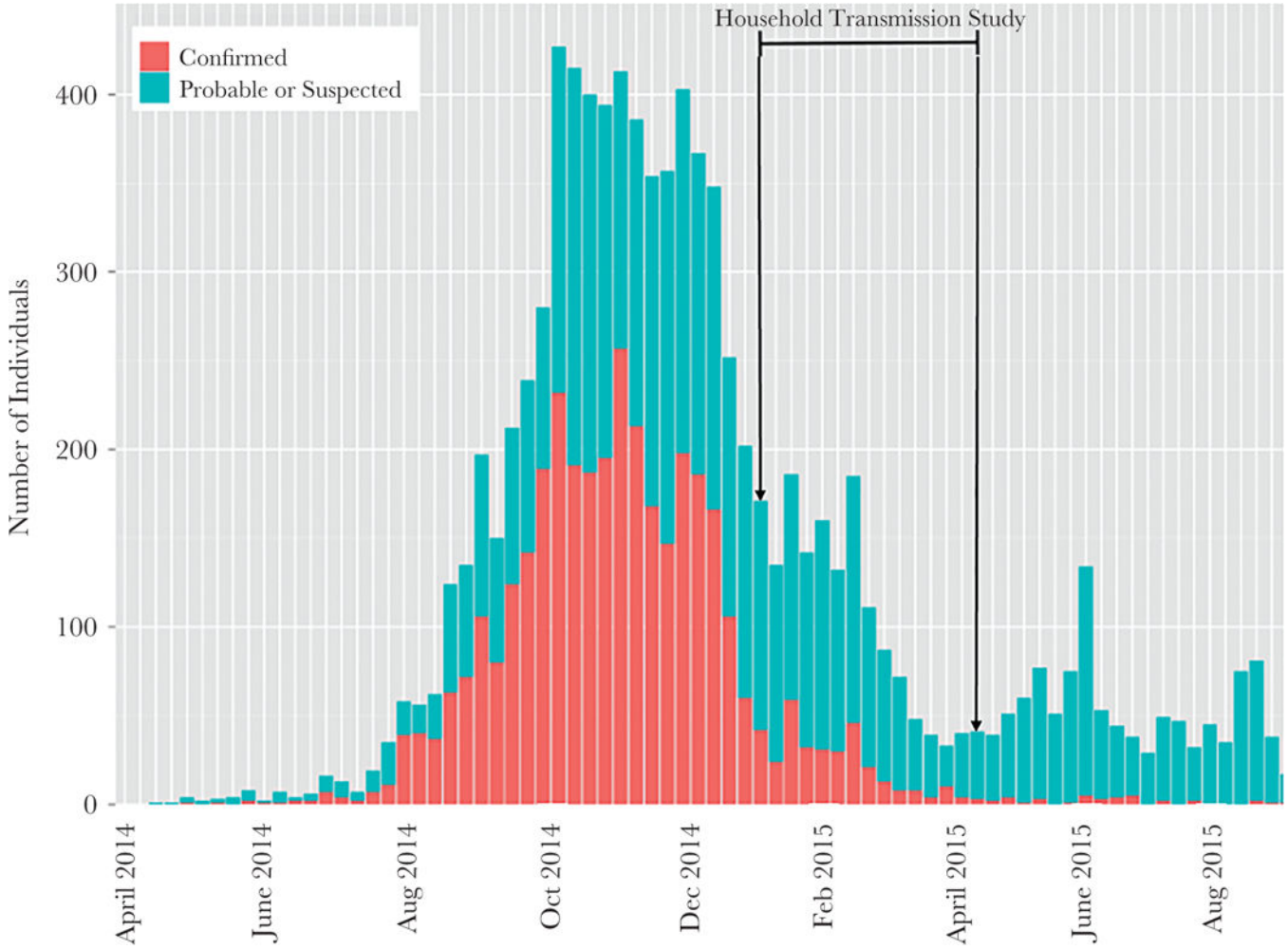

Figure 1.
Epidemic curve of study enrollment compared with Western District, Sierra Leone Ebola outbreak, 2014–2015.

Table 1.

Characteristics of the Study Population (150 Ebola Index Cases, 150 Households, 838 Household Contacts)

Variable	Level	N (%)
Index cases (n = 150)		
Age of index case	<5 years	5 (3)
	5–19 years	16 (11)
	20–39 years	81 (54)
	40–59 years	37 (25)
	≥ 60 years	11 (7)
Sex	Female	65 (43)
	Male	85 (57)
Religion	Christian	31 (21)
	Muslim	117 (78)
	None	1 (1)
	Unknown	1 (1)
Source of information	Case	28 (19)
	Proxy	122 (81)
Status of case when removed from house	Alive	129 (86)
	Dead	21 (14)
Days in household with symptoms	1–2	30 (20)
	3–4	72 (48)
	5–6	36 (24)
	≥ 7	12 (8)
First reported symptom	Fever	67 (45)
	Headache	25 (17)
	Muscle/joint pain	19 (13)
	Abdominal pain, vomiting	8 (5) each
	Chest pain	7 (5)
	Backache, weakness/fatigue	5 (3) each
	Diarrhea, sore throat	2 (1) each
	Bleeding	1 (1)
Individual symptoms	Weakness/fatigue	121 (81)
	Fever[a]	112 (75)
	Muscle or joint pain	107 (71)
	Headache	92 (61)
	Vomiting	76 (51)
	Abdominal pain	69 (46)
	Red eye	62 (41)
	Diarrhea	58 (39)
	Sore throat	42 (28)
	Chest pain	39 (26)

Variable		Level	N (%)
		Backache	30 (20)
		Bleeding	15 (10)
		Jaundice	11 (7)
		Neck rigidity	9 (6)
		Rash	6 (4)
		Bruising	2 (1)
Symptom group[b]		Wet and dry symptoms	88 (59)
		Dry only	62 (41)
Length of phases	Dry[c]	Phase 1 median (min, max)	3 (1, 9) (n = 109)
	Wet[c]	Phase 2 median (min, max)	2 (1, 12) (n = 88)
	Dead[c,d]	Phase 3 median (min, max)[d]	1 (1, 2) (n = 21)
Household information (n = 150)			
Location of household		Urban	107 (71)
		Rural	43 (29)
Dwelling type		Apartment	90 (60)
		Detached house	39 (26)
		Makeshift house	21 (14)
Household water source		Piped	77 (51)
		Other	73 (49)
Toilet facilities		Pit latrine	118 (79)
		Flush	19 (13)
		No facility	13 (9)
Case separated withinhousehold[e]		Yes	55 (37)[e]
		No	95 (63)
Household size[f]		Median (min, max)	5 (1, 21)
Household contacts (n = 838)			
Age category		<5	122 (15)
		5–19	308 (37)
		20–39	279 (33)
		40–59	101 (12)
		60+	28 (3)
Sex		Male	367 (44)
		Female	471 (56)
Relationship to index patient[g]		First-degree relative	419 (50)
		Other relative	225 (27)
		Nonrelative	194 (23)
Religion		Muslim	650 (78)
		Christian	185 (22)
		None	3 (0.4)

Variable	Level	N (%)
Reported medical condition[h]	Yes	27 (3)
	No	807 (96)
	Unknown	4 (0.5)

[a]All index cases with no reported fever had other Ebola virus disease symptoms.

[b]Wet symptoms included vomiting, diarrhea, and bleeding; there were no cases that had wet symptoms only.

[c]Dry phase is the number of days in the house with dry symptoms only, wet phase is the number of days in the house with wet symptoms, and dead phase refers to the number of days in the house after the index case was deceased.

[d]Where the case died in the house, 81% (17/21) of cases were removed on the same day that they died. This was counted in calculation of means and median as a phase 3 length of 1 day (but it actually was <24 hours).

[e]Among households where the index case was separated, 84% (n = 46) of index cases slept separately; 62% (n = 34) were moved to a separate room; 55% (n = 30) index cases slept on a separate mat; 44% (n = 24) index cases had separate eating utensils; 11% (n = 6) had their laundry handled separately, and 9% (n = 5) used a separate toilet.

[f]Household size is the number of contacts in the household, excluding the index case.

[g]First-degree relative includes spouse, parents, children, and siblings.

[h]The 27 reported medical conditions included cardiovascular disease (8), ulcer (6), sickle cell disease (2), asthma (2), HIV (2), diabetes mellitus (1), other (6).

Table 2.

Index Case and Household Risk Factors (n = 838 Individuals in 147 Households)

		Household Transmission Rate			Individual Secondary Attack Rate		
Risk Factor	**Level**	**% of Households ≥ 1 EVD Secondary Case (Households With EVD Cases/Total)**	**OR (95% CI)[a]**	***P* value**	**% of Household Contacts EVD Positive (Cases/Total)**	**OR (95% CI)[a]**	***P* value**
Index case risk factors							
Overall		**27.2 (40/147)**			**9.9 (83/838)**		
Sex (index case)	Female	30.8 (20/65)	1.38 (0.7–2.9)	.39	9.2 (37/403)	0.81 (0.4–1.7)	.58
	Male	24.4 (20/82)	Ref		10.6 (46/435)	ref	
Age category (index case)	<20 Years	55.0 (11/20)[b]	Ref	.003	13.0 (17/131)[b]	ref	.31
	20–39 Years	16.3 (13/80)	0.16 (0.1–0.5)		7.8 (30/385)	0.44 (0.2–1.2)	
	40–59 Years	29.7 (11/37)	0.35 (0.1–1.1)		9.7 (23/238)	0.67 (0.2–1.9)	
	60+ Years	50.0 (5/10)	0.82 (0.2–3.7)		15.5 (13/84)	1.12 (0.3–4.0)	
District	Urban	29.5 (31/105)	1.54 (0.7–3.6)	.32	11.5 (66/574)	1.50 (0.6–3.9)	.41
	Rural	21.4 (9/42)	Ref		6.4 (17/264)	ref	
Month (symptom onset of index case)	December	21.7 (5/23)	1.21 (0.8–1.8)	.36	6.6 (9/137)	1.29 (0.9–1.9)	.17
	January	25.0 (6/24)			7.8 (11/142)		
	February	27.4 (20/73)			11.6 (44/378)		
	March-April	33.3 (9/27)			10.5 (19/181)		
Status of case at time of removal	Dead	50.0 (10/20)	3.23 (1.2–8.5)	.017	22.4 (28/125)	4.05 (1.6–10.1)	.0027
	Alive	23.6 (30/127)	Ref		7.7 (55/713)	ref	
Days in household with symptoms	1–2	27.6 (8/29)	1.07 (0.9–1.3)[c]	.48[c]	9.3 (18/194)	1.05 (0.9–1.2)[b]	.59[b]
	3–4	26.8 (19/71)			10.3 (38/368)		
	5–6	25.7 (9/35)			8.3 (16/192)		
	≥ 7	33.3 (4/12)			13.1 (11/84)		
Wet symptoms	Yes	28.4 (25/88)	1.16 (0.6–2.5)	.69	10.8 (53/491)	1.09 (0.5–2.4)	.82
	No	25.4 (15/59)	Ref		8.6 (30/347)	ref	
Days in household with wet symptoms	0–1	24.7 (19/77)	1.17 (1.0–1.4)[c]	.08[c]	9.5 (43/451)	1.06 (0.9–1.2)[b]	.50[b]
	2–3	25.5 (13/51)			10.3 (28/272)		
	4+	42.1 (8/19)			10.4 (12/115)		

Risk Factor	Level	Household Transmission Rate			Individual Secondary Attack Rate		
		% of Households ≥ 1 EVD Secondary Case (Households With EVD Cases/Total)	OR (95% CI)[a]	*P* value	% of Household Contacts EVD Positive (Cases/Total)	OR (95% CI)[a]	*P* value
Weakness or fatigue	Yes	27.1 (32/118)	0.98 (0.4–2.4)	.96	9.7 (64/658)	0.69 (0.3–1.8)	.46
	No	27.6 (8/29)	Ref		10.6 (19/180)	ref	
Fever[d]	Yes	22.7 (25/110)	0.43 (0.2–1.0)	.04	8.0 (49/610)	0.46 (0.2–1.0)	.06
	No	40.5 (15/37)	Ref		14.9 (34/228)	ref	
Muscle or joint pain	Yes	25.0 (26/104)	0.69 (0.3–1.5)	.35	9.7 (57/589)	0.74 (0.3–1.7)	.49
	No	32.6 (14/43)	Ref		10.4 (26/249)	ref	
Headache	Yes	22.5 (20/89)	0.55 (0.3–1.1)	.11	7.4 (37/498)	0.41 (0.2–0.9)	.02
	No	34.5 (20/58)	Ref		13.5 (46/340)	ref	
Vomiting	Yes	27.6 (21/76)	1.04 (0.5–2.2)	.91	10.3 (43/417)	0.88 (0.4–1.9)	.73
	No	26.8 (19/71)	Ref		9.5 (40/421)	ref	
Abdominal pain	Yes	23.2 (16/69)	0.68 (0.3–1.4)	.30	8.0 (31/389)	0.68 (0.3–1.5)	.33
	No	30.8 (24/78)	Ref		11.6 (52/449)	ref	
Red eye	Yes	27.4 (17/62)	1.02 (0.5–2.1)	.96	12.3 (38/309)	1.64 (0.8–3.5)	.20
	No	27.1 (23/85)	Ref		8.5 (45/529)	ref	
Diarrhea	Yes	29.3 (17/58)	1.19 (0.6–2.5)	.64	10.2 (36/352)	1.01 (0.5–2.1)	.99
	No	25.8 (23/89)	Ref		9.7 (47/486)	ref	
Sore throat	Yes	16.7 (7/42)	0.44 (0.2–1.1)	.07	6.2 (16/258)	0.63 (0.2–1.6)	.34
	No	31.4 (33/105)	Ref		11.6 (67/580)	ref	
Chest pain	Yes	20.5 (8/39)	0.61 (0.3–1.5)	.28	5.8 (13/223)	0.44 (0.2–1.1)	.07
	No	29.6 (32/108)	Ref		11.4 (70/615)	ref	
Backache	Yes	13.8 (4/29)	0.36 (0.1–1.1)	.08	6.3 (8/126)	0.57 (0.2–2.1)	.40
	No	30.5 (36/118)	Ref		10.5 (75/712)	ref	
Bleeding	Yes	40.0 (6/15)	1.92 (0.6–5.8)	.25	8.2 (6/73)	0.98 (0.4–2.5)	.96
	No	25.8 (34/132)	Ref		10.1 (77/765)	ref	
Jaundice	Yes	54.5 (6/11)	3.60 (1.0–12.5)	.04	26.8 (15/56)	3.60 (1.2–10.4)	.11
	No	25.0 (34/136)	Ref		8.7 (68/782)	Ref	
Neck rigidity	Yes	11.1 (1/9)	0.32 (0.0–2.6)	.29	3.3 (1/30)	0.45 (0.1–3.8)	.46
	No	28.3 (39/138)	Ref		10.1 (82/808)	ref	

J Infect Dis. Author manuscript; available in PMC 2019 May 09.

		Household Transmission Rate			Individual Secondary Attack Rate		
Risk Factor	**Level**	**% of Households ≥ 1 EVD Secondary Case (Households With EVD Cases/Total)**	**OR (95% CI)[a]**	***P* value**	**% of Household Contacts EVD Positive (Cases/Total)**	**OR (95% CI)[a]**	***P* value**
Household risk factors							
Dwelling type	Detached house	24.3 (9/37)	Ref	.76	9.8 (25/255)	ref	.77
	Apartment	27.0 (24/89)	1.15 (0.5–2.8)		9.5 (47/494)	0.74 (0.3–1.8)	
	Makeshift	33 (7/21)	1.56 (0.5–5.1)		12.4 (11/89)	0.96 (0.3–3.3)	
Piped drinking water source	No	35.6 (26/73)	2.37 (1.1–5.0)	.02	12.9 (54/420)	2.18 (1.0–4.9)	.06
	Yes	18.9 (14/74)	Ref		6.9 (29/418)	ref	
Toilet type	No facility	15.4 (2/13)	0.97 (0.1–6.8)	.26	7.1 (6/84)	2.51 (0.3–20.2)	.13
	Pit latrine	30.4 (35/115)	2.33 (0.6–8.5)		11.4 (74/652)	3.48 (1.0–11.7)	
	Flush	15.8 (3/19)	Ref		2.9 (3/102)	ref	
Case separated within household	No	30.5 (29/95)	1.64 (0.7–3.6)	.22	12.0 (64/534)	1.95 (0.8–4.6)	.13
	Yes	21.2 (11/52)	Ref		6.3 (19/304)	ref	
Moved to separate room	No	20.0 (4/20)	0.89 (0.2–3.5)	.87	3.7 (4/109)	0.46 (0.1–1.8)	.27
	Yes	21.9 (7/32)	Ref		7.7 (15/195)	ref	
Slept on a separate mat	No	29.2 (7/24)	2.47 (0.6–9.8)	.20	9.2 (13/141)	1.97 (0.4–9.0)	.38
	Yes	14.3 (4/28)	Ref		3.7 (6/163)	ref	
Separate bowls, cups, utensils	No	20.0 (6/30)	0.85 (0.2–3.2)	.81	6.6 (12/181)	0.91 (0.2–4.0)	.90
	Yes	22.7 (5/22)	Ref		5.7 (7/123)	ref	
Household size (≥ 6 contacts)	Yes	27.5 (14/51)	1.02 (0.5–2.2)	.96	5.9 (30/508)	0.33 (0.2–0.7)	.004
	No	27.1 (26/96)	Ref		16.1 (53/330)	ref	

Abbreviation: EBV, Ebola virus disease.

[a]Odds ratio (OR) and *P* values are calculated from a statistical model accounting for household clustering (generalized estimating equations), OR may not be the same as the crude OR.

[b]Household transmission rate was 60% and 57% when index cases were <5 and 5–19 years of age, respectively; the individual secondary attack rate was 14.3% and 12.4% when index cases were <5 and 5–19 years of age, respectively.

[c]Number of days in household with symptoms and with wet symptoms was entered into the model in a continuous form; OR represent the increase in odds for each additional symptomatic day in the household.

[d]All index cases with no reported fever had other EVD symptoms.

Table 3.

Univariable Models for Household Contact Individual Risk and Protective Factors (N = 83 Secondary Cases Among 838 Contacts)

		Individual Secondary Attack Rate		
Risk Factor	**Level**	**% of Household Contacts EBV Positive (Cases/Total)**	**OR (95% CI)[a]**	***P* value[a]**
Gender (contact)	Female	11.3 (53/471)	1.25 (0.9–1.8)	.21
	Male	8.2 (30/367)	ref	
Age (contact)	<5	9.0 (11/122)	ref	.19
	5–19	9.1 (28/308)	0.99 (0.5–1.8)	
	20–39	10.0 (28/279)	1.41 (0.8–2.5)	
	40–59	12.9 (13/101)	1.88 (1.0–3.5)	
	60+	10.7 (3/28)	1.34 (0.57–3.18)	
Relation to index case	First-degree relative[b]	14.6 (61/419)	2.43 (1.1–5.4)	.004
	Other relative	5.3 (12/225)	1.0 (0.4–2.7)	
	Unrelated	5.2 (10/194)	ref	
Sleep in same room	Yes	17.1 (38/222)	1.89 (1.1–3.3)	.02
	No	7.3 (45/616)	ref	
Share blanket or bed	Yes	14.8 (32/216)	1.56 (0.9–2.6)	.09
	No	8.2 (51/622)	ref	
Shared vehicle	Yes	14.7 (14/95)	1.42 (0.8–2.5)	.23
	No	9.3 (69/742)	ref	
Shared toilet	Yes	11.7 (62/529)	1.52 (0.9–2.5)	.11
	No	7.0 (21/302)	ref	
Share meals	Yes	14.4 (31/215)	1.65 (1.0–2.9)	.07
	No	8.1 (50/621)	ref	
Use same plate	Yes	13.8 (26/188)	0.78 (0.2–3.6)	.75
	No	18.5 (5/27)	ref	
Use same utensils/cup	Yes	15.4 (27/175)	2.52 (0.6–10.4)	.20
	No	10.0 (4/40)	ref	
Bed linens (touch or wash)	Yes	17.6 (33/188)	2.05 (1.3–3.2)	.002
	No	7.8 (50/645)	ref	

Risk Factor	Level	Individual Secondary Attack Rate		
		% of Household Contacts EBV Positive (Cases/Total)	OR (95% CI)[a]	*P* value[a]
Washed case clothes	Yes	20.9 (24/115)	2.30 (1.5–3.6)	.0003
	No	8.3 (59/715)	ref	
Wear case clothes	Yes	28.0 (7/25)	2.57 (1.2–5.7)	.02
	No	9.5 (76/798)	ref	
Contact with body fluids	Yes	21.4 (24/112)	3.12 (1.7–5.7)	.0002
	No	7.8 (56/718)	ref	
Physical contact	Yes	17.3 (50/289)	2.29 (1.5–3.6)	.0004
	No	6.0 (33/548)	ref	
Provide care to index case	Yes	23.7 (37/156)	3.13 (1.9–5.1)	<.0001
	No	6.7 (46/682)	ref	
And used some form of protection[c]		22.7 (5/22)	1.00 (0.3–3.5)	1.00
No protection		23.9 (32/134)	ref	
Cleaned body	Yes	27.3 (15/55)	1.42 (0.7–2.8)	.32
Fluids	No	21.8 (22/101)	ref	
Stay 1 meter away[d]	Yes	7.3 (36/491)	0.57 (0.3–1.0)	.03
	No	13.7 (46/337)	ref	
Stop sleeping with case[d]	Yes	7.4 (36/487)	0.59 (0.3–1.1)	.09
	No	13.8 (47/340)	ref	
Stop talking to case	Yes	9.6 (12/125)	0.93 (0.5–1.9)	.84
	No	10.1 (71/702)	ref	
Stop eating with case[d]	Yes	7.5 (38/510)	0.52 (0.3–0.9)	.03
	No	13.5 (43/318)	ref	
Avoid touching case[d]	Yes	6.5 (33/510)	0.40 (0.2–0.7)	.002
	No	15.4 (49/318)	ref	
Avoid index case[d]	Yes	7.0 (43/613)	0.38 (0.2–0.7)	.002
	No	18.4 (40/218)	ref	

[a]Odds ratio (OR) and *P* values are calculated from a statistical model accounting for household clustering (generalized estimating equations), OR may not be the same as the crude OR.

[b] Includes parent, children, siblings, and spouse.

[c] Protection included gloves or plastic bags over the hands or any other improvised barrier.

[d] Avoidance behaviors were highly collinear and were combined into 1 variable (AVOID INDEX CASE) for consideration in multivariable models.

Table 4.

Multivariable Models for Risk Factors Associated With Household and Individual Secondary Attack Rates, Sierra Leone, 2015

		Household Transmission Rate	
Factor	**Level**	**OR (95% CI)**	***P* value**
Model I. Factors for index case only			
Age of index case[a]	<20 Years	ref	.002
	20–39 Years	0.14 (0.0–0.4)	
	40+ Years	0.36 (0.1–1.1)	
Index case with fever[b]	Yes	0.40 (0.2–0.98)	.04
	No	ref	
Days in household with wet symptoms		1.30 (1.0–1.6)	.02
		ref	
Died in the house	Yes	3.51 (1.2–10.6)	.03
	No	ref	
Model II. Including factors for index case and household			
Age of index case[a]	<20 Years	ref	.009
	20–39 Years	0.11 (0.0–0.4)	
	40+ Years	0.40 (0.1–1.3)	
Piped drinking water source	No	4.11 (1.6–10.3)	.003
	Yes	ref	
Index case with fever[b]	Yes	0.31 (0.1–0.8)	.02
	No	ref	
Days in household with wet symptoms		1.32 (1.1–1.6)	.01
		ref	
Died in the house	Yes	4.05 (1.3–12.8)	.02
	No	ref	

		Individual Secondary Attack Rate	
Factor	**Level**	**OR (95% CI)**	***P* value**
Model III. Including factors for index case, household, and contacts			

		Individual Secondary Attack Rate	
Factor	**Level**	**OR (95% CI)**	***P* value**
Contact provided care to the index case	Yes	2.30 (1.44–3.67)	.0005
	No	Ref	
Index case died in the household	Yes	3.49 (1.40–8.69)	.007
	No	Ref	
Piped drinking water source	No	3.04 (1.45–6.38)	.003
	Yes	Ref	
Index case with fever[b]	Yes	0.41 (0.22–0.76)	.005
	No	Ref	
Contact avoid index case[c]	Yes	0.34 (0.16–0.73)	.005
	No	Ref	
First-degree relative[d]	Yes	1.85 (1.07–3.20)	.03
	No	Ref	

Abbreviations: CI, confidence interval; OR, odds ratio.

[a] For model parsimony, and because of limited sample sizes in certain age classes, adjacent age classes were collapsed when not statistically significantly different in final multivariate.

[b] All index cases with no reported fever had other Ebola virus disease symptoms.

[c] Among persons doing some type of avoidance (n = 613): 83% (n = 510) stopped eating with the index case; 83% (n =510) stopped touching; 79% (n = 487) stopped sleeping; and 80% (n = 491) stayed 1 meter away from the index case.

[d] First-degree relative includes spouses, siblings, parent, and children.