

Contextual data

KQ 10 – “Should health workers who have direct or indirect contact with patients who have Ebola or Marburg disease be sprayed versus not sprayed during the doffing of personal protective equipment?”

Guideline recommendations

Table 1 summarizes recommendations regarding doffing of PPE by the WHO, US CDC and European CDC.^{1 2 3}

Figure 1 and 2 displays the doffing procedures according to the WHO 2014 guides, including coverall and gown, respectively. **These procedures do not involve spraying.**¹

Section 9C of the US CDC 2014 guides outlines the PPE doffing procedure for the Powered Air-Purifying Respirator (PAPR) option, including 19 steps and in particular, steps related to disinfecting of outer gloves, inner gloves and washable shoes with either a disinfectant wipe or alcohol-based hand rub (ABHR), and allow drying. Section 9D outlines the PPE doffing procedure for N95 respirator option, including 23 steps and in particular similar disinfecting steps. **None of the disinfecting steps involves spraying.**²

Section 5.3 of the European CDC 2014 guides describe the PPE doffing procedures, including 16 steps. **None of the steps involves spraying.**³ The procedures call for using alcohol-based hand disinfectant or a disinfectant for non-enveloped viruses at various steps of the doffing process. The procedures suggest that during the doffing process, the assistant can wear up to four pairs of gloves on top of each other, which saves time on changing the gloves. Instead of having to put on a new pair of gloves every time, the assistant will simply remove the outer pair. The use of this approach needs to be balanced with its limitations, as wearing four layers might compromise tactility and motility.

Contextual data

Table 2 summarizes the contextual data.

Key findings

- We identified 14 studies describing steps of the doffing protocols. None of the doffing protocols includes a discrete step describing the practice of spraying PPEs. Eleven studies did not use the word “spray”. Three studies mentioned the word “spray” as part of the study reporting.
- PPE can both protect and put health workers at risk for self-contamination throughout the doffing process, even among experienced HCWs doffing with a trained observer.
- During PPE doffing, common protocol deviations included touching outer gloves with inner-gloved hands and touching the outside of gloves with bare hands. Hand hygiene and glove removal are high-risk opportunities for health-worker self-contamination.
- Doffing protocols need to incorporate *highly effective glove and hand hygiene agents*. Optimizing doffing protocols may require reinforcing careful handling of scrubs and good glove/hand hygiene with effective agents.
- Hands-free alcohol based hand rub delivered directly into the HCWs’ palm keeping the dispenser uncontaminated.
- In the UK, a consensus protocol calls for three layers of gloves: • Inner personal protection glove (standard short non-sterile glove) • Middle glove (long cuffed glove), taped to gown • Outer glove comprising either standard short non-sterile gloves for basic care, or heavier duty gloves for cleaning up of extreme bodily fluid episodes.

Casanova et al. 2016 conducted a practice simulation study in which 15 health workers donned PPE, surrogate virus was applied to PPE, and a trained monitor guided them through the doffing protocol.⁴ Of the 15 participants, ten participants used alcohol-based hand rub (ABHR) for glove and hand hygiene and 5 used hypochlorite for glove hygiene and ABHR for hand hygiene. Inner gloves, hands, face, and scrubs were sampled after doffing. *For the last 5 subjects, each step that called for sanitizing gloved hands was performed with liquid hypochlorite at a concentration of 1,850 ppm (Fuzion Healthcare Disinfectant, Clorox Co., Pleasanton, CA) applied by spraying onto gloves.* The authors report that after doffing, MS2 virus was detected on the inner glove worn on the dominant hand for 8 of 15 participants, on the non-dominant inner glove for 6 of 15 participants, and on scrubs for 2 of 15 participants. *All MS2 on inner gloves was observed when ABHR was used for glove hygiene; none was observed when hypochlorite was used.* When using hypochlorite for glove hygiene, 1 participant had MS2 on hands, and 1 had MS2 on scrubs. According to the authors' conclusion, a structured doffing protocol using a trained monitor and ABHR protects against enveloped virus self-contamination. *Non-enveloped virus (MS2) contamination was detected on inner gloves, possibly due to higher resistance to ABHR.* Doffing protocols protective against all viruses need to incorporate *highly effective glove and hand hygiene agents.*

Casanova et al. 2017 assessed contamination of skin, gloves, and scrubs after doffing Ebola-level PPE contaminated with surrogate viruses: bacteriophages MS2 and $\Phi 6$.⁵ In a medical biocontainment unit, HCWs (n = 10) experienced in EVD care donned and doffed PPE following unit protocols that incorporate trained observer guidance and alcohol-based hand rub (ABHR). A mixture of $\Phi 6$ (enveloped), MS2 (non-enveloped), and fluorescent marker was applied to 4 PPE sites, approximating body fluid viral load ($\Phi 6$, 10^5 ; MS2, 10^6). They performed a patient care task, then doffed. Inner gloves, face, hands, and scrubs were sampled for virus, as were environmental sites with visible fluorescent marker.

Among 10 HCWs there was no $\Phi 6$ transfer to inner gloves, hands, or face; 1 participant had $\Phi 6$ on scrubs at low levels (1.4×10^2). MS2 transfer (range, 10^1 – 10^6) was observed to scrubs (n = 2), hands (n = 1), and inner gloves (n = 7), where it was highest. Most (n = 8) had only 1 positive site. According to the authors' conclusion, among experienced HCWs, structured, observed doffing using ABHR protected against hand contamination with enveloped virus. Non-enveloped virus was infrequent on hands and scrubs but common on inner gloves, suggesting that inner gloves, but not necessarily ABHR, protect against hand contamination. *Optimizing doffing protocols to protect against all types of viruses may require reinforcing careful handling of scrubs and good glove/hygiene with effective agents.*

McLaws et al. 2016 reviewed video guidelines and guidelines considered to lead infection control globally and a modified Centers for Disease Control and Prevention (CDC) video and a local video from the New South Wales Ministry of Health.⁶ Each video was reviewed with the intent of identifying exemplary doffing for the principle that no used PPE surface should come into contact with mucous membranes, face, or hair. Their review identified a lack of consensus for three critical areas: sequence, assistance, and environment.

The Médecins Sans Frontières video illustrates spraying the heavy duty apron with bleach, but later sequencing of the removal of the facial protection would improve the margin of error. For the removal of boots, that have already been decontaminated in a 0.5% chlorine footbath but that may have become re-contaminated during doffing of coveralls, the North Carolina video instructs the HCW to keep boots within the doffing zone while turning to sit on a chair that is located inside the clean zone. This modification to the CDC video includes an excellent additional step that prevents the environment outside the doffing area from becoming contaminated. This video also demonstrates the HCW standing in a basin of bleach for 1 minute before stepping onto a mat that is in accordance with the MSF guideline used in Ebola treatment units. *The study authors suggest that hands-free alcohol based hand rub (ABHR) delivered directly into the HCWs' palm keeping the dispenser uncontaminated.*

Reidy et al. 2017 describe the process of selecting the combination of personal protective equipment (PPE) together with donning and doffing protocols for British and Canadian military medical personnel in the Kerry Town Ebola Treatment Unit (ETU) in Sierra Leone.⁷ *In the last step of the doffing protocol, the HCWs step on rubber disinfection mat, scrape soles of boots on mat, step out of chlorine bath and boot-spraying area, and exit.* The doffing protocol calls for repeated washing gloved hands in 0.5% chlorine; clean tap by rinsing with chlorine before turning tap off.

Poller, 2018 conducted a simulation-based exercise to assess the safety of PPE ensembles in use in the UK during first assessment of a patient with a possible high-consequence infectious disease (HCID).⁸ A mannequin was adapted to expose volunteer HCWs to synthetic bodily fluids (vomit, sweat, diarrhoea and cough), each with a different colored fluorescent tracer, invisible other than under ultraviolet (UV) light. After exposure, HCWs were examined under UV lights to locate fluorescent contamination, and were screened again after removing PPE (doffing) to detect any personal contamination. The exercise was videoed, allowing retrospective analysis of contamination events and user errors.

The simulation testing *identified significant HCW contamination events after doffing*, related to protocol failure or complications in PPE doffing, providing conclusive evidence that improvements could be made. *At a workshop with an expert stakeholder group, the data were examined and a unified PPE ensemble agreed. This ensemble was then tested in the same simulation exercise and no evidence of any HCW contamination was seen after doffing.* Following further review by the working group, a consensus agreement has been reached and a unified 'HCID assessment PPE' ensemble, with accompanying donning and doffing protocols, is presented here. *The final protocol used three layers of gloves: • Inner personal protection glove (standard short non-sterile glove) • Middle glove (long cuffed glove), taped to gown • Outer glove comprising either standard short non-sterile gloves for basic care, or heavier duty gloves for cleaning up of extreme bodily fluid episodes.*

References

1. Organization WH. *Personal protective equipment for use in a filovirus disease outbreak: rapid advice guideline*. World Health Organization; 2016.
2. Center for Disease Control. Rationale and Considerations for Chlorine Use in Infection Control for Non- U.S. General Healthcare Settings. <https://www.cdc.gov/vhf/ebola/clinicians/non-us-healthcare-settings/chlorine-use.html>.
3. European Centre for Disease Prevention and Control. Safe use of personal protective equipment in the treatment of infectious diseases of high consequence. Stockholm: ECDC; 2014. 2014.
4. Casanova LM, Teal LJ, Sickbert-Bennett EE, et al. Assessment of Self-Contamination During Removal of Personal Protective Equipment for Ebola Patient Care. *Infection control and hospital epidemiology*. 2016;37(10):1156-1161.
5. Casanova LM, Erukunuakpor K, Kraft CS, et al. Assessing Viral Transfer During Doffing of Ebola-Level Personal Protective Equipment in a Biocontainment Unit. *Clinical infectious diseases : an official publication of the Infectious Diseases Society of America*. 2018;66(6):945-949.
6. McLaws ML, Chughtai AA, Salmon S, MacIntyre CR. A highly precautionary doffing sequence for health care workers after caring for wet Ebola patients to further reduce occupational acquisition of Ebola. *American journal of infection control*. 2016;44(7):740-744.
7. Reidy P, Fletcher T, Shieber C, et al. Personal protective equipment solution for UK military medical personnel working in an Ebola virus disease treatment unit in Sierra Leone. *The Journal of hospital infection*. 2017;96(1):42-48.
8. Poller B, Tunbridge A, Hall S, et al. A unified personal protective equipment ensemble for clinical response to possible high consequence infectious diseases: A consensus document on behalf of the HCID programme. *The Journal of infection*. 2018;77(6):496-502.
9. Cummings KJ, Choi MJ, Esswein EJ, et al. Addressing Infection Prevention and Control in the First U.S. Community Hospital to Care for Patients With Ebola Virus Disease: Context for National Recommendations and Future Strategies. *Ann Intern Med*. 2016;165(1):41-49.
10. Andonian J, Kazi S, Therkorn J, et al. Effect of an Intervention Package and Teamwork Training to Prevent Healthcare Personnel Self-contamination During Personal Protective Equipment Doffing. *Clinical infectious diseases : an official publication of the Infectious Diseases Society of America*. 2019;69(Suppl 3):S248-s255.
11. Bell T, Smoot J, Patterson J, Smalligan R, Jordan R. Ebola virus disease: The use of fluorescents as markers of contamination for personal protective equipment. *IDCases*. 2015;2(1):27-30.
12. Chughtai AA, Chen X, Macintyre CR. Risk of self-contamination during doffing of personal protective equipment. *American journal of infection control*. 2018;46(12):1329-1334.
13. Kwon JH, Burnham CD, Reske KA, et al. Assessment of Healthcare Worker Protocol Deviations and Self-Contamination During Personal Protective Equipment Donning and Doffing. *Infection control and hospital epidemiology*. 2017;38(9):1077-1083.
14. Lim SM, Cha WC, Chae MK, Jo IJ. Contamination during doffing of personal protective equipment by healthcare providers. *Clinical and experimental emergency medicine*. 2015;2(3):162-167.
15. Mumma JM, Durso FT, Ferguson AN, et al. Human Factors Risk Analyses of a Doffing Protocol for Ebola-Level Personal Protective Equipment: Mapping Errors to Contamination. *Clinical infectious diseases : an official publication of the Infectious Diseases Society of America*. 2018;66(6):950-958.
16. Mumma JM, Durso FT, Casanova LM, et al. Common Behaviors and Faults When Doffing Personal Protective Equipment for Patients With Serious Communicable Diseases. *Clinical infectious diseases : an official publication of the Infectious Diseases Society of America*. 2019;69(Suppl 3):S214-s220.

17. Suen LKP, Guo YP, Tong DWK, et al. Self-contamination during doffing of personal protective equipment by healthcare workers to prevent Ebola transmission. *Antimicrobial resistance & infection control*. 2018;7(1):157-157.
18. Jinadatha C, Simmons S, Dale C, et al. Disinfecting personal protective equipment with pulsed xenon ultraviolet as a risk mitigation strategy for health care workers. *American journal of infection control*. 2015;43(4):412-414.
19. Lee M-a, Huh K, Jeong J, et al. Adherence to protocols by healthcare workers and self-contamination during doffing of personal protective equipment. *American journal of infection control*. 2018;46(6):S11.

Table 1: Summary of guideline recommendations regarding disinfection of Ebola-exposed surfaces by the WHO, US and European CDC

Source	Should health workers who have direct or indirect contact with patients who have Ebola or Marburg disease be sprayed versus not sprayed during the doffing of PPE?
WHO	2014
Doffing procedure ¹	Figure 1 and 2 displays the doffing procedures including coverall and gown, respectively. The procedures do not involve spraying.
US CDC ²	2014
Doffing procedure	Section 9C of the US CDC guides outlines the PPE doffing procedure for the Powered Air-Purifying Respirator (PAPR) option, including 19 steps and in particular, steps related to disinfecting of outer gloves, inner gloves and washable shoes with either an disinfectant wipe or alcohol-based hand rub (ABHR), and allow to dry. Section 9D outlines the PPE doffing procedure for N95 respirator option, including 23 steps and in particular similar disinfecting steps. None of the disinfecting steps involves spraying.
European CDC ³	2014
Doffing procedure	Section 5.3 describes the PPE doffing procedures, including 16 steps. None of the steps involves spraying. The procedures call for using alcohol-based hand disinfectant or a disinfectant for non-enveloped viruses at various steps of the doffing process. The procedures suggest that during the doffing process, the assistant can wear up to four pairs of gloves on top of each other, which saves time on changing the gloves. Instead of having to put on a new pair of gloves every time, the assistant will simply remove the outer pair. The use of this approach needs to be balanced with its limitations, as wearing four layers might compromise tactility and motility.

Table 2. Summary of contextual data

Author, year	Study methods	Method details, measures or findings relevant to the extraction of contextual data	Data type	Contextual data
Casanova, 2016 ⁴	Testing study (N.B. Spraying for disinfecting purposes)	A total of 15 HCP donned EVD PPE for this study. Virus was applied to PPE, and a trained monitor guided them through the doffing protocol. Of the 15 participants, 10 used alcohol-based hand rub (ABHR) for glove and hand hygiene and 5 used hypochlorite for glove hygiene and ABHR for hand hygiene. Inner gloves, hands, face, and scrubs were sampled after doffing. For the last 5 subjects, each step that called for sanitizing gloved hands was performed with liquid hypochlorite at a concentration of 1,850 ppm (Fuzion Healthcare Disinfectant, Clorox Co., Pleasanton, CA) applied by spraying onto gloves.		Results: After doffing, MS2 virus was detected on the inner glove worn on the dominant hand for 8 of 15 participants, on the non-dominant inner glove for 6 of 15 participants, and on scrubs for 2 of 15 participants. All MS2 on inner gloves was observed when ABHR was used for glove hygiene; none was observed when hypochlorite was used. When using hypochlorite for glove hygiene, 1 participant had MS2 on hands, and 1 had MS2 on scrubs. Conclusions: A structured doffing protocol using a trained monitor and ABHR protects against enveloped virus self-contamination. Non-enveloped virus (MS2) contamination was detected on inner gloves, possibly due to higher resistance to ABHR. Doffing protocols protective against all viruses need to incorporate highly effective glove and hand hygiene agents.
McLaws, 2016 ⁶	Review of video guidelines	We reviewed video guidelines and guidelines considered to lead infection control globally ¹⁰⁻¹² and a modified Centers for Disease Control and Prevention (CDC) video ¹³ and a local video from the New South Wales Ministry of Health. ¹⁴ Each video was reviewed with the intent of identifying exemplary doffing for the principle that no used PPE surface should come into contact with mucous membranes, face, or hair. Our review identified a lack of consensus for 3 critical areas: sequence, assistance, and environment (Table 1).	Implementation	The Médecins Sans Frontières video illustrates spraying the heavy duty apron with bleach, but later sequencing of the removal of the facial protection would improve the margin of error. For the removal of boots, that have already been decontaminated in a 0.5% chlorine footbath but that may have become re-contaminated during doffing of coveralls, the North Carolina video instructs the HCW to keep boots within the doffing zone while turning to sit on a chair that is located inside the clean zone. This modification to the CDC video includes an excellent additional step that prevents the environment outside the doffing area from becoming contaminated. This video also demonstrates the HCW standing in a basin of bleach for 1 minute before stepping onto a mat that is in accordance with the MSF guideline used in Ebola treatment units. The study authors suggest that hands-free alcohol based hand rub (ABHR) delivered directly into the HCWs' palm keeping the dispenser uncontaminated.
Reidy, 2017 ⁷	PPE protocol description	The combination of personal protective equipment (PPE) together with donning and doffing protocols was designed to protect British and Canadian military medical personnel in the Kerry Town Ebola Treatment Unit (ETU) in Sierra Leone. The PPE solution was selected to protect medical staff from infectious risks, notably Ebola virus, and chemical (hypochlorite) exposure. In the last step of the doffing protocol, the HW steps on rubber disinfection mat and scrape soles of boots on mat. She/he then steps out of chlorine bath, boot-spraying area and exits.	Implementation	The selected PPE maximized dexterity, enabled personnel to work in hot temperatures for periods of up to 2 h, protected mucosal membranes when doffing outer layers, and minimized potential contamination of the doffing area with infectious material by reducing the requirement to spray PPE with hypochlorite. Competency in using PPE was developed during a nine-day pre-deployment training program. This allowed over 60 clinical personnel per deployment to practice skills in PPE in a simulated ETU and in classrooms. Overall, the training provided: (i) an evidence base underpinning the PPE solution chosen; (ii) skills in donning and doffing of PPE; (iii) personnel confidence in the selected PPE; and (iv) quantifiable testing of each individual's capability to don PPE, perform tasks and doff PPE safely. (N.B. The doffing protocol calls for repeated washing gloved hands in 0.5% chlorine; clean tap by rinsing with chlorine before turning tap off)
Cummings, 2016 ⁹	Practice reflection (N.B. No spraying for disinfecting purposes)	After admission of the first patient with EVD, a multidisciplinary team from the Centers for Disease Control and Prevention (CDC) joined the hospital's infection prevention to implement a system of occupational safety and health controls for direct patient care, handling of clinical specimens, and managing regulated medical waste. Existing engineering and administrative controls were strengthened. The personal protective equipment (PPE) ensemble was standardized, HCP were trained on donning and doffing PPE, and a system of trained observers supervising PPE donning and doffing was implemented. Standardized PPE ensembles for all HCP. Instituted a system of trained observers (donning/doffing coaches), including a 22-step doffing procedure, which does not involve disinfection spraying.	Implementation	The experiences of the authors and others informed national policies for the care of patients with EVD and protection of HCP, including new guidance for PPE, a rapid system for deploying CDC staff to assist hospitals ("Ebola Response Team"), and a framework for a tiered approach to hospital preparedness. Hygiene of hands and gloved hands appear to be conducted with hospital-grade disinfecting chlorine wipes.

Casanova, 2017⁴	Testing study (N.B. No spraying for disinfecting purposes)	We assessed contamination of skin, gloves, and scrubs after doffing Ebola-level PPE contaminated with surrogate viruses: bacteriophages MS2 and Φ6. Methods: In a medical biocontainment unit, HCWs (n = 10) experienced in EVD care donned and doffed PPE following unit protocols that incorporate trained observer guidance and alcohol-based hand rub (ABHR). A mixture of Φ6 (enveloped), MS2 (non-enveloped), and fluorescent marker was applied to 4 PPE sites, approximating body fluid viral load (Φ6, 105; MS2, 106). They performed a patient care task, then doffed. Inner gloves, face, hands, and scrubs were sampled for virus, as were environmental sites with visible fluorescent marker.	Implementation	Results. Among 10 HCWs there was no Φ6 transfer to inner gloves, hands, or face; 1 participant had Φ6 on scrubs at low levels (1.4 × 10 ²). MS2 transfer (range, 101–106) was observed to scrubs (n = 2), hands (n = 1), and inner gloves (n = 7), where it was highest. Most (n = 8) had only 1 positive site. Conclusions. Among experienced HCWs, structured, observed doffing using ABHR protected against hand contamination with enveloped virus. Non-enveloped virus was infrequent on hands and scrubs but common on inner gloves, suggesting that inner gloves, but not necessarily ABHR, protect against hand contamination. Optimizing doffing protocols to protect against all types of viruses may require reinforcing careful handling of scrubs and good glove/hand hygiene with effective agents.
Andonian, 2019¹⁰	Randomized controlled trial (N.B. No spraying for disinfecting purposes)	A set of interventions based on previously identified failure modes was designed to mitigate the risk of self- contamination during PPE doffing. These interventions were tested in a randomized controlled trial of 48 participants with no prior experience doffing enhanced PPE. Contamination was simulated using a fluorescent tracer slurry and fluorescent polystyrene latex spheres (PLSs). Self-contamination of scrubs and skin was measured using ultraviolet light visualization and swabbing followed by microscopy, respectively. Doffing sessions were videotaped and reviewed to score standardized teamwork behaviors.	Implementation	An intervention package addressing the PPE doffing task, tools, environment, and teamwork skills significantly reduced the amount of self-contamination by study participants. These elements can be incorporated into PPE guidance and training to reduce the risk of pathogen transmission. None of the elements is related to spraying or not spraying for disinfection during PPE doffing.
Bell, 2015¹¹	Randomized controlled trial (N.B. No spraying for disinfecting purposes)	PPE testing has historically been done by individual component, rather than as a bundle for contact isolation. Fluorescent agents are commonly used in training for infection control techniques. The purpose of our study was to compare 2 PPE bundles and to evaluate the feasibility of fluorescent markers as an assessment tool for PPE effectiveness. Eight healthcare providers volunteered for this preliminary study. Participants were randomized to 1 of 2 PPE bundles that meet current 2014 CDC recommendations. A training mannequin was contaminated with fluorescent agents to simulate bodily fluids. Participants were then given clinical tasks to care for the EVD “patient.”	Implementation	One participant in each PPE arm had evidence of contamination. One of the contamination events was suspected during the patient care exercise. The other contamination event was not suspected until black light examination. In spite of a large difference in cost of PPE, the two bundle arms performed similarly. Bundle testing using fluorescent markers could help identify optimal PPE systems. None of the PPE doffing procedures involves spraying for disinfecting purposes.
Chughtai, 2018¹²	Testing study (N.B. No spraying for disinfecting purposes)	Methods: We tested 10 different PPE donning and doffing protocols, recommended by various health organizations for Ebola. Ten participants were recruited for this study and randomly assigned to use 3 different PPE protocols. After donning of PPE, fluorescent lotion and spray were applied on the external surface of the PPE to simulate contamination, and ultraviolet light was used to count fluorescent patches on the skin.	Implementation	Results: After testing 30 PPE sequences, large fluorescent patches were recorded after using “WHO coverall and N95” and “North Carolina coverall and N95” sequences, and small patches were recorded after using “CDC coverall and N95” and “Health Canada gown and N95” sequences. Commonly reported problems with PPE use were breathing difficulty, suffocation, heat stress, and fogging-up glasses. Most participants rated PPE high (18/30) or medium (11/30) for ease of donning/doffing and comfort. PPE sequences with powered air-purifying respirators (PAPRs) and assisted doffing were generally associated with fewer problems and were rated the highest. Conclusion: This study confirmed the risk of self-contamination associated with the doffing of PPE. PAPR containing protocols and assisted doffing should be preferred whenever possible during the outbreak of highly infectious pathogens.
Kwon, 2017¹³	Testing study	A total of 36 HCWs were included in this study: 18 donned/doffed contact precaution (CP) PPE and 18 donned/doffed Ebola virus disease (EVD) PPE. HCWs donned PPE according to standard protocols based on CDC recommendations. Fluorescent liquid and MS2 bacteriophage were applied to HCWs. HCWs then doffed their PPE. After doffing, HCWs were scanned for fluorescence and swabbed for MS2. MS2 detection was performed using reverse transcriptase PCR. The donning and doffing processes were videotaped, and protocol deviations were recorded.	Implementation	Hand hygiene and glove removal protocol deviations were common during doffing of both EVD and CP PPE (67% and 39% of HCWs made ≥ 1 error, respectively). <i>During EVD PPE doffing, common protocol deviations included touching outer gloves with inner-gloved hands and touching the outside of gloves with bare hands. Hand hygiene and glove removal are high-risk opportunities for HCW self-contamination.</i> For both the EVD and CP groups, we found fluorescence on HCW hands more often than any other site. HCWs may benefit from targeted training in the correct method for glove removal during EVD PPE doffing.

Lim, 2015 ¹⁴	Doffing practice simulation study (N.B. No spraying for disinfecting purposes)	We recruited study participants among physicians and nurses of the emergency department of Samsung Medical Center in Seoul, Korea. Participants were asked to carry out doffing and donning procedures with a helper after a 50-minute brief training and demonstration based on the 2014 Centers for Disease Control and Prevention protocol. Two separate cameras with high-density capability were set up, and the donning and doffing processes were videotaped. A trained examiner inspected all video recordings and coded for intervals, errors, and contaminations defined as the outside of the equipment touching the clinician's body surface.	Implementation	For the doffing process, the average interval until the end was 183.7 seconds (SD, 38.4), and the most frequent errors occurred during disinfecting the feet (37.9%), discarding the scrubs (17.2%), and putting on gloves (13.7%), respectively. During the doffing process, 65 incidences of contamination occurred (2.2 incidents/person). The most vulnerable processes were removing respirators (79.2%), removing the shoe covers (65.5%), and removal of the hood (41.3%). Conclusion <i>A significant number of contaminations occur during the doffing process of personal protective equipment.</i>
Mumma, 2018 ¹⁵	Doffing practice simulation study (N.B. No spraying for disinfecting purposes)	Eleven HCWs experienced with doffing Ebola-level PPE participated in simulations in which HCWs donned PPE marked with surrogate viruses ($\phi 6$ and MS2) and completed a clinical task. They were assessed for contamination after doffing. Simulations were video recorded, and a failure modes and effects analysis and fault tree analyses were performed to identify errors during doffing, quantify their risk (risk index), and predict contamination data. This protocol used a method for removing gloves and alcohol-based hand rub (ABHR) for all hand hygiene except after removing the inner gloves (final doffing step), when soap and water were used. HCWs used manual (patient's room) and automatic (anteroom) foam dispensers.	Implementation	Results. Fifty-one types of errors were identified, many having the potential to spread contamination. Hand hygiene and removing the powered air purifying respirator (PAPR) hood had the highest total risk indexes (111 and 70, respectively) and number of types of errors (9 and 13, respectively). $\phi 6$ was detected on 10% of scrubs and the fault tree predicted a 10.4% contamination rate, likely occurring when the PAPR hood inadvertently contacted scrubs during removal. MS2 was detected on 10% of hands, 20% of scrubs, and 70% of inner gloves and the predicted rates were 7.3%, 19.4%, 73.4%, respectively. Fault trees for MS2 and $\phi 6$ contamination suggested similar pathways. Conclusions. Ebola-level PPE can both protect and put HCWs at risk for self-contamination throughout the doffing process, even among experienced HCWs doffing with a trained observer. Human factors methodologies can identify error-prone steps, delineate the relationship between errors and self-contamination, and suggest remediation strategies.
Mumma, 2019 ¹⁶	Doffing practice simulation study (N.B. No spraying for disinfecting purposes)	We observed 41 HCWs across 4 Ebola treatment centers in Georgia doffing PPE for simulated patients with serious communicable diseases. Using human factors methodologies, we obtained the details, sequences, and durations of doffing steps; identified the ways each step can fail (failure modes [FMs]); quantified the riskiness of FMs; and characterized the workload of doffing steps.	Implementation	Results. Eight doffing steps were common to all hospitals—removal of boot covers, gloves (outer and inner pairs), the outermost garment, the powered air purifying respirator (PAPR) hood, and the PAPR helmet assembly; repeated hand hygiene (e.g., with hand sanitizer); and a final handwashing with soap and water. Across hospitals, we identified 256 FMs during the common doffing steps, 61 of which comprised 19 common FMs. Most of these common FMs were above average in their riskiness at each hospital. At all hospitals, hand hygiene, removal of the outermost garment, and removal of boot covers were above average in their overall riskiness. Measurements of workload revealed that doffing steps were often mentally demanding, and this facet of workload correlated most strongly with the effort of a doffing step. Conclusions. We systematically identified common points of concern in protocols for doffing high-level PPE. Addressing FMs related to hand hygiene and the removal of the outermost garment, boot covers, and PAPR hood could improve HCW safety when doffing high-level PPE.
Poller, 2018 ⁸	Doffing practice simulation study (N.B. No spraying for disinfecting purposes)	A simulation-based exercise was developed to assess the safety of PPE ensembles in use in the UK during first assessment of a patient with a possible HCID. A mannequin was adapted to expose volunteer HCWs to synthetic bodily fluids (vomit, sweat, diarrhea and cough), each with a different colored fluorescent tracer, invisible other than under ultraviolet (UV) light. After exposure, HCWs were examined under UV lights to locate fluorescent contamination, and were screened again after removing PPE (doffing) to detect any personal contamination. The exercise was videoed, allowing retrospective analysis of contamination events and user errors.	Implementation	The simulation testing identified significant HCW contamination events after doffing, related to protocol failure or complications in PPE doffing, providing conclusive evidence that improvements could be made. At a workshop with an expert stakeholder group, the data were examined and a unified PPE ensemble agreed. This ensemble was then tested in the same simulation exercise and no evidence of any HCW contamination was seen after doffing. Following further review by the working group, a consensus agreement has been reached and a unified 'HCID assessment PPE' ensemble, with accompanying donning and doffing protocols, is presented here. The final protocol used three layers of gloves: • Inner personal protection glove (standard short non-sterile glove) • Middle glove (long cuffed glove), taped to gown • Outer glove comprising either standard short non-sterile gloves for basic care, or heavier duty gloves for cleaning up of extreme bodily fluid episodes

Suen, 2018 ¹⁷	Practice simulation study (N.B. No spraying for disinfecting purposes)	This study aimed to compare the efficacy of three PPE ensembles, namely, Hospital Authority (HA) Standard Ebola PPE set (PPE1), Dupont Tyvek Model, style 1422A (PPE2), and HA isolation gown for routine patient care and performing aerosol-generating procedures (PPE3) to prevent EVD transmission by measuring the degree of contamination of HCWs and the environment. Methods: 59 participants randomly performed PPE donning and doffing. The trial consisted of PPE donning, applying fluorescent solution on the PPE surface, PPE doffing of participants, and estimation of the degree of contamination as indicated by the number of fluorescent stains on the working clothes and environment. Protocol deviations during PPE donning and doffing were monitored.	Implementation	PPE2 and PPE3 presented higher contamination risks than PPE1. Environmental contaminations such as those originating from rubbish bin covers, chairs, faucets, and sinks were detected. Procedure deviations were observed during PPE donning and doffing, with PPE1 presenting the lowest overall deviation rate (%) among the three PPE ensembles ($p < 0.05$). Considering that hand hygiene methods using alcohol hand sanitizer fail to remove the fluorescent solution, handwashing with soap and water was performed by the participants. Although alcohol gel is commonly used nowadays during PPE donning/doffing, hand cleansing with soap and water is recommended in cases of visible contamination in various situations, such as when areas are contaminated by vomitus, respiratory secretions, or fecal matter.
Jinadatha, 2015 ¹⁸	Testing study	Pulsed xenon ultraviolet (PX-UV) disinfection has been used to disinfect surfaces in hospital settings. This study examined the impact of PX-UV disinfection on an Ebola surrogate virus on glass carriers and PPE material to examine the potential benefits of using PX-UV to decontaminate PPE while worn, thereby reducing the pathogen load prior to doffing. Ultraviolet (UV) safety and coverage tests were also conducted.	Implementation	PX-UV exposure resulted in a significant reduction in viral load on glass carriers and PPE materials. Occupational Safety and Health Administration-defined UV exposure limits were not exceeded during PPE disinfection. Pre-doffing disinfection with PX-UV has potential as an additive measure to the doffing practice guidelines. The PX-UV disinfection should not be considered sterilization; all PPE should still be considered contaminated and doffed and disposed of according to established protocols.
Lee, 2018 ¹⁹	Doffing practice simulation study	The study was conducted as a part of training of the dedicated response team for high-consequence emerging infectious diseases (HCEID). HCWs donned PPE that consisted of a coverall, an apron, double gloves, a powered air-purifying respirator (PAPR), and shoe covers. After donning, trainees conducted various simulated activities including intubation and insertion of central venous catheters. Before doffing the PPE, the surface of PPE was artificially contaminated with fluorescent fluid. Doffing of PPE was monitored by another trainee who verbally instructed each step using a checklist. Performance of each step was recorded by infection prevention. Self-contamination was evaluated by the visualization of fluorescent fluid on HCWs using a handheld ultraviolet light.	Implementation	Results: 75 subjects were evaluated. At least one violation of protocol was observed in 22.7% of subjects. Most common violation occurred during decontamination of shoes (9.3%), followed by doffing coverall (8.0%), doffing shoe covers (6.7%), visual inspection for gross contamination (5.3%), doffing gloves (4.0%), doffing PAPR (2.7%), and hand hygiene (1.3%). Self-contamination was detected in 64.0% of subjects. The neck was most commonly contaminated (45.3%), followed by arms (28.0%), hands (26.7%), and the head (20.0%). No specific type of violation was shown to be significantly associated with self-contamination. However, all subjects who missed decontamination of gloves or those who failed to doff gloves properly or PAPR were contaminated. Conclusions: Violation of doffing protocol was common during an intensive training session. Self-contamination was also common during PPE doffing.

Figure 1. Steps to take off personal protective equipment including coverall (Sources: WHO)¹

Steps to take off personal protective equipment (PPE) including coverall

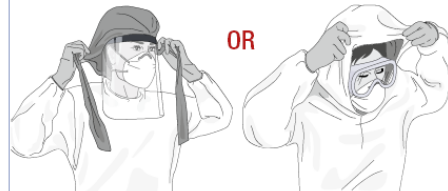
1 Always remove PPE under the **guidance and supervision of a trained observer** (colleague). Ensure that infectious waste containers are available in the **doffing area** for safe disposal of PPE. Separate containers should be available for reusable items.

2 Perform **hand hygiene** on gloved hands.¹

3 Remove **apron** leaning forward and taking care to avoid contaminating your hands. When removing disposable apron, tear it off at the neck and roll it down without touching the front area. Then untie the back and roll the apron forward.



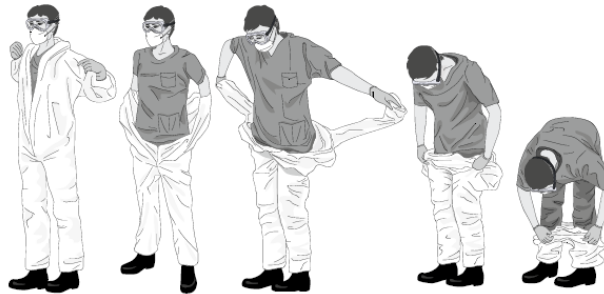
5 Remove **head and neck covering** taking care to avoid contaminating your face by starting from the bottom of the hood in the back and rolling from back to front and from inside to outside, and dispose of it safely.



4 Perform **hand hygiene** on gloved hands.

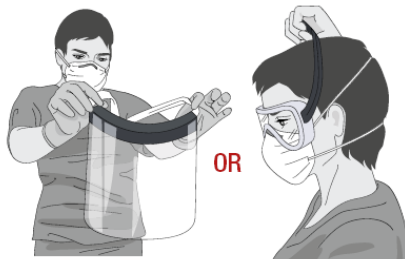
6 Perform **hand hygiene** on gloved hands.

7 Remove **coverall and outer pair of gloves**: Ideally, in front of a mirror, tilt head back to reach zipper, unzip completely without touching any skin or scrubs, and start removing coverall from top to bottom. After freeing shoulders, remove the outer gloves² while pulling the arms out of the sleeves. With inner gloves roll the coverall, from the waist down and from the inside of the coverall, down to the top of the boots. Use one boot to pull off coverall from other boot and vice versa, then step away from the coverall and dispose of it safely.



8 Perform **hand hygiene** on gloved hands.

9 Remove **eye protection** by pulling the string from behind the head and dispose of it safely.



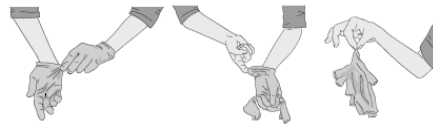
11 Remove the **mask** from behind the head by first untying the bottom string above the head and leaving it hanging in front; and then the top string next from behind head and dispose of it safely.



12 Perform **hand hygiene** on gloved hands.

10 Perform **hand hygiene** on gloved hands.

15 Remove **gloves** carefully with appropriate technique and dispose of them safely.



13 Remove **rubber boots** without touching them (or overshoes if wearing shoes). If the same boots are to be used outside of the high-risk zone, keep them on but clean and decontaminate appropriately before leaving the doffing area.³

14 Perform **hand hygiene** on gloved hands.

16 Perform **hand hygiene**.

¹ While working in the patient care area, outer gloves should be changed between patients and prior to exiting (change after seeing the last patient)

² This technique requires properly fitted gloves. When outer gloves are too tight or inner gloves are too loose and/or hands are sweaty, the outer gloves may need to be removed separately, after removing the apron.

³ Appropriate decontamination of boots includes stepping into a footbath with 0.5% chlorine solution (and removing dirt with toilet brush if heavily soiled with mud and/or organic materials) and then wiping all sides with 0.5% chlorine solution. At least once a day boots should be disinfected by soaking in a 0.5% chlorine solution for 30 min, then rinsed and dried.


Figure 2. Steps to take off personal protective equipment including gown (Sources: WHO)¹

Steps to take off personal protective equipment (PPE) including gown

1 Always remove PPE under the **guidance and supervision of a trained observer** (colleague). Ensure that infectious waste containers are available in the doffing area for safe disposal of PPE. Separate containers should be available for reusable items.

2 Perform **hand hygiene** on gloved hands.¹

3 Remove **apron** leaning forward and taking care to avoid contaminating your hands. When removing disposable apron, tear it off at the neck and roll it down without touching the front area. Then untie the back and roll the apron forward.




4 Perform **hand hygiene** on gloved hands.


5 Remove **outer pair of gloves** and dispose of them safely. Use the technique shown in Step 17

6 Perform **hand hygiene** on gloved hands.

7 Remove **head and neck covering** taking care to avoid contaminating your face by starting from the bottom of the hood in the back and rolling from back to front and from inside to outside, and dispose of it safely.

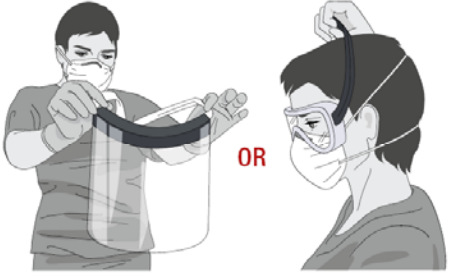


9 Remove the **gown** by untying the knot first, then pulling from back to front rolling it from inside to outside and dispose of it safely.




8 Perform **hand hygiene** on gloved hands.

11 Remove **eye protection** by pulling the string from behind the head and dispose of it safely.



10 Perform **hand hygiene** on gloved hands.

13 Remove the **mask** from behind the head by first untying the bottom string above the head and leaving it hanging in front; and then the top string next from behind head and dispose of it safely.




12 Perform **hand hygiene** on gloved hands.

15 Remove **rubber boots** without touching them (or overshoes if wearing shoes). If the same boots are to be used outside of the high-risk zone, keep them on but clean and decontaminate appropriately before leaving the doffing area.²

16 Perform **hand hygiene** on gloved hands.

14 Perform **hand hygiene** on gloved hands.


17 Remove **gloves** carefully with appropriate technique and dispose of them safely.



18 Perform **hand hygiene**.

¹ While working in the patient care area, outer gloves should be changed between patients and prior to exiting (change after seeing the last patient)

² Appropriate decontamination of boots includes stepping into a footbath with 0.5% chlorine solution (and removing dirt with toilet brush if heavily soiled with mud and/or organic materials) and then wiping all sides with 0.5% chlorine solution. At least once a day boots should be disinfected by soaking in a 0.5% chlorine solution for 30 min, then rinsed and dried.



World Health Organization

All reasonable precautions have been taken by the World Health Organization to verify the information contained in this publication. However, the published material is being distributed without warranty of any kind, either expressed or implied. The responsibility for the interpretation and use of the material lies with the reader. In no event shall the World Health Organization be liable for damages arising from its use.

WHO/NIS/2019/206.3