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Highlights

- Healthcare personnel are at risk for pathogen contamination during personal protective equipment doffing.
- Variation in reviewed studies' methodology make it difficult to identify determinants or patterns of post-doffing contamination across studies.
- Many doffing protocols are insufficient to prevent post-doffing contamination.
- Studies where healthcare personnel used a specific type of personal protective equipment and followed a doffing protocol had lower post doffing contamination rates.
- Effective doffing protocol, personal protective equipment sizing and design, and training in doffing can help reduce the risk of pathogen contamination among healthcare personnel.

Assessing Patterns of Body Contamination after Personal Protective Equipment Removal among Healthcare Workers: A Scoping Review

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ABSTRACT

Background: It is now widely recognized that healthcare personnel (HCP) are at risk of contamination with pathogens during personal protective equipment (PPE) doffing. Studies of this phenomenon, have utilized a variety of PPE ensembles, doffing methods and experimental methods.

Methods: A scoping review was performed, consistent with PRISMA guidance. The PubMed and sciVerse Scopus databases were searched using an *a priori* search strategy. Data were extracted for analysis using the matrix method, and then a narrative analysis performed. Articles were classified based on PPE ensemble.

Results: Only 19 of 151 articles were included in the final analysis. All included studies reported some post-doffing contamination, and this contamination was most frequently observed on the hands, wrist, face and neck. Reviewed studies used a variety of tracer contaminants, PPE ensembles, doffing protocols, tracer assessment locations and methods, making it difficult to identify patterns across studies.

Discussion&Concluisons: Additional research is needed to improve study methodology related to the selection and placement of tracers to ensure sensitive detection of post-doffing contamination, compare how specific doffing procedures or pieces of PPE influence post-doffing contamination, and to understand what post-doffing contamination means for patient and HCP infection risk.

Keywords

Healthcare workers; PPE; tracers; contamination; doffing; contaminant

INTRODUCTION

Healthcare personnel (HCP) can come into contact with pathogens shed by infected patients, putting them at risk for occupationally-acquired infections. Pathogens of recent concern include emerging pathogens, such as Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) and Ebola Virus Disease (EVD), as well as endemic pathogens like norovirus and seasonal influenza.¹⁻³ Personal protective equipment (PPE) remains the primary infection prevention

strategy in healthcare facilities and is used to protect both patients and HCP from exposure to pathogens.^{4,5} PPE is typically worn in an ensemble, involving more than one piece of equipment. For most infectious diseases, the choice of ensemble used during clinical activity is typically based on the disease transmission route: 1) contact precautions (CP) include gloves and a gown 2) droplet precautions include a surgical mask, and 3) airborne precautions include a respirator.⁵ Multiple transmission-based precautions can be used simultaneously, or supplemented using principles of standard precautions, depending upon the potential exposures and context of patient care. For infectious diseases with high mortality, enhanced precautions are used, which typically include fully-body coverage with fluid-resistant clothing and respiratory protection.⁶⁻⁸

Prior to the 2014-2015 EVD outbreak, enhanced precautions were primarily used in specialized biocontainment facilities and emergency response, but the outbreak led to use of enhanced precautions by a large number of HCP for the first time. It quickly became clear that doffing these complex PPE ensembles created an opportunity for virus exposure.^{9,10} This was highlighted by the acquisition of EVD by two HCP in Dallas, Texas, which has been attributed to issues with PPE use.¹¹ Healthcare facilities, as a result, engaged in extensive training activities to improve PPE procedures, with particular focus on doffing so as to prevent contamination; doffing protocols often included the use of trained observers or assistants.¹²⁻¹⁵ These issues spurred a growth of research on this topic, and many studies used simulation to assess the frequency, magnitude and determinants of post-doffing contamination.

The objective of this study was to review the literature about doffing PPE ensembles, which surged after the 2014-2015 EVD outbreak. A review is warranted because previous studies used a variety of designs and methods to evaluate post-doffing contamination, making it difficult to compare findings across studies. Methods varied not only with respect to the type of tracer contaminant used, but also the location of pre-doffing contamination and post-doffing observations, the PPE ensemble worn, and the doffing procedure used.^{6,16,17} Two guiding questions for this review were: 1) What are the determinants of post-doffing contamination? 2) Where is post-doffing contamination most likely to occur after PPE doffing? By answering these two questions, the review sought to identify key determinants of post-doffing contamination, and illuminate research gaps that can direct future research and practice.

METHODS

The method used was a scoping literature review. This methodology was appropriate because the study objective was to describe the extent of knowledge related to the research questions and perform a narrative synthesis. We used the following steps, consistent with best practices, to: 1) forming a guiding research question(s), 2) define search terms, 3) define inclusion/exclusion criteria, 4) select studies, 5) extract data using the matrix method, and 6) synthesis the narrative.

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This study was guided by an overarching interest in characterizing existing knowledge about patterns and determinants of post-doffing contamination of HCP's body and clothing, to improve doffing practices and doffing contamination study designs. Two research questions were formed: 1) What are the determinants of post-doffing contamination? 2) Where is post-doffing

contamination most likely to occur after PPE doffing? Potential determinants were considered to include aspects of the study design and methods, the PPE ensemble, and the doffing procedure.

The two databases identified to complete the review were PubMed (biomedical sciences, 1946–present) and sciVerse Scopus (multidisciplinary; 1823–present). These databases were chosen because they have a good representation of literature in infection prevention, occupational health, and healthcare.¹⁹ The search did not include limits on dates, subject, or article type. The search query was: (PPE OR precautions) AND doffing AND (healthcare OR "infectious disease" OR "infection prevention"). The search was implemented on October 23, 2019 and updated November 19, 2021. Title and abstracts of identified articles were imported into the systematic review software, Covidence (Veritas Health Innovation, Melbourne, Australia).

Articles were eligible for inclusion if they reported 1) doffing PPE used in healthcare and 2) qualitatively or quantitatively measured contamination on the clothing or body after doffing. Articles were excluded if they did not report the location of contamination on the participant and/or PPE before or after removal. The two authors reviewed each title and abstract, and conflicts were resolved through discussion. The two authors also reviewed the full text of each article using the same inclusion and exclusion criteria, and conflicts were resolved through discussion.

Data extraction used the matrix method, with templates constructed in Microsoft Excel®. Data extracted included two broad themes: 1) study design – e.g., number and characteristics

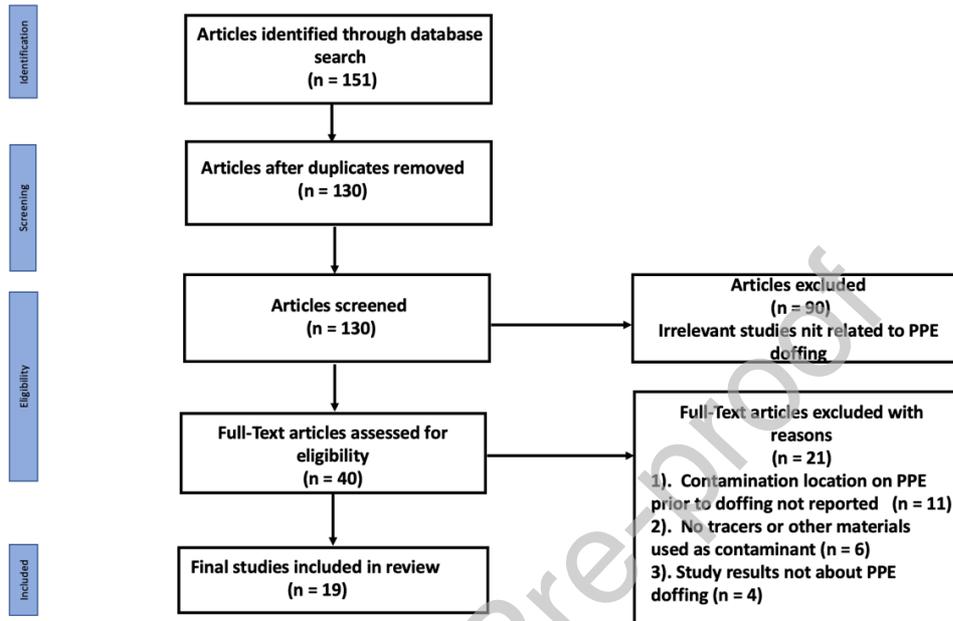
of participants, contaminant tracer, tracer application and detection methods, PPE and doffing procedure utilized – and 2) study findings, including location and frequency of post-doffing contamination. Extraction was performed by one investigator (OO) and reviewed by a second investigator (RMJ). Narrative synthesis of the extracted data was used to answer the study questions.

RESULTS

Search and Screening Results

A total of 151 articles were identified. As shown in Figure 1, twenty-one duplicate references were identified and removed. Ninety articles were excluded during title and abstract screening with most excluded because the article was not related to PPE doffing. A total of 21 studies were excluded during full-text review because: 1) locations of contaminated body parts were not reported before or after PPE doffing (n = 11), 2) study results were not about PPE doffing (n = 6), and 3) contamination tracers were not used (n = 4). A total of 19 articles were included for data extraction and narrative synthesis.

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow chart of the studies identification and selection process



General Study Information

Included studies were published between 2006 and 2021, with only 2 of 19 studies published prior to the 2014-2015 EVD outbreak.^{7,20} Supplementary Table 1 identifies the pieces of PPE in each ensemble studied. Studies were grouped by the PPE ensemble evaluated: 1) enhanced ensembles, such as used for EVD were evaluated in eleven studies (Table 1); 2) contact precautions (gloves and gowns) were evaluated in six studies (Table 2); and 3) intermediate levels of PPE ensembles were evaluated in seven studies (Table 3). Eighteen studies involved HCP as participants, while one study involved only medical students. All studies used experimental simulation to assess post-doffing contamination, but several studies used study

designs to compare training methods, doffing protocols,^{15,21} PPE ensembles,^{20–23} design of PPE,^{23,24} or a combination of interventions.^{6,22}

A variety of tracer contaminants were used. Seventeen studies used a fluorescent liquid (e.g., Glo Germ™) and two studies using fluorescent polystyrene latex spheres (PSLs).^{6,17} Other tracers used included: MS2 bacteriophage (n = 5), Φ 6 bacteriophage (n = 2), and *Staphylococcus epidermidis* (n = 1). Eight studies used more than one tracer.^{6,7,10,14–17,25} Most studies used qualitative or semi-quantitative methods to detect the tracers. Five studies quantitatively measured the tracer (e.g., mean probable number of phage recovered, PSL/cm²).^{6,7,16,17,26} Only one study characterized or reported limits of detection – e.g., 0.25 PSL/cm² on 50 cm² areas.¹⁷ Three studies^{7,16,25} used methods for which recovery efficiency had been previously reported.²⁷

When multiple tracers were used in the same study, the different tracers did not exhibit the same post-doffing contamination patterns. Two studies used PSL spheres and fluorescent slurry as tracers, and while nearly all participants in both studies had post-doffing contamination, the two tracers were not frequently co-located.^{6,17} Osei-Bonsu et al.¹⁵ used fluorescent powder and *S. epidermidis*, reporting fluorescent powder contamination was observed at more locations and more frequently than *S. epidermidis*. Three studies used a mixture of MS2 bacteriophage and fluorescent liquid as tracers, but had mixed results about the comparability of the tracers.^{7,10,14} When placed on gloved hands, Tomas et al.¹⁰ found good concordance for the event of any post-doffing contamination for the two tracers, find 48% of participants were contaminated with both tracers, 4% only with MS2 and 10% only with fluorescent liquid. Kwon et al.¹⁴ observed participants to be more frequently contaminated with fluorescent liquid than MS2 (44% to

5.5%), while Casanova et al.⁷ found the opposite. Similarly, in a study using MS2 and $\Phi 6$ bacteriophage with fluorescent liquid as tracers, Casanova et al.²⁶ observed post-doffing contamination more frequently with MS2 than $\Phi 6$, and observed no fluorescein contamination. MS2, a non-enveloped bacteriophage, appears to be a more sensitive tracer than $\Phi 6$, an enveloped bacteriophage.^{16,25}

Enhanced PPE Ensembles

Eleven studies involving enhanced PPE are shown in Table 1. The studies used varied pieces of PPE (Supplemental Table 1) and doffing protocols, with one study using multiple doffing protocols²¹ and one study using an unspecified protocol.²³ The most common doffing protocol used was that from the Centers for Disease Control and Prevention (CDC), which was used in five studies. Four studies provided doffing training to participants (Table 1), with all participants trained in two studies^{14,21} and only certain groups trained in two studies.^{6,23}

Pre-doffing location of tracer contamination varied among the studies of enhanced PPE ensembles (Table 1): Six studies placed the tracer at extensive locations across the body, while three studies placed the tracer at a few locations, and two studies placed tracer to the environment and noted pre-doffing contamination.^{23,28} Studies using fluorescent tracer assessed post-doffing contamination on the entire body, or nearly the entire body, while other tracers were typically assessed more selectively. Kwon et al.¹⁴ for example, swabbed areas showing fluorescent contamination for MS2, and Andonian et al.⁶ swabbed the hands, wrists, face, and ears for PSLs. In all studies conducted by Casanova et al.,^{7,16,26} the bare hands, face, and scrubs

worn under PPE were assessed for all tracers, where these locations were chosen based on observed locations of PPE and body contamination during patient care.

Post-doffing contamination was reported in three ways (Table 1), including: 1) number or percent of participants with contamination anywhere or at specific locations,^{6,7,16,17,20,26} 2) number of sites with contamination observed across all locations and participants,²⁹ and 3) median number and/or size of contamination sites (e.g., droplets) on the body or body part.^{6,21} Among those studies reporting data by body location, regardless of the metric, ten studies found post-doffing contamination on the hands or arms, while Hall et al.²³ reported no contamination on the hands. Contamination on locations such the head or face were observed by five of these studies.^{17,20,21,23,29} Therkorn et al.¹⁷ observed a higher percent contamination on the head or face compared to other studies.

Potential determinants of post doffing contamination were explored in seven studies.^{7,14,16,20,23,28} Three studies attributed contamination to deviation from doffing protocol.^{7,14,23} One study attributed observed neck contamination to pre-doffing application of tracer.²⁰ Casanova et al.¹⁶ observed contamination of inner glove was more common when an alcohol-based hand rub was used for glove sanitizing steps, compared to hypochlorite. Kang et al.²⁸ identified ill-fitting PPE, such as large size/sagging coveralls, as leading to contamination, and that contamination was lower with the use of a long sleeved apron and in participants' second doffing trial.

Contact Precautions

Among the studies involving CPs, five studies evaluated ensembles of gloves and gowns, while one study used gowns only (Supplemental Table 1). Two studies trained study participants on CP PPE doffing prior to PPE removal (Table 2).^{10,22} Four studies used specified doffing protocols, most commonly the CDC doffing protocol, but one did not specify a doffing protocol and one also allowed doffing by participants using their accustomed methods.

All studies used fluorescent tracers and two also used MS2 bacteriophage (Table 2). Tracers were applied pre-doffing mostly on the hands or upper body of participants, but Kang et al.²⁸ applied tracers to a mannequin and bed rails with which participants contacted. Three studies assessed post-doffing contamination for fluorescent tracer over the whole body,^{14,22,28} while the remaining studies with fluorescent tracer and studies with MS2 bacteriophage only assessed specific locations.^{10,14,30,31} Five studies reported the percentage of participants with post-doffing contamination overall or at specific locations, while Guo et al.²² reported summary statistics of staining scores. The most frequently contaminated site was the hands, but Tomas et al.¹⁰ observed different frequencies of contamination depending upon whether the tracer was placed on gloved hands or gowns.

Four studies explored potential determinants of post-doffing contamination with CPs PPE.^{10,14,22,30} Kwon et al.¹⁴ attributed hand, wrist, and face contamination to deviation in procedure of glove and gown removal, and hand hygiene. John et al.³⁰ observed that deviation from glove doffing techniques led to skin contamination. Tomas et al.¹⁰ observed participants that had been trained in PPE doffing still practiced incorrect gown and gloves removal procedures that led to contamination frequency on the neck, chin, and hand. Guo et al.²² reported

that irrespective of the doffing procedure, use of a gown produced less contamination than an apron.

Intermediate PPE Ensembles

Seven studies explored post-doffing contamination for intermediate levels of PPE ensembles (Table 3). Three studies provided doffing training to participants, either to all participants, the group trying on a new PPE ensemble, or to the intervention group.^{22,24,32} Doffing procedures were specified by five studies,^{15,21,22,24,33} where one study used a combination of CDC protocol and participants' customary doffing method.²² Another study assigned different removal procedures such as CDC protocol, hospital authority protocol, or one step protocol to different groups.¹⁵ Hajar et al.³³ used the CDC doffing protocol with the intervention group.

Pre-doffing location of tracer contamination varied widely among the studies of intermediate PPE ensembles, with three studies involving broad placement of tracer^{21,22,32} and three studies involving more selective placement (e.g., glove hands, arms, abdomen).^{15,24,33} Specific post-doffing body contamination locations were assessed by three studies,^{15,24,33} and four studies explored the entire body for contamination.^{21-23,32} Post-doffing contamination was frequently reported on the hands and arms (Table 3), but three of the studies also observed contamination on the face and neck.^{15,21,23}

Potential determinants of contamination after PPE doffing were identified in three studies.^{15,23,33} Hall et al.²³ attributed post-doffing contamination to glove contamination and incorrect doffing

techniques. Hajar et al.³³ found that participants who were not given a doffing protocol experienced a higher number of sites of contamination post-doffing, compared to participants who followed the CDC protocols and had significantly less detectable contamination post-doffing contamination. Osei-Bonsu et al.¹⁵ observed doffing protocol deviations among three doffing groups caused contamination, including difficulty in gown removal (OS and CDC group), dropping and recovering of unclean gloves (CDC group), and leaking of contaminant solution between glove and gown cuffs.¹⁵

DISCUSSION

PPE is worn during patient care activities to prevent HCP from exposure to pathogens, as well as to prevent transmission to susceptible patients. As the reviewed literature has shown, material present on PPE can be transferred to locations on the body and clothing of HCP, or aerosolized and inhaled by HCP, during doffing. Because HCP cannot always change their clothing or shower after doffing PPE, it is important to prevent body and clothing contamination during doffing. This review found that there was an increased interest in this topic after the 2014-2015 EVD outbreak, which was expected owing to the increased use of enhanced PPE ensembles and the severity of health outcomes that could result from EVD. The issue of contamination with PPE doffing, however, is not limited to enhanced ensembles but can occur with CP and other PPE ensembles (Tables 1-3).

The studies reviewed all used experimental simulation with tracers applied to PPE before doffing, and measured tracer contamination on HCP' bodies and clothing after doffing. However, the tracers used, locations of pre-doffing tracer placement, PPE ensembles, doffing

protocols, locations of post-doffing tracer assessment, and measures of post-doffing tracer contamination varied widely among studies (Tables 1, 2, and 3). As a result, it is difficult to synthesize findings across studies with respect to determinants and patterns of post-doffing contamination. Regarding our first guiding question, the reviewed literature suggests: 1) training in doffing protocols could decrease post-doffing contamination^{6,22,32,33}; 2) that the sizing and design of PPE can affect post-doffing contamination^{22,28}; and 3) that the sites of post-doffing contamination vary with the PPE used, doffing protocol, and locations of pre-doffing contamination.^{6,20,28} The study review by Verbeek et al³⁴ found low evidence that type of PPEs used, and CDC doffing protocol reduces the risk of contamination³⁴.

With respect to the second guiding question of this review, post-doffing contamination was frequently observed on the hands (100% of studies), wrists, face (40%) and neck, though this may be somewhat biased by the study methods that frequently placed and observation of tracer in these locations (Tables 1, 2, and 3). Not all locations of post-doffing contamination are likely to contribute to infection risk for HCP. Hand hygiene, for example, is frequently performed by HCP and may be effective at removing post-doffing contamination, but it is unlikely HCP will wash their face after PPE doffing. For many pathogens, such a respiratory viruses, the concern is not that post-doffing contamination will initiate infection through the skin, but that the pathogen will be transferred to other locations after doffing where it can initiate infection, such as the facial mucous membranes of the HCP or to a susceptible patient. Assessing the fate of post-doffing contamination requires further experimental studies or exposure modelling.

This study excluded articles that did not report the location of tracer contamination prior to doffing because this could determine the likelihood and location of post-doffing contamination as the tracer must be moved through contact. This review also excluded articles that did not identify the tracer used, as the tracer may influence the transfer characteristics. The composition and placement of tracers is important to determine the transfer of tracers pre- and post-doffing. Fluorescent materials were most commonly used, likely because they are easy to detect under ultraviolet light. However, there was not strong concordance when fluorescent materials were coupled with bacteria or bacteriophage, indicating the tracer material influences the transfer during doffing. Overall, the body of research suggests that additional research is needed to understand how well tracers mimic the behavior of pathogen-laden body fluids. However, the conservative approach at this time would be to use an easily transferred tracer and hardy microorganism like MS2 bacteriophage.^{7,16,26} Further, because the observed post-doffing contamination location is influenced by the location of tracer application^{7,16,26}, it is important that future research use tracer placements consistent with or more extensive than the anticipated contamination during care delivery.

Because this was a scoping literature review, included articles were not formally assessed for reporting quality. This means some included studies may be at risk of bias in their design and reporting. To minimize this risk, data extraction included several aspects of study design and methodology, as these characteristics reflect aspects of study quality. Further, we found that some aspects of study methodology, such as the selection of tracers, are determinants of the study findings. Publication bias is another concern but was unlikely to have played a critical role in our study because there was a significant interest in finding doffing protocols that

prevented post-doffing contamination, and in understanding the extent of post-doffing contamination that occurred. Despite the lack of formal quality assessment, we were still able to systematically summarize the state of knowledge about patterns and determinants of body contamination after PPE doffing removal among HCWs.

CONCLUSIONS

Review of this literature identifies a need for further research in three key areas. First is study methodology, where there is a need to better understand how tracers can be selected and placed to provide high fidelity to exposures occurring during healthcare activities, or to be assured that the methods utilized provide a health-conservative representation of potential post-doffing exposures. Second is comparative research to evaluate how specific doffing procedures or pieces of PPE influence post-doffing contamination. The reviewed literature showed that different post-doffing contamination patterns occur with different PPE ensembles, but the variety of study method limit the ability to distinguish the effect of PPE ensemble from study method on post-doffing contamination. Third is to understand what post-doffing contamination means for patient and HCP infection risk. None of the studies reviewed observed no post-doffing contamination among participants, indicating post-doffing contamination must be anticipated for HCP during healthcare activities. Without further research, however, it is not clear what location, magnitude, or frequency of post-doffing contamination poses an acceptable level of infection risk for patients and HCP. This issue can be approached through further simulation or exposure and risk

modeling, as the effects being observed are likely to be too small or infrequently observed in field work or epidemiologic studies.

COMPETING INTERESTS

The authors declare that they have no competing interests

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Table 1. Studies of post-doffing contamination involving Enhanced PPE ensembles.

| Reference | Study Design | Sample Size | Prior Experience | Doffing Procedure | Tracer Placement | Tracer Type (Detection) | Activity Before Doffing | Locations Assessed | Observed Contamination |
|-----------|--|-------------|------------------|--|--|---|--|--|---|
| 9 | RCT. Training intervention about teamwork concepts | 48 | No | CDC protocol with DA and TO. Intervention group received teamwork cues. Doffing training provided. | Sprayed all over body | FL liquid (Qual) and PSLs (Qual & Quant) | No | PSL: hands, wrist, ears, and face FL: Entire body | Intervention group 84.6% HCWs contaminated on ≥ 1 body area with FL and 100% with PSL. Median sites: 6 (IQR 3-8) Sites: Thigh front, R&L inner wrists, R&L ears, forehead, R&L cheek, R back of hand Control group 100% HCWs contaminated on ≥ 1 body area with FL and PSL. Median sites: 11 (IQR 6-13) Sites: Front mid-torso, R arm, F&B thighs, F&B knees, F&B lower leg, F ankle, R&L back of hand, R&L fingers R&L cheek, R&L ear, forehead, chin. |
| 10 | Experimental simulation | 10 | Yes | Doffing protocol ¹⁰ with guidance by TO. No doffing training provided. | Placed on palm of DH and gown shoulder, top of PAPR, toe of shoe cover opposite DH. | MS2 mixed with $\Phi 6$ (Quant) in FL liquid (Qual) | Emptied urinary catheter bag on mannequin and cleaned room | Bare hands, face, and scrubs worn under PPE | $\Phi 6$: Scrubs 10% MS2: Inner glove 70%, hand 10%, scrubs 20% FL Liquid: None |
| 11 | Experimental simulation | 15 | Yes | Doffing protocol (listed in paper) with guidance by TO. No doffing training provided. | Placed on palm of DH, top face shield on DH side, and gown shoulder and toe of boot opposite DH. | MS2 mixed with $\Phi 6$ (Quant) | Gown change on mannequin | Bare hands, face, and scrubs worn under PPE | $\Phi 6$: None MS2: Hands 6.7%, DH Inner gloves 53.3%, NDH inner glove 40%, scrub shirt 13.3% |
| 12 | Experimental simulation | 10 | Not specified | CDC doffing protocol (listed in paper). No doffing training provided. | Placed on front shoulder of gown, back shoulder of gown, right side of N95 respirator, upper right front of goggles, palm of dominant hand | MS2 and FL liquid (Quant & Qual) | Measuring blood pressure on mannequin | Bare hands, NDH glove and scrubs worn under PPE | FL liquid: NDH glove 10%, R hand 20%, scrub shirt 10% MS2: NDH glove 80%, R hand 80%, LH 70%, scrub shirt 100%, scrub pants 75% |
| 13 | Experimental simulation | 11 | Yes | Checklist (not specified). Doffing training provided for new ensembles. | Exposure to varied body locations during clinical assessment of mannequin (cough, sweat, vomitus, diarrhea), ¹³ screened before doffing | Multiple FL liquids (Qual) | Clinical assessment of mannequin | Entire body | Results aggregate 4 PPE ensembles. Cough: forearm 0.17% Sweat: neck 0.34% Vomit: face 1.4%, Lower legs 1.4% Feces: None. |
| 14 | Experimental simulation | 30 | Yes | Korea CDC protocol with TO; participants allowed to use accustomed practice. No doffing training provided. | Exposure to contaminated emergency care simulator during patient care; screened before doffing | FL powder (Qual) | 1-min patient care | Entire body; measured at each doffing step | Level C: Shirt (45%), Arm-wrist (20%), Scalp-hair-ear (50%) Level D: neck-collar (25%), shirt (88.9%), Arm-wrist (86.1%), pants (82.7%), foot-shoes (25%), Scalp-hair-ear (27.8%), face (22.2%), hands-fingers (5.6%), foot-shoes (11.1%) |
| 15 | Experimental simulation | 18 | Not specified | CDC protocol with TO and DA, ¹⁵ and facility protocol. Doffing training provided. | Placed on palms, abdomen, and ankles | MS2 mixed with FL liquid (Qual) | Patient care activities (not described) | Entire body for FL. Hands, coat sleeves or wrist, facial areas, and FL areas swabbed for MS2 | FL Liquid: 44% HCWs had any contamination, 21 unique sites, including: hands 33%, forearms 5.5%, knee 5.5%, sleeves/wrist 5.5%. MS2: 5.5% HCWS had any contamination, was on hands |
| 16 | RCT, different body coverings | 6 | Yes | WHO recommendation. No doffing training provided. | Sprayed spots over entire body and hands | FL liquid (Qual) | No | Entire body | Contamination observed in all trials with all body coverings. Surgical Gown 17 contamination sites observed among 6 trials, distributed as: head 6%, shoulder 6%, hands 12%, upper back 12%, lower back 6%, abdomen 6%, thighs 12% and legs 41% Full body coverall 24 contamination sites observed among 6 trials, distributed head 4%, upper arms 4%, forearms 17%, hands 8%, thorax 4%, upper back 4%, lower back 4%, abdomen 25%, thighs 4%, legs 25%. Non-surgical isolation gown 17 contamination sites observed among 6 trials, distributed: head 12%, hands 18%, thorax 12%, abdomen 6%, thighs 12%, legs 41% |

| | | | | | | | | | |
|----|-------------------------|----|------|--|---|--|----|--|--|
| 59 | Experimental simulation | 59 | Some | Hospital Authority or WHO protocol, ¹⁷ TO. Doffing training provided. | Sprayed on face shield, arms, gloves, and front of gown | FL liquid (Qual) | No | Entire body | <p>PPE1 Median # Small [#Large] size contamination areas: Hair & head 1 [0], face 1 [0], F neck 2.5 [0], B neck 2 [0], R arm 3.5 [0], L arm 2 [0], hand/wrist 1 [8], upper clothes 8.5 [21], lower clothes 2 [12], shoes 3 [121].</p> <p>PPE2 Median # Small [#Large] size contamination areas: Hair & head 2 [0], face 4 [0], F neck 5 [0], B neck 1 [0], R arm 1 [0], L arm 2 [0], hand/wrist 1 [61], upper clothes 9 [49], lower clothes 2.5 [146], shoes 5 [55].</p> |
| 5 | Experimental simulation | 5 | No | CDC protocol ¹⁸ with TO and DA. No doffing training provided. | Sprayed all over body | FL slurry (Qual) and PSLs (Qual & Quant) | No | Entire body for FL Swabs of forehead, cheeks, chin, ear, inner wrist, back of hand, index finger to thumb swabbed for PSL. | <p>PSL: 100% of HCWs had contamination. Chin 40%, R ear 20%, L ear 40%, L cheek 20%, R cheek 20%, L inner wrist 100%, R inner wrist 60%, L back hand 40%, R back hand 40%, L finger to thumb 60%, R finger to thumb 40%.</p> <p>FL Slurry: 100% of HCWs had contamination. F legs 100%, B legs 100%, Hands 40%, R arm 60%, F torso 60%, back 20%, neck/head 40%.</p> |
| 50 | RCT, sequence of PPE | 50 | Yes | Study written doffing instructions. No doffing training provided. | Sprayed onto front of face shield and torso; forearms and palms | FL liquid and "invisible" detection paste (Qual) | No | Entire body | <p>E-RCP: 96% HCWs had some contamination, including on face 4%, F neck 96%, B neck 18%, hands/wrist/forearms 76%, torso, F torso/upper arms 10%, Back and posterior upper arms 2%, below the beltline 2%.</p> <p>PAPR: 26% HCWs had some contamination, including on F neck 6%, B neck 2%, hands/wrist/forearms 18%.</p> |

FL = Fluorescent, PSL = Polystyrene latex sphere, RCT = Randomized control trial, TO = Trained observer, E-RCP = Enhanced respiratory and contact precaution, PAPR = Powered air-purifying respirator, MS2 = MS2 Bacteriophage, Φ6 = Phi6 bacteriophage, CDC = Center of Disease control and Prevention, DA = Doffing Assistant, Qual = Qualitative detection method, Quant = Quantitative detection method, NDH = Non Dominant Hand, DH = Dominant Hand, PPE = Personal Protective Equipment, R = Right, L = Left, F = Front, B = Back, WHO = World Health Organization, HCW = Health Care Workers

Table.2. Contact Precautions PPE post-doffing contamination determinants.

| Reference | Study Design | Sample Size | Doffing Procedure | Tracer Placement | Tracer Type (Detection) | Activity Before Doffing | Locations Assessed | Contamination observed |
|-----------|---|---|--|--|---------------------------------|-------------------------|--|---|
| 13 | Experimental simulation | 147 (standard gloves) 171(modified doffy gloves) | Not specified. No doffing training provided. | Wetted gloved hands | FL Solution (Qual) | no | Hands, wrist, fingers, palm, and thumbs | Standard Gloves: 73.3% of participants had contamination. Locations include: R Thumb 4.1%, L thumb 5.2%, R finger 6.1%, L finger 3.9%, R palm 24.5%, L palm 15.6%, R Wrist 65.3%, L Wrist 75.3% Modified Doffly Gloves: 15.8% of participants had contamination. Locations include: R Thumb 49%, L thumb 56.5%, L finger 8.7%, L palm 17.4%, R Wrist 40%, L Wrist 17.4% |
| 14 | RCT, sequence of PPE | 50 | Accustomed practice and then CDC gown removal method. Doffing training provided. | Sprayed on upper body | FL liquid (Qual) | No | Entire body | PPC 1 with Accustomed Doffing: mean number of hand stain 2.38, shoe stain 1.08, and clothing stain 0.06 PPC1 with CDC Doffing: mean number of hand stain 1.82, shoe stain 1.25, and clothing stain 0.0 PPC 2 with Accustomed Doffing: mean number of hand stain 2.24, shoe stain 0.00, and clothing stain 1.58 PPC with CDC Doffing: mean number of hand stain 1.68, shoe stain 0.06, and clothing stain 2.48 |
| 15 | Experimental simulation | 27 | Not specified. No doffing training provided. | Placed on gloved hands | FL liquid (Qual) | No | Hands and wrists | 44% participants had contamination on hands/wrist |
| 16 | Experimental simulation | 7 | Korea CDC protocol with TO; participants allowed to use accustomed practice. No doffing training provided. | Exposure to contaminated emergency care simulator during patient care | FL powder (Qual) | 1-in patient care | Entire body; measured at each doffing step | 100% of participants had contamination somewhere Scalp-hair-ear 28.6%, face 28.6%, neck-collar 14.3%, shirt 28.6%, arm-wrist 14.3%, hands-fingers 57.1% |
| 17 | Experimental simulation | 18 | CDC protocol. ¹⁸ No doffing training provided. | Placed on palms, abdomen, and ankles | MS2 mixed with FL liquid (Qual) | No | Entire body for FL. Hands, coat sleeves or wrist, facial areas, and FL areas swabbed for MS2 | FL Liquid: 28% HCWs had any contamination. Locations include hands 28%, chest 11%, knees 6%, thigh 6%, face 6%. MS2: 17% HCWS had any contamination. Locations include sleeves/wrist 11%, face 6% |
| 18 | Experimental simulation, Quasi-experimental training intervention | 50 (MS2+FL) 435 (FL only) | CDC protocol ¹⁸ and accustomed practices. Doffing training provided. | MS2+FL study placed on gloved hands. FL only studies placed on gloved hands or front of gown. | MS2 (Quant) & FL lotion (Qual) | No | Hand, forearms, neck, face, hair, shirt. | MS2-FL Study 48% participants contaminated with MS2 and FL, 4% with MS2 only and 10% with FL only. FL Study – Gloves 53% participants contaminated, observed at 19 sites, including: R palm 50%, L palm 40%, wrists 30%, fingers 20-30%, shirt 20%, legs 10% FL Study – Gowns 38% participants contaminated, observed at 18 sites, including: neck 50%, chest 40%, palms 30%, fingers 20-30%, wrist 20%, arms 10-20%, legs 10%. Training intervention reduced percent of participants with FL contamination from 60% to < 20%. |

FL = Fluorescent, RCT = Randomized control trial, CDC = Center of Disease Control and Prevention, Qual = Qualitative detection method, Quant = Quantitative detection method, L, R, MS2 = MS2 Bacteriophage, PPC = Personal Protective Clothing, R = Right, L = Left, F = Front, B = Back, HCW = Health Care Worker

Table 3. Intermediate PPE post-doffing contamination determinants

| Reference | Study Design | Sample Size | Doffing Procedure | Tracer Placement | Tracer Type (Detection) | Activity Before Doffing | Post doffing Location assessed | Post-Doffing Location frequency & magnitude |
|-----------|---|-------------|--|--|---|--|---|--|
| 22 | RCT, sequence of PPE | 50 | Accustomed practice and then CDC gown removal method. Doffing training provided. | Sprayed on upper body | FL liquid (Qual) | No | Entire body | Accustomed Doffing mean number of hand stain 8.56, shoe stain 10.44, and clothing stain 2.32 CDC Doffing mean number of hand stain 3.18, shoe stain 3.48, and clothing stain 0.56 |
| 23 | Cross-over trial with training intervention; RCT, gown design | 100 | Accustomed practiced, or trained in CDC doffing protocol ²⁴ | Placed on gloved hands | FL liquid (Qual) | No | Hands and wrists | Accustomed Method: Standard gown: 53% HCWs had contamination, locations: fingers 40%, palms 30%, wrists 10%, dorsum 5% Alternative gown: 27% HCWs had contamination, locations: fingers 20%, palms 10%, wrists 3%, dorsum 5% Doffing Training: Standard gown: 23% HCWs had contamination, locations: fingers 10%, palms 15%, wrists 10% Alternative gown: 5% HCWs had contamination, locations: fingers 5% |
| 24 | Experimental simulation | 11 | Checklist (not specified). No training provided. | Exposure to varied body locations during clinical assessment of mannequin (cough, sweat, vomitus, diarrhea), ²⁵ screened before doffing | Multiple FL liquids (Qual) | Clinical assessment of mannequin | Entire body | 3% participants had post-doffing contamination; 15% had skin contamination after simulation. |
| 25 | RCT for doffing protocol | 51 | CDC standard protocol ²⁶ , One Step (OS) protocol, Hand Hygiene (HH) protocol and Double Glove (DG) protocol with TO. No training provided. | Brushed on both arms, hands, and abdomen | <i>S. epidermidis</i> (Qual) & FL powder (Qual) | Both arms, hands, abdomen | Hands, arms, wrist, neck, ear, face, and scrubs for FL. FL areas swabbed for culture. | CDC Protocol with FL [<i>S. epidermidis</i>]: 92% [70%] had any contamination, locations include: R hand 67% [42%], L hand 50% [0%], R arm 17% [0%], L arm 42% [0%], R wrist 33% [8%], L wrist 17% [0%], neck 42% [17%], ear 33% [8%], 33% [0%], scrubs 25% [8%] OS with FL [<i>S. epidermidis</i>]: 80% [13%] had any contamination, locations include: both hands 73%, both arms 40%, both wrist 13%, neck 26%, face 13%, scrub 20% [13%], ear 7% HH with FL [<i>S. epidermidis</i>]: 100% [50%], had any contamination, locations include R hands 64%, L hand 57% [hands 14%], both arms 57% [R arm 7%], both wrist 30%, neck 79% [14%], ear 7%, face 36% [21%], scrub 36% [7%] DG with FL [<i>S. epidermidis</i>]: 90% [20%], had any contamination, locations include: both hands 50%, both arms 40%, both wrist 50%, neck 30%, face 40% [30%], scrub 30%, ear 10% |
| 26 | RCT, order of doffing respirator with or without tabs | 20 | CDC protocol. Training provided. | Placed on the outer surface of the respirator and hands | FL liquid (Qual & Quant) | Computer based simulation of an interaction with influenza patient | Hands and hair | Contaminated Hands: 100% participants transferred contamination to head, face and/or hair. Contaminated Respirator: Average lumens with tabs 55.19 compared to 97.12 without tabs. |
| 27 | Experimental simulation | 59 | Hospital Authority protocol | Sprayed on face shield, arms, gloves, and front of gown | FL liquid (Qual) | No | Entire body | Median # Small [#Large] size contamination areas: Hair & head 2.5 [0], face 2 [8], F neck 11 [24], B neck 18.5 [0], R arm 4 [28], L arm 1 [49], hand/wrist 6 [0], upper clothes 7 [42], lower clothes 6 [17.5], shoes 13.5 [133]. |
| 28 | RCT, training intervention | 56 | Checklist (not specified). Doffing training provided; intervention group had simulation training. | Exposure to contaminated mannequin and bed rails | FL lotion (Qual) | Carried mannequin to bed from wheelchair | Entire body | Intervention Group Mean area of contamination was 16.6 cm ² Contamination on 42 sites, including: hands 90%, face 7% body 3% Control group Mean area of contamination was 95.4 cm ² Contamination on 89 sites, including hands 71%, face 10%, hair 9%, body 10% |

FL = Fluorescent, RCT = Randomized control trial, CDC = Center of Disease control and Prevention, Qual = Qualitative detection method, Quant = Quantitative detection method, R = Right, L = Left, F = Front, B = Back, *S. epidermidis* = *Staphylococcus epidermidis*