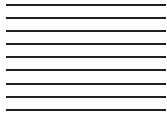




Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



Brief Report

Reuse of Personal Protective Equipment: Results of a Human Factors Study Using Fluorescence to Identify Self-Contamination During Donning and Doffing

Devin Doos, MD,^a Paul Barach, B.MED.SCI., MD, MPH,^{b,c} Elisa Sarmiento, MSPH-EPAP,^a and Rami Ahmed, DO, MHPE^a

^aDepartment of Emergency Medicine, Indiana University School of Medicine, Indianapolis, Indiana, ^bJefferson College of Population Health, Thomas Jefferson University, Philadelphia, Pennsylvania, and ^cUniversity of Queensland, Brisbane, Queensland, Australia
Reprint Address: Devin Doos, MD, Department of Emergency Medicine, Indiana University School of Medicine, 720 Eskenazi Avenue, FT 3, Indianapolis, IN 46202.

□ **Abstract—Background:** At least 115,000 health and care workers (HCWs) are estimated to have lost their lives to COVID-19, according to the the chief of the World Health Organization (WHO). Personal protective equipment (PPE) is the first line of defense for HCWs against infectious diseases. At the height of the pandemic, PPE supplies became scarce, necessitating reuse, which increased the occupational COVID-19 risks to HCWs. Currently, there are few robust studies addressing PPE reuse and practice variability, leaving HCWs vulnerable to accidental contamination and harm. **Objective:** The objective of this study was to assess potential HCW contamination during PPE donning, doffing, and reuse. **Methods:** The study included 28 active acute care physicians, nurses, and nurse practitioners that evaluated 5 simulated patients with COVID-like symptoms while donning and doffing PPE between each patient encounter. An N95 mask was contaminated with a transparent fluorescent gel applied to the outside of the N95 mask to simulate contamination that might occur during reuse. Participants were evaluated after PPE doffing for each encounter using a black light to assess for face and body contamination. **Results:** All participants had multiple sites of contamination, predominantly on their head and neck. None of the participants were able to don and doff PPE without contaminating themselves during five consecutive simulation cycles. **Conclusions:** The current Centers for Disease Control and Prevention PPE guidelines for donning and doffing fall short in protecting HCWs. They do not adequately protect HCWs from contamination. There is an urgent need for

PPE and workflow redesign. © 2021 Published by Elsevier Inc.

□ **Keywords—personal protective equipment; PPE; donning; doffing; PPE reuse; occupational risks**

Introduction

COVID-19 has shone a bright light on the physical and emotional safety burdens that frontline health care workers (HCWs) around the world face. Unsafe working conditions and a lack of personal protective equipment (PPE) remain major challenges for HCWs throughout the recurrent waves of the pandemic and reflect on our society's failings.

PPE offers a critical barrier for preventing disease transmission in health care settings, but its widespread use during the COVID-19 pandemic has changed the experience of care delivery. In the United States, an estimated 3600 HCWs perished from COVID-19, which was most likely contracted during work (1). Centers for Disease Control and Prevention (CDC) guidelines and PPE availability were unable to keep HCWs safe from harm. HCWs in low-income countries have been particularly affected due to limited protective equipment and delayed vaccinations (2). Globally, the Director-General of the World Health Organization has documented

HCW infections in the hundreds of thousands, with at least 115,000 HCWs reported to have died from COVID-19 occupational exposure (3). These figures are likely a significant underestimate, given that many governments have not collected official data, or have done so only partially (1).

The outer surface of PPE is considered contaminated once exposed to a pathogen and dangerous to HCWs during reuse (4). All PPE reuse is an opportunity to expose HCWs and others to pathogens from prior patient encounters and it is not recommended by the CDC except during health crises (4). There are no national guidelines for PPE reuse, instead, the CDC recommends that HCWs follow their own institutional policies, which are often inconsistent and have no required reporting or auditing oversight(5). PPE reuse remains a serious occupational hazard, as doffing is recognized as a high-risk activity for self-contamination (4,6). However, little is known regarding the safety and unintended consequences of PPE reuse, despite significant recommendations against it (4).

We describe fomite transmission occurring during subsequent episodes of HCWs donning and doffing of reused PPE and explored the implications for HCW contamination that can result from PPE reuse.

Methods

Setting and Participants

Twenty-eight practicing physicians, nurses, and nurse practitioners from a large academic medical center voluntarily participated in a simulated emergency department (ED) acute patient encounter. The HCWs were tasked to evaluate the clinical status of 5 patients, including PPE donning and doffing after each encounter to protect from contamination. Participants' ED tenure varied from 1 to 25 years (average 4 years) and included men and women (36% and 64%, respectively). All participants gave written consent and were active providers trained to use PPE according to CDC and institutional guidelines. The study was approved by the Indiana University institutional Review Board.

Data Collection

We coated the outer surface of standard N95 masks with fluorescent gel using a standard method by one member of the research team (D.D.) in a similar fashion and with the same amount. The fluorescent petroleum gel tracer simulated pathogen contact transfer that occurs from PPE donning and doffing after encountering an infectious patient. For consistency and logistics, a single

batch of gel mixture was applied 1–3 hours prior to study participant's arrival. Preliminary testing did not reveal a significant change in fluorescence or gel transfer if applied up to 6 hours prior to use. The petroleum-based gel was odorless, clear, and had minimal tactile surface as to not be an obvious source of contamination. Each mask was assessed with black light to ensure only the outer surface was covered with gel equally and did not contaminate other surfaces, such as the mask straps or interior surfaces that touch the face and neck.

The participants were given a disposable gown, face shield, N95 mask, and gloves per CDC recommendations. Except for gloves, all PPE was reused for the entirety of the 5-patient scenario. Each patient encounter had a clinical symptom that would put them at high risk for COVID-19 diagnosis and would require the HCW to wear full PPE. Prior to each patient encounter, the participants were asked to fully don their provided PPE as they would in their real-world clinical settings. Once they felt they were fully protected and ready, they would enter the patient's room and were instructed to perform a targeted history and physical examination. The participants were encouraged to behave as they would in their real-world clinical roles. All equipment needed to perform an examination, such as a stethoscope, was available in the examination room. Both the room and any equipment used were thoroughly cleaned in between each patient encounter. Upon exiting the room, participants would completely doff their equipment, including their N95 mask, which was stored on their workstation. Hand sanitizer was available to be used as often as participants perceived necessary during their donning and doffing process. The participant workstation was thoroughly cleaned before and after each scenario to ensure that any contamination was solely from the N95 mask. Prior to the start of the study, each participant was reviewed under blacklight to confirm they did not have contaminated surfaces. In addition, to eliminate unintended transfer from the patient examination room, the rooms were cleaned and checked under black light guidance between each patient encounter.

Results

A total of 28 of 28 participants (100%) had multiple contamination sites using black light by the end of the 5 patient encounters. The body sites most contaminated were the head and dominant hand (Figure 1). Every participant had multiple sites of fluorescent dye transfer to either their face, neck, or hands, or a multi-site contamination (Figure 2). The HCW participants were able to doff PPE safely once at most, and only during one-quarter of the simulated patient encounters, without contaminating their other body sites.

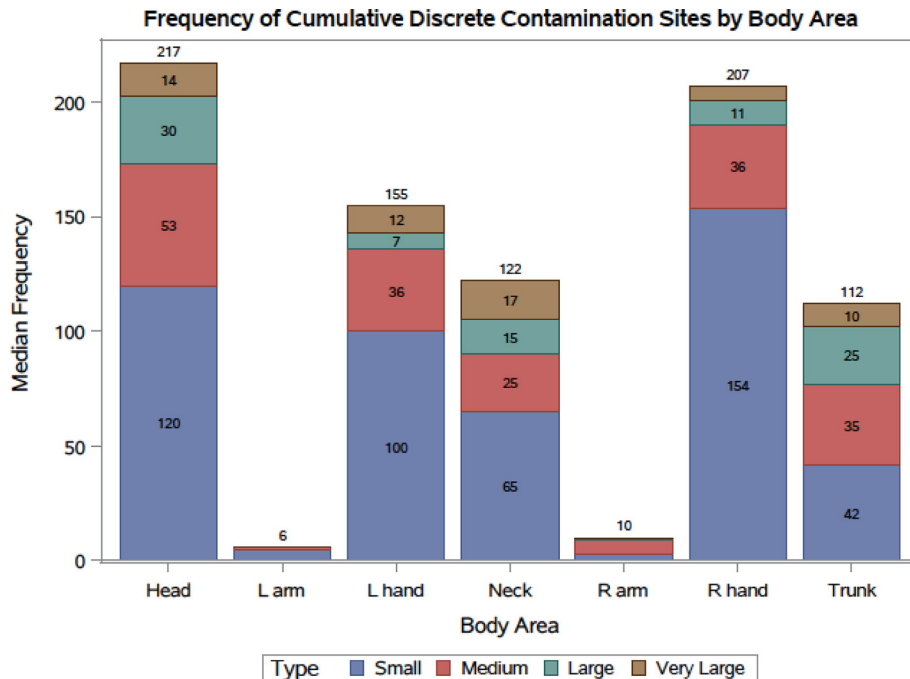


Figure 1. Frequency of cumulative discrete contamination sites by body area. Sites are designated as small ($\leq 1 \text{ cm}^2$), medium ($1\text{--}2.5 \text{ cm}^2$), large ($>2.5\text{--}5 \text{ cm}^2$) to very large ($\geq 5 \text{ cm}^2$).

Discussion

Reuse of PPE exposes HCWs to contamination when using inadequate and unsafe equipment, as seen during the COVID-19 pandemic. The data suggest that even when strictly following CDC guidelines, it is impractical not to touch the outer portions of a reused mask and gown when donning PPE. This is further supported by recent data demonstrating transmission of COVID-19 from asymptomatic individuals to HCWs in healthcare settings despite PPE protection (7). Furthermore, these guidelines require both hands to ensure adequate mask seal and fit (8). Although the results are not surprising, the implications of causing routine self-contamination during standard PPE reuse are deeply troubling.

Our study’s strengths include the consistently high rate of contamination, diversity of clinical roles, and the identification of specific aspects of PPE reuse that led to HCW self-contamination. Our findings challenge the widely accepted assumption that reused PPE is safe and raise the question of whether additional measures are needed to enhance respiratory protection and source control in healthcare.

Limitations

This study has several limitations and must be interpreted in the context of its design. First, this study lacks population level data quantifying the frequency of trans-

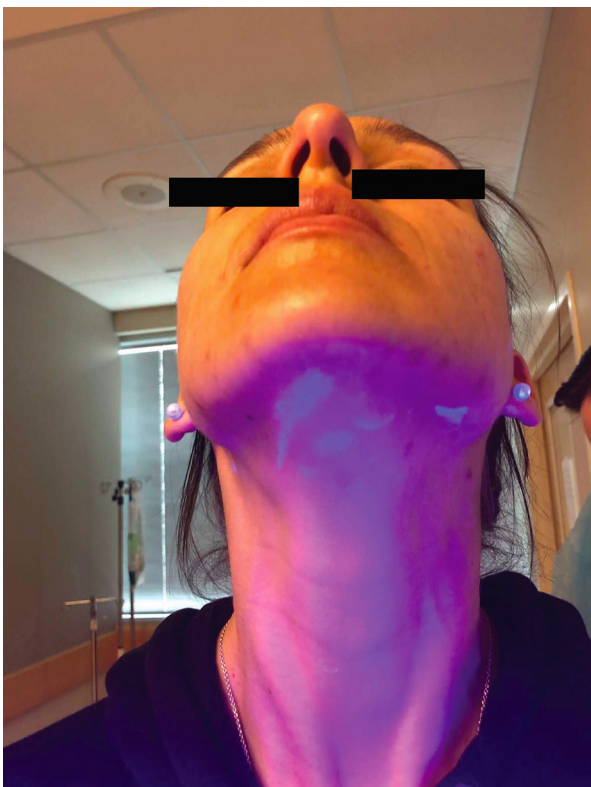


Figure 2. Participant with contaminated fluorescent dye on neck as visualized under black light.

missions despite PPE and had a small sample size that focused on practitioners in emergent care settings at one hospital. The fact that 100% of participants were contaminated during our study, however, speaks to the external generalizability and potential significance of our findings. The only source of possible contamination was from the participant PPE failure and not via fomites, so any further transfer was due to unintentional participant contamination during donning and doffing. We believe that our study's results have great relevance in protecting HCWs and have external generalizability to other hospitals and countries. Second, the amount of fomite transfer, although impressive, does not necessarily correlate with clinical infection.

Conclusions

Our findings have important implications for hospital management practices. We believe that there is an urgent need for better human factors and ergonomic research to improve the functional design and usability of PPE, redesign the PPE workflow, and question whether respirators should be used more widely. HCWs need regular feedback (i.e., spotter guardianship) about contamination risks, and how best to mitigate the risks faced by HCWs during care of COVID-19 patients (8,9). It is imperative to seriously address HCW occupational hazards and risks as the ravages of COVID-19 variants continue to accelerate with devastating health, social, and economic consequences to HCWs around the world.

References

1. Lost on the frontline: US healthcare worker deaths. The Guardian. Published April 8, 2021. Accessed October 26, 2021. Available at: <https://www.theguardian.com/us-news/ng-interactive/2020/aug/11/lost-on-the-frontline-covid-19-coronavirus-us-healthcare-workers-deaths-database>.
2. McMahon DE, Peters GA, Iers LC, Freeman EE. Global resource shortages during COVID-19: bad news for low-income countries. *PLoS Negl Trop Dis* 2020;14(7).
3. Ghebreyesus TA. Director-General's Opening Remarks at the World Health Assembly –24 May 2021. Accessed July 17, 2021. <https://www.who.int/director-general/speeches/detail/director-general-s-opening-remarks-at-the-world-health-assembly-24-may-2021>.
4. . Implementing filtering facepiece respirator (FFR) reuse, including reuse after decontamination, when there are known shortages of N95 respirators. Centers for Disease Control and Prevention; 2020 Updated October 19 Accessed July 22, 2021. Available at: <https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html>.
5. . Use personal protective equipment (PPE) when caring for patients with confirmed or suspected COVID-19. Centers for Disease Control and Prevention; 2021 Updated June/3/2020. Accessed Oct. 27 Available at: https://www.cdc.gov/coronavirus/2019-ncov/downloads/A_FS_HCP_COVID19_PPE.pdf.
6. Tomas ME, Kundrapu S, Thota P, et al. Contamination of health care personnel during removal of personal protective equipment. *JAMA Intern Med* 2015;175:1904–10.
7. Michael Klompas, Meghan A Baker, Diane Griesbach, Robert Tucker, Glen R Gallagher, Andrew S Lang, Timelia Fink, Melissa Cumming, Sandra Smole, Lawrence C Madoff, Chanu Rhee, for the CDC Prevention Epicenters Program, Transmission of Severe Acute Respiratory Syndrome Coronavirus 2 (SARSCoV-2) From Asymptomatic and Presymptomatic Individuals in Healthcare Settings Despite Medical Masks and Eye Protection, *Clinical Infectious Diseases*, Volume 73, Issue 9, 1 November 2021, Pages 1693–1695, <https://doi.org/10.1093/cid/ciab218>
8. Hignett S, Welsh R, Banerjee J. Human factors issues of working in personal protective equipment during the COVID-19 pandemic. *Anaesthesia* 2021;76:134–5.
9. Patel AB, O'Donnell A, Bonebrake A, et al. Stewardship of personal protective equipment (PPE): an important pandemic resource for PPE preservation and education. *Infect Control Hosp Epidemiol* 2021;42:636–7.

ARTICLE SUMMARY

1. Why is this topic important?

Nearly 2 years into the COVID-19 pandemic and many health care workers (HCWs) are still getting infected and dying. HCWs are still reusing personal protective equipment (PPE) due to limited supplies and uncertain future. There is a large gap in the literature to guide HCW practices and minimize occupational risks associated with COVID-19 disease transmission from PPE reuse.

2. What does this study attempt to show?

The study evaluated the susceptible areas of contamination that occur from PPE reuse. Current PPE guidance is inadequate to protect HCWs from contamination and potential infection.

3. What are the key findings?

PPE reuse increases HCWs' risk of self-contamination and potential infections. Common areas of contamination during PPE reuse are the head and neck. Current methods for PPE reuse are inadequate, vague, and increase HCWs' occupational risks. It is urgent to question whether respirators should be used more widely by HCWs in high risk settings.

4. How is patient care impacted?

Minimizing HCW contamination can decrease patient contamination and harm risks. Better PPE protection and human factors redesigned workflow will lead to less HCW contamination and improved workforce capacity.