Kelly L Edmunds et al.

Disposal of waste contaminated with Ebola virus

This online first version has been peer-reviewed, accepted and edited, but not formatted and finalized with corrections from authors and proofreaders.

Recommendations for dealing with waste contaminated with Ebola virus: a Hazard Analysis of Critical Control Points approach

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(Submitted: 8 September 2015 – Revised version received: 2 January 2016 – Accepted: 12 January 2016 – Published online: 3 March 2016)
Abstract

Objective To assess, within communities experiencing Ebola virus outbreaks, the risks associated with the disposal of human waste and to generate recommendations for mitigating such risks.

Methods A team with expertise in the Hazard Analysis of Critical Control Points framework identified waste products from the care of individuals with Ebola virus disease and constructed, tested and confirmed flow diagrams showing the creation of such products. After listing potential hazards associated with each step in each flow diagram, the team conducted a hazard analysis, determined critical control points and made recommendations to mitigate the transmission risks at each control point.

Findings The collection, transportation, cleaning and shared use of blood-soiled fomites and the shared use of latrines contaminated with blood or bloodied faeces appeared to be associated with particularly high levels of risk of Ebola virus transmission. More moderate levels of risk were associated with the collection and transportation of material contaminated with bodily fluids other than blood, shared use of latrines soiled with such fluids, the cleaning and shared use of fomites soiled with such fluids, and the contamination of the environment during the collection and transportation of blood-contaminated waste.

Conclusion The risk of the waste-related transmission of Ebola virus could be reduced by the use of full personal protective equipment, appropriate hand hygiene and an appropriate disinfectant after careful cleaning. Use of the Hazard Analysis of Critical Control Points framework could facilitate rapid responses to outbreaks of emerging infectious disease.

Introduction

Emerging infectious diseases present threats to global health. The 2014–2016 Ebola virus disease outbreak in western Africa – caused by the Democratic Republic of the Congo strain – caught local and global health-care communities unaware and unprepared. By 2 September 2015, the outbreak had been associated with at least 28 073 confirmed, probable or suspected cases – reported in 10 countries – and more than 11 290 deaths. There were extraordinary challenges for the health-care systems and local governments involved in the response to the outbreak – and many of those challenges will persist long after the outbreak has passed. One such challenge was the safe disposal of potentially infected faecal and health-care waste – especially in the overcrowded urban communities where many of the cases occurred. It has been estimated that a patient in a bed within an African centre for Ebola treatment produced up to 300 litres of liquid waste and excreta per day. Every one of those litres could have been contaminated with Ebola virus and needed to be disposed of in such a way as to minimize the risks of transmission. The safe disposal of waste that could harbour Ebola virus is particularly challenging when that waste
has been produced beyond any formal health-care setting. In the three countries most affected by the recent outbreak – i.e. Guinea, Liberia and Sierra Leone – severe shortages of water and sanitation services in health-care facilities and the affected communities often complicated the safe disposal of waste. According to the most recent data, nearly one third of health-care facilities in Guinea, Liberia and Sierra Leone have no piped water, 22% have no improved sanitation and 40% have no system to manage health-care waste. The corresponding percentages for households within the same countries are probably higher.

Most transmission of Ebola virus probably results from direct contact with the bodily fluids of people who are in the latter stages of Ebola virus disease. The survival time of the virus outside of its human host is relatively short but – given the size and location of the recent outbreak and the frequent lack of disposal systems – we cannot exclude the possibility that, in some instances, people became infected indirectly, after coming into contact with contaminated waste.

In the present study, we used the Hazard Analysis of Critical Control Points framework to generate recommendations for mitigating the risks posed by virus-contaminated waste within health-care facilities and communities experiencing outbreaks of Ebola virus disease. Although this framework was originally developed for food production systems, it has been successfully adapted to manage and mitigate the risks associated with drinking water. It is increasingly being used to reduce the risks related to emerging infectious diseases and other health threats. Since its use is both low-technology and relatively cheap, the framework may be particularly useful in addressing the risks associated with emerging infectious disease in areas where the capacity of existing health-care systems is insufficient to cope with the impact of the disease. The framework’s methods encourage the use of interdisciplinary expertise while enabling the rapid generation of evidence-based recommendations. It therefore offers the potential to manage risks when the quick control of an outbreak is essential even though – as with the survival of Ebola virus in sewage and other waste – the relevant research data are incomplete or can only be inferred.

In our analyses, we defined waste as both human waste – e.g. faeces and urine – and the fomites generated by health-care activities. We identified those behaviours and practices linked to waste collection and disposal that are likely to present risks of direct or indirect transmission of Ebola virus between humans. We then evaluated the potential of assessments based on the
Hazard Analysis of Critical Control Points framework as a response tool during outbreaks of emerging infectious disease.

Methods

In conducting our Hazard Analysis of Critical Control Points analysis, we adapted the guidance contained within an annexe to the Codex Alimentarius Commission’s *General Principles of Food Hygiene*.\(^{15}\) Although this guidance refers to 12 steps in the analysis, we ignored some of the later steps in the process because we would not ultimately be responsible for implementing the recommended control measures or for establishing the subsequent on-the-ground monitoring. We used a seven-step process – similar to that used for highly pathogenic avian influenza.\(^{13}\) The seven steps were: (i) assemble a team with appropriate expertise in Hazard Analysis of Critical Control Points analysis; (ii) identify waste products within the system of care of cases of Ebola virus disease; (iii) construct flow diagrams illustrating the system of care; (iv) test and confirm the accuracy of each flow diagram; (v) list potential hazards associated with each step in each flow diagram and conduct a hazard analysis; (vi) determine critical control points; and (vii) establish critical limits for each critical control point.

Team

The international and multidisciplinary nature of the problems posed by Ebola virus meant that we – i.e. the members of the research team – were obliged to conduct our analysis via a mixture of face-to-face meetings and email exchanges. The research team included experts in disaster response, environmental health, Hazard Analysis of Critical Control Points protocols, infection control nursing, infectious disease epidemiology, public health, risk assessment, small water systems, virology and water and sanitation engineering. The team members were drawn from 19 different institutional departments spread across multiple countries within Africa, Europe and North America. Our analysis began when team members from the University of East Anglia (Norwich, England) held a series of small meetings. The progress made in these meetings was then shared with a wider group of team members – for comment and feedback – before a two-day face-to-face meeting in Nairobi, Kenya, that was attended by all of the team members from Africa and several of those from Europe.

Process
In the analysis, a systematic approach that allows for the synthesis of expert opinion is combined with the available evidence. This can bring clarity in an otherwise complex public health system. In our early meetings we concentrated on defining the most important waste products – in terms of risk of transmission – and then creating initial flow diagrams representing the pathways that could be used for the collection and disposal of each of these waste products. The diagrams were then shared with other team members, by email – so that a wider group of experts could comment on them – before they were reviewed and simplified in a face-to-face meeting. At the two-day meeting, experts from the fields of health interventions, sanitation and waste water hygiene gave their views on the flow diagrams. This review and a final critical analysis by an international panel of experts led to further modifications to – and simplifications of – the diagrams.

We considered a hazard to be a process – within a developing world setting – that could lead to human contact with waste material contaminated with Ebola virus and so provide the opportunity for transmission of the virus to another person. Taking into account the likely viral load of the contaminated material and based on the frequency with which each hazard was likely to occur, we grouped the hazards into high-, medium- and low-risk categories.

Following the validation of each flow diagram, the research team determined appropriate critical control points – i.e. the points at which there is an opportunity to reduce or eliminate the risks of virus transmission. The team then made so-called critical limits, for each identified critical control point, using a combination of expert knowledge – followed by validation via examination of the relevant published data on the epidemiology, prevention and control of Ebola virus disease – and the current relevant recommendations of Médecins Sans Frontières and the World Health Organization (WHO).

**Recommendations**

We used the results of the analysis to develop recommendations for the management of waste produced in the care of cases of Ebola virus disease.
Results

Hazard analysis

Our assessment of waste disposal within developing world settings affected by Ebola virus disease revealed multiple hazardous practices linked to the collection, transportation, disposal, cleaning and storage of waste (Table 1). We believe that, if managed poorly, each of these practices presents an unacceptable level of risk of the transmission of Ebola virus. All the practices that we categorized as high-risk involved potential contamination with blood: the collection, transportation, cleaning and shared use of blood-soiled fomites and the shared use of latrines contaminated with blood or bloodied faeces (Table 1). The practices identified as medium-risk were the collection and transportation of material contaminated with bodily fluids other than blood, the shared use of latrines soiled with such fluids, the cleaning and shared use of fomites soiled with such fluids and the contamination of the environment during the collection and transportation of blood-contaminated waste (Table 1). All of the other activities and practices linked to waste disposal were deemed to present a lower level of risk of the transmission of the virus.

Control points and limits

We identified 13 critical control points – i.e. 13 points at which there is an opportunity to adopt measures to reduce the risks of transmission. For each such point, following extensive consultation and cross-referencing with the existing literature, one or more potential hazards were identified. Then, one or more sets of recommendations were made for reducing the risk presented by each identified hazard (Table 1). All of the critical control points identified could be assigned to one of five categories: waste collection, waste transportation, waste disposal, waste storage or waste cleaning. The recommendations that we made for each critical control point derive from a combination of basic infection control – e.g. employing thorough hand hygiene measures – Ebola-virus-specific recommendations produced following consultation with the existing literature and suggested behaviour changes that could reduce the chances of a person exposing themselves to increased transmission risk.

Several of the recommendations we made include fundamental aspects of infection prevention and control – e.g. the correct and proper use of full personal protective equipment,
appropriate hand hygiene and thorough cleaning followed by the use of an appropriate disinfectant.

Discussion

We used analysis based on the Hazard Analysis of Critical Control Points framework to make recommendations for protecting health workers, other staff in health facilities and the wider public from the risks posed by the disposal of potentially infected liquid and solid waste generated in the care and treatment of patients infected with Ebola virus. During this analysis, 13 critical control points associated with the collection, transportation, disposal, storage and cleaning of waste, the use and emptying of latrines and fomite re-use were identified. Our analysis took account of existing evidence presented in the published literature and guidance published by international organizations. When there were no or few relevant data available, expert opinion from an international panel of experts with expertise in environmental health, epidemiology, health-care provision in low-income countries, virology and water and sanitation engineering was sought.

The framework allows for a rapid identification of the risks associated with a known hazard. In the present study, that known hazard was the transmission of Ebola virus between humans. The 2014–2016 Ebola virus disease outbreak resulted in widespread localized transmission of the virus. Much of this transmission was attributed to the social, environmental and cultural characteristics of the worst-affected countries, including inadequate health-care infrastructures that, even before the outbreak, were under great stress as the result of high population densities in urban areas. For Ebola virus disease, multiple gaps still exist in our understanding of potential transmission mechanisms and control measures. In the context of such knowledge gaps, the framework provides a useful systematic approach that focuses on the prevention of harm and synthesizes hard evidence and expert opinion. Given such knowledge gaps, however, it remains possible that future research may produce results that require our current recommendations to be modified.

Previous studies have shown that direct contact with a symptomatic person with Ebola virus disease is typically associated with relatively high risks of transmission during the early stages of the disease – whereas the risk of indirect transmission increases as the disease progresses. The transmission of the virus during burial rituals – which fall outside the
scope of the present study – are known to be particularly hazardous practices.\textsuperscript{11,18,19} The transport and disposal of potentially contaminated waste also present opportunities for the virus to leave the household or care centre and enter the wider community or environment. In our analysis, taking into account the likely viral load within the contaminated waste and the likely opportunity for transmission of the virus via a particular activity, we only associated activities involving blood-soiled waste with relatively high risks of Ebola virus transmission. For blood-soiled waste, the highest risks were associated with activities that could bring the waste into direct contact with either another person – e.g. the cleaning of a blood-contaminated container – or a potential viral vehicle – e.g. a container used to transport bloodied waste or a contaminated fomite passed to another person without being adequately cleaned. Each of these risks could be eliminated or, at least, substantially decreased through the careful implementation of the recommendations outlined in Table 1. As there is some evidence to suggest that spraying a potentially contaminated surface with disinfectant may promote transmission,\textsuperscript{20} we recommend containment of the spill, followed by cleaning of the surface with water and detergent and finally wiping with 0.5\% chlorine solution. This recommendation, which follows published guidelines,\textsuperscript{21–23} was kept relatively simple because many of those undertaking the cleaning and the preparation of solutions for disinfecting within non-clinical settings would not be able to record times or determine chemical concentrations accurately.

Ebola virus can rarely be detected in the faeces or rectal swabs from persons with Ebola virus disease, even during periods of acute illness,\textsuperscript{12,25–27} and little is known about the persistence of the virus within faeces.\textsuperscript{11} With this in mind, we considered faeces to be less of a transmission risk than blood. It has been estimated that approximately one in four samples of non-blood bodily fluids collected during active illness was likely to contain viable virus.\textsuperscript{14} It remains possible that these non-blood bodily fluids only contain Ebola virus when contaminated with non-visible blood. Whenever fomite-related transmission has been suspected, it has rarely been possible to exclude the possibility of direct human-to-human contact as the transmission route.\textsuperscript{9} We considered the risks of transmission via food crops and via disposal of waste directly onto the ground to be low – primarily because of the lack of evidence of such transmission\textsuperscript{28} but also because solar radiation and other environmental stressors, such as antiviral microbial activity in soils, may rapidly inactivate the virus. However, it is worth noting that there is evidence
highlighting contact with raw sewage as a transmission route for many other pathogens.\textsuperscript{29} Previous research into filoviruses has shown that, on clear days at tropical latitudes, it can take as little as 20 min to decrease the infectivity of sun-exposed virus by 90\%.\textsuperscript{30} Although some researchers have been concerned about the potential risk to wastewater workers posed by viable Ebola virus in sewer systems,\textsuperscript{31} others believe that any predisposal treatment of sewage that would be potentially contaminated with Ebola virus could increase the transmission risk.\textsuperscript{32} Although some Ebola virus survived more than two days in sterilized wastewater,\textsuperscript{33} the United States Centers for Disease Control and Prevention believes that standard personal protective equipment for sewage workers provides sufficient protection.\textsuperscript{34}

In conclusion, our analysis has shown that, while there is limited relevant literature, waste from the care of cases of Ebola virus disease should not be discounted as a potential transmission route. The cleaning, collection, disposal, storage and transportation of waste contaminated with blood probably present the greatest waste-related transmission risks, particularly when the blood has come from a person in the advanced stages of the disease. We believe that waste contaminated with other bodily fluids poses a substantially lower transmission risk, which decreases further with time after contamination. However, it is important to keep in mind that our analysis was mainly based on the 2014–2016 Ebola virus disease outbreak. This outbreak was unusual because it expanded into densely populated urban centres and there was sustained transmission of the virus within such environments. Previous outbreaks of Ebola virus disease have predominantly occurred in small, rural communities where containment and isolation were more feasible. The 2014–2016 outbreak was far larger than any previously recorded outbreak and it is possible that the elevated quantity of virus entering the environment may yet reveal transmission routes that have gone undetected or unnoticed in previous outbreaks. In the meantime, our recommendations should be followed to ensure that the potential for Ebola virus transmission via waste materials is minimized.

\textbf{Acknowledgements}

We thank everyone who commented on the flow diagram and hazard analysis of this manuscript. We also thank A Chepurnov, Institute of Clinical Immunology, Novosibirsk, Russian Federation.

\textbf{Competing interests:}

MM is an employee of WHO.
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PMID:9988169

PMID:25619149


PMID:25875372


Table 1. **Summary of the Hazard Analysis of Critical Control Point assessment for the disposal of waste potentially contaminated with Ebola virus**

<table>
<thead>
<tr>
<th>Potential hazard by critical control point</th>
<th>Level of concern about contaminated materials with blood</th>
<th>Level of concern about contaminated materials with bodily fluids other than blood</th>
<th>Recommendations$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Latrine use</strong></td>
<td>High</td>
<td>Medium</td>
<td>- Suspected and confirmed cases use isolated and segregated latrines and keep secure for 7 days$^{10,24}$ after last use by suspected case.</td>
</tr>
<tr>
<td>Contamination of environment</td>
<td></td>
<td></td>
<td>- Avoid surface water inflow by using external channels or concrete surroundings, and ensure adequate quality of construction to limit risk of collapse and contamination of groundwater sources.$^{35}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Using a single-use cloth – which should subsequently be incinerated – clean surfaces with water and detergent. Then wipe 0.5% chlorine solution$^{22-24,36,37}$ over all surfaces, including door handles, toilet seat, floor and walls.$^7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Wash hands with soap and water after using latrine.</td>
</tr>
<tr>
<td><strong>2. Washing and cleaning</strong></td>
<td>High</td>
<td>Medium</td>
<td>- Provide proper training of cleaners and ensure experienced supervision.</td>
</tr>
<tr>
<td>Contamination of cleaner</td>
<td></td>
<td></td>
<td>Use water and detergent for cleaning, followed by 0.5% chlorinated water for disinfecting.$^{10,22,23}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Treat wastewater as per CCP12.</td>
</tr>
<tr>
<td><strong>3. Reuse or shared use of fomite</strong></td>
<td>High</td>
<td>Medium</td>
<td>- Avoid reuse where possible and dispose as per CCP8. If reuse is essential, wear full PPE when washing reusable materials or products.$^c$</td>
</tr>
<tr>
<td>Inadequate cleaning</td>
<td></td>
<td></td>
<td>- Check fomite for damage and suitability for reuse. If reuse is possible, clean fomite using a moist single-use cloth, which should then be incinerated. Following cleaning, if possible, with a wash with water at &gt; 60 °C.$^{24,38}$ If not possible, soak in 0.5% chlorine solution$^{22,23}$ for a minimum of 30 min, after removing most organic material,$^{10,24,37,38}$ and then let air dry before transporting for reuse.</td>
</tr>
<tr>
<td><strong>4. Transport</strong></td>
<td>High</td>
<td>Medium</td>
<td>- Avoid handling fresh waste. If unavoidable, wear full PPE and employ appropriate hand hygiene measures.$^c$</td>
</tr>
</tbody>
</table>
Contamination of vehicles and/or containers

<table>
<thead>
<tr>
<th>Contamination level</th>
<th>High</th>
<th>Medium</th>
</tr>
</thead>
</table>
- At end of each transportation or shift, using a moist single-use cloth that should subsequently be incinerated, clean vehicles and containers with water and detergent. Following cleaning, disinfect using 0.5% chlorine solution. If cloth must be reused, wash with warm water and detergent while wearing appropriate PPE to remove organic matter. Then soak in 0.5% chlorine solution for a minimum of 30 min and rinse with cold water.
- Always wear full PPE when cleaning vehicles and containers and disinfect or burn PPE after use.
- Use leak-proof containers – e.g. plastic barrels with secure lids – for contaminated items.
- Using a single-use cloth that should subsequently be incinerated, clean outer surfaces of vehicles and containers before and after use with water and detergent. If cloth must be reused, wash with warm water and detergent, while wearing appropriate PPE, to remove organic matter. Then soak in 0.5% chlorine solution for a minimum of 30 min and rinse with cold water.
- Enclose and/or isolate site.
- Spills should be covered first with a cloth, to avoid splashing or dispersion of fluids. Then wipe up spill with rags and dispose of rags through incineration. Clean the area with a detergent and water and then disinfect by wiping with 0.5% chlorine solution.

5. Disposal of sharps

<table>
<thead>
<tr>
<th>Contamination level</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
</table>
- Sharps should be segregated from other waste at point of generation, placed in puncture-resistant, sealed biohazard-labelled containers and disposed of appropriately, as local facilities allow.

6. Emptying of latrine when more than two thirds full

<table>
<thead>
<tr>
<th>Contamination level</th>
<th>Variable, depending on age of waste, construction of latrine etc.</th>
<th>Variable, depending on age of waste</th>
</tr>
</thead>
</table>
- Wait a minimum of 7 days after last use by a known case before desludging.
- If not possible to wait 7 days, wear full PPE.

7. Storage

<table>
<thead>
<tr>
<th>Exposure to contaminated waste</th>
<th>Variable, depending on age of waste</th>
</tr>
</thead>
</table>
- Segregate waste into a secure nonporous container and destroy within 24 h.
Incomplete combustion

- If waste is to be burned, use an incinerator – that reaches sufficient complete burning temperatures and meets environmental emission standards – according to manufacturer’s operating manual. If an incinerator is not available, burn in a barrel or pit with sufficient additional combustible material to ensure complete combustion.23
- If large volumes of waste need to be burned, divide into smaller volumes before burning.23
- PPE should be worn but extreme caution needs to be taken to avoid the handler’s PPE catching alight.

9. Cleaning and disinfecting of non-human waste

Stealing

- For fabric waste – e.g. bed linen and clothing – discard if possible. If reuse necessary, wash with warm water and detergent, while wearing appropriate PPE, to remove organic matter. Then soak in 0.5% chlorine solution for a minimum of 30 min and rinse with cold water.
- For hard waste – e.g. crockery and buckets – wash with a detergent, while wearing appropriate PPE, to remove organic matter. Then soak in 0.5% chlorine solution for a minimum of 10 min and rinse with cold water.
- Items can be reused if not damaged. For items not suitable for reuse, dump in a secure area and limit animal access to the secure area.10,22–24,37

10. Burial of waste

Digging up or stealing of health-care waste

- Bury in reliably secure areas, with limited access to animals, and keep secure for 14 days after last disposal.
- Acidify or soak in 0.5% chlorine solution for 30 min before dumping.10,22–24,37

11. Disposal on ground

Contamination of food crops

- Prevent disposal onto ground used for food crops and ensure that all crops are handled and prepared according to appropriate food safety guidelines.44
- Ensure water supply point is designed to prevent contamination following principles of sanitary assessments included in water safety plans.12
- Encourage safe water handling and storage practices and encourage proven household water treatment methods – e.g. filtration, chlorination or boiling.12,23

Contamination of water supply

12. Discharge and treatment of wastewater through sewer

Contact of general public with virus via open sewers

- Give public health education to community representatives and construct physical barriers.12
- Ensure appropriate conditions of carriage – in many places effluent streams are used by neighbours35 – by following sanitation safety planning guidelines.35,45
<table>
<thead>
<tr>
<th>Contact of sewage workers with virus</th>
<th>Low</th>
<th>Low</th>
<th>- Ensure standard PPE and hygiene practices are followed.(^{34})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human and animal contact with virus via human excrement</td>
<td>Low</td>
<td>Low</td>
<td>- Discourage open defecation and encourage pit latrine use. Remove excrement to a pit latrine or bury at a minimum depth of 0.5 m. If unavoidable, dump excrement in secure area.</td>
</tr>
</tbody>
</table>

CCP: critical control point; PPE: personal protective equipment.

\(^a\) Including urine, faeces and wash water.

\(^b\) During the execution of this recommendation, appropriate hand hygiene must be employed and full PPE worn, with the correct protocols observed. After each use, PPE should be treated as an infected fomite and either disinfected or burned.

\(^c\) Due to the nature of Ebola viruses, there must be 100% compliance with this recommendation.