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*Commentary*

# Personal Protective Equipment: Protecting Health Care Providers in an Ebola Outbreak

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## ABSTRACT

**Purpose:** The recent Ebola epidemic that devastated West Africa has infected and killed more health care providers than any other outbreak in the history of this virus. An improved understanding of pathogen transmission and the institution of strategies to protect health care providers against infection are needed in infectious disease outbreaks. This review connects what is known about Ebola virus transmission with personal protective equipment (PPE) designed to arrest nosocomial transmission.

**Methods:** Articles pertaining to filovirus transmission and PPE in filovirus outbreaks were reviewed and findings are presented. In addition, studies that evaluated PPE and donning and doffing strategies are presented.

**Findings:** PPE is one step in a comprehensive infection prevention and control strategy that is required to protect health care providers. Given that the Ebola virus is primarily transmitted through direct contact of mucous membranes and cuts in the skin with infected patients and/or their bodily fluids, it is necessary to cover these potential portals of infection with PPE as part of a structured and instructed donning and doffing procedure.

**Implications:** Current recommendations about PPE and the donning and doffing processes are based on anecdotal experience. However, the use of non-human viruses can help provide evidence-based guidelines on both PPE and donning and doffing processes.

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**Key words:** Ebola, infection prevention and control, outbreak, personal protective equipment, transmission.

## INTRODUCTION

The recent Ebola epidemic that devastated West Africa evolved within months from a regional humanitarian crisis to a global public health emergency. As of May 27, 2015, 27,049 cases and 11,149 deaths from Ebola were reported by the World Health Organization (WHO), an underestimate that already eclipses the numbers of infections and deaths in all previous outbreaks combined.[1] With fewer than 0.1 physicians per 10,000 people in Liberia, Sierra Leone, and Guinea, the infection of 869 health care providers and the death of 507 in this epidemic alone has depleted an already precious resource.[2] Although the rate of confirmed cases has declined dramatically in West Africa, the loss of health care providers will continue to affect the people of this area for decades to come.

Despite major advances in the prevention and treatment of infectious diseases in general, there are currently no licensed vaccines, proven effective antiviral therapies, or proven postexposure prophylaxis strategies for Ebola virus disease (EVD). Personal protective equipment (PPE) plays a critical role in mitigating the risk of health care personnel (HCP)

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exposure to contaminated body fluids in the care of patients with communicable infectious diseases, including EVD. The importance of PPE was recognized during the outbreak of severe acute respiratory syndrome (SARS), in which HCP accounted for ~20% of persons who were infected with SARS.[3] Evidence of continued SARS transmission despite the use of droplet, contact, and airborne precautions drew attention to the possibility of nosocomial transmission during PPE removal or doffing.[4,5] In addition, recent studies suggest that viruses, including Ebola, have the potential to remain infectious on PPE for longer than it is typically worn, creating an opportunity for transmission during doffing. Historically, development of PPE strategies has been driven by the paradigm that infectious agents are transmitted by 1 of 3 routes: contact, droplet, or airborne. However, the consideration of self-inoculation in the removal of PPE is emerging as a major potential route of HCP infection.[6] To this end, we reviewed the major routes of Ebola virus transmission and the use of PPE to prevent HCP exposure and infection.

## TRANSMISSION

Once the Ebola virus enters the human population, outbreaks are sustained through human-to-human transmission, which is facilitated by the presence of the virus in every body fluid, including blood, diarrhea, vomit, sweat, breast milk, vaginal secretions, and semen.[7,8] Ebola virus increases logarithmically in the blood during acute infection, and often the highest levels of viremia are achieved at the time of death.[9] In addition, patients in the later stages of disease have more severe symptoms, including diarrhea, vomiting, and bleeding complications, thus increasing the potential of spread via infectious body fluids. This coupled with limited health care infrastructure in the areas where most Ebola outbreaks occur contribute to the outbreak amplification that is often seen in health care settings.[10–12]

Epidemiologic studies suggest that the virus is spread primarily through direct contact with the patient and virus-laden body fluids, especially late in the clinical course of disease.[11,13,14] Of 173 household contacts of 27 infected patients, 28 (16%) developed EVD.[13] All 28 cases reported direct physical contact with the index patient (risk ratio = 3.6; 95% CI, 1.9–6.8).[13] Importantly, none of the 78 household members who reported no direct contact with the index patient developed EVD. In a separate study those family members who provided direct nursing care to the index patient had a 5.1-fold increased risk of infection, highlighting the importance of direct contact.[11] The risk of secondary transmission, in a separate study, increased with exposures that continued through the later states of illness (crude prevalence proportion ratio [PPR] = 6 [95% CI, 1.33–27.1] in the early stage of illness; crude PPR = 8.57 [95% CI, 1.95–37.66] when care was provided until the patients' death at the hospital; and crude PPR = 13.33 [95% CI, 3.2–55.59] when care was delivered until death at home).[14] Infection from direct contact likely results from the interaction between virus and mucosal membranes as animal models have demonstrated infection can occur through oral, nasal, and conjunctival routes.[15]

Given the high levels of virus in body fluids and on the skin of patients at the time of death, postmortem contact is also associated with an increased risk of infection (adjusted risk ratio = 2.1; 95% CI, 1.1–4.2).[13,16] The increased potential for transmission during contact with a dead body, as occurs during traditional burial practices, can be partly attributed to the durability of virus in body fluids even after death. In a nonhuman primate study of viral persistence after death, replication competent virus was detectable in oral, nasal, and blood samples from dead animals. Blood contained the highest concentrations of viable virus ($2 \times 10^5$ median culture infectious dose/mL) and remained positive for the longest duration, 7 days postmortem.[17] Viral RNA was detectible from oral nasal and blood swabs for up to 3 weeks postmortem.[17] Together, these data highlight close contact with a dead body, as is custom during preparing a body for funeral, is a potential route of transmission.

Of 316 people infected in the Kikwit outbreak (in 1995) only 5 reported no physical contact with a confirmed patient, suggesting that alternative routes of transmission, including droplet or fomite-mediated transmission, may be possible but are unlikely events.[18] Theoretically, fomite transmission is possible, but the conditions, including the environmental surface and ambient temperature, affect the viability of the virus. In 1 study, filoviruses, including Ebola, were found to remain infectious in liquid media at room temperature for at least 46 days, but infectious virus could not be isolated when allowed to dry on a plastic or glass substrate at room temperature.[19] Reports from the current outbreak indicate that multiple environmental

samples obtained from an Ebola treatment unit were positive for polymerase chain reaction.[10] However, when sampling occurred after routine cleaning in a separate study, all 31 environmental samples were negative, suggesting that routine sanitation, as part of environmental control, can decrease the potential of fomite transmission.[20]

Recently, the potential for airborne transmission has received considerable attention.[10,21] Although animal studies suggest that this is possible when virus is experimentally aerosolized, epidemiologic studies of household contacts indicate that this is not a primary means of transmission.[11,13,14,22–24] In addition, the institution of barrier protection with the use of surgical masks that do not protect against airborne transmission has historically been sufficient to eliminate nosocomial transmission and HCP infection.[25] Higher risks of airborne or droplet transmission is likely to occur in health care settings during aerosol-generating procedures such as induced sputum procedures and/or intubation.

## INFECTION PREVENTION AND CONTROL

The combination of high viral loads, the ubiquitous presence of virus in all body fluids, and the low inoculum required for infection substantially increases the risk of HCP, family members, and loved ones who provide direct care to Ebola-infected patients.[26] In addition, patients infected with EVD often present with nonspecific symptoms that frequently mirror more common, but less contagious, infectious diseases. For this reason it is imperative that HCP implement the use of standard precautions consistently when providing care to all patients.[27,28] The strict adherence to standard precautions before the identification of an Ebola-infected patient is paramount to preventing nosocomial transmission to HCP.

Key elements of standard precautions include the following[27,29,30]: (1) hand hygiene, (2) risk assessment for appropriate PPE, (3) respiratory hygiene, (4) prevention of needle-stick and injuries from other sharp instruments, (5) proper waste management, and (6) environmental cleaning and disinfection of patient care equipment and environmental surfaces.

Although a disproportionate amount of attention and debate have been directed to the components of PPE, the most effective means of reducing health care–associated infection include the implementation of environmental and administrative controls.[31] Environmental controls include not only the construction and maintenance of appropriate facilities for isolating potentially infected patients but also the establishment of clean water and sanitation and effective waste management that reduce environmental contamination and serve to limit HCP exposure at the source. Similarly, administrative controls alter the delivery of care to mitigate potential exposures such as implementation of infection control precautions, patient triage for rapid identification of suspect cases of EVD with immediate isolation of the patient in a single room, establishment of specific donning and doffing protocols, the presence of donning and doffing monitors, and policies on medical procedures. During the Ebola outbreak in Kikwit, Zaire, in 1995, 67 HCPs were infected while providing care in an isolation unit plagued by a lack of water and electricity, a shortage of PPE, and an absence of appropriate waste disposal.[25] After the implementation of environmental and administrative controls in the establishment of a properly functioning Ebola treatment unit the rate of HCP infections decreased dramatically.[25] Collectively, environmental and administrative controls are critical infection control measures that work to arrest potential chains of transmission in health care settings.

### Personal Protective Equipment

Despite the lethal nature of this virus and the potential ease of transmission, infection can be prevented. Although the most effective interventions to protect HCP are those that physically separate HCP from infectious patients and body fluids, mortality rates of Ebola-infected patients can be decreased with more aggressive care that requires close contact with these patients.[32] In this setting, PPE serves as the last physical barrier between a health care provider and infectious body fluids. In prior outbreaks, infection of HCP was substantially reduced with the institution of barrier precaution.

Although the actual PPE is the most visible aspect of infection control, it must be used as part of a larger infection prevention and control strategy that incorporates environmental and administrative controls, including the establishment of physically separate donning and doffing areas from the space in which actual clinical care is provided, training on the correct use of PPE, sufficient supply of all PPE components, and the use of a trained doffing instructor. Designated areas that allow for clear separation between donning and doffing is critical because doffing involves

potential exposure to contaminated body fluids on the outside of used PPE. Moreover, clear delineation between high- and low-risk areas and when PPE is needed and not needed are paramount to ensuring that PPE is used appropriately to mitigate risks of exposure to sources of infection. Secondly, training in the use of PPE before providing care for suspect or confirmed patients is crucial because there is a learning associated with providing routine tasks in unfamiliar situations. In addition, the heat stress associated with the use of PPE in tropical climates is an occupational hazard that, in some instances, can increase the risk of accidents and thus exposure if not recognized early. Behavioral controls are also a fundamental aspect of infection control strategies. On average a person will touch his or her eyes, lips, and nostrils at a rate of 15.7 times per hour.[33] In Ebola endemic countries during this epidemic, there was a policy of no touch in which people do not hug, kiss, or shake hands to avoid potential transmission outside of Ebola treatment units. Refraining from touching one's face and frequent handwashing is encouraged to reduce the potential of self-inoculation. Collectively, the logistics of PPE are also necessary to protect health care providers.

### Mucous Membrane Protection and Head Cover

Although there is no consensus on each of the specific components of PPE among the major organizations providing care to infected patients in the field, all agree that it should uniformly protect the major portals of virus entry, including mucous membranes and breaks in the skin. Centers for Disease Control and Prevention (CDC) guidelines, which are directed toward the use of PPE in US hospitals, recommend mucous membrane coverage with either an N-95 particulate respiratory or a powered air-purifying respirator (PAPR) that incorporates a full-face shield, helmet, or headpiece.[34] If an N-95 respiratory is used, it must be accompanied by a single-use surgical hood that extends to the shoulders and a full-face shield. Similarly, if a PAPR is used with a helmet or headpiece, it also must be used in combination with a disposable hood that extends to the shoulders and fully covers the neck. The WHO recommendations, which pertain to care of Ebola-infected patients regardless of location, include the use of a face shield or goggles to protect conjunctival membranes and either a fluid-resistant medical/surgical mask that does not collapse against the mouth (eg, duckbill or cup shape) or a fluid-resistant particulate respiratory if aerosol-generating procedures will be performed.[35] In both cases, the WHO offers a conditional recommendation that health care providers also wear a separate head cover that protects the head and neck. This recommendation is conditional because there is no evidence to support the use of a head cover or hair cap for preventing infection.[35]

Although the use of a PAPR provides enclosed protection and full visualization of the provider's face, the logistical obstacles of disinfection after each use, need for reliable electricity to power the unit, and the cost limit these from being widely used in the field. Similarly, because Ebola does not appear to be efficiently transmitted via an aerosol route, a surgical mask can be used to protect against droplet transmission, although an N-95 if available provides better protection against airborne agents. However, given the length of time it takes to don and doff PPE and the inability to change components of PPE while inside a high-risk area, many in the field enter with a particulate respirator in case a patient is coughing, aggressively vomiting, or undergoing a procedure that could generate secondary aerosolization. No evidence is found of increased efficacy of either face shields or goggles in the prevention of Ebola virus transmission, but both have advantages and disadvantages. Goggles offer complete enclosure around the eyes, preventing inadvertent touching with potentially soiled gloves, but they provide a more limited range of view compared with face shields. However, face shields allow more of the HCP's face to be visible during patient care, which facilitates communication and potentially decreases patient anxiety. Although fogging affects both face shields and goggles, reducing visibility, it may affect face shields to a lesser degree.

### Gloves

Both the CDC and the WHO recommend the use of 2 pairs of gloves with at least the outer pair having an extended cuff that reaches beyond the wrist.[34,35] The inner pair of gloves rests against the HCP's skin and underneath the gown/coverall (described in the Body and Skin Protection section), whereas the outer pair is worn on top of the gown/coverall to effectively protect the wrist from contamination. This also allows the outer glove to be changed between patients to mitigate risks of nosocomial transmission between patients.

The use of 2 pairs of gloves also protects against damage to the outer glove by disinfectants such as chlorine and may reduce the risk of parenteral exposure from sharp injuries while the loss of tactile sensation is minimal. As described in the next section, the use of double gloves has also been used to decrease the incidence of hand contamination particularly during PPE removal. No evidence suggests that >2 pairs of gloves allots additional protection but instead may increase risk as the doffing sequence becomes more complicated.

### Body and Skin Protection

Given the high risk of transmission through direct patient contact, the CDC and the WHO recommend the use a single-use fluid-resistant gown or coverall to prevent contamination of underlying skin and surgical scrubs. Although it is not known if the Ebola virus can penetrate intact skin, the presence of virus on skin or clothing could be a source of self-inoculation. The resistance of commercially available gowns/coveralls is assessed by their ability to prevent passage of a nonenveloped DNA virus, phiX174, under different degrees of pressure.[36] Resistance, however, must be balanced by tolerance of use by health care providers who work in tropical conditions because increased resistance impairs evaporative cooling and may decrease the time HCP can provide care. If a fluid-resistant gown is worn, it should extend beyond the top of the footwear or shoe covers (see Foot Protection). The integration of thumb loops may be beneficial in securing complete protection of the wrist area. The WHO guidelines recommend against the use of tape to attach gloves to gowns/coveralls because this may increase the risk of tearing the gown/coverall and complicate the doffing procedure at a time when health care providers are potentially most vulnerable.[35,37] The use of a waterproof or impermeable apron worn over the gown/coverall is recommended to provide further protection against infectious body fluids. Both the CDC and the WHO recommend using a disposable apron if feasible because a reusable one will require decontamination after each use.

### Foot Protection

Given the high degree of environmental contamination due to substantial diarrhea and vomiting, HCP are advised to wear waterproof boots or shoe covers if used with a coverall that has integrated socks.[32] In addition to being easier to decontaminate, waterproof boots offer some protection against sharps injuries.[35]

The feasibility of such an approach in the field must be considered however because the countries in which most Ebola outbreaks have occurred are among the poorest in the world with the least developed health care infrastructure available. In Sierra Leone, a country already among the countries with the lowest health care expenditures (ranked 141 of 192 nations) and devastated by the current epidemic, the use of full containment PPE as recommended by the CDC and WHO was deemed neither affordable nor practical in peripheral health care units that were visited initially by many patients infected with EVD.[38]

### Structured and Instructed Donning and Doffing Processes

Although the various forms of PPE recommended by the WHO, CDC, and Medecins Sans Frontiers (or Doctors Without Borders) all mitigate risks of exposure to infected body fluids while caring for Ebola-infected patients, the presence of PPE alone is not enough. PPE must be donned correctly before entry into a high-risk area, must remain in place while inside a high-risk area, and must be removed safely when leaving the high-risk area to be effective. PPE must not be adjusted during patient care because adjusting goggles or a face shield can lead to mucous membrane exposure and potential infection.

Risk of indirect exposure to infected bodily fluids is likely highest when removing PPE because, depending on the step, the major portals of entry may be exposed in close proximity to clothing contaminated with infected bodily fluids. These risks may be decreased by implementing a systematic process of instructed doffing in which safe removal of contaminated clothing is directed by a trained and rested doffing instructor. This is different than the buddy system of donning. When donning, it is sufficient to have the person you are entering with check to ensure that your PPE is intact and on correctly. However, given that doffing is the highest risk activity, it is critical that the person guiding you through the process of removal has not been inside the high-risk zone recently, is well rested, and is solely focused on getting you out of the high-risk area safely. The variability in recommended PPE by different organizations and hospitals necessitates variation in donning and doffing order because the order will change with each PPE item added or

removed. It is imperative that this order is established, optimized, and taught before it is being used to ensure feasibility and success.

## EVIDENCE BASE FOR RECOMMENDATIONS

Although PPE in its various forms and designs cover the major portals of virus entry, the efficacy of actual protection is unknown and remains poorly studied. A nonpathogenic nonenveloped bacteriophage, MS2, has been used to assess safety of PPE and donning and doffing protocols in non-Ebola settings.[39] Although filovriuses are single-stranded enveloped RNA viruses, the use of MS2 is a conservative surrogate because the absence of an envelope likely improves the ability of this virus to maintain its infectiousness in the environment. In addition, the current CDC recommendations for environmental decontamination of an Ebola care area are consistent with those needed to decontaminate nonenveloped viruses.

The use of MS2 allows for the systematic evaluation of PPE and processes to ensure they have been optimized for health care provider safety. After the SARS outbreak the CDC sequence for removing PPE was evaluated with the use of a nonenveloped, nonpathogenic RNA virus and Glogerm (Glo Germ Company, Moab, Utah) fluorescent synthetic beads.[40] The fluorescent tracer was found not to be a reliable indicator of virus contamination because virus was recovered from both areas that fluoresced and areas that did not fluoresce. In this study, virus was recovered from the scrub shirt of 100% of participants, the nondominant hand in 80%, and scrub pants in 75%.[40] The highest virus titer was recovered from the scrub shirt. The use of fluorescent tracer provided false confidence because it was found on the shirt, nondominant hand, and scrub pants in 10%, 10%, and 0% of research participants, respectively.[40] The use of double gloving, however, significantly reduced not only the incidence of hand contamination with virus but also the quantity of virus that was transmitted to HCP hands, thus providing better protection against viral contamination during PPE removal.

A comparison of 2 personal protective systems found that the PAPR system that included a second outer layer was less likely to experience contamination than an enhanced respiratory and contact precautions system that lacked a second outer layer.[5] In the PAPR PPE set HCP wore a Tyvek (DuPont, Wilmington, Delaware) suit, shoe covers, a surgical gown, and a large hood, whereas the enhanced respiratory and contact precautions system included only a surgical gown, indicating that a second covering significantly reduced exposure to contaminated body fluids and provided evidence for the use of aprons on top of gowns or coveralls in the care of Ebola-infected patients. Areas that were more likely to be contaminated included the anterior neck, forearm, hands, and wrists. However, those persons donning the PAPR system were more likely to commit donning procedure violations, highlighting the increased difficulty of donning and doffing with more complex PPE. Fortunately, there were no significant differences in doffing procedure violations between the 2 groups.[5]

Although PPE is often only worn for short periods of time, pathogenic viruses such as influenza, SARS, and Ebola can survive for extended periods of time on surfaces and be sources of transmission via surface-to-hand and hand-to-face/mucous membrane contact. Despite 2 layers of protective clothing and 2 pairs of gloves, hand hygiene remains an essential aspect of PPE because previous studies have reported that organisms can spread from gloves to hands after glove removal.[41]

## RISKS OF PPE

Outbreaks of EVD, with the exception of the Reston subtype, have occurred exclusively in central sub-Saharan Africa and more recently in West Africa where the climates are known for high ambient temperatures and humidity throughout the year. PPE worn in these settings significantly increase the risk of heat stress and pose yet another risk to the HCP. The risk of heat stress when wearing PPE depends on a number of factors, including length of work shift, ambient temperatures, hydration status, and preexisting medical conditions among others. Strategies to mitigate the risk of heat stress for HCP must be implemented such as the use of buddy systems to monitor the health of providers inside the high-risk area, hydration breaks in between shifts, and consideration of time limitations in staffing determinations. In addition, other strategies were used in the current outbreak, including the use of cooling vests and air conditioning, which have extended the time that providers can spend with patients. Ongoing studies by the National Institute for Occupational Safety and Health are evaluating the effect of different types of PPE on core body temperature.[42]

Recommendations from the CDC for reducing heat stress–related complications include the following[43]: (1) educate HCP how PPE places them at a higher risk of heat-related illness, (2) acclimatize HCP to PPE conditions by gradually increasing their time working in PPE, (3) stay well hydrated, (4) watch for signs and symptoms of heat-related illness, and (5) ensure adequate breaks in between shifts to rest and cool down.

## CONCLUSION

The devastation in West Africa exacted by Ebola will be felt for decades to come. In addition to the unprecedented numbers of infections and deaths, this epidemic has also decimated the HCP population that will leave an already susceptible region at risk well beyond the end of this epidemic. In this epidemic 869 HCP were infected and 507 died to date, more than any other Ebola outbreak and likely more than all previous outbreaks combined. Protection of HCP who bravely work on the front lines must be a priority. Although the use of PPE is an integral part of HCP safety, it must be used as part of a universal infection prevention and control strategy that incorporates environmental and administrative controls, sustained logistical support, and the use of scientific evidence to back current recommendations. There have been 25 outbreaks since the Ebola virus was discovered in 1976, and they are occurring with increased frequency. The question is not whether another outbreak will occur, but when. Improved PPE and evidence-based recommendations are a priority.

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Drs. Fischer, Weber, and Wohl contributed equally to this work.

## CONFLICTS OF INTEREST

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## REFERENCES

1. World Health Organization. Statement on the 1st meeting of the IHR Emergency Committee on the 2014 Ebola outbreak in West Africa. http://www.who.int/mediacentre/news/statements/2014/ebola-20140808/en/. Accessed February 1, 2015.
2. The World Bank. Physicians (per 1,000 people). http://data.worldbank.org/indicator/SH.MED.PHYS.ZS?order=wbapi_data_value_2010+wbapi_data_value&sort=asc. Accessed August 18, 2014.
3. Weber DJ, Rutala WA, Schaffner W. Lessons learned: protection of healthcare workers from infectious disease risks. *Crit Care Med*. 2010;38(8 Suppl):S306–S314.
4. Ofner M, Lem M, Sarwal S, et al. Cluster of severe acute respiratory syndrome cases among protected health care workers-Toronto, April 2003. *Can Commun Dis Rep*. 2003;29:93–97.
5. Zamora JE, Murdoch J, Simchison B, Day AG. Contamination: a comparison of 2 personal protective systems. *CMAJ*. 2006;175:249–254.
6. MacIntyre CR, Chughtai AA, Seale H, et al. Uncertainty, risk analysis and change for Ebola personal protective equipment guidelines. *Int J Nurs Stud*. 2015;52:899–903.
7. Feldmann H, Geisbert TW. Ebola haemorrhagic fever. *Lancet*. 2011;377:849–862.
8. Rodriguez LL, De Roo A, Guimard Y, et al. Persistence and genetic stability of Ebola virus during the outbreak in Kikwit, Democratic Republic of the Congo, 1995. *J Infect Dis*. 1999;179(Suppl 1). S170-6.
9. Towner JS, Rollin PE, Bausch DG, et al. Rapid diagnosis of Ebola hemorrhagic fever by reverse transcription-PCR in an outbreak setting and assessment of patient viral load as a predictor of outcome. *J Virol*. 2004;78:4330–4341.
10. Osterholm MT, Moore KA, Kelley NS, et al. Transmission of Ebola viruses: what we know and what we do not know. *MBio*. 2015;6:e00137.
11. 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.
12. Ebola haemorrhagic fever in Sudan, 1976. Report of a WHO/International Study Team. *Bull World Health Organ*. 1978;56:247–270.
13. Dowell SF, Mukunu R, Ksiazek TG, et al. Transmission of Ebola hemorrhagic fever: a study of risk factors in family members, Kikwit, Democratic Republic of the Congo, 1995. Commission de Lutte contre les Epidemies a Kikwit. *J Infect Dis*. 1999;179(Suppl 1):S87–S91.
14. Francesconi P, Yoti Z, Declich S, et al. Ebola hemorrhagic fever transmission and risk factors of contacts, Uganda. *Emerg Infect Dis*. 2003;9:1430–1437.
15. Jaax NK, Davis KJ, Geisbert TJ, et al. Lethal experimental infection of rhesus monkeys with Ebola-Zaire (Mayinga) virus by the oral and conjunctival route of exposure. *Arch Pathol Lab Med*. 1996;120:140–155.

16. Kreuels B, Wichmann D, Emmerich P, Schmidt-Chanasit J, de Heer G, Kluge S, Sow A, Renne T, Gunther S, Lohse AW, Addo MM, Schmiedel S. A case of severe Ebola virus infection complicated by gram-negative septicemia. *N Engl J Med*. 2014;371:2394–2401.
17. Prescott J, Bushmaker T, Fischer R, et al. Postmortem stability of Ebola virus. *Emerg Infect Dis*. 2015;21:856–859.
18. Roels TH, Bloom AS, Buffington J, et al. Ebola hemorrhagic fever, Kikwit, Democratic Republic of the Congo, 1995: risk factors for patients without a reported exposure. *J Infect Dis*. 1999;179(Suppl 1):S92–S97.
19. Piercy TJ, Smither SJ, Steward JA, et al. The survival of filoviruses in liquids, on solid substrates and in a dynamic aerosol. *J Appl Microbiol*. 2010;109:1531–1539.
20. Bausch DG, Towner JS, Dowell SF, et al. Assessment of the risk of Ebola virus transmission from bodily fluids and fomites. *J Infect Dis*. 2007;196(Suppl 2):S142–S147.
21. What we're afraid to say about Ebola. *NY Times (Print)*. September 11, 2015, A31.
22. Wong G, Qiu X, Richardson JS, et al. Ebola virus transmission in guinea pigs. *J Virol*. 2015;89:1314–1323.
23. Jaax N, Jahrling P, Geisbert T, et al. Transmission of Ebola virus (Zaire strain) to uninfected control monkeys in a biocontainment laboratory. *Lancet*. 1995;346:1669–1671.
24. Weingartl HM, Embury-Hyatt C, Nfon C, et al. Transmission of Ebola virus from pigs to non-human primates. *Sci Rep*. 2012;2:811.
25. Kerstiens B, Matthys F. Interventions to control virus transmission during an outbreak of Ebola hemorrhagic fever: experience from Kikwit, Democratic Republic of the Congo, 1995. *J Infect Dis*. 1999;179(Suppl 1):S263–S267.
26. Franz DR, Jahrling PB, Friedlander AM, et al. Clinical recognition and management of patients exposed to biological warfare agents. *JAMA*. 1997;278:399–411.
27. Centers for Disease Control and Prevention. Infection Prevention and Control Recommendations for Hospitalized Patients Under Investigation (PUIs) for Ebola Virus Disease (EVD) in U.S. Hospitals. http://www.cdc.gov/vhf/ebola/hcp/infection-prevention-and-control-recommendations.html. Accessed June 6, 2015.
28. World Health Organization. Infection prevention and control (IPC) Guidance Summary: Ebola guidance package, August 2014. http://www.searo.who.int/srilanka/documents/infection_prevention_and_control_guidance_summary.pdf. Accessed June 6, 2015.
29. Centers for Disease Control and Prevention. Basic Infection Control and Prevention Plan for Outpatient Oncology Setings. http://www.cdc.gov/HAI/settings/outpatient/basic-infection-control-prevention-plan-2011/standard-precautions.html. Accessed June 6, 2015.
30. World Health Organization. Standard precautions in health care. http://www.who.int/csr/resources/publications/EPR_AM2_E7.pdf. Accessed 2015.
31. Centers for Disease Control and Prevention. Workplace Safety and Health Topics: Hierarchy of Controls. http://www.cdc.gov/niosh/topics/hierarchy/. Accessed June 6, 2015.
32. Bah EI, Lamah MC, Fletcher T, et al. Clinical presentation of patients with Ebola virus disease in Conakry, Guinea. *N Engl J Med*. 2015;372:40–47.
33. Nicas M, Best D. A study quantifying the hand-to-face contact rate and its potential application to predicting respiratory tract infection. *J Occup Environ Hyg*. 2008;5:347–352.
34. Centers for Disease Control and Prevention. Guidance on Personal Protective Equipment To Be Used by Healthcare Workers During Management of Patients with Ebola Virus Disease in U.S. Hospitals, Including Procedures for Putting On (Donning) and Removing (Doffing). http://www.cdc.gov/vhf/ebola/healthcare-us/ppe/guidance.html. Accessed June 6, 2015.
35. World Health Organization. Personal protective equipment in the context of filovirus disease outbreak response; October 2014. http://apps.who.int/iris/bitstream/10665/137410/1/WHO_EVD_Guidance_PPE_14.1_eng.pdf?ua=1. Accessed June 6, 2015.
36. Sprecher AG, Caluwaerts A, Draper M, et al. Personal protective equipment for filovirus epidemics: a call for better evidence. *J Infect Dis*. 2015. [Epub ahead of print].
37. Fischer WA 2nd, Hynes NA, Perl TM. Protecting health care workers from Ebola: personal protective equipment is critical but is not enough. *Ann Intern Med*. 2014;161:753–754.
38. Levy B, Rao C, Miller L, et al. Ebola infection control in Sierra Leonean health clinics: a large cross-agency cooperative project. *Am J Infect Control*. 2015;43:752–755.
39. Casanova L, Rutala WA, Weber DJ, Sobsey MD. Methods for the recovery of a model virus from healthcare personal protective equipment. *J Appl Microbiol*. 2009;106:1244–1251.
40. Casanova L, Alfano-Sobsey E, Rutala WA, et al. Virus transfer from personal protective equipment to healthcare employees' skin and clothing. *Emerg Infect Dis*. 2008;14:1291–1293.
41. Doebbeling BN, Pfaller MA, Houston AK, Wenzel RP. Removal of nosocomial pathogens from the contaminated glove. Implications for glove reuse and handwashing. *Ann Intern Med*. 1988;109:394–398.

42. Centers for Disease Control and Prevention. NIOSH Science Blog; Fighting Ebola: A Grand Challenge for Development - How NIOSH Is Helping Design Improved Personal Protective Equipment for Healthcare Workers; 2015. http://blogs.cdc.gov/niosh-science-blog/2015/02/05/ebola-ppe/. Accessed June 6, 2015.
43. Centers for Disease Control and Prevention. Interim Guidance for Healthcare Workers Providing Care in West African Countries Affected by the Ebola Outbreak: Limiting Heat Burden While Wearing Personal Protective Equipment (PPE). http://www.cdc.gov/vhf/ebola/hcp/limiting-heat-burden.html. Accessed June 6, 2015.

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