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Contributing Risk Factors to Self-Contamination During the Process of Donning and Doffing Personal Protective Equipment

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Brief Report

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Abstract

Objective: The goal of this study is to explore the risk factors associated with self-contamination points during personal protective equipment (PPE) donning and doffing among health care workers (HCWs).

Methods: In total, 116 HCWs were randomly sampled and trained to don and doff the whole PPE set. We smeared the whole PPE set with the fluorescent powder. After each participant finished PPE doffing, the whole body was irradiated with ultraviolet light in order to detect contamination points and record the position and quantity. Sociodemographic characteristics and previous infection prevention control (IPC) training experience, among others, were collected by using electronic questionnaires. Poisson regression was used in identifying risk factors that are associated with the number of contamination points, and the relative risk (RR) and its 95% confidence interval (CI) were calculated.

Results: About 78.5% of participants were contaminated. Ever training experience (RR = 0.37; 0.26, 0.52), clinical departments (RR = 0.67; 0.49, 0.93), body mass index (BMI) (RR = 1.09; 1.01, 1.18), and shoulder width (RR = 1.07; 1.01, 1.13) were associated with the number of contamination points.

Conclusions: Previous IPC training experience, department types, BMI, and shoulder width were associated with self-contamination points after the PPE was removed.

Over the past few decades, health care settings have met multiple infectious disease pandemics, from the severe acute respiratory syndrome (SARS) outbreak in 2003 to the Ebola virus, Middle East respiratory syndrome (MERS), and coronavirus disease (COVID-19), which is an emerging disease that caused a worldwide pandemic due to its strong infectivity and the general susceptibility of the population.[1] As of January 2023, > 600 million confirmed cases of COVID-19 have been reported worldwide, which results in > 6.7 million deaths.[2] Health care workers (HCWs), as frontline responders, are more susceptible to infection than the general population because of their high frequency of contact with patients.[3,4] Studies have shown a startling increase in the number of people who are infected with SARS and a corresponding increase in health-care-associated SARS nosocomial infection.[5] The use of personal protective equipment (PPE), including an N95 respirator, face shield, coverall, and gloves, remains a fundamental and standard practice in regular epidemic prevention and control for the HCWs during the COVID-19 pandemic.[6,7]

However, many HCWs are not trained enough to don and doff their PPE, which easily causes contamination and then cross-infection with pathogens while working due to inappropriate methods of PPE donning and doffing. The American Centers for Disease Control and Prevention (CDC) has developed some standardized procedures and protocols for PPE donning and doffing in order to minimize occupational exposure and cross-infection.[8] Several published qualitative studies used fluorescent labeling in detecting contamination points and identified risks or failure modes in PPE doffing assessment based on human factor methodology, which involves the PPE design, environmental design, team skills, and so forth.[9–12] However, to date, few studies have investigated factors associated with the severity of self-contamination during HCWs' PPE doffing process quantitatively, and whether personal characteristics (eg, body size, profession, working experience) affecting doffing safety remain unknown. Thus, this study was designed to detect self-contamination points and quantitatively explore the potential risk factors associated with occupational exposure severity (quantified as the amount of self-contamination points counts) during PPE removal using Poisson regression, to facilitate training on the correct application of PPE and provide more references for occupational exposure prevention for HCWs.

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Methods

Study Participants

The study was conducted from May to July 2022 in a tertiary hospital, Suzhou, China. The hospital infection control team took a simple random sample of 116 HCWs from all the hospital departments. The inclusion criterion was as follows: Participants had no significant physical activity limitations and no mobility impairment that affected donning and doffing. The exclusion criteria were as follows: Participants did not fill in questionnaire information completely, or they dropped out of the study during the PPE donning and doffing process. In total, 116 participants met the criteria and joined the training and study. The study protocol was approved by the Ethics Committee of the Second Affiliated Hospital of Soochow University, and all participants provided written consent before participating.

Research Methods

Table 1 shows the whole study process and PPE donning and doffing procedure. Five rooms for study conduction were prepared in order to simulate the real settings of infections wards: room 1, for theoretical education about infection prevention and control (IPC) and body measurement; room 2, for PPE donning; rooms 3 and 4, for fluorescent simulations and PPE doffing; and room 5, for recording and assessment of contamination points. All the rooms were equipped with hand sanitizers (alcohol-based hand rubs), full-length mirrors, and medical waste bins. We arranged each room with 1 or 2 workers from the infection control team in order to provide HCW instructions. The whole process was in line with the PPE donning and doffing guidelines during the COVID-19 epidemic issued by the China National Health Commission.[13] The details are listed in Table 1. The detailed information of the PPE set, including manufacture and size, is shown in Table 2. Participants selected their appropriate PPE size.

The whole process followed the following principles: (1) face-to-face training in PPE use; (2) correct PPE donning and doffing order based on the guidance and instruction; (3) sealed coverall and glove combination; a better fitting coverall around the neck, wrists, and hands; a better cover of the coverall-wrist interface; and double gloving; (4) taking off PPE from the top to the bottom (from the head, neck, shoulders, upper body, lower body to the feet); rolling inside out, avoiding touching the inner cleaning side with contaminated hands and keeping the body away from the outer contaminated side of the coverall; (5) 1-step glove and coverall removal; and (6) carrying out hand hygiene after each step of PPE removal. These are also in accordance with the CDC donning and doffing guidelines, which are recognized as safer strategies.[14] Figure 1 shows the whole set of PPE for the HCWs during the COVID-19 pandemic in China.

Contamination Assessment

The simulation practices were assessed using glo germ (fluorescent powder) with ultraviolet lighting. In Room 3, the worker simulated pathogen contamination by smearing the whole PPE set with fluorescent powder. After each participant finished PPE doffing in Room 4, the 2 workers in Room 5 turned off the natural light and illuminated the whole body with ultraviolet light in order to detect contamination points and record the position and quantity.

Research Variables

Each participant scanned the Quick Response code in Room 1 and filled out the electronic questionnaire with variables such as age, gender, department, profession, title, working years, and prior IPC training experience. The study included all major clinical departments, including the surgery and internal medicine departments. The medical technical departments included radiology, pharmacy, pathology, and ultrasound diagnosis. The other departments included administrative and logistics, among others. Information about a previous training experience was obtained by using the following question: *Have you ever had IPC training?* By following a standardized procedure, a trained nurse conducted body measurements, which included height, weight, waist circumference, and shoulder width with an accuracy of 0.1 cm. The departments were divided into clinical, medical technology, and other departments. Professions were divided into doctors, nurses, and medical technicians; professional titles were divided into junior, intermediate, and senior. BMI was calculated as weight (kg)/height (m).[2]

Statistical Analysis

Data were exported from the electronic questionnaires, and the SPSS 23.0 (IBM Corp, Armonk, NY) software was used for statistical analysis. Descriptive analysis for quantitative data was expressed as mean ± standard deviation (SD), and qualitative data were expressed as percentages. Poisson regression was used to evaluate influencing factors related to the number of contamination points, and the relative risk (RR) and its 95% confidence interval (CI) were calculated. We examined the robustness of our results through sensitivity analyses based on sex and BMI stratification. Two-sided $P \leq 0.05$ was considered statistically significant.

Results

Medical technical departments accounted for a higher proportion than that of the other two. The study participants had an average age of 35.3 (9.71) years and worked for 11.9 (10.5) years, and the majority of them (66.4%) were females. About 50.9%, 25.0%, and 24.1% of them had primary, intermediate, and senior professional titles, respectively. The number of doctors (45.7%) was higher than that of the nurses (32.8%) and medical technicians (21.6%). Their mean BMI, waist circumference, and shoulder width were 22.3 (3.13) kg/m^2, 81.3 (11.6) cm, and 43.7 (3.41) cm, respectively. The details are listed in Table 3.

Table 4 provides the contamination status of all participants after PPE removal according to the locations and quantities of contamination points. In total, 228 contamination points were observed among all participants after doffing. Participants' whole bodies or specific body parts were contaminated to varying degrees with different contamination counts (ranging from 0 to 10). We respectively showed total, maximum, and minimum contamination counts across the whole body or specific body parts among all participants in Table 4. In total, 91 out of 116 participants were contaminated, with a 78.5% contamination rate. The neck and shoulders, hands, and chests were the most contaminated body sites, with contamination rates of 34.5%, 32.8%, and 27.6%, respectively, whereas the feet, hair, and face were less exposed.

The results of the Poisson regression model are provided in Table 5. The data indicated that participants with any IPC training

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Table 1. The whole process of PPE donning and doffing simulation practice[a]

Process	Area	Procedure	Content	Researchers
Preparation (step 1)	Room 1	a. Theory education	IPC guidelines: knowledge about COVID-19 epidemiology, personal protection, hand hygiene, disinfection, isolation, PPE use protocols, occupational exposure prevention, etc.	1 worker
		b. Questionnaire survey	Collecting information about age, gender, work number, department, profession, title, working years, training experience, etc.	
		c. Body measurement	Collecting body measurements including weight, height, waist circumference, and shoulder width	
Donning (step 2)	Room 2	a. Hand hygiene and putting on scrubs or working suits	Following the hand hygiene recommended by the WHO guidelines	1 worker
		b. Putting on the N95 respirator	Doing air tightness tests and ensuring the mask is air-tight	
		c. Putting on a working cap	Making sure all hair is wrapped in the cap	
		d. Putting on inner gloves	Choosing the appropriate size	
		e. Putting on the coveralls	Choosing the appropriate size	
		f. Putting on outer gloves	Making sure there is a tighter connection between the outer gloves and coverall sleeves	
		g. Putting on the face shield and then entering Room 3	Making sure the face shield fits tightly on the head and protects the entire face	
Smearing fluorescent powder (step 3)	Room 3	Fluorescent simulation.	Making sure the whole PPE set is covered in the fluorescent powder	1 worker
Doffing (step 4)	Room 3	a. Hand hygiene and taking off the face shield	Making sure movements are gentle and slow to avoid airflow	
		b. Hand hygiene and taking off the coverall and outer gloves together	Rolling out the clean side; not touching the contaminated side; not touching the clean side and body with contaminated hands; one-step removal of outer gloves and coverall	
		c. Hand hygiene and taking off inner gloves		
	Room 4	a. Hand hygiene and taking off the working map		1 worker
		b. Hand hygiene and taking off the N95 respirator		
		c. Conducting hand hygiene, putting on a new surgical mask, and then entering Room 5.		
Assessment (step 5)	Room 5	a. Turning off natural light and illuminating the participant with UV light		2 workers
		b. Detecting and recording the contamination points		

[a]PPE, personal protective equipment; IPC, infection prevention and control training.

Table 2. Personal protective equipment (PPE) used in donning and doffing simulation process

Personal protective equipment item	Product name	Manufacturer	Size
N95 respirator	Health care particulate respirator and surgical mask 1860	3M, USA	Uniform size
Working cap	Disposal medical non-woven cloth cap	Baixue, China	Uniform size
Gloves	Rubber surgical gloves (sterile)	Xiangshu, China	S; M; L
Coveralls	Medical disposable protective clothing	Qiji, China	170 cm; 175 cm; 180 cm; 185 cm
Face shield	Medical isolation mask	Lifeng Biothec, China	Uniform size

experience were less contaminated than those without, with an RR of 0.37 (0.26, 0.52). In comparison with the other 2 departments, the participants in clinical departments had fewer contamination points, with an RR of 0.67 (0.49, 0.93). A positive association between BMI, shoulder width, and the number of contamination points was observed, with RR of 1.09 (1.01, 1.08) and 1.07 (1.01, 1.13), respectively. No other variables were associated with contamination points. Sensitivity analyses presented results

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Figure 1. The whole PPE set for the HCWs during the COVID-19 pandemic in China.

Table 3. Sociodemographic characteristics of participants

Characteristic	Results
Sex (%)	
Male	33.6
Female	66.4
Age (years)	35.3 ± 9.71
Department (%)	
Clinical	39.7
Technical	42.2
Other	18.1
Profession (%)	
Doctor	45.7
Nurse	32.8
Technician	21.6
Level (%)	
Primary	50.9
Intermedia	25.0
Senior	24.1
Training experience (%)	
Yes	44.8
No	55.2
Working time (years)	11.9 ± 10.5
BMI [a] (kg/m^2)	22.3 ± 3.13
Shoulder width (cm)	43.7 ± 3.41
Waist circumference (cm)	81.3 ± 11.6

[a]BMI, body mass index.

stratified by sex and BMI (Supplementary Table 1). Participants with prior training experience were less contaminated, no matter for males or females, overweight or non-overweight participants.

Discussion

The study identified contamination points and first assessed the factors that were associated with contamination points after PPE removal. Previous studies reported that doffing protocols, environmental designs, teamwork skills, and other influencing factors all greatly affected the safety of PPE applications.[9–12] In the current study, participants in an appropriate PPE size donned and doffed based on the standardized guidelines. In the same environmental settings, the personal variables were collected to explore the self-contributing factors of exposure during the doffing process. Previous training experience, department type, BMI, and shoulder width were found to be associated with the contamination points during PPE removal.

Previous studies reported that the contamination rate ranged from 46 to 90% with various PPE item removal.[10,15,16] Ja-Hyun Kang selected the HCWs who most frequently used PPEs with years of working experience in the study and reported a 66.2% contamination rate after removing the whole PPE set.[15] In this study, the total contamination rate was 78.5% after removing the whole PPE set. The figure was high, despite the fact that HCWs were trained to use PPEs as instructed, and the workers provided verbal instructions. The study found that the neck, shoulders, hands, and chests were most susceptible to contamination. Myreen E. Tomas et al. also reported that the shoulder and neck were contaminated more during the PPE doffing process.[17] A Chinese study with fluorescent fluid simulation showed that the hands, wrists, chest, and abdomen were the sites that were most prone to contamination.[18] These findings are similar to our results, which further imply that the PPE design should consider these elements to help mitigate such barriers. Moreover, hand hygiene, as a basic but very effective means of pathogen infection prevention, should be emphasized in HCWs' routine work.[19–21]

In this study, less than half of the participants (44.8%) had ever IPC training experience, and they had fewer contamination points than those without. Furthermore, results in several sensitivity analyses showed that such an association was robust (Supplementary data). Systematic IPC training is directly associated with decreased nosocomial infection rate,[22,23] and the previous studies have repeatedly highlighted the need for homogenization of the training contents and opportunities.[24] Usually, IPC training methods in health care institutions are a combination of theory and practical teaching, including knowledge of disease prevention and control, hospital infection prevention, disinfection and sterilization, medical waste management, PPE donning and doffing practices, and many other infection control strategies,[25] which will assist health care workers avoid cross-infection from the perspective of knowledge, attitude, and practice.[26] However, a review involving data from some countries published in 2020 reported that HCWs had little or limited systematic training associated with specific infections (SARS and tuberculosis) aside from their initial professional education.[27] In addressing these problems, hospital management departments should support mandatory training during the COVID-19 pandemic,

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Table 4. Contamination status of participants (n = 116)

Contamination positions	Total contamination counts among participants	Maximum contamination counts of a participant	Minimum contamination counts of a participant	Total contaminated participants	Contamination rate (%)
All	228	10	0	91	78.5
Hair	6	2	0	5	4.31
Face	6	2	0	4	3.45
Shoulder and neck	56	2	0	40	34.5
Chest	42	2	0	32	27.6
Back	20	2	0	15	12.9
Abdomen	15	1	0	15	12.9
Upper limbs	8	1	0	8	6.90
Lower limbs	21	2	0	16	13.8
Hands	48	3	0	38	32.8
Feet	6	1	0	6	5.17

Table 5. Associations of risk factors and self-contamination points in HCWs[a]

Variables	Estimate	Sd. error	*Wald* χ^2	*P*	RR (95% CI)
Intercept	−2.93	1.538	3.94	0.047	
Sex					
Male	−0.20	0.232	0.97	0.326	0.82 (0.56, 1.22)
Female	0.00				1
Age	0.03	0.035	0.74	0.390	1.03 (0.97, 1.10)
Department					
Clinical	−0.40	0.170	5.76	0.019	0.67 (0.49, 0.93)
Medical technology	−0.32	0.330	1.73	0.323	0.72 (0.45, 1.17)
Other	0.00				1
Profession					
Doctor	0.00				1
Nurse	0.06	0.250	0.07	0.826	1.06 (0.70, 1.59)
Technician	0.13	0.310	0.38	0.672	1.14 (0.75, 1.73)
Title					
Primary	0.00				1
Intermedia	0.12	0.180	0.53	0.524	1.12 (0.82, 1.53)
Senior	−0.02	0.270	0.01	0.942	0.98 (0.58, 1.65)
Prior training experience					
Yes	−0.99	0.170	32.30	< 0.001	0.37 (0.26, 0.52)
No	0.00				1
Working years	−0.03	0.029	0.76	0.384	0.98 (0.92, 1.03)
BMI	0.09	0.038	4.76	0.029	1.09 (1.01, 1.18)
Waist circumference	−0.02	0.011	2.94	0.087	0.98 (0.96, 1.00)
Shoulder width	0.07	0.030	4.65	0.031	1.07 (1.01, 1.13)

[a]HCWs, health care workers; BMI, body mass index; CI, confidence interval; RR, relative risk.

especially in PPE donning and doffing practice. Moreover, hospital IPC teams should be adequately staffed with appropriately trained and educated members. In comparison with the other 2 departments, the participants in clinical departments were less contaminated because they had rich experience in sterile surgical operations. They also may have better cognition of aseptic procedures and operate more standardly than the workers in medical technology or other departments. The results indicated that both shoulder width and BMI were positively associated with contamination points. One possible explanation for such an association might be that BMI was related to shoulder width in our sample. Indeed, the correlation analysis showed that the Spearman rank coefficient between BMI and shoulder width was 0.48. This reminded us that a big body size may be a risk factor for self-contamination during the doffing process. Even though all participants chose loose coveralls in order to avoid contamination caused by the tighter size, we observed that participants with bigger body shapes and wider shoulders may don and doff PPE with lesser flexibility. They usually experienced difficulty in following the doffing protocol: rolling inside out and avoiding self-contamination

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caused by the coveralls' outer surface (contaminated side), especially at the shoulder. Therefore, the infection control team should carefully consider these people and develop individualized training strategies. Intensive training and practice may help them form muscle memory and doff PPE with more flexibility.[28] Moreover, a PPE design should further consider shoulder convenience. A trained doffing assistant should be added during the management of patients with confirmed cases in some situations as recommended,[8] who can provide "hands on" assistance in the doffing rooms.

Some limitations should be considered in this study. First, we cannot determine the probability of pathogen infection with the glo germ powder because of its inability to simulate the pathogen's invasiveness and environmental survival. However, it is well simulated that its transmission mode is through physical contact and air so that we can objectively and intuitively observe the contamination status after PPE removal.[29,30] We also need to prospectively monitor the HCWs who are exposed to highly infectious diseases in order to detect more real-life evidence in the future. Second, both too-loose and too-tight coveralls have been reported to affect safe doffing.[11] The size of PPEs on the market in China is limited, with only 170 cm, 175 cm, 180 cm, and 185 cm available, which may affect the accuracy of results due to incomplete fitness for HCWs. Furthermore, the study was mainly conducted among the HCWs with higher education levels and aseptic awareness. The body measurements were based on the Chinese population. Thus, the generalization of results may not be extended to other populations, but our findings may provide references for the other populations who potentially use PPEs. Finally, as the first study to explore factors associated with contamination points, variables were selected based on the practical training experience in routine clinical practice. Additionally, the conservation of PPEs for clinical use during the COVID-19 pandemic reduced their availability for a larger sample size. Further, we should recruit more participants from different populations and select more variables in order to explore occupational exposure during PPE removal.

PPE donning and doffing is a structured and complex process, where many protocols and details should be considered. This study detected self-contaminated sites and found that previous IPC training experience, department types, BMI, and shoulder width were associated with self-contamination points during the PPE doffing process. Corresponding measures and policies based on the above factors such as intensive and individualized IPC training for HCWs, and well-designed PPEs, can be targeted to minimize the exposure risk and better maintain the safety of medical institutions.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/dmp.2023.234

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