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How Can Personal Protective Equipment Be Best Used and Reused: A Closer Look at Donning and Doffing Procedures

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Abstract

Objective: The aim of this study was to examine safety-related contamination threats and risks to health-care workers (HCWs) due to the reuse of personal protective equipment (PPE) among emergency department (ED) personnel.

Methods: We used a Participatory Design (PD) approach to conduct task analysis (TA) of PPE use and reuse. TA identified the steps, risks, and protective behaviors involved in PPE reuse. We used the Centers for Disease Control and Prevention (CDC) guidance for PPE donning and doffing specifying the recommended task order. Then, we convened subject matter experts (SMEs) with relevant backgrounds in Patient Safety, Human Factors and Emergency Medicine to iteratively identify and map the tasks, risks, and protective behaviors involved in the PPE use and reuse.

Results: Two emerging threats were associated with behaviors in donning, doffing, and re-using PPE: (i) direct exposure to contaminant, and (ii) transmission/spread of contaminant. Protective behaviors included: hand hygiene, not touching the patient-facing surface of PPE, and ensuring a proper fit and closure of all PPE ties and materials.

Conclusions: TA was helpful revealed that the procedure for donning and doffing of re-used PPE does not protect ED personnel from contaminant spread and risk of exposure, even with protective behaviors present (e.g., hand hygiene, respirator use, etc.). Future work should make more apparent the underlying risks associated with PPE use and reuse.

> "I'm putting on my PPE. So, I must be safe."
>
> - Adapted from Efstathiou et al.[1]

The coronavirus disease 2019 (COVID-19) pandemic is an ongoing existential threat to patients and healthcare workers (HCWs) world-wide. According to the World Health Organization (WHO), in May 2021, approximately 115,000 HCWs, including more than 3,600 United States (US) HCWs, had died from COVID-19 and millions of HCW have been infected while caring for patients.[2,3] By the end of June 2020, US HCWs filed 4,100 safety complaints surrounding safety concerns due to personal protective equipment (PPE) shortages to the Occupational Safety and Health Administration (OSHA), the US Labor Department's workplace safety agency.[4,5(p1),6] The Centers for Disease Control and Prevention (CDC) officially recognized "crisis" and "contingency" plans to guide staff protection amidst PPE shortages.[7] "Crisis" periods of reuse admittedly do not adhere to standards of care; however, periods of "crisis" demand reuse of key pieces of PPE (e.g., N-95 respirator) as facilities were unable to meet the standard PPE safety utilization rates.[8]

Protocols for donning and doffing of PPE remain ambiguous, lacking an evidence base, and often differ by PPE product, manufacturer and clinical location, resulting in wide deviations in practice.[9] PPE donning and doffing protocol deviations commonly result in self-contamination, but, have not been addressed at the source.[10,11] Removal of PPE, for instance, is a deceptively complex procedure, associated with high rates of doffing errors and likely contamination even with basic PPE.[12] Emerging data suggest that most HCWs were contaminated during doffing PPE during single use periods, revealing an urgent need to examine the root causes of self-contamination risks,[13,14] and, particularly, when considering crisis periods for when PPE shortages required routine reuse.

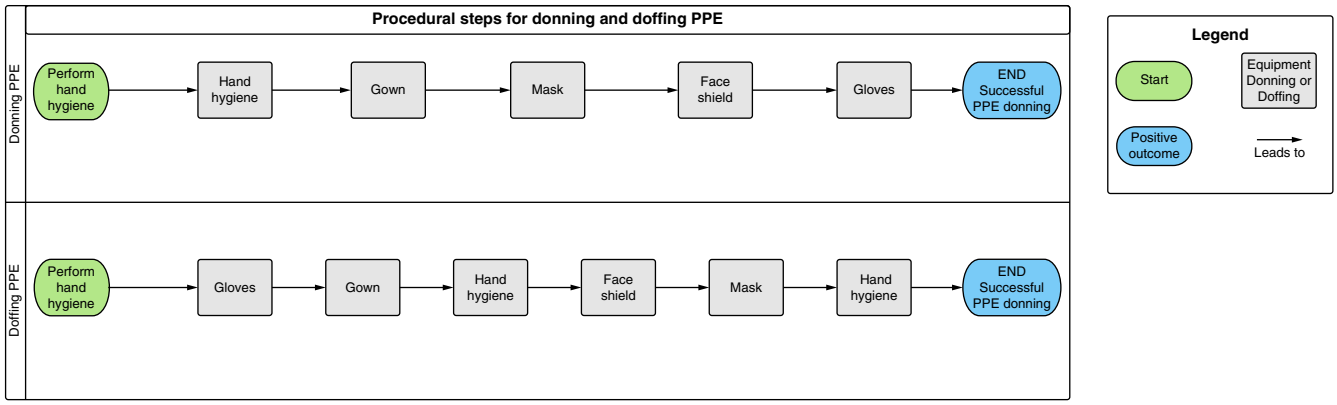

Figure 1. CDC donning and doffing PPE procedural steps.

PPE reuse presents an unresolved global occupational HCW hazard due to the COVID-19 pandemic.[6] The need for improved PPE reliability to protect HCWs has been known for several decades.[13,15–17] However, critical PPE shortages have resulted in increased occupational HCW exposure risks by HCWs to both COVID-19 and other contagious diseases,[18–20] forcing health-care institutions to consider alternative PPE management approaches.[21] The current literature on contamination during PPE use maintains a hyper focus on specific pieces of PPE (e.g., mask, gloves),[22–24] and storage or doffing area spatial designs.[24–26] However, latent sources of preventable errors in routine donning and doffing need to be identified to mitigate ongoing risks of contamination.[27,28] These errors place HCWs at heightened risks for infection further depleting HCW ranks.[15]

The goal of this study was to identify behaviors related to HCW safety associated with reusing PPE. Our intent is to more deeply understand the risks and processes that could protect HCW by mitigating against HCW exposure and self-contamination.

Methods

We used a Participatory Design (PD) approach to task analysis (TA) to better understand the risks involved in PPE reuse. TA research focuses on the end user requirements and the application of human factors and ergonomics (HF/E) principles to improve the system's design and performance. This study was reviewed and approved by the Institutional Review Board at Indiana University School of Medicine, Protocol #: 2005953971.

Setting: Emergency Department (ED)

ED personnel on the frontline of care may be at higher risk for infection, making this a prime setting to understand and intervene where heightened risks are present with PPE reuse.[29]

Approach: Participatory Design (PD)

PD is a co-design methodology which engages end users directly in the development of prospective solutions and applications to the problems and challenges they face.[30,31] PD approaches are used by researchers to better understand complex task flows and generate a step-by-step procedure which can inform the design of new technologies, workflow modifications, and clinical training.[32] The recruitment and management of stakeholders, use of outcome measures, and robust tools are key methodological elements in PD research.[33] This iterative process elicits user's expert knowledge, perceptions, and opinions to generate a thorough depiction of occupational challenges.

We used the 3 PD key phases proposed by Papautsky and colleagues[32] to conduct the study, which includes: (1) identifying steps and sequence of the task(s), (2) developing initial task flows, and, (3) refining task flows through multiple iterations. Agendas, visual aids, PD literature, and reoccurring meetings were used in accordance with best practices to clarify roles, responsibilities, and vision of the PD approach.[34] We detail how we engaged in each of the 3 phases below.

Phase 1. Identify steps and sequence

Phase 1 involves the identification of the steps and sequences involved in successful completion of the task at-hand. We used guidance from the CDC regarding PPE use (donning and doffing) and information related to PPE re-use to establish the task sequence.[35,36] CDC guidance controlled for variations in PPE donning and doffing sequences which are common in real-world clinical settings, allowing the current TA to focus on safety of PPE re-use. We used the CDC recommended sequence for donning and doffing for the purposes of satisfying Phase 1 of the TA in creating a common sequence of tasks as follows (see Figure 1).

Phase 2. Develop initial task flow

To conduct the second and third phases (below) of the TA, we convened a panel of subject matter experts (SMEs), with backgrounds in Emergency Medicine (EM), Critical Care (CC), Patient Safety, Epidemiology, and HF/E. We elicited SME input to deeply understand the step-by-step behaviors involved in successful donning, doffing, re-donning, and re-doffing of PPE. The SMEs provided expert end user insights into PPE reuse under real-world constraints (e.g., personnel shortage) and pressures (e.g., patient volume). This information was compiled in the initial task flow to create a visual representation of the underlying tasks and risks to HCW. We supplemented this information with the literature on HFE infection control and PPE use.[9,11,13,24,25,37–39]

Phase 3. Produce multiple iterations of task flow

The third phase of the TA produced multiple iterations of the task flow and involved reconvening SMEs until all members of the panel agreed the TA was complete and wholly representative of the tasks. Task flow modifications were done using a modified Delphi method to establish consensus, with modifications to task

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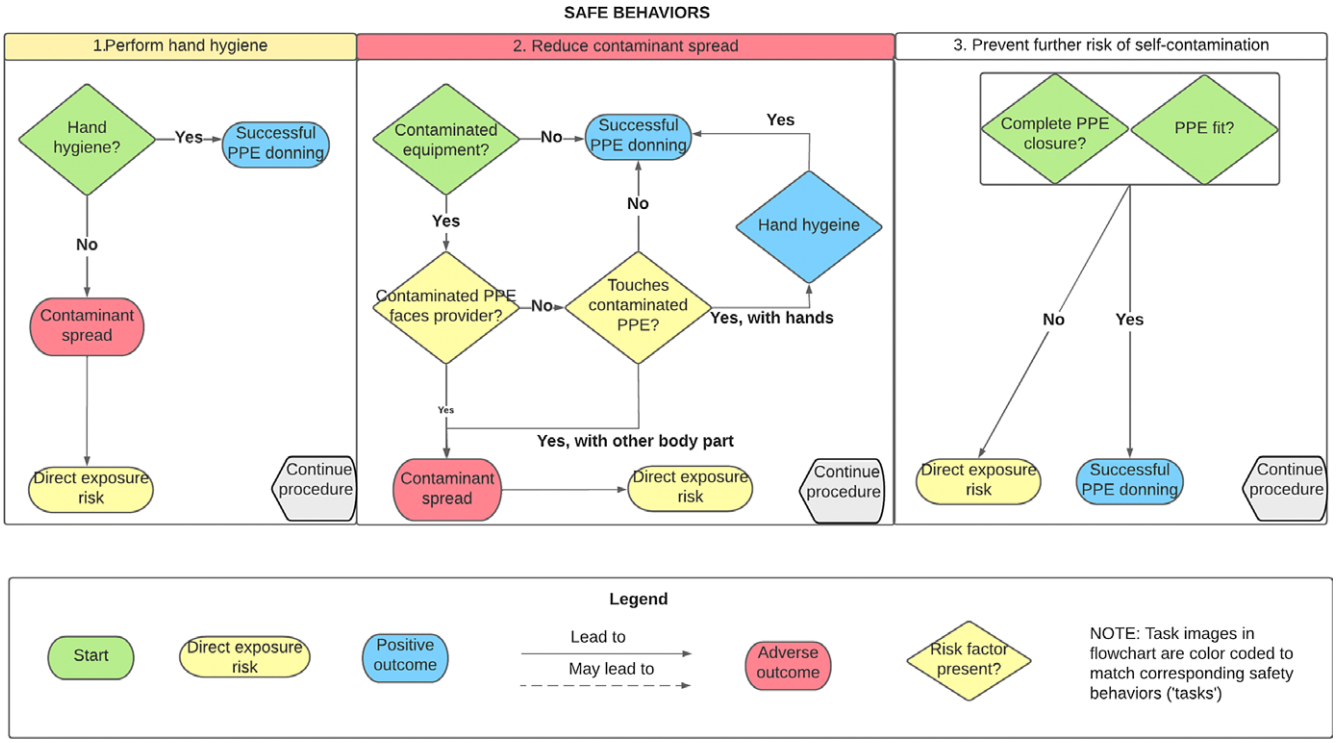

Figure 2. PPE donning and doffing taskflows and safety behaviors.

flows developed using LucidChart and Adobe software tools. This iterative process progresses task flows toward a more thorough task understanding by relying on repeated rounds of expert group consensus.[40] The task flows underwent 4 iterations in total.

Results

Three key task flows illustrate the safety behaviors and identified the presence of 2 key threats to HCWs in PPE reuse. The 3 task flows fit within the procedural steps recommended by CDC[41] and include: i) hand hygiene, ii) avoid touching patient-facing surface of PPE, and iii) ensure proper fit and closure of all PPE ties/materials. Interestingly, the task flows that highlight key safety behaviors and mishaps were conducted in the constant presence of occupational hazards. Two main emerging threats were associated with protective behaviors while donning, doffing, and re-using of PPE. These behaviors promote self-contamination and contaminant spread.[7,42] We organized the results based on the risk(s) present during PPE donning and doffing: risk(s) of direct exposure (i.e., HCW has *potential* for direct contact with contaminant due to improperly fitted or open PPE) and contaminant spread (i.e., HCW mishandles PPE allowing contaminant to be further *transmitted to self or other pieces of PPE*), which may increase the likelihood of direct exposure.

(I) Risks of Direct Exposure

The risk of HCW direct exposure was the first threat to emerge. Two channels create a risk of direct contact in which PPE does not provide adequate coverage. This task flow involves improper fit of PPE (e.g., face shield, mask, gown, gloves) and/or failure to close all PPE ties correctly. Of interest, the risks of direct exposure are predominantly present during PPE *donning*. Safety behaviors which mitigate the risks of direct exposure require verifying that key pieces of PPE *are fastened correctly and closed completely*. The second safety behavior to emerge requires the *PPE to be the proper size and fit securely* on HCWs such that no gaps are present that could directly expose HCWs to the virus (see Figure 2). Achieving appropriate fit can be especially difficult for those with diverse, large, or petite body types due to ongoing limited PPE sizes.[24,43]

(II) Risks of Transmission/Contamination Spread

The second risk identified involves the persistent threat of spreading viral contaminant during doffing PPE and subsequent donning of PPE during periods of reuse. For our purposes, viral contaminant spread was defined as, when *contaminated PPE touches other pieces of PPE during doffing or when a HCW touched the patient-facing sides of PPE directly*. Engaging in proper hand hygiene and avoiding interaction with patient-facing sides of PPE in doffing and re-donning are key safety behaviors which may reduce the risks of contaminant spread. Hand hygiene emerged as a key task flow which could mitigate the risk of transmission and contaminant spread. However, hand hygiene does not adequately prevent all forms of contaminant spread (e.g., viral contaminant touching other parts of the body and/or PPE).[7] For example, patient-facing PPE (e.g., gown) can spread contaminant to a body-size surface area (e.g., should the gown be re-donned with patient facing side toward the HCW). Therefore, touching the patient-facing side of PPE with one's body (i.e., not hands) *may NOT* be remedied with *hand hygiene alone*. Safely doffing and re-donning contaminated PPE means taking precautions to avoid touching or incorrectly donning PPE which requires covering large body surface areas. Other instances in which hand hygiene may *not* add a layer of protection include the spread during gown removal (*see* "Hand hygiene" in

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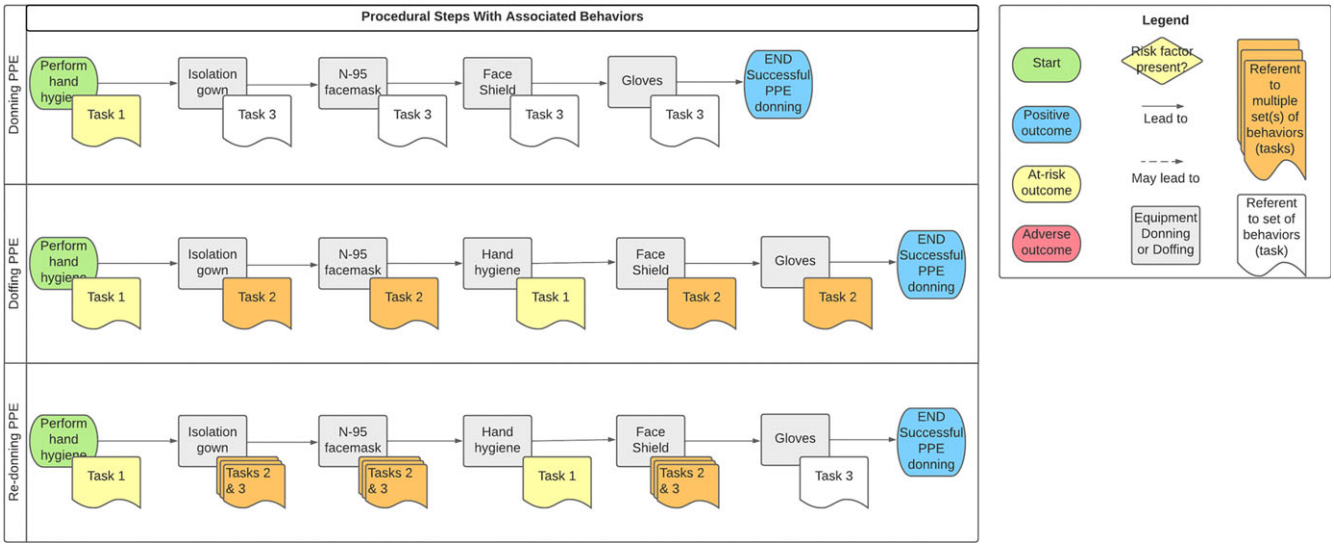

Figure 3. PPE donning and doffing procedural steps with associated risks and safety behaviors.

task flow 2; Figure 2), which may result in viral particles spreading to arms, face, or other PPE (e.g., face shield or mask).

(III) PPE Reuse and Compounded Risk

Each protective behavior and risk in single use PPE offers additive safety in effective HCW protection. However, the complexity of task flows, behaviors, and risks in the context of repeated procedural steps in donning and doffing the same PPE (i.e., reuse) can escalate the risks of further exposure and subsequent infections. Each safety behavior *can* act as a protective additive factor against the ever-present risks posed by improper donning and doffing of PPE (including reused PPE). However, the TA also reveals several critical "gaps" that could impose additive risks should a HCW misstep occur in donning or doffing reused PPE. In other words, critical "at-risk" steps within the task flows reveal the layers of prospective or latent risks in health workflows, which are often opaque to HCW users. Even with staff spotters HCW can progress beyond a critical step where the process is highly likely to lead to an infection (i.e., latent risk).[44]

The procedural steps, task flows, and behaviors involved in donning and doffing are repeated with each reuse (see Figure 3). In other words, coupling the procedural steps (i.e., task sequence) with their underlying task flows exposes HCW to enhanced risks with *each* PPE's reuse, thereby, heightening the risks of HCW exposure. Initially, hospitals trained and some offered support known as a "spotter" who offered PPE feedback and HCW protection stewardship by observing the proper HCW donning and doffing PPE steps.[45] While this short-lived intervention can help mitigate contamination risks, there are no current solutions that offer fail-safe PPE reuse and regular monitoring of the potential spread of contaminant to HCW.

Discussion

The study found that inadequate process and PPE design allows routine improper PPE donning and doffing, allowing unintentional but common human errors in PPE reuse.[46] The ease of unsafe equipment use directly conflicts with the goal of PPE use.[7,47,48] This dissonance motivated the current work to better protect health systems and workers.

It is important to reiterate that re-using PPE is not standard practice and carries safety risks. It is only sanctioned by the CDC for select pieces of PPE (i.e., N95 respirator)[49] during crisis scenarios. Yet, the severe shortage of PPE under the COVID-19 pandemic led to extraordinary circumstances encouraging PPE reuse. Not all PPE equipment can be reused (disposable isolation gown) and CDC recommended close attention be paid to the make and model of equipment for reuse guidance. The results bear two important implications for PPE use in crisis scenarios. First, the findings highlight several risky activities including improper or inadequate hand hygiene, spread contaminant across PPE and/or to self, and failure to secure fit and/or closure of PPE ties. These behaviors escalate the risks for HCW direct exposure and possible infection. The results can be used to inform the re-engineering of PPE and redesign of equipment that can better protect HCWs against risks when doffing and donning PPE. In particular, this study specifies the novel pathways of PPE use which can lead to HCW infections.[50] Notably, data are limited on estimating the likelihood of self-contamination or infection; however, previous studies attribute the relatively low rates of self- infection as a matter of "luck" rather than adequate PPE protection.[47,51–53]

The second implication of our findings is the seminal concept of compounded exposure risks with continued PPE reuse. For instance, in the process of donning reused PPE, there is a unique, yet possible, pathway in which PPE is donned incorrectly during reuse so that a HCW is self-contaminated *immediately*. This finding is specific to isolation gowns that do not touch face, mouth, eyes, or nose directly. Isolation gowns designed for multi-use are explicitly not sanctioned by CDC due to associated exposure risks; however, reusable gowns exist and were reused by HCW. Furthermore, isolation gowns cover a large surface area. In instances of repeated use, "self-contamination" from improper reuse of isolation gowns may increase the likelihood of further spread to self and/or other pieces of PPE. This is critical as risk of exposure *may be present AFTER* direct patient contact. For instance, contaminated PPE may spread contagion to other HCW body parts and/or other pieces of PPE during re-donning. This highlights the urgent need to recognize and contain contagion

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immediately to prevent further spread. Hand hygiene may help prevent spread of contaminant; however, even correct hand hygiene may not fully protect against contaminant spread—particularly to other pieces of PPE. Failure to prevent contaminant spread may result in a compounded risk of HCW direct exposure with each instance of PPE reuse.

Recognize and Mitigate Risks

COVID-19 and other contagious diseases pose a pervasive threat to HCW safety and well-being. The study reports on PPE safety and design by identifying the underlying tasks involved in PPE reuse through participation of SMEs, an approach successfully leveraged in computer[54] and engineering[55] sciences. PD is a preferred approach to bridge the research-practice implementation gaps based on the HFE and safety literature,[56] and is particularly effective when leveraging a systems' perspective to support patient and staff safety in complex clinical care procedures.[57]

HFE approaches analyze prospective risks and can be used to prevent HCW harm stemming from human error compounded by poorly designed PPE systems.[58–60] Understandably, some of the identified pathways in our study can increase the risks of infection. Additionally, the risks of direct exposure are likely increased in the presence of production pressures, cognitive workload, and HCW fatigue. New PPE design, policy, and donning/doffing areas need to be considered in promoting safe and well-being working conditions without sacrificing the quality of care.[16]

Assistance With Human-Centered Solutions

Human factors are essential in the development, design, and engineering of new interventions, particularly for equipment and devices.[61] The study's results highlight the ever-present risks in reusing PPE beyond standard of care. Mitigating the risks of contamination requires a multi-pronged approach to increased awareness and countermeasures to combat contaminant spread. Interventions will need to target the underlying risks involved in PPE reuse and should consider work-related factors such as length of shifts, night shifts, heavy workload, chronic fatigue, etc.[62,63]

Recommendations

Our study focused on the perceptions and work of ED personnel who are responsible for stabilizing COVID-19 and non-COVID patients.[64] Coupled with long shifts, high production pressures, and frequent protocol changes (e.g., screening), ED personnel may face additional challenges to maintaining a sense of heightened awareness for COVID spread. We offer several recommendations for redesigning clinical workflows to help protect HCWs:

(I) Improve Training and Competency Enhancement Techniques

Most HCWs receive training on proper use of PPE.[65,66] However, not all training opportunities are equally effective. In fact, most HCWs report receiving limited immersive training before treating COVID-19 patients,[64,67,68] offering limited time and guidance and feedback for effective training in protective practices such as guided and audited practice.[48] Protecting HCW from self-contamination requires real-time feedback and greater transparency about the relative risk(s) associated with each step of PPE use. Solutions to these issues could be provided by a spotter providing immediate guidance from institutional experts (human),[48] video, or by using transparent materials (such as Glo Germ™) to make visible contaminated equipment during training.[50,69] Guided practice or simulation-based training is a low-resource method for improving PPE donning and doffing techniques by accelerating improved knowledge, skills, and attitudes relative to risk mitigation.[23,48,61,64] Training solutions may not decrease risks at the source; however, transparent feedback approaches offer an approach to increase HCW's awareness to encourage changing HCW behaviors during PPE donning and doffing.

(II) Implement Stewardship for PPE Preservation

Spotters (personnel directly observing HCW don and doff PPE in situ) are potentially helpful in assuring and auditing that PPE is placed appropriately.[50] Not much detail is available on the helpfulness, receptiveness, or impact of spotters in the correct application of PPE; however, understaffing and high patient volumes can limit availability and consistency of spotter support. In other words, spotters may offer an added layer of protection and support in appropriate PPE donning and doffing; however, their relative benefits remain unclear.

(III) Re-design Environment for Infection Control

Hospital spatial re-design can change workflows and be used to promote quality and safety.[70] Unfortunately, current hospital space, flow, and PPE design will continue to facilitate nosocomial (hospital borne) infections unless root sources of infection spread are addressed by better design of hospitals.[71] One way to successfully plan and implement spatial design is through implementation of standardized protocols. And herein lies the problem: validated protocols designed to prevent COVID-19 transmission do not yet exist; therefore, hospitals are implementing spatial redesigns on the fly.[24,72] This means that HCW safety takes a backseat awaiting implementation of effective and feasible PPE design adaptations and overall design guideline changes. PD offers practical and low-cost mitigation approaches to solve real world problems in health systems combatting the COVID-19 pandemic until the implementation of effective PPE design adaptations and guideline changes.[37]

(IV) Enhance PPE Design to Promote Risk Awareness

On-the-job tools, coupled with effective training, can increase awareness to PPE donning/doffing/reuse best practices, and thus, decrease the risks to HCW. A scanner or light source to detect the presence of the HCWs skin coming in contact with the exterior of the reused PPE before re-donning used equipment or after doffing used equipment might be helpful.[73] Other potential options offer greater transparency and immediate awareness of infection through PPE re-design. For instance, a simple redesign solution may include color coding the patient-facing sides of PPE garments to reflect the side facing the patient, which could prevent significant errors from occurring during PPE reuse. One example is the use of applying Glo Germ™ for self-identification of ineffective or high-risk doffing with a black light in the clinical environment.[74] Further recommendations include re-design of PPE (improved fit, color coding) and other multi-level system design considerations (eg, policy, procedure, physical environment changes) for safety (Table 1).[37,75]

Limitations

The study has several limitations and must be interpreted in the context of its exploratory design. First, the study reveals potentially

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Table 1. Human centered recommendations for protecting health care workers

Targeted risk	Recommendation	Recommendation components
Prevent further risk of self-contamination; Reduce contaminant spread	Improve training and competency enhancement techniques	Real-time feedback; Guided practice through spotters or technologies (eg, Glo Germ™)[23,48,50,59,64]
Prevent further risk of self-contamination	Implement stewardship for PPE	Spotters and infection control involvement[50]
Reduce contaminant spread	Re-design environment for infection control	Standardized protocols and guidelines[37]
		Scanner/light to detect or disinfect[73]
	Enhance PPE design to promote risk awareness	Physical re-design of doffing area(s)[76]
		Color-coded PPE gown[74]
		Just-in-time screen-based guidance[37,77]

risky behaviors in the everyday tasks of ED personnel during PPE donning, doffing, and associated reuse; however, the study does not specify the measures to determine how much these risky behaviors increased the likelihood of COVID-19 infections. Second, in following the procedural steps outlined by Papautsky et al.,[32] we constrained our first step of the analysis to CDC-recommended procedural steps to donning and doffing, introducing a variant that may accommodate PPE reuse (addition of hand hygiene in a procedural step). However, the actual HCW practices of donning and doffing may vary by setting and provider preference. Third, the analysis reveals several risks that may increase the chances of HCW infection; however, our data cannot quantify the extent to which this risk is heightened during periods of PPE reuse. Finally, our study reflects the context and distinct constraints of emergency medicine workflows in the US health-care systems, which might differ from other health-care systems and limit its generalizability. Health institutions outside the United States (e.g., India, where outbreak rates are high and PPE resources are low)[76,77] may face heightened or differing risks in supporting PPE reuse. We, therefore, believe that the results of the study have direct relevance for all HCW at risk.

These limitations invite a more detailed analysis of the factors affecting potential variations in CDC recommended donning and doffing procedures in the reuse of PPE. There is a need to examine the prospective benefits of design solutions proposed in light of our findings, and we highlight the need to quantify the increased risks of contaminant spread and self-infections caused by PPE reuse.[13,16,78]

Conclusions

COVID-19 poses an existential risk to HCW due to inadequate PPE and poorly designed clinical workflows and PPE.[79] PPE reuse is not consistent with standards of care and standards for occupational safety and health, and it should only be condoned when it is truly essential due to supply constraints. However, the practice of PPE reuse will likely arise again throughout the COVID-19 pandemic and during future infectious crises, especially in countries with limited resources.

The results have important implications for health-care management and training practices to prepare for crisis scenarios and equipment shortages. Prior research and the results of the current study reveal an ever-present risk of exposure in *each* procedural step in the PPE standard procedure donning, doffing, and re-using of PPE sequence.

Our study reports on the first application of a PD approach to identifying the safety of protective behaviors and underlying risks in reusing PPE during the global pandemic. Future work is needed to consider the real-world compounded risks and variations in PPE donning and doffing practices and their implications for clinical practice. It is imperative to reexamine the design of system PPE protocols and PPE equipment to maximize HCW safety and well-being.

Eliminating infection risks is impossible, however, reducing the likelihood of harm and minimizing risk to HCWs is possible through better design.[80]

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Conflict of interest. None to report.

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