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Major Article

Alternative doffing strategies of personal protective equipment to prevent self-contamination in the health care setting

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Key Words:
Staphylococcus epidermidis
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Isolation gown
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Background: Health care workers routinely contaminate skin and clothing when doffing personal protective equipment (PPE). Alternative doffing strategies, such as hand hygiene on gloved hands and double gloving, have been suggested but not validated by comparison against the standard Centers for Disease Control and Prevention procedures.

Methods: Participants were assigned to doff PPE following 1 of 4 specific strategies. Prior to doffing, PPE was "contaminated" with Glo Germ and fluorescing *Staphylococcus epidermidis* at the recommended level of 1.5×10^8 colony forming units/mL. After doffing, areas of self-contamination were detected using a black light. Cultures were taken from these areas using cotton swabs, inoculated onto blood agar plates, and incubated for 48 hours. Each participant completed a survey regarding usability. The Fisher exact test and the Kruskal-Wallis test were used for data analysis with SAS 9.4.

Results: There were 51 participants who completed the study. Breaches in PPE were observed in only 5 of 51 doffs (10%). However, 46 of 51 (90%) had areas of self-contamination that was apparent by transfer of Glo Germ to skin or clothing. A subset (16%) of these sites also grew fluorescing *S epidermidis*. Assigned doffing strategy was associated with bacterial contamination ($P = .0151$), but not usability ($P = .2372$).

Conclusions: Participants experienced self-contamination when doffing PPE with both a surrogate marker and live bacteria. Close attention to doffing technique is necessary for optimal results, and one-step procedures may be more effective.

The use of personal protective equipment (PPE) in transmission-based precautions is a fundamental element of infection prevention in health care settings. Although contact isolation for some endemic organisms has become controversial,[1] the use of PPE in the settings of *Clostridium difficile* infections, infection or colonization with multidrug-resistant gram-negative rods, and other organisms of high epidemiologic concern remains standard practice. Nevertheless, there is a growing awareness that health care workers (HCWs) routinely self-contaminate when using PPE, particularly during doffing.[2-8] The issue was highlighted during the Ebola crisis (2014-2016), when breaches in PPE use resulted in HCW acquisition of a high-profile hemorrhagic fever.[9] More routine breaches on our hospital wards do not generally result in highly visible disease outbreaks, but may well contribute to the ongoing transmission of nosocomial infection.

Studies have found opportunities for HCW improvement in both selection and optimal removal of PPE. Tomas et al[8] found that HCWs who were trained using the Centers for Disease Control and Prevention (CDC) procedures for doffing had lower rates of self-contamination than those without such training. However, self-contamination rates in the group trained to use the CDC procedures were still 18.9%.[9] Modifications to doffing practices have been suggested, including using a double glove (DG),[2] additional hand hygiene (HH),[10] and an alternative procedure endorsed by the CDC, the one-step (OS) (Fig 1, example 2).[11] This study is designed to compare the

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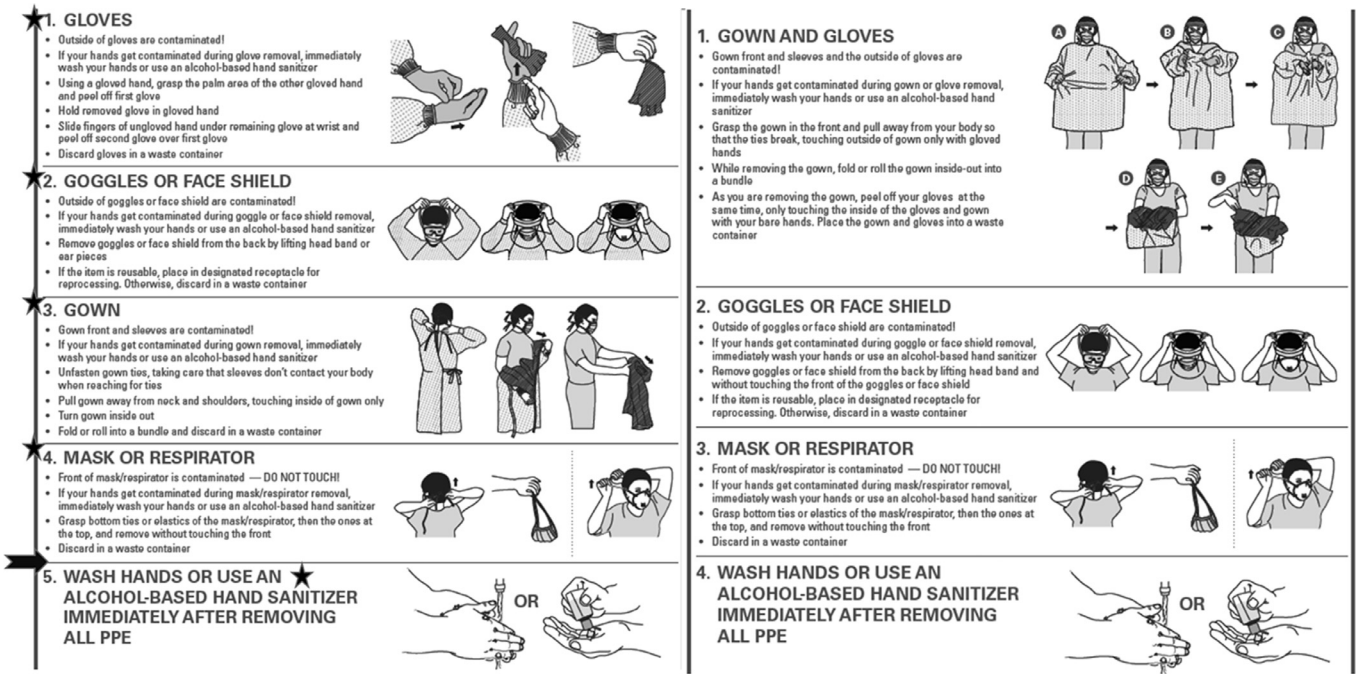

Fig 1. Personal protective equipment sequences. Centers for Disease Control and Prevention (CDC) procedures[9] for doffing personal protective equipment and adaptions to include double gloving or additional hand hygiene events. Study procedures are as follows. (1) CDC standard, left panel. (2) CDC alternative/one-step, right panel. (3) Hand hygiene, left panel with additional hand hygiene steps depicted by stars. (4) Double glove, left panel with removal of inner glove pair inserted between steps 4 and 5 (arrow).

efficacy and practicality of these proposed methods for doffing PPE in routine clinical practice.

METHODS

Participants were recruited from staff members of an 865-bed university medical center via fliers, e-mails, and word-of-mouth. Interested participants were provided with informed consent, including the risks and benefits of the study. Inclusion criteria included clinical providers and microbiology laboratory personnel as well as life safety administrators. Laboratory personnel and life safety administrators do not use PPE in the context of patient care, but do use it as occupational PPE (ie, gowns, gloves, masks, and goggles) in the laboratory or to train other staff on proper PPE usage. Exclusion criteria included medical, nursing, or allied health students; individuals <18 years of age or >65 years of age; pregnancy or breastfeeding; history of joint replacements or other prosthetic medical devices; and active inflammatory skin conditions or open wounds. This study was approved by the Virginia Commonwealth University institutional review board.

Participants donned PPE, including a disposable gown, gloves, goggles, and a surgical mask. Participants were then randomly assigned to 1 of 4 different doffing procedures: (1) the CDC standard[11], (2) the OS[11], (3) the HH, or (4) the DG. Procedures 3 and 4 (HH and DG, respectively) were variations on the standard CDC procedure, but included additional glove removal steps and HH events (Fig 1).[11] The procedures state that HH is to be performed with soap and water or an alcohol-based hand rub.[11] This study used a 70% alcohol-based hand rub as this is general practice on inpatient wards. Participants were assigned a procedure by having them pick a doffing procedure at random from a closed envelope. In order to simulate PPE contamination, after donning PPE, study assistants (KO, NM, and MD) used a wedge foam paint brush to liberally coat participants with Glo Germ fluorescent powder (Glo Germ Company, Moab, UT) on both arms, hands, and the abdomen. The brush was dipped back into the powder after coating each arm or abdomen. These areas were thought most likely to be contaminated in the course of patient care activities at the bedside. Participants were then also coated with 1 mL of *Staphylococcus epidermidis* in a 0.5 McFarland suspension (1.5×10^8 colony forming units/mL) in the same distribution on the body. The *S epidermidis* was genetically engineered[12] to stably express a green fluorescent protein that is visible under a black light in bacterial cultures. The solution was applied by dripping droplets over the PPE with a 1,000 uL pipette by the study staff (K.O., N.M., and M.D.). After the opportunity to review the assigned procedure and ask questions, participants were then asked to doff PPE under guided observation by the study investigators (K.O., N.M., and M.D.). There was no training or practice of the doffing techniques prior to the simulation. Prompts were given as needed to ensure the participants followed the assigned procedure. Observed breaches in doffing protocol were noted and recorded. Upon completion of doffing, a black light was used to assess for areas of self-contamination with the fluorescing powder. Areas of apparent powder transfer were documented and cultured using cotton swabs, inoculated onto blood agar plates, and incubated for 48 hours. Plates were then observed for the growth of fluorescing bacterial colonies and recorded as a presence or absence of contamination for each site.

Each participant completed a survey at the end of the doffing simulation to assess their perceptions of the method in terms of usability and perceived ability to effectively prevent the spread of nosocomial infections (ie, perceived utility). The survey was developed using Nielsen's usability attributes[13] and is included as Appendix A. Usability is a user's experience with a given system, tool, or interface and is derived from the following qualities: learnability, memorability, efficiency, errors, and user satisfaction.[13] Survey questions were asked on a 5-point Likert scale, with 5 indicating "strongly agree" and 1 indicating "strongly disagree."

The presence of contamination with fluorescing powder or fluorescent *S epidermidis* was compared between the 4 doffing variations as well as between provider types and years of experience using the

Table 1
Characteristics of participants assigned to each doffing procedure

Participant characteristic	Standard (N = 12)	HH (N = 14)	DG (N = 10)	OS (N = 15)
Provider type				
MD (N = 9)	3	1	4	1
RN (N = 34)	7	10	6	11
Nonclinician (N = 5)	2	0	0	3
Care partner (N = 3)	0	3	0	0
Experience (y)				
0-2 (N = 22)	5	8	5	4
3-5 (N = 11)	2	3	2	4
6-10 (N = 8)	4	0	1	3
11-15 (N = 2)	0	1	1	0
16+ (N = 6)	1	1	0	4

DG, double glove; *HH*, hand hygiene; *MD*, doctor of medicine; *OS*, one-step; *RN*, registered nurse.

Fisher exact test. Usability survey responses were summed for each participant and compared by assigned procedure group using the Kruskal-Wallis test. Data analysis was completed using SAS 9.4 (SAS Institute, Cary, NC).

Simulations took place in a simulation center, and the room was thoroughly cleaned by study staff with bleach wipes between each test session. The room surfaces and study supplies (ie, boxes of PPE and goggles) were checked with black lights for evidence of residual fluorescent powder.

RESULTS

A total of 51 participants completed the study: 9 physicians (17%), 34 nurses (67%), 3 nursing aides (6%), and 5 nonclinician, hospital employees from a life safety/microbiology laboratory (10%). Of these 51 participants, 12 (24%) were assigned to the standard CDC procedure, 14 (27%) to HH, 10 (20%) to DG, and 15 (29%) to OS. Characteristics of the participants in each group are shown in Table 1.

Contamination with fluorescent powder

Breaches in doffing PPE were observed in only 5 of 51 doffs (10%) and included difficulty in ripping off the gown (OS and CDC group ×2), dropping of dirty gloves and retrieving them (CDC group), and seepage of bacterial solution in between glove and gown cuff (HH group). Despite limited observed breaches, most (46 of 51, 90%) participants had areas of self-contamination, apparent by the transfer of fluorescing powder to the skin or clothing. Areas of contamination by procedure are shown in Table 2. The most commonly contaminated areas were the hands (right [65%] greater than left [49%]), arms (left [53%] and right [43%]), and chin or neck (35%). Most participants had multiple areas of contamination with the fluorescent powder. Only 5 participants avoided any self-contamination with the powder (1 in the CDC group, 1 in the DG group, and 3 in the OS groups).

Contamination with fluorescing S epidermidis

Of the 46 participants with powder contamination on skin and clothing that went on to be cultured, the fluorescent *S epidermidis* was recovered from 19 individual participants (41%). However, the burden of sites from which live bacteria was recovered differed, such that only 23 of 142 (16%) total sites cultured grew the organism. The most frequent sites of contamination mirrored those of powder alone, the right hand and the chin or neck (Fig 2). Although all participants succeeded in completing the final HH step at the end of doffing, fluorescent *S epidermidis* was recovered from the hands of 5 participants after they had used a 70% alcohol-based rub used in several wards of the facility.

Doffing strategy comparison

Assigned doffing strategy was associated with fluorescing *S epidermidis* contamination ($P = .02$), with the OS method of doffing having the lowest rates of self-contamination (Fig 3). No significant differences were detected when doffing strategies were compared in terms of fluorescent powder contamination.

Table 2
Locations of contamination for each doffing procedure

Contamination and locations	Standard (N = 12)	HH (N = 14)	DG (N = 10)	OS (N = 15)	*P* value
Fluorescent powder					
R hand	8	9	2	5	—
L hand	6	8	3	6	—
R arm	2	4	2	3	—
L arm	5	4	2	3	—
R wrist	4	4	2	1	—
L wrist	2	3	3	1	—
Neck	5	11	3	4	—
Ear	4	1	1	1	—
Face	4	5	4	2	—
Scrubs	3	5	3	3	—
No. of participants with any contamination	11 (92%)	14 (100%)	9 (90%)	12 (80%)	.07
Green fluorescent protein secreting *Staphylococcus epidermidis*					
R hand	5	1	0	0	—
L hand	0	1	0	0	—
R arm	0	1	0	0	—
L arm	0	0	0	0	—
R wrist	1	0	0	0	—
L wrist	0	0	0	0	—
Neck	2	2	0	0	—
Ear	1	0	0	0	—
Face	0	3	2	0	—
Scrubs	1	1	0	2	—
No. of participants with any contamination	8 (70%)	7 (50%)	2 (20%)	2 (13%)	.02

DG, double glove; *HH*, hand hygiene; *L*, left; *OS*, one-step; *R*, right.

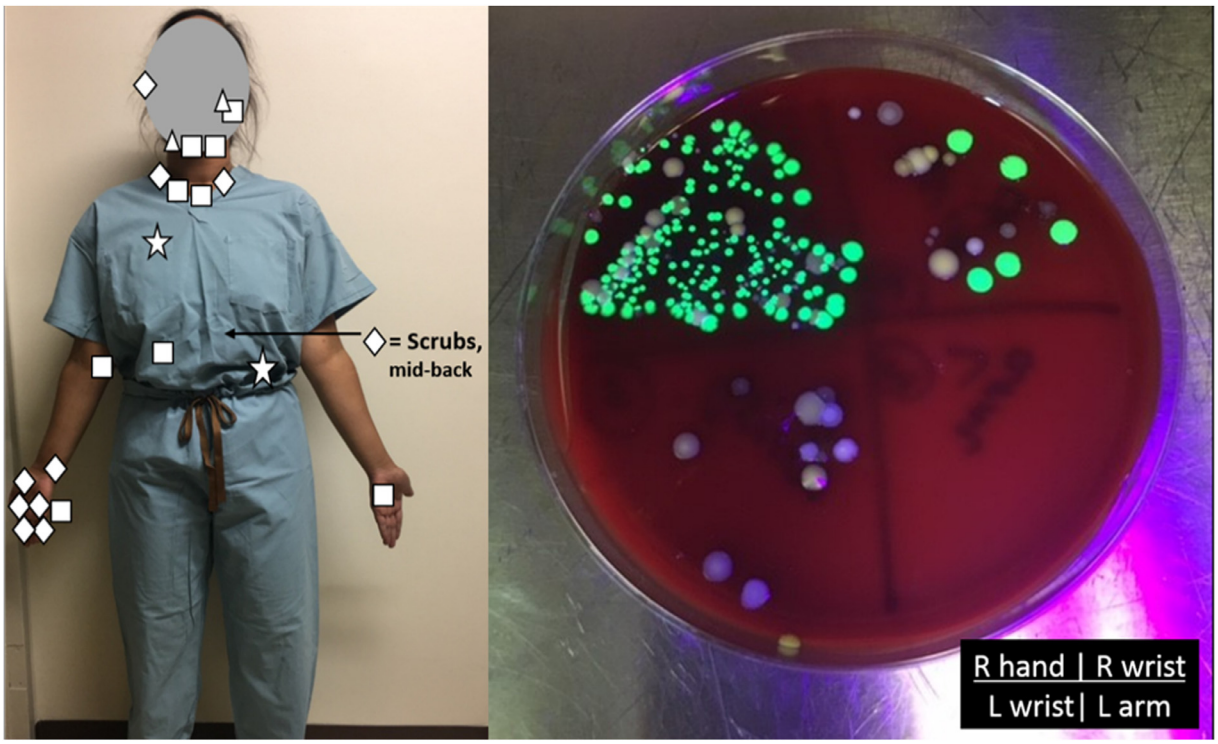

Fig 2. Common sites of self-contamination with live *Staphylococcus epidermidis* by doffing strategy. The 23 sites from which viable bacteria were recovered are depicted by shapes to designate assigned doffing strategy in the left panel. Sites resulting from standard Centers for Disease Control and Prevention (CDC) doffs (diamonds), hand hygiene doffs (squares), double glove doffs (triangles), and the one-step doff (stars). The right panel shows an example of fluorescent *S epidermidis* growth as seen in the laboratory under black light; these colonies appear as a striking fluorescent green. In grayscale, fluorescent colonies are bright white in the upper-right and upper-left quadrants of the agar plate, corresponding to a participant's right hand and wrist. *L*, left; *R*, right.

Usability survey

The results of the usability portion of the survey are displayed by doffing strategy in Figure 4.

Overall, assigned doffing strategy was not significantly associated with total usability score ($P = .24$).

The survey question regarding perceived utility (ie, perceived ability of PPE to prevent transmission) received similar Likert

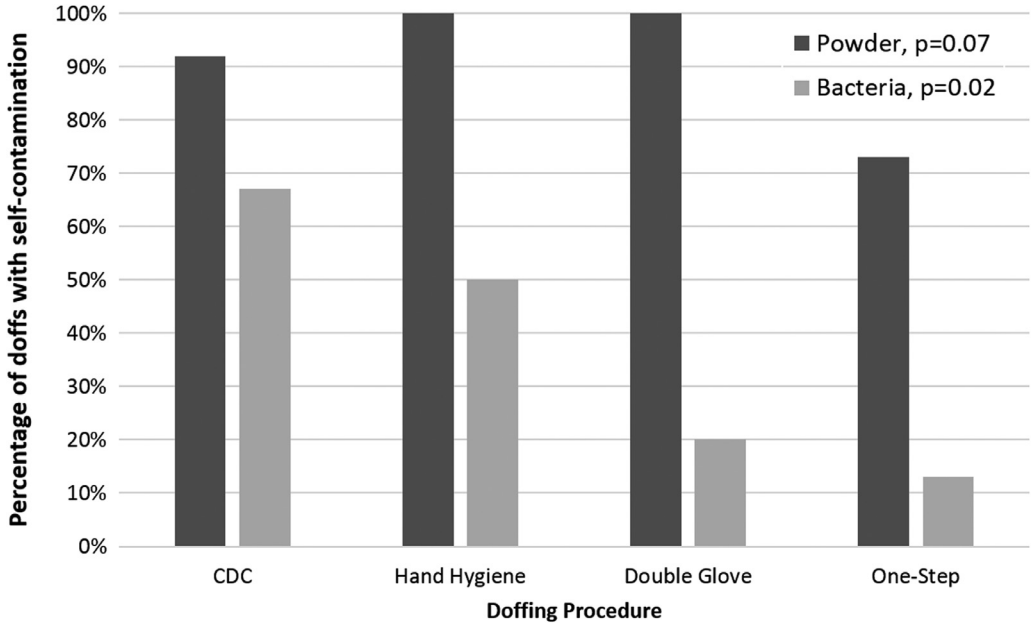

Fig 3. Self-contamination with fluorescent powder and fluorescing *Staphylococcus epidermidis* when doffing personal protective equipment.

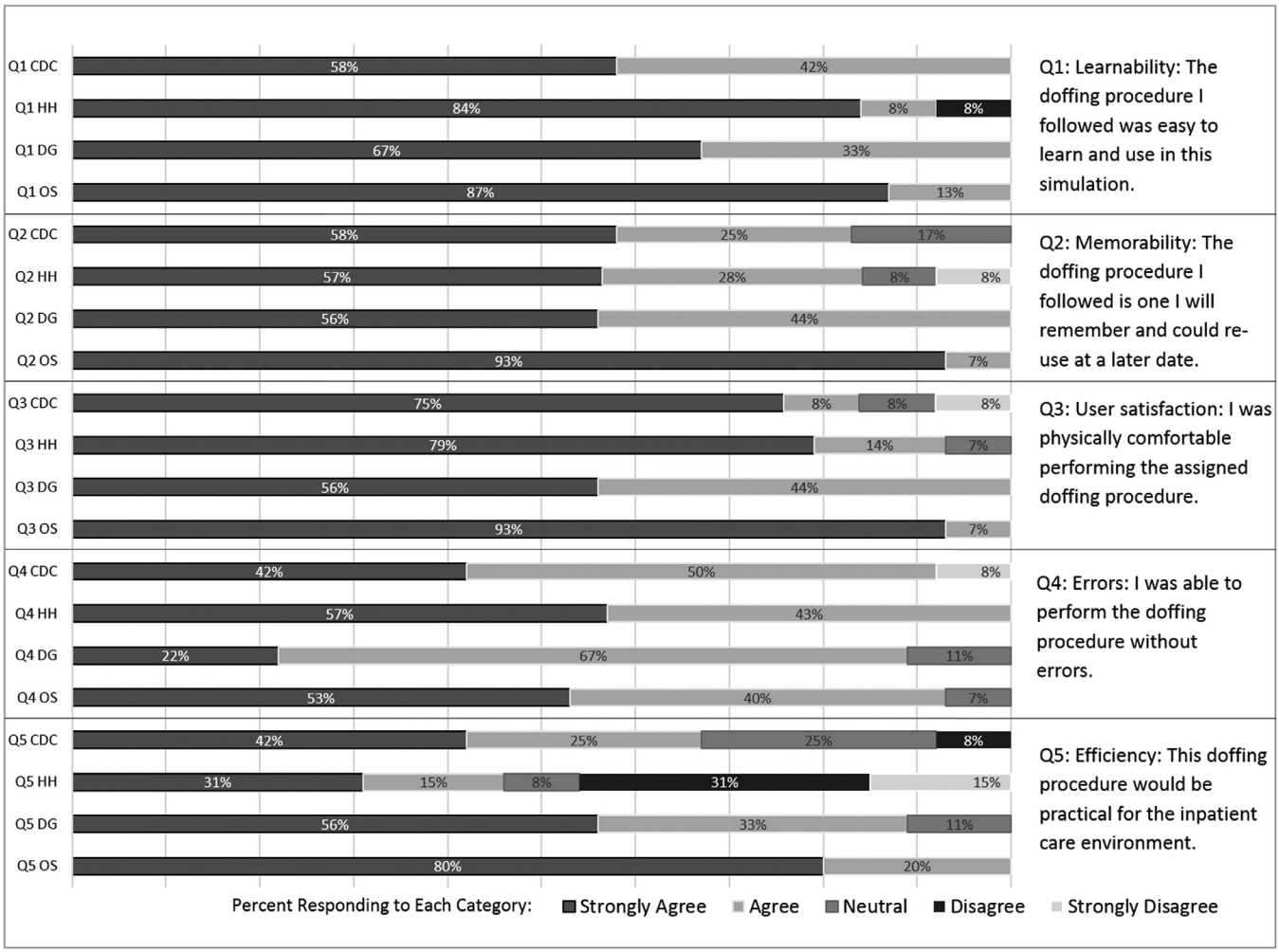

Fig 4. Select usability questions and responses by assigned doffing strategy. *CDC*, Centers for Disease Control and Prevention; *DG*, double glove; *HH*, hand hygiene; *OS*, one-step.

scale responses from each group with average scores of 4.0 (CDC), 3.7 (HH), 4.1 (DG), and 4.0 (OS), with $P = .93$.

DISCUSSION

While under observation when doffing PPE, HCWs frequently self-contaminated with both a surrogate marker and live *S epidermidis.* Whereas gowns and gloves may limit the bioburden of potential pathogens on provider skin and clothing, close attention to doffing technique is necessary for optimal results. Although adaptions to our currently recommended doffing methods have been proposed, we found limited evidence in these simulations that the addition of extra HH steps on gloved hands or double gloving would be more effective in preventing self-contamination in a highly motivated volunteer cohort with interest in PPE. However, we did note a possible decrease in the self-contamination rate in the participants using an OS approach to doffing, as recommended in example 2 of the CDC procedure. This method of doffing is most commonly observed on the inpatient units at our institution,[6] and was acceptable to participants in terms of feasibility in practice. We hypothesize that the decrease in self-contamination using this OS approach is attributable to the minimal manipulation of PPE in removing it. We suggest emphasizing this doffing strategy in provider PPE training programs pending additional comparative data.

Surprisingly, we were able to culture viable fluorescent *S epidermidis* from the hands of some providers at the conclusion of the doffing simulation, despite the use of standard hospital 70% alcohol-based hand rub as a final step. This study has important implications for the transmission of *Staphylococcus* spp and other bacteria on hospital wards and calls into question the quality of HH performed by providers. Similar to the discussion on PPE, it is not only the compliance that patient safety advocates must audit and provide feedback, but also the adequacy of HH practices that must be addressed.

There were several limitations in this study. It is unknown what amount of self-contamination is clinically meaningful in terms of transmission of infectious diseases. We chose a concentration of *S epidermidis* likely to represent contamination expected from contact with a patient wound or perineal care; we applied arguably more bacteria than would be expected from a cursory exam. Selection bias may exist in that the providers who volunteered for this study could be those more interested in PPE. Study participants were also aware of being watched while doffing PPE and were likely more careful. However, rates of self-contamination were high among the participants despite direct observation. Finally, the small sample size of participants at a single academic medical center limits evaluation of contamination by provider characteristics.

We add to the body of literature on HCW self-contamination using a novel marker of fluorescently-tagged, live *S epidermidis*, which may more precisely represent the cross-transmission of both resident and transient flora in clinical settings. To our knowledge, it is also the first study that systematically evaluates additional HH, double gloving, and OS alterations to standard doffing practices.

CONCLUSIONS

This study highlights the need for additional investigation in the area of optimal doffing practices, particularly considering increasing HCW PPE education and training programs.

An OS doffing method with minimal manipulation of PPE may be best suited for use in a hospital isolation room setting based on possibly decreased contamination risk and provider usability feedback. Clearly, ongoing attention to the quality of PPE and HH techniques is needed to optimize the benefit from these core infection prevention practices.

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SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ajic.2018.11.003.

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