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Original Article

Human factors–based risk analysis to improve the safety of doffing enhanced personal protective equipment

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Abstract

Objective: To systematically assess enhanced personal protective equipment (PPE) doffing safety risks.
Design: We employed a 3-part approach to this study: (1) hierarchical task analysis (HTA) of the PPE doffing process; (2) human factors-informed failure modes and effects analysis (FMEA); and (3) focus group sessions with a convenience sample of infection prevention (IP) subject matter experts.
Setting: A large academic US hospital with a regional Special Pathogens Treatment Center and enhanced PPE doffing protocol experience.
Participants: Eight IP experts.
Methods: The HTA was conducted jointly by 2 human-factors experts based on the Centers for Disease Control and Prevention PPE guidelines. The findings were used as a guide in 7 focus group sessions with IP experts to assess PPE doffing safety risks. For each HTA task step, IP experts identified failure mode(s), assigned priority risk scores, identified contributing factors and potential consequences, and identified potential risk mitigation strategies. Data were recorded in a tabular format during the sessions.
Results: Of 103 identified failure modes, the highest priority scores were associated with team members moving between clean and contaminated areas, glove removal, apron removal, and self-inspection while preparing to doff. Contributing factors related to the individual (eg, technical/ teamwork competency), task (eg, undetected PPE contamination), tools/technology (eg, PPE design characteristics), environment (eg, inadequate space), and organizational aspects (eg, training) were identified. Participants identified 86 types of risk mitigation strategies targeting the failure modes.
Conclusions: Despite detailed guidelines, our study revealed 103 enhanced PPE doffing failure modes. Analysis of the failure modes suggests potential mitigation strategies to decrease self-contamination risk during enhanced PPE doffing.

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The 2014 Ebola virus disease (EVD) outbreak was the largest in history, claiming more than 10,000 lives.[1] More than 600 healthcare workers (HCWs) died as a result of contracting EVD while caring for patients.[2] Self-contamination while doffing personal protective equipment (PPE) likely accounts for some of the HCW risk. In guidance to reduce this risk, the Centers for Disease Control and Prevention (CDC) recommends specific PPE components, steps for safe removal, and 2 new roles to assist the HCW.[3] The 'doffing team' consists of the HCW, a trained observer (TO) to verbalize instructions and monitor safety of the doffing procedure, and a doffing assistant (DA) to help the HCW remove PPE components.

Guidelines alone do not guarantee consistent adherence to best practices or protocols.[4,5] To protect HCWs, a better understanding is needed of how self-contamination occurs and specific strategies that can be employed to mitigate risk. A human factors (HF) approach provides a useful framework to identify, analyze, and mitigate safety risks during PPE doffing.

Human factors (HF) is a scientific discipline concerned with understanding interactions among humans and other system elements, and the profession that applies theory, principles, data, and methods to optimize human well-being and overall system performance.[6] Human factors experts complete advanced training in engineering or psychology.[7] Human factors principles and methods are useful to improve safety and infection prevention (IP) practices.[4,5,8–12]

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In this study, we aimed to conduct an HF-informed failure modes and effects analysis (FMEA)[13] to identify self-contamination risks during PPE doffing, to prioritize areas of risk, investigate contributing factors and consequences, and to develop strategies to mitigate risks. This methodology engages key stakeholders to identify system-level factors that jeopardize safety and performance.[14,15]

Methods

The HF-informed FMEA involved 5 steps: (1) conducting a hierarchical task analysis (HTA) of the PPE doffing process, (2) identifying failure modes (ie, different ways a subtask can fail to accomplish its purpose), (3) prioritizing each failure mode based on a composite score of its severity, probability and detectability, (4) identifying contributing factors and potential consequences of the prioritized failure modes, and (5) designing solutions to eliminate or mitigate risks.[13,16–18] The Systems Engineering Initiative for Patient Safety (SEIPS) model[19] was the conceptual framework guiding the FMEA. The SEIPS is an HF model previously used for other IP improvement initiatives[20–23] to identify safety risks and to develop effective mitigation strategies. SEIPS examines 5 elements of the work system (ie, people, tasks, tools and technologies, physical environment, and organization) and their interactions with each other to improve processes and outcomes. Self-contamination risks during PPE doffing emerge because of characteristics of any of the 5 work-system elements or interactions between them. The Johns Hopkins University School of Medicine Institutional Review Board approved this study.

Participants and setting

Five IP experts at the Johns Hopkins Hospital in Baltimore, Maryland, all certified by the Board of Infection Control and Epidemiology, participated in 6 focus-group FMEA sessions, each ~2 hours. In addition, 3 IP experts (2 physicians board certified in infectious diseases and 1 nurse certified by the Board of Infection Control and Epidemiology), who were not part of the initial FMEA sessions, participated in a seventh focus-group FMEA validation session.

Procedure

First, 2 HF experts conducted an HTA of the PPE doffing process.[24,25] Hierarchical task analysis is an HF methodology used to provide a detailed understanding of tasks an actor needs to complete to achieve a certain goal. In this study, we used HTA to describe the PPE doffing task in terms of the individual steps, the sequence of these steps, and the tools used to complete each step.[25]

The HF experts conducted the HTA by reviewing the CDC guidelines and web-based training for the powered air purifying respirator (PAPR) and gown PPE combination[26] and by observing 7 simulated doffing sessions. Next, findings were displayed in tabular and graphical formats and were used to facilitate discussion during the focus groups.

An HF expert (A.D.) was the facilitator in focus group sessions, and 2 others (A.P.G., L.B.) assisted and recorded data in the FMEA worksheet (Table 1). Also, 5 IP subject-matter experts viewed the documented data and asked for any corrections in real time. Based on a semistructured discussion guide, participants completed the following 5 steps:

(1) Reviewed the HTA for accuracy and completeness.
(2) Identified failure mode(s) for each doffing step.
(3) Rated each failure mode using a 10-point scale based on its severity (none to catastrophic), probability (remote to very high), and detectability (almost certain to absolutely uncertain) using a consensus approach. These 3 scores were multiplied to obtain a risk priority number (RPN) using a modified version of the scale developed by Department of Defense (Table 2).[27]
(4) Identified contributing factors and potential consequences for each prioritized failure mode.
(5) Identified potential solutions to mitigate the effects of the contributing factors.

A seventh focus group session with 3 IP experts not involved in the previous sessions was conducted for review and validation of the FMEA worksheet data, and any gaps or inaccuracies were corrected. We analyzed 4 newly identified failure modes using the process outlined above.

Results

Flowchart representation of the hierarchical task analysis

Figure 1 provides an overview of the 19 main PPE doffing tasks. A full graphical depiction of the HTA, including 82 subtasks, is available in Appendix 1 (online).

Failure modes and risk priority numbers

Appendix 2 (online) provides a complete listing of the 103 failure modes identified and the corresponding RPNs, contributing factors, potential consequences, and proposed risk mitigation strategies. The IP experts identified at least 1 failure mode for all, but 10 of the 82 subtasks, with RPNs ranging from 6 to 630 (mean, 115.28; median, 90; mode, 144). A failure mode with an RPN of 84 or greater was considered high priority and was further investigated. Table 3 depicts the failure modes with the 5 highest RPN values. The highest RPN (630) was associated with the DA or TO moving between clean and potentially contaminated areas. Other high-priority failure modes were associated with glove removal, apron removal, and self-inspection while preparing to doff.

Contributing factors

Further investigation was conducted to explore why the identified failure modes occur and to inform the development of risk mitigation strategies. Here, we briefly describe contributing factors associated with the high-priority failure modes; Appendix 2 includes a complete list.

Contributing factors were classified based on the work-system elements of the SEIPS model. Identified person (ie, HCW) factors included anthropometric and physiological characteristics, technical and teamwork-related competencies, and psychophysiological responses of HCWs. For example, it is more difficult for HCWs with shorter arms to keep contaminated PPE away from their body during removal. Conversely, larger HCWs have a greater surface area to inspect, increasing the probability of missing a breach or contamination. The flexibility and dexterity of HCWs can impact risk when doffing PPE (eg, removing boot covers without contamination). Healthcare workers need not only technical competency but also spatial awareness of where they are

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Table 1. Example of Failure Modes and Effects Analysis (FMEA) Worksheet[a]

						Contributing Factors						
Step	Failure Mode	S	P	D	RPN	Person	Tools/Tech	Organization	Environment	Task	Consequences	Risk Elimination or Mitigation Strategies
1.0 Prepare to Doff PPE												
1.1 [HCW] Inspect PPE	1. HCW pushes shroud down to see below it	3	8	6	144	• Physical and mental fatigue • Anxiety/concern for physical contamination	• Very limited vision in PAPR, obstructing HCW view • No mirror to see/ help with inspection		• Not enough space to maneuver	• Rigorous patient activity (eg, reaching over bed to roll patient) • Difficult patient (eg, combative, anxious, or inadvertent movement)	HCW contamination	• Have mirror available • Ensure communication channel between TO/ HCW in pt. room • Pull HCW from room immediately if they are trying to fix shroud themselves

Note. S, severity; P, probability; D, detectability (see Table 2 for detailed description of the rating scales for S, P, D); RPN, risk priority score (S × P × D); HCW, healthcare worker; pt., patient.
[a]The entire data set is available in the supplementary material (online).

Table 2. Risk Priority Number Rating Scales (adapted from Department of Defense)[27]

Severity		
Rating	Description	Definition
10	Catastrophic	Death of individual or complete system failure
9		
8	Major injury	Major injury of individual or major effect on system
7		
6	Minor injury	Minor injury of individual or minor effect on system
5		
4	Moderate	Significant effect on individual or system with full recovery
3		
2	Minor	Minor annoyance to individual or system
1	None	Would not affect individual or system
Probability		
Rating	Description	Definition
10	Very High	Failure almost inevitable
9		
8	High	Repeated failures
7		
6	Moderate	Occasional failures
5		
4		
3	Low	Relatively few failures
2		
1	Remote	Failure is unlikely
Detectability		
Rating	Description	Definition/ Likelihood of Detection
10	Absolute Uncertainty	Cannot detect failure mode
9	Very Remote	Very remote chance of detecting failure mode
8	Remote	Remote chance of detecting failure mode
7	Very Low	Very low chance of detecting failure mode
6	Low	Low chance of detecting failure mode
5	Moderate	Moderate chance of detecting failure mode
4	Moderately High	Moderately high chance of detecting failure mode
3	High	High chance of detecting failure mode
2	Very High	Very high chance of detecting failure mode
1	Almost Certain	Will be able to detect failure mode

relative to other team members and objects; they also need teamwork-related skills to effectively communicate, to assertively speak out if they are uncomfortable, and to stay focused to avoid complacency. Also, HCWs must be able to overcome physical and mental fatigue, anxiety, distraction, and other factors engendered by the PPE doffing task.

Tools and technology-related factors, such as the design of PPE elements, can precipitate failure modes. For instance,

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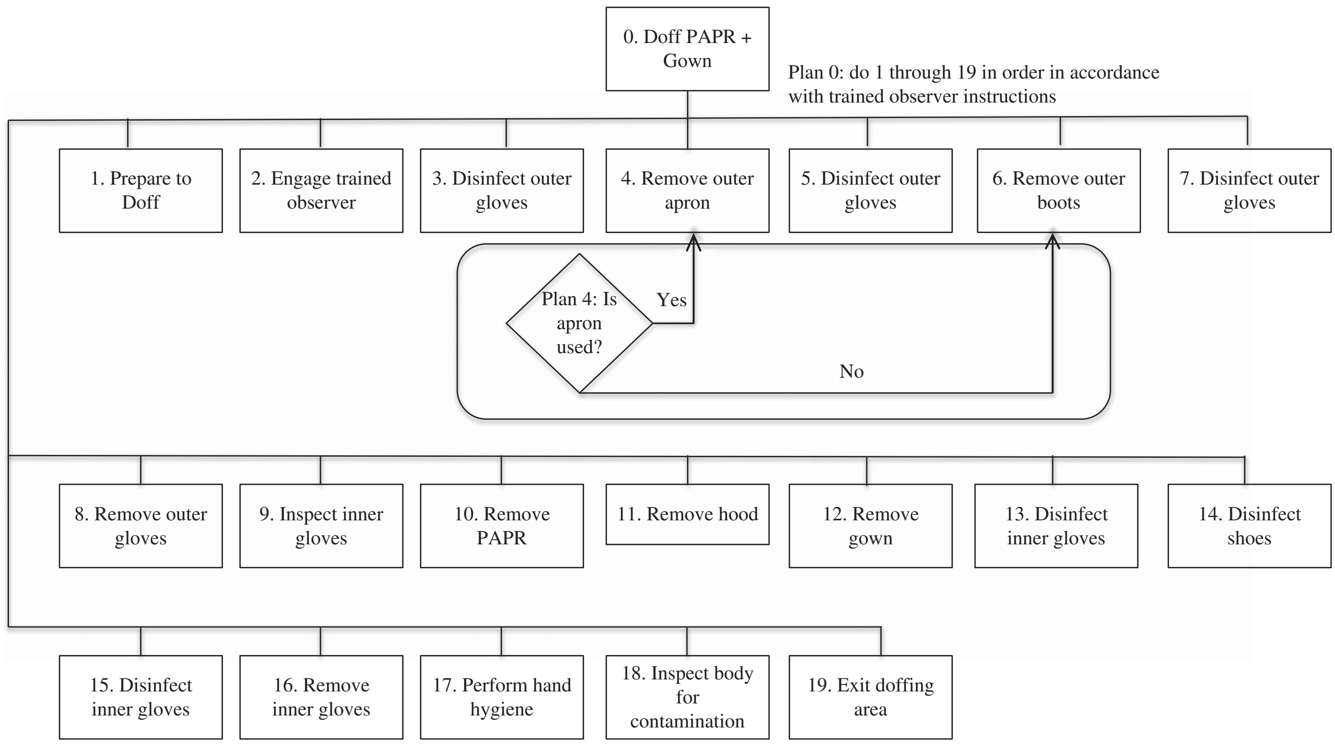

Fig. 1. Overview of enhanced PPE doffing process depicting the 19 main steps based on hierarchical task analysis.

breaches and contamination are more likely and more difficult to detect if the PPE size is too big or too small for a particular user. The risk of PAPR hood contamination is higher if hoods are long, and aprons are of higher risk if their removal requires the HCW to lift it over their head rather than to tear it away.

Organizational contributing factors include culture (eg, discomfort speaking up), availability of various training opportunities in the organization needed to enhance skills, and organizational commitment and efforts for readiness (eg, having updated and user-friendly protocols and adequate resources).

Most environmental contributing factors concern the size and configuration of the doffing area. Small doffing areas that cannot easily accommodate 3 people with comfortable space between them and room for trash make it more likely for team members to bump into equipment or each other, potentially causing contamination. Visual cues are important to help team members identify clean versus contaminated areas of the doffing room.

Finally, the PPE doffing task itself, and the characteristics of tasks performed before doffing, contribute to failure modes. For example, more PPE contamination likely occurs following care of a patient with active diarrhea. Also, combative or anxious patients may pose a greater risk of PPE contamination. Furthermore, a small breach or PPE contamination may not be visible.

Risk mitigation strategies

We identified 86 risk mitigation strategies; Table 4 provides example strategies and Appendix 3 includes the complete list. Training and education were the primary considerations for mitigating risk. The 4 primary areas for doffing training include the correct use of tools and technology (eg, PPE, communication technologies), teamwork skills (eg, closed-loop communication),[28] IP topics (eg, gross decontamination strategies), and resiliency skills (eg, recovery from errors or task perturbations). Further, participants emphasized the importance of matching the physical characteristics of the training environment to the actual doffing environment and incorporating elements such as time pressure, stress, and patient activities to elicit similar cognitive, behavioral, and attitudinal reactions from the doffing team as they might experience in actual situations.

A main organizational risk-mitigation strategy focuses on reducing guideline and protocol ambiguity. This aspect includes provision of explicit guidance for managing breaches and/or contamination, and systematically evaluating, and validating protocols and instructional materials prior to implementation. Participants suggested that the development, testing, and evaluation of institutional protocols should involve a transdisciplinary team of infection preventionists, HF experts, clinicians, laboratory technicians, and other relevant personnel.

With respect to tools and technology, a recurring theme was to employ visual cues, such as PPE elements with distinct colors, to help differentiate between the inside (clean) and outside (contaminated). Additionally, participants identified that aprons should tear away easily, allowing the HCW to pull it off themselves and reducing unnecessary risk associated with another team member helping with removal. Participants also suggested securing gloves to the gown to prevent the cuff from slipping and possibly exposing the HCW to contamination. Another identified strategy was to include technology that provides a bidirectional communication channels amongst the doffing team members and personnel outside the doffing room.

Environmental strategies centered on room configuration optimization with respect to both the room size and the relative positions of equipment and people. Participants noted the importance of (1) visual zoning to clearly demarcate clean versus contaminated areas and (2) equipping the room with mirrors to help HCW complete visual inspection to identify and address gross contamination prior to leaving the patient room.

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Table 3. Failure Modes with the Top 5 Risk Priority Number (RPN) Values

Step	Failure Mode	Severity	Probability	Detectability	RPN
General/Applicable to all steps	**Assistant walks back and forth between dirty and clean areas**	**9**	**10**	**7**	**630**
Contributing factors Person - TO inexperience; TO failure understand risk; lack of spatial awareness; distraction/attentional narrowing Organization - Organization does not provide training in the understanding of germ theory (and viruses/bacteria) and competency in disinfection/identifying and assessing risks Environment - No clear designation between clean and warm areas. Task - TO is focusing on multiple things simultaneously; ambiguity of whether the TO should always stay on the clean side **Potential consequences** 1. TO contaminates 'clean' area of doffing room 2. Others who pass through clean area become contaminated and do not know it (eg, carry it out of hall) **Potential solutions for risk mitigation** • Provide visual indication of contamination vs contamination free areas of doffing room • Provide education/ training in the understanding of germ theory (and viruses/bacteria) and competency in disinfection/identifying and assessing risks • Training should involve spatial orientation awareness between team members, environment, and equipment in relation to team-member body movements • Team members should utilize assertiveness techniques and speak up if they are unsure or uncomfortable • Ensure there is both a TO and assistant to facilitate the doffing process for the HCW; 1 person providing assistance alone will consistently cross into both clean/contaminated zones					
3.1 Examine outer gloves for contamination	**Assistant/ TO do not identify all contamination**	**7**	**6**	**9**	**378**
Contributing factors Person - False sense of security due to previous hand hygiene; false sense of security due to PPE being outer layer; vigilance decrement; TO/DA not comfortable to speak up; DA uncomfortable being too close to HCW Organization - Inadequate training for HCW and TO/DA on identifying contamination Environment - Physical distance between DA/TO and HCW **Potential consequences** 1. Further contamination by not identifying 2. Risk contaminating otherwise uncontaminated people or equipment **Potential solutions for risk mitigation** • Training for contamination identification • Education on contamination and assessing risks (why it is important and why it varies) • Utilize appropriate assertiveness techniques to speak up when concerned for contamination					
1.1 Prepare to doff and inspect PPE	**HCW does not complete full self-inspection prior to entering doffing room**	**7**	**6**	**8**	**366**
Contributing factors Person - Inherent field of view limitations (ie, unable to see entire body without assistance); physical and mental fatigue; anxious reaction to potential breach; HCW did not communicate to TO that they are ready to leave the room and have completed self-inspection Tools/Technology – Folds in PPE Environmental – No mirror to see/help with inspection Task - Ambiguity on what exactly to assess/inspect; combative patient; only 1 HCW in room **Potential consequences** 1. HCW leaves patient room before they should 2. HCW unaware of contamination 3. HCW unaware of breach 4. HCW contaminated environment 5. HCW contaminates team member(s) **Potential solutions for risk mitigation** • Engage the TO earlier that HCW has completed pt. care and prepared to doff • If other HCW is in the room, have them assist • Provide HCWs with multiple body length mirrors in patient room • TO should utilize poly com if possible to always be able to communicate with and see (if possible) HCW					
3.3 Disinfect outer gloves by rubbing top/bottom of both hands and in between fingers and thumbs	**HCW does not thoroughly disinfect all surfaces**	**8**	**6**	**7**	**336**
Contributing factors Person - Complacency of doffing team to ensure this is done effectively at all doffing stages; TO/DA not empowered to speak up; slip lapse Tools/Technology - Color of gloves can make it difficult to see; not enough ABHR Organization - Incomplete education and training on performing hand hygiene with gloves Environment - Location of ABHR dispenser not practical Task - Difficult HCW; ambiguity on performing hand hygiene on gloves vs hands **Potential consequences** 1. Incomplete disinfection **Potential solutions for risk mitigation** • Both visual and verbal cues should be provided. • Recommend fully extending arms during this step. • Empowerment and assertiveness training for TO/DA to speak up if actions deviate from safe practice/ verbalized instructions					

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Table 3. (*Continued*)

Step	Failure Mode	Severity	Probability	Detectability	RPN
4.1 Remove outer apron by untying apron strap	**Assistant does not perform hand hygiene after untying strap**	**8**	**5**	**8**	**320**
Contributing factors Person - TO is paying too much attention to the HCW at the expense of DA; HCW and DA do not have adequate spatial and self-awareness Tools/Technology - Type of apron (one that is not a tear-away type), must be removed over the head or may require assistance to remove Environment - More likely to bump into HCW when the space is small Task - Assistant helps with task that is not necessary; no guidance on how to remove a grossly contaminated apron **Potential consequences** 1. Risk of assistant contamination **Potential solutions for risk mitigation** • HCW should be removing apron by themselves before entering the doffing area (if you cannot because of space, need to add a disinfectant step); second most contaminated PPE • Only use aprons where the HCW worker is able to pull off outer apron individually • If those are not available, should cut off apron rather than pulling over head					

Note. TO, trained observer; HCW, healthcare worker; DA, doffing assistant; PPE, personal protective equipment; ABHR, alcohol-based hand rub.

Table 4. Example of Synthesis of Risk Mitigation Strategies Worksheet[a]

Category	Definitions and Examples	Risk Mitigation Strategy[b]
Training/Education		
Teamwork skills	Training and education aimed at enhancing the interactions between the HCW, TO, and DA	5. Team members should utilize assertiveness techniques and speak up if they are unsure or uncomfortable (13, 21, 25, 31, 53, 56, 68, 69, 95, 98, 100, 101, 102) 6. Ensure all team members know the roles and functions of all team members engaged in the doffing process (13) 7. Practice communication and information exchange between (eg, closed-loop communication) the TO, DA, and HCW, beyond simple dictation of steps (13, 70, 75) 8. Training should include back-up behaviors and cross-checking between all team members, not just the HCW (14, 26, 29, 31, 33, 36, 37, 44, 98) 9. HCW should be turning around to help TO/DA with assessment (15, 16) 10. Need to avoid overreliance on the expectation that the HCW is able to identify contamination and DA/TO do not need to pay as close attention (15, 16) 11. All team members should be cross-trained to enhance the mutual understanding of all roles and responsibilities.

Note. TO, trained observer; HCW, healthcare worker; DA, doffing assistant.
[a]The complete list of risk mitigation strategies can be found in the supplementary material (Appendix 3 online).
[b]Number denotes the corresponding failure mode(s) in Appendix 2 (online).

Several strategies were identified to improve safety of the PPE doffing task itself. Participants pointed to the importance of employing all team roles as outlined by the CDC guidance; asking 1 person to perform the duties of both TO and DA hinders their ability to perform effectively. Participants also identified strategies to eliminate unnecessary steps and to improve the clarity of instructions. Improving steps involved with removing the gown (eg, folding back the gown to avoid touching outer surfaces), gloves, apron, and PAPR hood were noted as having the greatest potential impact.

Discussion

Failure modes while doffing PPE can lead to HCW contamination, and potentially severe or fatal consequences. Using HF methodology, we systematically mapped the complex PPE doffing process and identified 103 ways the doffing process can fail, leading to self-contamination. Among these failure modes, 54 were identified as priority areas. Findings from this analysis led to the following conclusions.

1. Safely doffing PPE requires knowledge, skills, and attitudes beyond the basic instructions for when and how to remove PPE elements.

The CDC guidance focuses on the correct technique and sequence of removal of each PPE element. This FMEA revealed important competencies beyond these technical aspects of PPE removal. First, exposure to high-consequence pathogens can invoke feeling of stress for team members. This stress can be exacerbated if a team member commits an error or must respond to a novel circumstance, if there are large amounts contamination, or if a PPE breach occurs. The negative effects of stress are well-known across research domains,[29–31] and managing stress is an important skill that can be gained through training.[32] Therefore, organizations should consider integrating task perturbations and error-recovery opportunities[33,34] into training scenarios so team members have the opportunity to practice recognizing and recovering from these types of situations. Additionally, training should aim to provide competency in identifying and assessing risks from an infection prevention and control standpoint during doffing. Current PPE guidelines focus on the role and actions of the HCW, with less emphasis given to skills required to safely fulfill the TO and DA roles. The FMEA revealed many teamwork skills underlying safe doffing such as effective communication and information exchange, assertiveness, and role clarity. Evidence demonstrates the effectiveness of team training on improving clinical staff's teamwork skills as

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well as patient and organizational outcomes (eg, safety climate).[35,36] Given the importance of teamwork in safe PPE doffing, organizations should emphasize relevant team skills during training. Beyond training, organizations can improve teamwork by incorporating prompts to encourage team skills such as closed-loop communication[28] and mutual performance monitoring.[28]

2. A comprehensive competency assessment system for PPE doffing is needed to reliably and accurately measure doffing team members' competencies.

Because competencies related to doffing, teamwork, and IP are critical for safety, organizations need to ensure that doffing team members are competent in these areas. Assessment is needed to accurately evaluate performance of doffing team members, to determine the impact of training or other improvement initiatives, to select team members correctly, and to provide structured feedback around key competency areas.[37,38]

3. The doffing team composition should include the HCW, TO, and DA.

Doffing PPE is complex, requiring assistance and vigilance to recognize and mitigate the self-contamination risk. Although staffing all 3 roles can stress an organization's resources, HCWs are at greater risk if the TO and DA are combined into a single role. The likelihood is higher that the person assisting the HCW might not notice a breach or contamination, contaminate themselves, or contaminate equipment if these roles are combined. Therefore, the CDC has amended their original guidance to recommend the TO and DA to be separate roles.[39]

In addition to ensuring this role structure, organizations should have contingencies in place if a TO or DA becomes contaminated or experiences an equipment breach while helping an HCW doff. Neither role should proceed to help other HCWs if they experience a breach or are exposed to contamination; this requires a contingency plan for continued support of HCW PPE doffing.

Another concern relates to staffing and the anthropomorphic differences of individuals. Doffing is a physically rigorous task that demands flexibility, balance, and constant vigilance. HCWs endure extreme heat, long periods of standing during patient care, and then remove PPE, which requires patience, attention, and some unusual movements. Selecting personnel based on their physical attributes (eg, fitness, physical endurance) is commonplace in other high-risk domains such as aviation and in the military.[40] Given the severity of potential risks associated with anthropometric characteristics of HCWs, organizations should consider, if feasible, the physical and other attributes of team members and their capacity to fill each role without endangering themselves or others.

4. Improved PPE designs and doffing protocols are needed to improve safety and provide additional guidance for intricate tasks.

In this study, we identified several opportunities for protocol improvement to enhance safety. Glove removal, for example, was identified as a major source of potential contamination. Current guidelines instruct the HCW to remove the first outer glove, ball it into their other hand, remove the second outer glove over the first one, and then discard them both. The safety and simplicity of this step can be improved if the HCW discards the first outer glove into a waste receptacle before removing and discarding the second one. This subtle change simplifies the second glove removal and reduces the possibility of the first outer glove touching and contaminating other PPE components. More detailed instructions for folding back the gown edges to provide the DA with an uncontaminated area to hold while helping the HCW can reduce the likelihood the DA or HCW becomes contaminated during gown removal. More explicit guidance about how to manage and respond to specific types of breaches should be undertaken to minimize ambiguity for how team members should respond.[4,5]

5. The doffing area must be optimized for team members and equipment.

Doffing areas that are too small result in the risk of team members bumping into one another or equipment. Organizations need to evaluate the extent to which their dedicated doffing space affords team members room to move around safely. Furthermore, clean and contaminated areas of the doffing room should be delineated using visual cues. Zoning clean from potentially contaminated areas reduces the likelihood that team members cross over between these areas, spreading contamination.

6. Guideline development should include human factors analyses.

Our findings also suggest the opportunity for integrating HF methods into guideline development. Similar to the US Food and Drug Administration requirement to incorporate HF evaluation prior to the approval of medical devices, HF could be integrated into infection prevention guideline development by proactively assessing potential failure modes and testing the usability of newly developed guidance.

This study has several limitations. First, focus groups were conducted at a single institution and examined only 1 specific PPE combination (PAPR and gown). Although the steps of the doffing sequence differ in terms of prescribed guidance for each type of PPE combination, many of the steps and substeps are the same, suggesting the generalizability of our findings across combination types. Institutions should evaluate the efficacy and likely breakdowns unique to manufacturer instructions for use during the development, testing, and evaluation of their doffing protocol. Finally, the IP experts study participants have developed, tested, and researched safe PPE doffing procedures but do not have direct experience caring for patients with Ebola.

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Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2018.292

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