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The dangers of reused personal protective equipment: healthcare workers and workstation contamination

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SUMMARY

Background: Personal protective equipment (PPE) is essential to protect healthcare workers (HCWs). The practice of reusing PPE poses high levels of risk for accidental contamination by HCWs. Scarce medical literature compares practical means or methods for safe reuse of PPE while actively caring for patients.

Methods: In this study, observations were made of 28 experienced clinical participants performing five donning and doffing encounters while performing simulated full evaluations of patients with coronavirus disease 2019. Participants' N95 respirators were coated with a fluorescent dye to evaluate any accidental fomite transfer that occurred during PPE donning and doffing. Participants were evaluated using blacklight after each doffing encounter to evaluate new contamination sites, and were assessed for the cumulative surface area that occurred due to PPE doffing. Additionally, participants' workstations were evaluated for contamination.

Results: All participants experienced some contamination on their upper extremities, neck and face. The highest cumulative area of fomite transfer risk was associated with the hook and paper bag storage methods, and the least contamination occurred with the tabletop storage method. Storing a reused N95 respirator on a tabletop was found to be a safer alternative than the current recommendation of the US Centers for Disease Control and Prevention to use a paper bag for storage. All participants donning and doffing PPE were contaminated.

Conclusion: PPE reuse practices pose an unacceptably high level of risk of accidental cross-infection contamination to healthcare workers. The current design of PPE requires complete redesign with improved engineering and usability to protect healthcare workers.

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Introduction

Continued mutation the severe acute respiratory syndrome coronavirus-2 means that coronavirus disease 2019 (COVID-19) continues to be a cause of significant illness globally. Recommended protective measures for healthcare workers (HCWs) remain variable and sometimes ambiguous. HCWs have relied on personal protective equipment (PPE) to protect themselves,

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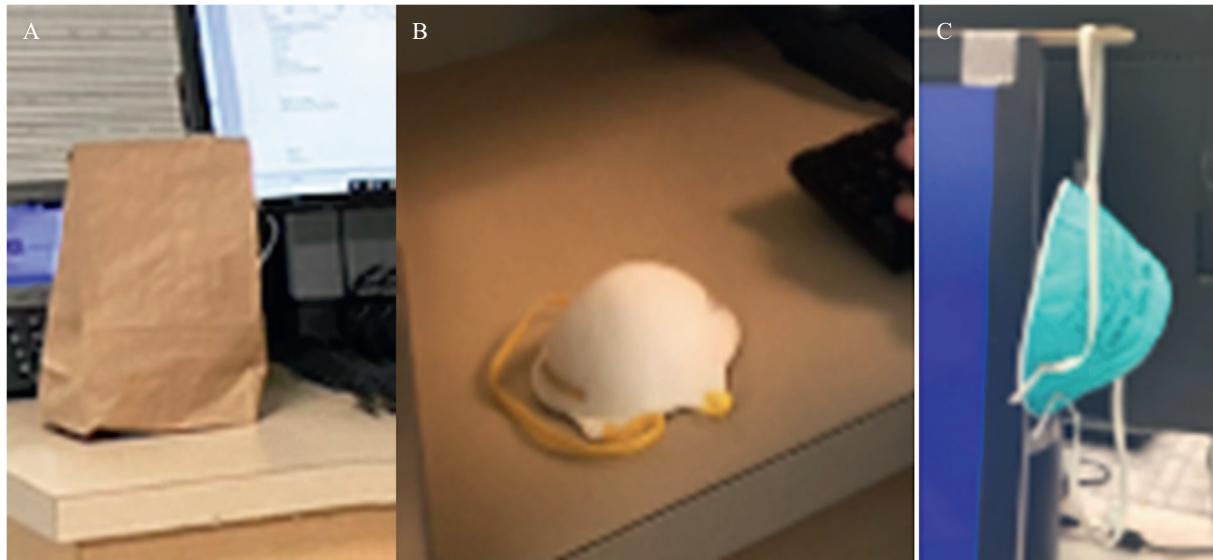


Figure 1. Personal protective equipment storage methods. (A) Paper bag; (B) tabletop; (C) monitor hook.

their patients and their families. Many HCWs became infected while caring for patients due to errors in the use of, or insufficient, PPE. There have been 4128 HCW deaths attributed to COVID-19 in the USA, and 115,000 deaths internationally, although the actual toll is likely to be much higher [1,2]. The US Centers for Disease Control and Prevention (CDC) recommends the use of a medical gown, gloves, respirator and eye protection for every encounter [3]. Unless stated explicitly, healthcare PPE is manufactured for single use [4]. The current universal single-use equipment was not designed to be worn for prolonged periods of time, and can cause issues with increased headaches, workload, discomfort, overheating, distraction and dehydration that necessitates frequent doffing [5]. However, due to increased demand and subsequent supply shortages, HCWs have had limited access to PPE, especially during the early stages of the COVID-19 pandemic. Extended use and reuse of PPE are needed to meet this operational challenge, with extended use considered the preferred method as it decreases the number of doffing cycles [6]. HCW require nutrition and restroom breaks, and often encounter numerous situations that require multiple rounds of doffing during a typical 8-h work shift. It is impractical to ask HCWs to wear PPE for an 8-h shift without removal.

Numerous studies have demonstrated that the process of PPE donning and doffing is difficult, variable and often results in self-contamination after each PPE use [7–9]. CDC guidelines recommend donning and doffing followed by disposal of contaminated equipment after a single use to minimize pathogen exposure of HCWs [10]. The outer surface of PPE should be considered contaminated following exposure to a patient, and contact should be avoided during the doffing process [11]. The directions for PPE doffing focus on avoiding touching the outer surfaces, taking care to keep the PPE away from the body, and immediate disposal once doffed [12]. Since March 2020, there have been minimal changes to the CDC guidelines for PPE donning and doffing [13]. Importantly, the guidelines advise that institutions that reuse PPE should adjust their donning and doffing protocols according to local guidelines, which has led to

wide variability in PPE practices and increased exposure risks among HCWs [13].

Very few studies have been undertaken regarding the safety profile of PPE reuse, recommendations for PPE reuse, or best practice guidelines on how to limit fomite exposure of HCWs between the reuse of PPE [14]. The CDC recommends a contingency strategy for placing used N95 respirators in a paper bag at the end of each shift for future reuse, and rotating with other reused respirators [6]. The aim is to prolong the life of the respirators, with the understanding that viable pathogens on respirators will degrade and no longer be infectious [6,15].

This study investigated the effectiveness and safety of PPE reuse practices by evaluating potential fomite transfer to HCWs and their work areas while donning and doffing extended-use, recycled PPE in a high-fidelity simulated ward. The study population consisted of active HCWs caring for hospital patients at the height of the COVID-19 pandemic.

Methods

Participants and inclusion criteria

Nurses, advanced practice providers and physicians were recruited from two academic hospitals. As this was an exploratory study, participants with at least 1 year of training and practice were selected for inclusion in order to reflect a level at which trainees are expected to assume responsibility for routine COVID-19 patient assessment. Participants were recruited through e-mail and word of mouth. Interested participants were provided with a written informed consent form that included the risks and benefits of the study. The inclusion criteria included active HCWs aged >18 years.

Simulation environment

This prospective study was conducted in a dedicated 30,000 square foot simulation center affiliated with a large public medical school in the USA. Each participant was assigned one



Figure 2. Nurse participant performing a physical examination on a high-fidelity mannequin.

fully furnished high-fidelity simulated emergency department examination room, with an adjacent workstation located outside the room that included the patient monitoring equipment routinely used in the hospital. They were provided digital access to simulated patient records via a computer screen, keyboard and telephone, and the room had a bottle of hand sanitizer and a wall hook to hang their personal protective equipment. An integrated audiovisual system digitally recorded all activity. The experimental environment has been validated and described in detail previously [16,17].

Simulated contaminant and utilization

The study was conducted over 7 days in February and March 2021 at the height of the COVID-19 pandemic. Three respirator storage designation options were assigned at random to one of the available days. Participants were able to sign up voluntarily in order to minimize researcher bias or predictability.

The three respirator storage cohort options included a brown paper bag (Group A), a tabletop surface (Group B) and a computer-monitor-mounted hook (Group C) (Figure 1).

The rooms were cleaned meticulously by the same investigator (DD) in a standardized manner between each patient encounter to reduce possible cross-contamination, and were

evaluated with a blacklight to ensure that no traces of contaminant were left between each simulation.

The authors used fluorescent material that glows only if visualized under blacklight to validate the method and assess for fomite transfer [16,17]. A tablespoon of equal parts Glo Germ and store brand petroleum jelly was applied to the outer surface of the N95 respirator to represent contamination, expected after a single use [11]. During pilot experimentation, this method of application was found to transfer only with direct contact, while providing for easy and consistent application. One half teaspoon of the combined mixture was applied by the same investigator (DD) to N95 respirators, with a uniform standard coating every morning prior to the arrival of participants. Standard alcohol-based hand sanitizer was used to remove all traces of the fluorescent material. Blacklight was used to ensure that a consistent layer was applied to the outer surface alone, avoiding the PPE straps.

Participants were blinded to the fomite source, which was a non-toxic odourless mixture with minimal tactile perception and nearly invisible to the naked eye. Participants were examined prior to study participation under blacklight for exposure to substances that might fluoresce before data collection.



Figure 3. Workstation data collection utilizing blacklight.

Simulation scenarios and patient evaluation

Participants were asked to perform five focused evaluations of simulated COVID-19 patients while reusing PPE. The CDC guidelines state that, unless otherwise indicated, the maximum number of times to don N95 respirators safely should be five, as fit and function decline after multiple uses [12,18]. A note with vital signs and a chief complaint was placed on the door prior to each encounter. The participants donned their PPE prior to entering the room, as per CDC and hospital guidance, and were instructed to conduct a targeted history and examine a high-fidelity mannequin (Figure 2). Each scenario included an adult patient with COVID-19 symptoms requiring PPE donning and doffing for the encounter. Volunteer clinicians were instructed to perform as if they were in the middle of a shift. PPE provided included 9500-N95 (Lot# 070320), face shield, gloves and gown, similar to that used by the HCWs every day. Participants were allowed to use new gloves and hand sanitizer as often as they felt necessary, but were required to reuse all other provided PPE. All equipment needed for an examination, such as a stethoscope or otoscope, was available in the patient's room. Upon exiting the room, participants would doff their PPE completely, hang the face shield and gown

on the door, and store their respirator using one of the three randomly assigned methods.

The primary endpoint for the study was the amount of fomite transfer assessed using blacklight after each of the five scenarios. The contaminated areas were documented after every doffing event using the authors' validated data collection tool (Appendix 1, see online supplementary material). This tool was piloted and refined based on feedback from clinical users. The participants typed their focused history and physical examination notes using the designated workstation computer. Once they had completed their history and physical examination notes, the subjects would begin the process again by donning PPE in preparation for the next patient scenario. The patient room was cleaned thoroughly between patient encounter to avoid accidental contamination.

Data acquisition

Cumulative and new areas of contamination were measured with a transparent ruler and blacklight. The workstation was examined under blacklight for any contamination sites without the knowledge of participants while they were in the patient room performing the patient history and physical examination

Table I
Total number of contamination events for each storage method

Storage methods	Number of contaminations	Total number of events	Contamination rate (%)
Paper bag	48	50	96
Tabletop	43	45	95
Hook	40	45	88
Total	131	140	93.6

(Figure 3). The workstation contamination area was assessed using the data collection tool (Appendix 1, see online supplementary material). Once participants completed doffing their PPE, they were asked to close their eyes and stand in the standard anatomical position (standing upright and facing forward with legs parallel and each arm hanging on either side of the body with the palms facing forward) while their clothing and body were examined by the same investigator (DD) under blacklight for signs of contamination. The study subjects were

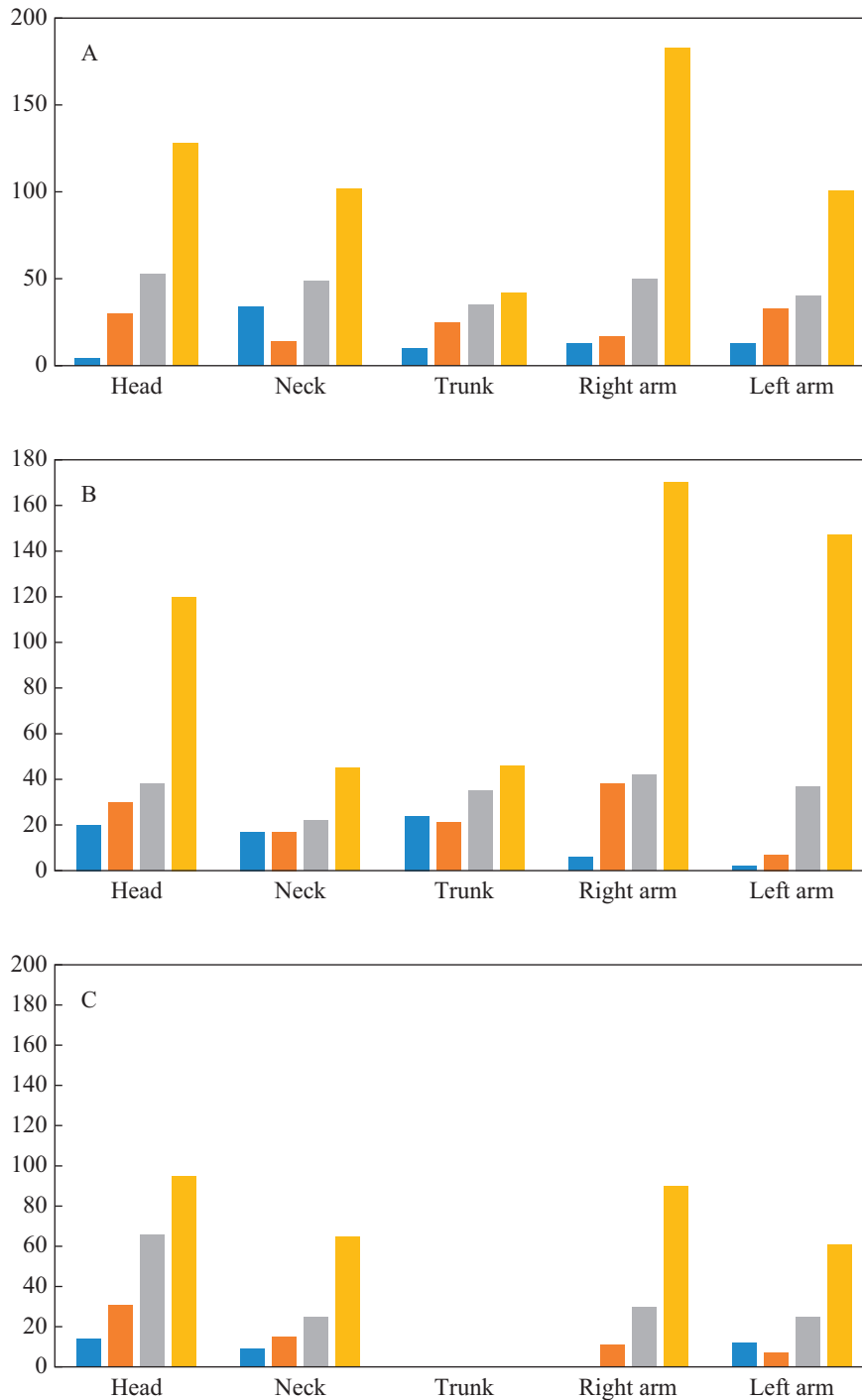


Figure 4. Total numbers and sizes of new contamination sites after five encounters using each of the three storage methods. (A) Paper bag; (B) hook; (C) tabletop. Areas of fluorescence: blue bars, very large ($\geq 5 \text{ cm}^2$); orange bars, large ($\geq 2.5\text{--}5 \text{ cm}^2$); grey bars, medium ($\geq 1\text{--}<2.5 \text{ cm}^2$); yellow bars, small ($<1 \text{ cm}^2$).

Table II
Average surface area contamination after five patient encounters^a

	Very large	Large	Medium	Small
Paper bag	13 cm ²	10.8 cm ²	23.3 cm ²	19.5 cm ²
Tabletop	6.7 cm ²	7.8 cm ²	16.9 cm ²	15.8 cm ²
Hook	14.4 cm ²	10.8 cm ²	20 cm ²	8 cm ²

^a Contamination area: small <1 cm²; medium ≥1–<2.5 cm²; large ≥2.5–5 cm²; very large ≥5 cm².

then instructed to type their patient encounter notes using the computer keyboard.

Blacklight measurements

Blacklight measurements were made looking for discreet locations of fluorescence, measured in cm² to account for the size of contamination that occurred on the workstation and on participants' bodies [16]. Areas of fluorescence were categorized as small (<1 cm²), medium (≥1–<2.5 cm²), large (≥2.5–5 cm²) or very large (≥5 cm²).

Study oversight

The study was approved by Indiana University Institutional Review Board (IU IRB# 2005953971). All authors contributed to data collection and acquisition, database development, discussion and interpretation of the results, and drafting of the manuscript.

Results

Study demographics and PPE training

Twenty-eight clinicians were recruited, resulting in 140 patient assessments; each participant completed all five patient scenarios. Females comprised 64% of the study population. Physicians accounted for 53%, nurse practitioners accounted for 7% and nurses accounted for 39%. Half of the participants had been in independent practice for ≤3 years. Most participants reported shift times of 9 or 12 h. All participants were right-hand dominant. Nearly all participants

reported receiving numerous PPE training sessions in the past year, and felt competent in donning and doffing PPE safely, although only 21% reported any direct training or discussion how to manage their reused PPE. All of the participants indicated that they would dispose of their PPE if it was visibly soiled or damaged.

Comparison of the three respirator storage techniques

All participants were evaluated for new contamination sites after each encounter. The paper bag, tabletop and hook methods each had two participants who were able to don and doff in one of the five encounters without contamination. The hook method was used by one participant who was able to successfully don and doff in three of five episodes without contamination. Twenty of the 28 participants were contaminated after each PPE donning and doffing encounter. No participants were able to don and doff without being contaminated in all five encounters (Table I).

The right arm had the greatest number of small fomite sites for the paper bag and hook methods; however, the tabletop storage method had the greatest number of small fomite sites on participants' heads. The areas with the largest areas of fomite transfer were on the head, neck and trunk (Figure 4).

Comparison of cumulative contamination sites

The cumulative contamination that occurred over the course of all five patient encounters was assessed, in addition to reviewing the number of new contamination sites after each patient encounter. The total surface area contamination was lowest when the respirator was stored using the tabletop method (Table II).

Cumulative sites – comparison of the three storage techniques

The results are shown in Table III and Figure 5. There was a gradual increase in contamination on the head, neck and trunk

Table III
Average areas of total contamination over five encounters using each of the three different storage methods

Storage method	Anatomic site	Encounter 1	Encounter 2	Encounter 3	Encounter 4	Encounter 5
Paper bag	Head	36 cm ²	68.5 cm ²	71 cm ²	84 cm ²	96 cm ²
	Neck	48 cm ²	70 cm ²	92.5 cm ²	107.5 cm ²	111.5 cm ²
	Trunk	35 cm ²	39 cm ²	44.5 cm ²	49 cm ²	74.5 cm ²
	Right arm	72 cm ²	78.5 cm ²	89 cm ²	83.5 cm ²	92.5 cm ²
	Left arm	85 cm ²	73 cm ²	56 cm ²	71.5 cm ²	63 cm ²
Tabletop	Head	49.5 cm ²	79 cm ²	91 cm ²	94.5 cm ²	88.5 cm ²
	Neck	24.5 cm ²	45 cm ²	45.5 cm ²	43 cm ²	52 cm ²
	Trunk	24.5 cm ²	33.5 cm ²	41.5 cm ²	46.5 cm ²	39.5 cm ²
	Right arm	34 cm ²	35.5 cm ²	37.5 cm ²	33 cm ²	30 cm ²
	Left arm	51.5 cm ²	61 cm ²	37.5 cm ²	38 cm ²	35.5 cm ²
Hook	Head	52 cm ²	72 cm ²	81 cm ²	86 cm ²	99 cm ²
	Neck	20 cm ²	32 cm ²	46.5 cm ²	61.5 cm ²	67.5 cm ²
	Trunk	40 cm ²	61 cm ²	65.5 cm ²	61.5 cm ²	78 cm ²
	Right arm	82 cm ²	83 cm ²	115.5 cm ²	73 cm ²	81.5 cm ²
	Left arm	62.5 cm ²	52 cm ²	46.5 cm ²	53.5 cm ²	52.5 cm ²

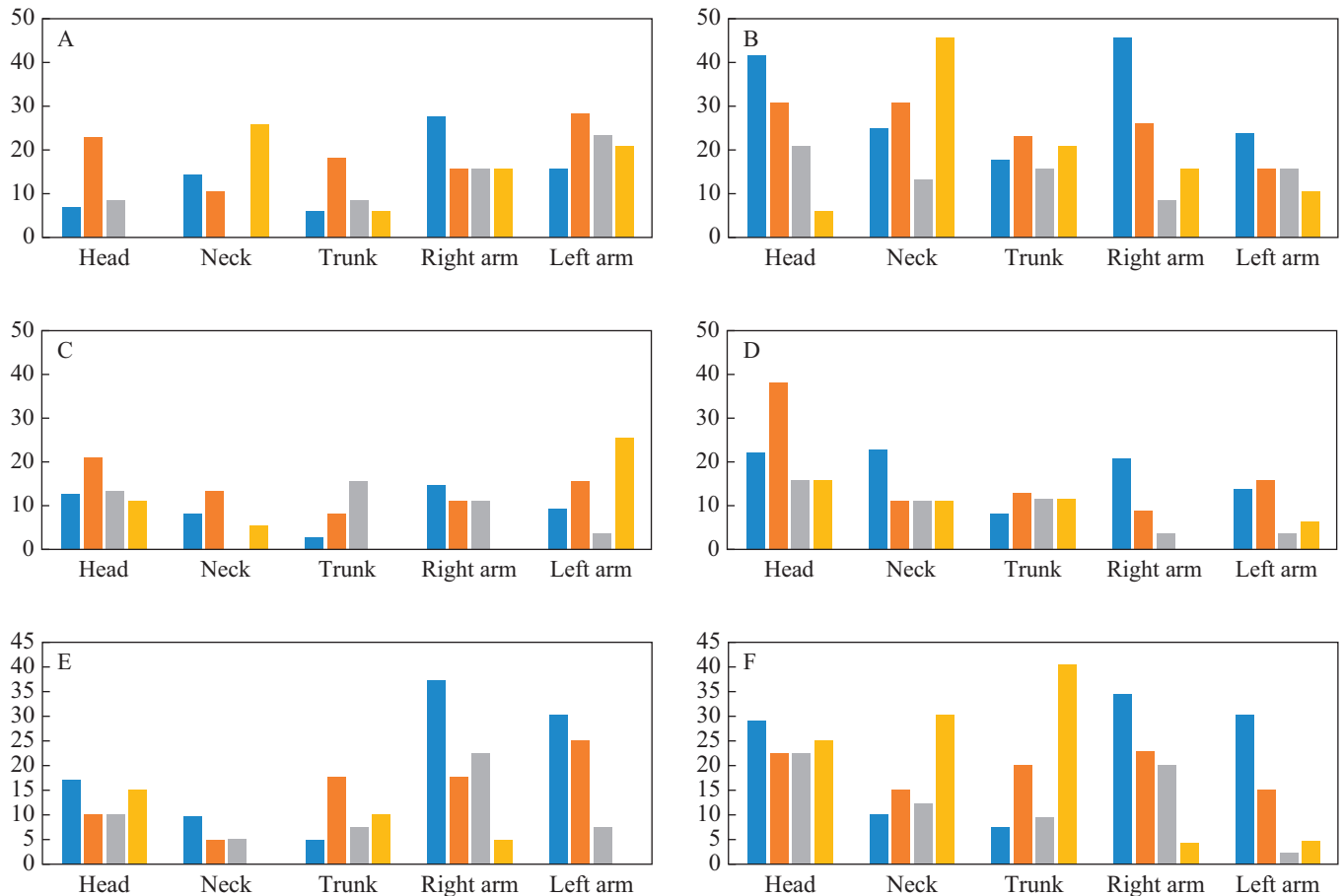


Figure 5. Total surface area contamination from Encounter 1 to Encounter 5 using each of the three storage methods. (A) Paper bag, Encounter 1; (B) paper bag, Encounter 5; (C) tabletop, Encounter 1; (D) tabletop, Encounter 5; (E) hook, Encounter 1; (F) hook, Encounter 5. Areas of fluorescence: blue bars, very large (≥ 5 cm²); orange bars, large (≥ 2.5 – 5 cm²); grey bars, medium (≥ 1 – < 2.5 cm²); yellow bars, small (< 1 cm²).

areas with all three storage methods. There was more variation in contamination of the two arms.

Internal respirator contamination

At the end of five patient encounters, each participant placed their respirator on their workstation. The respirators were evaluated by the same investigator (DD) with blacklight for any internal contamination. The hook method led to the least internal contamination at 50%, compared with 88% and 75% for the paper bag and tabletop methods, respectively.

Workstation contamination

Of the 28 participants, 85.7% had some form of workstation contamination at the end of the five encounters. The areas with the most notable contamination were the keyboard (spacebar and middle keys) and the counter areas near the keyboard that were used by the tabletop respirator storage cohort. The tabletop method was the only method to have very high contamination, although the contamination was confined to the area of respirator storage and was dependent on whether the outside portion of the N95 respirator was placed

down against the tabletop. The paper bag method had the highest overall number of small contamination sites (Figure 6).

Discussion

There were wide variations in the donning and doffing of PPE practices by HCWs across different simulated patient encounters. All three methods used for respirator storage between doffing and donning episodes resulted in a significant amount of contamination of the HCWs and their workstations. A new area of contamination was found in 75% of participants after each patient encounter, and by the end of five donning and doffing cycles, 100% of participants had some form of fomite contamination. Fomite contamination of the head, neck and trunk increased gradually during the five patient encounters. However, the arms had notable variation in comparison with other body areas. The total surface area of contamination was greatest with the paper bag and hook methods of PPE storage, and lowest with the tabletop method. Additionally, a significant proportion of participants had fluorescent contamination on the inside of their N95 respirators; remarkably, the hook storage method demonstrated the lowest contamination of the three storage methods. Finally, in 24 of the 28 study participants

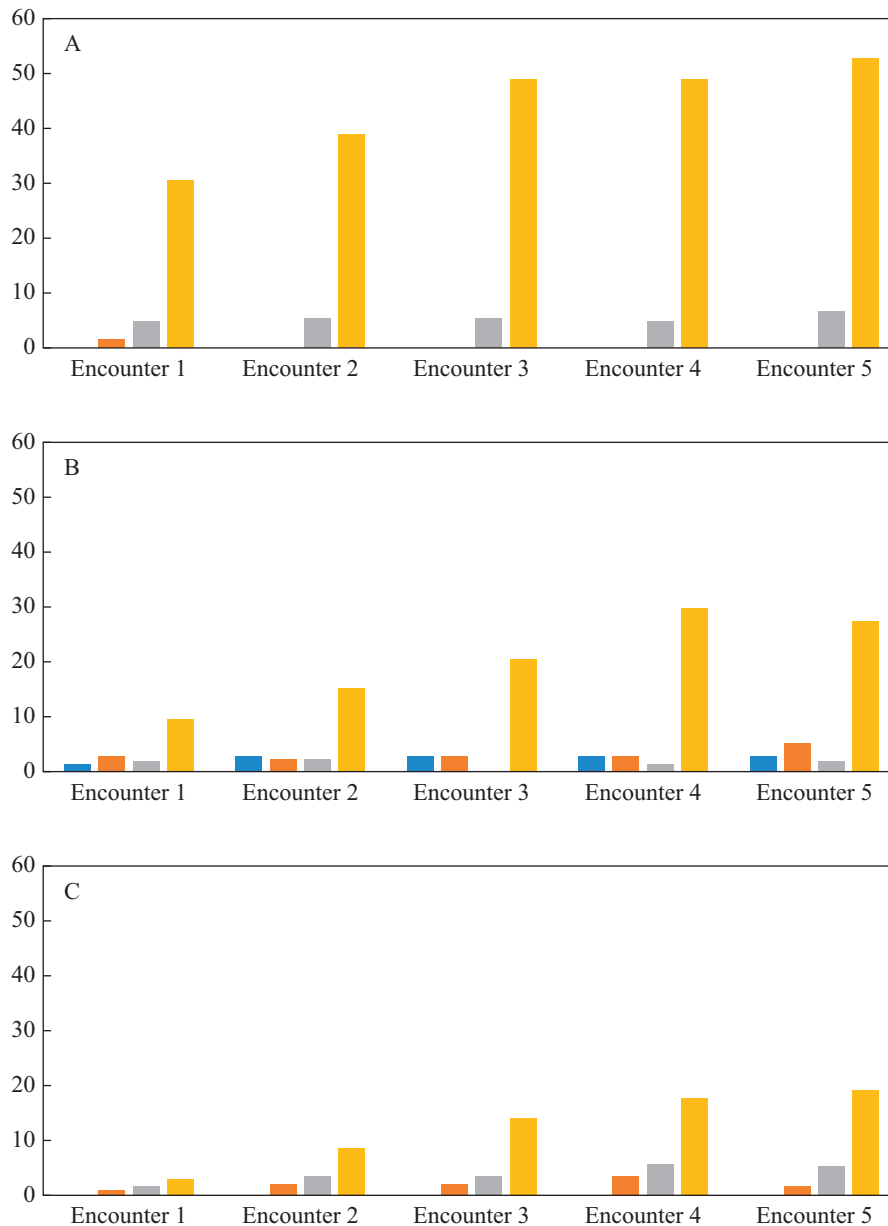


Figure 6. Workstation contamination by storage method. (A) Paper bag; (B) tabletop; (C) hook. Areas of fluorescence: blue bars, very large ($\geq 5 \text{ cm}^2$); orange bars, large ($\geq 2.5\text{--}5 \text{ cm}^2$); grey bars, medium ($\geq 1\text{--}<2.5 \text{ cm}^2$); yellow bars, small ($< 1 \text{ cm}^2$).

(85%), the workstations were contaminated by fomite transfer at the end of the five patient encounter cycles.

The results of this study demonstrate the risk of cross-infection to HCWs associated with reusing PPE. The area most affected by small areas of contamination was the right arm (all participants being right-hand dominant). The areas of lowest contamination on the rest of the body were significant as they represented areas accidentally exposed to contamination, with some of these areas developing into much larger contamination sites from repeated additive exposure during the five encounters.

This study also demonstrated that certain respirator storage methods are riskier for contamination than others. All three PPE storage methods showed cumulative increases in total

surface area contamination of the head, neck and trunk regions as the study progressed. Interestingly, right and left arm contamination were attributed to the amount of hand sanitizer utilized. In the pilot phase of the study, hand sanitizer was shown to remove hand fluorescence easily, so this likely represents real-world variability in contamination affected by how HCWs use hand sanitizer. Unfortunately, other vulnerable areas, such as the head and neck, which are not cleaned routinely during clinical shifts are at risk of cumulative contamination from potential pathogens [19]. Additionally, some areas of contamination that were initially small expanded into larger areas of contamination over the five simulated encounters. Intuitively, this could be an expected result of an HCW exposed repeatedly to contamination that was not addressed

immediately. The results indicate that storing a reused N95 respirator face up on a tabletop during a shift could be a better alternative to the paper bag method recommended by CDC.

Another important finding was the number of respirators that had contamination on their internal surfaces. It should be clear that the contamination was not apparent to the naked eye, similar to aerosol contamination by airborne pathogens [5]. This contamination likely occurred through accidental direct hand contact, and through facial contamination that was then transferred to the respirator. This represents a serious occupational risk to HCWs from reusing a N95 respirator because of the high risk of self-contamination and infection. The hook method performed best in this regard, perhaps not unexpectedly given that this method facilitates handling the respirator by the straps.

The workstation with the most overall contamination was noted when the CDC-recommended paper bag method was used. The act of reaching repeatedly into a paper bag holding a contaminated respirator could explain this. Interestingly, the tabletop method, which involved placing the respirator directly on the workstation work site, led to a much lower number of contaminated areas of the workstation, but the contaminated areas were much larger.

The focus of this study was the evaluation of HCW and workstation contamination, but contamination and its risk of further transfer does not occur in a vacuum. Any residual contamination of an HCW must be considered as a serious risk to patients and other HCWs. Anecdotally, while cleaning the patient examination room between encounters, fluorescent transfer to the nasal canula, patient wrists and handrails of the bed was observed. These areas were cleaned thoroughly to limit external areas of potential contamination of the study subjects. In real-world care, this source of contamination would be a risk to patient and staff safety.

Limitations

This study was undertaken at a time during the COVID-19 pandemic when PPE supplies were extremely limited, meaning that HCWs were already familiar with PPE reuse; at the outset of any future pandemic, HCWs unfamiliar with PPE reuse may perform at a lower level than observed in this study. The simulated context of this study represents a potential confounder in that HCWs may be less careful than when having patient contact. Nevertheless, simulation offered access to events that cannot otherwise be observed directly, and in a safe and controlled environment [20]. Structured scenarios that set up specific settings that evoke and replicate features of real-world clinical situations during COVID-19 care were used, with the aim of producing data that can be analysed to improve HCW wellness [21]. To increase the external generalizability of the findings, variability in the HCW workflow was allowed in order to replicate current clinical practice during the pandemic. However, although high-fidelity simulation was used, participants were aware that they were being evaluated and the Hawthorne effect may have applied. Glo Germ was used as the measure of contamination, and it cannot be concluded that the observations would apply to the transfer of infectious virus particles. Additionally, patients will have variable levels of viral load depending on severity and type of disease, and the burden of respirator contamination in real-life settings may be limited by the use of visors, or by particles

being trapped in the respirator. Finally, this study was conducted in the USA where N95 respirators are used commonly, but may not represent PPE usage in other countries.

In conclusion, this study demonstrated deficits in PPE reuse among all observed HCWs, with a significant amount of contamination found when PPE is reused and stored by any method, including the paper bag method recommended by CDC. There is still no reputable evidence to guide HCWs on how to approach PPE reuse during clinical care. This study found that the main areas of contamination were the dominant arm, head and neck. There was no clearly superior storage method for respirators during shifts, although placing respirators on a hook or leaving them on the tabletop seemed preferable to the CDC-recommended paper bag method. High areas of contamination should be taken into consideration when redesigning PPE, physical space design of clinical wards, and better ways for HCWs to reuse PPE safely [22]. Future studies should focus on practical doffing methods for reused PPE, while incorporating a deeper appreciation of human factors to support safe and consistent doffing practices [23].

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Conflict of interest statement

None declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jhin.2022.05.016>.

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