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Major article

Environment and body contamination: A comparison of two different removal methods in three types of personal protective clothing

Y.P. Guo PhD [a], Yi Li PhD [a,*], Peony L.H. Wong MS [b]

[a] Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
[b] Schools of Nursing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

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Training

Background: This study aimed to examine the body contamination rates and environmental contamination levels during the removal of 3 types of personal protective clothing (PPC) by the individual accustomed removal method (IARM) and gown removal methods recommended by the Centers for Disease Control and Prevention (CDC).

Methods: Fifty participants performed IARM and CDC-recommended gown removal methods to remove 3 types of PPC (ie, cotton gown, water resistant gown, and plastic apron) in random order at 2 separate sessions after applying Glo Germ simulated germ lotion on the gown's surface. A video demonstrating the CDC-recommended gown removal method was shown between the 2 sessions. After PPC removal, fluorescent stains were counted by an ultraviolet scan under dim light.

Results: Following IARM, contaminants were splashed in the surroundings, particularly on the front part of the subject. The plastic apron and cotton gown obtained the highest and lowest contaminative hazards, respectively, to the hands, shoes, and environment. Females, nurses, and senior staff had serious hand or shoe contamination. The CDC removal method more significantly reduced body and environmental contamination of small fluorescent stains (<1 cm^2), but not of large patches (>1 cm^2), than IARM.

Conclusion: The effect of gown removal, PPC type, discarding PPC location, training of infection control measures, hand hygiene, and special work shoes should be considered daily.

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Standard precautions have suggested that hand hygiene and the use of appropriate personal protective equipment (PPE) to prevent the transmission of pathogens among patients and HCWs (HCWs) should be an essential part of routine nursing care.[1] The Center for Health Protection in Hong Kong recommends that HCWs wear an isolation gown or apron when anticipating a splashing procedure and when a large part of their clothing might come into contact with patients or their immediate environment.[2]

Using protective clothing is one of the most effective strategies to prevent cross infection in such a situation.[3,4] However, an isolation gown or apron can be contaminated when the wearer cares for a patient colonized or infected with infectious pathogens.[5,6] Casanova et al[7] showed that the body of the subject, especially the dorsum of the hands, is contaminated and virus transfers to the hands and clothing during PPE removal. Zamora et al examined the self-contamination rates when removing 2 personal protective systems and found that the anterior neck, forearms, wrists, and hands were the likeliest zones for contamination.[8] Similarly, Wong et al[9] conducted a simulated viral load test and observed contamination sites on the subjects' face, dorsum and palm, and trunk. These studies mainly focused on the body self-contamination rates. However, environmental contamination levels during PPE removal were not known. Our recent study examined both body contamination rates and environmental contamination levels and revealed that the front part of the subject and the rubbish bin were contaminated during the removal of latex gloves.[10] However, the study did not involve personal protective gown.

The outbreak of severe acute respiratory syndrome in 2003 alerted HCWs to the fact that they had to comply with protocols of donning and removing personal protective clothing (PPC) to minimize risk of infection by the disease among HCWs.[11] PPC

* Address correspondence to Yi Li, PhD, Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China.
E-mail addresses: tcliyi@polyu.edu.hk, tcliyi@inet.polyu.edu.hk (Y. Li).

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should be removed before leaving the patient care area to prevent possible contamination of the environment outside the patient's room in a manner that prevents contamination of clothing or skin, and an accurate process has been delineated by the CDC-recommended removal method.[1] Our recent study examined 2 different methods of removing gloves and found that the CDC gown removal method significantly decreased the rate of contamination of the environment and HCWs.[10] The aforementioned studies of Zamora et al[8] and Wong et al[9] did not follow the CDC protocol. Casanova et al[7] adopted the CDC protocol during PPE removal but did not compare with individual accustomed removal method (IARM).

Woven and nonwoven isolation gowns are available in clinical settings. Wong et al[9] found that the physical material properties of these gowns differ and suggested that the traditional surgical woven gown absorbs liquid contaminants, whereas the nonwoven gown resists them. However, no concrete evidence indicates the level of contamination of the environment and body caused by different methods of removal of different types of PPC. Considering that, until present time, studies about both body contamination rates and environmental contamination levels, and 2 methods during removal of different types of PPC have not been very full-scale, the present study aimed to examine the body contamination rates and environmental contamination levels during 2 different methods (IARM and CDC-recommended gown removal method) of removing 3 types of PPC (cotton gown, water-resistant gown, and plastic apron). We hypothesized that (1) IARM and CDC-recommended gown removal methods have different effects on body contamination rates and environmental contamination levels; (2) a significant difference in contamination levels during the removal of the 3 types of protective clothing can be observed between the 2 removal methods; and (3) reduced environmental and bodily contaminations are associated with the CDC-recommended gown removal method.

METHODS

Subjects

Fifty HCWs were recruited for this study. Because a high number of health care staff comprise females, 34 (68%) subjects were female, and 16 (32%) were male. The 50 subjects included nurses (n = 20, 40%), support staff (n = 15, 30%), doctors (n = 10, 20%), and allied health workers (n = 5, 10%). The average age was 32.9 years at a range of 22 years to 50 years (standard deviation ± 5.7). The average working experience was 10.9 years at a range of 2 years to 24 years (standard deviation ± 5.1).

All HCWs were given information about the purpose and procedures of the study. Written consent was obtained prior to the study. Ethical approval was obtained from the Human Subject Ethics Sub-committee of the Hong Kong Polytechnic University and the Clinical Research Ethics of the Joint Chinese University of Hong Kong and New Territories East Cluster before the study was conducted.

Sample size

Sample size was determined by reference to another study.[8] The standard deviation of the small patch of fluorescent stain (<1 cm^2) on the front of doffed gloves in the post-test and pretest was 7.65. The clinically relevant difference (δ) was 6.7 (pretest small patch, 15.9; post-test small patch, 9.2). The significance level (α-2-sided) was .05. Power in the experimental study design was (1-β) and should not be lower than 0.8.

According to Fang,[12]

$$N = \left[\frac{2\left(\mu_\alpha + \mu_\beta\right)\sigma}{\delta}\right]^2$$

Therefore,

$$N = \left[\frac{2(1.64 + 1.28)7.65}{15.9 - 9.2}\right]^2 = 45$$

As a result, each removal method for each gown required 45 samples. Fifty subjects were required in case of any possible error in the study. Each of the 50 subjects was required to test 3 types of protective clothing following 2 different removal methods.

PPC

Table 1 illustrates the 3 kinds of PPC used in the experiment: PPC1: Disposable water-resistant gown. PPC2: Reusable cotton gown. PPC3: Disposable plastic apron. The anticipation of fluid contaminant during the procedure determined the type of isolation gown used. PPC was evaluated (Table 1).

Testing of PPC fabric characteristics

Fabric characteristics, including weight, thickness, fabric water repellency, and fabric liquid penetration, were evaluated. The fabric face was measured for water repellency and wettability. A spray test was completed according to American Association of Textile Chemists and Colorists standard 22.[13] Grade 5 indicates no sticking or wetting of the upper surface (ie, maximum water repellency), whereas a 0 indicates the complete wetting of the entire upper and lower surfaces (ie, the poorest water repellency). The liquid penetration test was performed according to American Association of Textile Chemists and Colorists standard 127.[14] For liquid penetration pressure, a zero value reflects no resistance to liquid water penetration under 60 mbar/min of the hydrostatic pressure of liquid water. The maximum value is 999 mbar/min, reflecting the highest resistance to liquid water penetration. The mean fabric physical characteristics are listed in Table 1.

Simulated germ lotion

Using fluorescent lotion to reproduce contaminants in assessing contamination rate is effective and can be utilized for comparison with body and environment contamination levels.[8-10] Therefore, a fluorescent powder (Glo Germ Co, Moab, UT) especially developed for determining hand hygiene compliance was used in this study. The Glo Germ powder was mixed with light olive oil and water to resemble human aerosol as closely as possible.[15] The Glo Germ powder is 100% synthetic organic colorant A-594-5 (blaze orange or invisible blue are the 2 available colors) with 5 microns or smaller particles, which is similar to bacteria size. Assuming that the density of the solution is 1, the weight of the splash in 5 strokes was 3.8 g as determined by an electronic analytical balance. The precision of the balance was 0.01 g.

Ultraviolet lamp

Ultraviolet (UV) light (model: OT4-JX with power of 220 V and 50 Hz; Tongxiang Datang Photoelectricity Technology, Tongxiang, Zhejiang, China) (Fig 1) is a useful tool to detect the fluorescent stains of contaminations on the body of the wearer, the PPC, and the surrounding environment. The UV lamp was tested and checked

Table 1
PPC evaluated and mean fabric physical characteristics of the tested PPC

PPC	Types	Weight (g/m^2) (mean ± SD)	Thickness (mm) (mean ± SD)	Water repellency and wettability (grade) (mean ± SD)	Hydrostatic pressure (mbar/min) (mean ± SD)
PPC1	Disposable water resistant nonwoven gown	0.26 ± 0.01	0.25 ± 0.04	4	73 ± 10.95
PPC2	Reusable woven cotton gown	159.21 ± 2.94	0.49 ± 0.01	0	0
PPC3	Disposable nonwoven plastic apron	0.30 ± 0.007	0.29 ± 0.009	5	906.80 ± 13.03

PPC, personal protective clothing; *SD*, standard deviation.

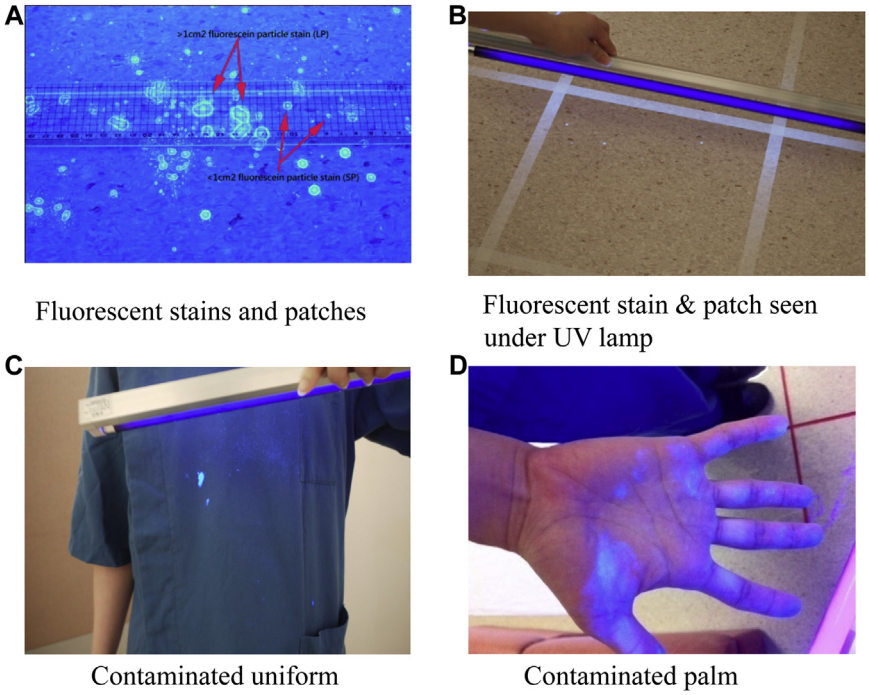

Fig 1. Fluorescent stains and patches on the body of the wearer, PPC and surrounding environment under the UV lamp. (A) Fluorescent stains and patches; (B) fluorescent stain and patch seen under UV lamp; (C) contaminated uniform; and (D) contaminated palm.

before use and was used for the entire study to avoid contradictory results during the examination.

Study procedures

At an infection control resource center in a local hospital with beds for 600 acutely ill patients was chosen as a venue for the study. Each subject completed the pretest (IARM) and post-test (CDC-recommended gown removal method) during 2 separate sessions. A video demonstrating the CDC-recommended PPC removal method was shown between the 2 sessions. After PPC removal, fluorescent patches were counted by a UV scan under dim light. Following Zamora et al[8] and Lai et al,[10] a contamination stain larger than 1 cm^2 was considered a large patch, whereas a stain smaller than 1 cm^2 was considered a small patch.[8,10] A skin test for Glo Germ powder allergy was performed prior to the study. Subjects who displayed any allergy reactions were excluded from the study.

The experiment was conducted in 3 areas, namely, area A (clean zone), area B (preparation zone), and area C (test zone). Area A was a clean zone where subjects donned their clean isolation gown or apron. The researcher checked for any fluorescent patches on the subject's body by the UV lamp. All fluorescent patches were thoroughly cleaned before a new isolation gown or apron was worn. After putting on the new gown or apron, the subject then went to area B.

In area B, the subject wore a face shield to avoid the contact of the simulated germ lotion with mucous membranes. The researcher then sprayed 3.8 g of the simulated germ lotion onto the upper body of the subject at a distance of 60 cm from the subject (ie, the length of a stethoscope). The subject was then asked to move to area C.

In area C, the setting was close to the gown down area in the general ward. The facilities contained a hand washing facility, a rubbish bin, and a mirror. For the pretest study, the subject used IARM to remove the isolation gown or apron. The subject was required to stand on a 3 ft × 3 ft checkered floor mat to remove the gown or apron. After the removal procedure, the researcher examined the surrounding environment and the subject's body for any fluorescent patch by the UV lamp.

Statistical analysis

All data were analyzed with Predictive Analytics Software 17 for Windows and SPSS 17.0 for Windows (SPSS Inc, Chicago, IL). Descriptive statistics were used for all independent variables, including the subjects' sex, age, rank, and length of experience. A repeated measures analysis of variance was performed to compare the results of PPC contamination and HCW body contamination at

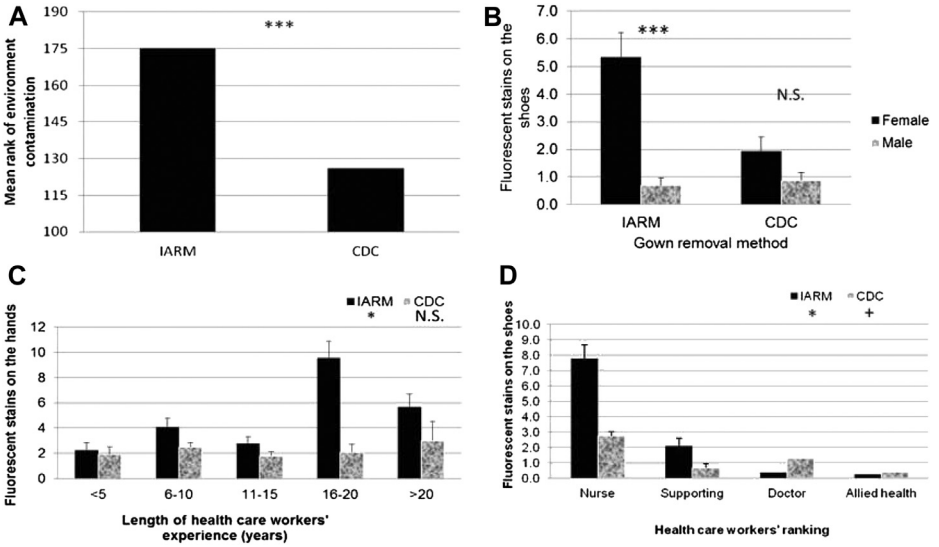

Fig 2. The environmental contamination level and the body contamination rates. (A) The overall environmental contamination level for 2 removal methods; (B) comparing shoes contamination between female and male for 2 removal methods; (C) comparing hands contamination among different lengths of HCWs experience for 2 removal methods; and (D) comparing shoes contamination among different HCW rankings for 2 removal methods; $^{***}P < .001$; $^{*}P < .05$ in individual accustomed removal method (IARM); $^{+}P = .05$ in CDC gown removal procedure (CDC); N.S., not significant in CDC gown removal procedure.

Table 2
Mean rank of small/large patches for environmental contamination and direction

Patch size	Contamination direction	Removal method	Mean rank	Mann-Whitney *U*	Z	*P* value
Small patch	Front	IARM	182.77	6,409.5	−8.11	<.001
		CDC	118.23			
	Back	TARM	148.5	10,950	−2.01	<.05
		CDC	152.5			
	Left	IARM	164.09	9,212	−5.29	<.001
		CDC	136.91			
Large patch	Left	IARM	145.23	10,460	−2.16	<.05
		CDC	155.77			

CDC, CDC gown removal procedure; *IARM*, individual accustomed removal method.

the pretest (IARM) and post-test (CDC gown removal method). A Kruskal-Wallis test was performed to examine the differences in the mean rank of environmental contamination by the removal methods, and a Wilcoxon signed-rank test was conducted to determine the difference in contamination areas for the size of fluorescent stain contamination. All reported differences were considered statistically significant at $P < .05$.

RESULTS

Environmental contamination and direction

Figure 2 shows the environmental contamination levels for the 2 removal methods. A significant difference was found in the environment contamination of IARM (mean rank = 175.06, n = 150) and CDC methods (mean rank = 125.94, n = 150; U = 7566.50, z = −5.27, $P < .001$, $r = 0.43$). The CDC-recommended gown removal method significantly reduced the overall environment contamination level.

The mean ranks of small/large fluorescent contamination patches in all directions, including the front, back, left, and right hand sides of the subjects, for both removal methods are shown in Table 2. The CDC gown removal method significantly reduced small stains in the front and left directions (U = 6409.5, z = −8.107, $P < .001$, $r = 0.66$; U = 9212, z = −5.291, $P < .001$, $r = 0.43$, respectively). However, the CDC method significantly increased environmental contamination from the back direction (U = 10950, z = −2.01, $P < .05$, $r = 0.16$). The method likewise significantly increased the environmental contamination of large patches from the left direction (U = 10460, z = −2.155, $P < .05$, $r = 0.18$).

PPC

Table 3 shows the average body and environment contamination of the 3 types of protective clothing between the 2 removal methods. For the 3 types of PPC, significantly fewer small and large patches were observed in the post-test than in the pretest ($P < .05$) except for large patches in PPC3, suggesting that the CDC gown removal procedure reduced the number of small patches. However, the same method significantly increased the environmental contamination of large fluorescent patches in PPC3 ($P < .05$), with an average of 1.62 to 5.00 fluorescent stains. The contamination levels of both large and small fluorescent stains were PPC3 > PPC1 > PPC2 ($P < .01$). Similarly, significantly fewer fluorescent stains in the environment, hands, and shoes were observed in the post-test than in the pretest ($P < .01$), and the contamination level was PPC3 > PPC1 > PPC2 ($P < .01$). The contamination level of underwear was PPC3 > PPC2 > PPC1, with a significant tendency ($.05 < P < .1$). The CDC-recommended gown removal method increased underwear contamination in PPC 2 at an average of 1.58 to 2.48 fluorescent stains.

Table 3
Level of contamination wearing 3 types of PPC

Types of PPC*	Small patch, IARM	Small patch, CDC	Large patch, IARM	Large patch, CDC	Environment number of stains, IARM	Environment number of stains, CDC
PPC1						
Mean	6.70	1.26	0.26	0.14	6.96	1.40
SEM†	0.87	0.52	0.08	0.05	0.90	0.52
PPC2						
Mean	0.10	0.08	0.02	0.00	0.12	0.08
SEM	0.04	0.03	0.02	0.00	0.04	0.03
PPC3						
Mean	16.98	1.88	1.62	5.00	18.60	6.88
SEM	2.12	0.25	0.20	0.84	2.17	0.86

Types of PPC	Number of hand stain, IARM	Number of hand stain, CDC	Number of shoe stain, IARM	Number of shoe stain, CDC	Number of underwear stain, IARM	Number of underwear stain, CDC
PPC1						
Mean	2.38	1.82	1.08	1.26	0.06	0.00
SEM	0.60	0.38	0.31	0.33	0.04	0.00
PPC2						
Mean	2.24	1.68	0.00	0.06	1.58	2.48
SEM	0.58	0.27	0.00	0.06	0.42	1.32
PPC3						
Mean	8.56	3.18	10.44	3.48	2.32	0.36
SEM	1.73	0.41	2.85	0.94	1.17	0.21

CDC, CDC gown removal procedure; *IARM*, individual accustomed removal method; *PPC*, personal protective clothing.
*PPC: PPC1, disposable water resistant gown; PPC2, reusable cotton gown; PPC3, disposable plastic apron.
†SEM: standard error of the mean.

HCW

Females and males

Figure 2B shows the sex of all subjects for fluorescent patches on shoe contamination at the pretest and post-test. Significant differences between females and males were observed in the pretest ($P < .001$). Females had significantly higher levels of contamination than males. However, the rate of contamination significantly improved after the CDC gown removal demonstration, with no significant differences between females and males observed in the post-test.

Length of experience of HCWs

Figure 2C shows the length of experience of HCWs in relation to the different levels of hand contamination. Senior staff (16-20 or > 20 years of experience) had more significant hand contamination than junior staff ($P < .05$) in the pretest. The CDC-recommended gown removal method reduced hand contamination during the procedure. All subjects had less significant hand contamination in the post-test, with no significant differences among the different lengths of experience in the post-test.

Figure 2D shows the HCW rankings for fluorescent patches on shoe contamination at the pretest and post-test. A significant difference on overall shoe contamination in HCWs with different ranks was observed ($P < .05$). Nursing staff had more significant shoe contamination than others. However, the rate of contamination significantly improved after CDC gown removal demonstration, with marginally significant differences among different types of staff in the post-test ($P = .05$).

DISCUSSION

Environmental contamination and direction

The result of the study indicates that, when a contaminated isolation gown or apron is removed, contaminants can be splashed around the surroundings in 4 directions, namely, the front, back, left, and right sides of the subject, particularly on the front side of the subject. The CDC-recommended gown removal method significantly reduced small fluorescent stains in the front and left directions (Table 2). The removal method is a significant factor in contamination; thus, choosing a suitable location is important. For instance, removal should not be conducted in front of patients, in nursing station areas, or in areas where medical equipment are stored. The effect of removal should not be underestimated, and, thus, removing the isolation gown or apron arbitrarily, without following proper procedures, such as by forcefully peeling off the gown or plastic apron, should be avoided. Rather, removal should be performed at the designated gown down area.

The CDC-recommended method of gown removal is not perfect. This study revealed that the CDC removal method has a higher chance of large fluorescent patch (>1 cm^2) contamination, although actual values in different removal methods are small. The reasons for the higher changes of large fluorescent patch contamination is that the CDC method recommends that the removed gown should be pulled away from the subject, held at a distance, and wrapped slowly into a smaller piece before discarded into the rubbish bin. However, the downside of this procedure is that contaminants can easily drop to the floor or splash to nearby areas during wrapping, which was also the reason for the increased small stains in the back direction.

PPC

PPC2 was composed of absorbent cotton fabric (zero value for water repellency and liquid penetration pressure) with the greatest thickness. PPC1 and PPC3 had grades 4 and 5 of water repellency, high resistance to liquid water penetration, and thinner fabric (Table 1). PPC2 carried the lowest contaminative hazards to the hands, shoes, and surroundings compared with PPC1 and PPC3. Cotton through its material and properties can absorb droplet contaminants and thereby reduce opportunities for such contaminants to spread to the environment. However, Table 3 shows that the absorbent fabric likewise increased underwear contamination by liquid crossing outerwear. This fact is particularly true with the

CDC method, which takes longer[8] because of the rusty technique, which increased the absorbent time of the cotton gown fabric and caused heavier underwear contamination in the CDC method (1.58 in IARM vs 2.48 in CDC method for fluorescent stains).

Plastic apron (PPC3) had a higher chance of contaminating the environment than PPC1 and PPC2. Because plastic had the lowest water-absorbing properties, the droplets that cannot be absorbed by the surface of the plastic might then drop to the floor or spread to the surrounding area, which especially increased contamination with large patches in the CDC removal method. The plastic apron had a smaller covered area, which also caused heavier underwear contamination (Table 3).

The results of this study and those of Wong et al[9] indicate that the traditional cotton surgical gown (woven gown) can absorb liquid contaminants and thus reduces environmental contamination. The other gown (nonwoven gown) can resist the absorption of liquid contaminants when the covered area is sufficient and thus provides better physical barrier protection than the woven gown. However, the nonwoven gown has weak liquid absorption ability. The liquid contaminant may easily drop to the floor or splash to the surrounding environment during movement. More important, an extra force added to the movement, such as by pulling off the isolation gown without unfastening the ties, tearing off the plastic apron, or removing the gown or apron forcefully, spreads droplet contaminants that can splash not only to the surrounding environment but also to nearby patients. Therefore, determining the type of isolation gown to use is important. The present results suggest that double gowns with outer absorbent cotton reduce the spread of contaminants to the environment, whereas inner water repellency gowns can resist contaminants and prevent them from penetrating into underwear and even the skin, providing better protection than a single gown in preventing HCW from coming into contact with patients' blood and body fluids during surgery and other splashing procedures. Although the gowns made from different materials had different characteristics, on the whole, the CDC removal method significantly reduced bodily and environmental contamination.

HCW

In this study, females tended to have more contaminated shoes than males (Fig 2B). This observation may be attributed to the fact that most of the staff within the HCW field was female. The nursing staff tended to have higher chances of shoe contamination than other groups in the pretest, such as doctors and support staff (Fig 2D). This result may be due to the fact that nursing staff come into contact with patients more often. The level of contamination indicated a significant improvement in the post-test. As a result, to enhance their knowledge and technique on the removal of used PPE, regular training on the proper handling of used PPE should be performed in a real clinical setting, and return demonstration must be required. The online training program on the handling of PPE might need rethinking.

Senior staff with working experience of 16 years to 20 years or above 20 years of experience had a higher chance of hand contamination in IARM (Fig 2C). This group of staff joined the health care field before the occurrence of severe acute respiratory syndrome in 2003, and they might have their previous practice or experience in gown removal well imprinted on their minds. However, significant improvement through a reduction of hand contamination was observed after the demonstration of the proper procedures of CDC, watching a demonstration video, and conducting procedures on their own.

Body contamination

When the isolation gown or apron is removed, the hands, uniforms, and shoes of HCWs can be contaminated, in accordance with previous studies that found virus transfer to hands and clothing following PPE removal protocol.[7] Thus, washing the hands immediately after the removal procedures to reduce the chances of cross infection in the clinical area is obviously important.

HCWs often ignore or underestimate the cleanliness of working shoes. This study demonstrates that shoes are extremely unhygienic. The best approach is to separate daily shoes from working shoes. Work shoes should be placed inside the shoe rack and not mixed with the uniform and other belongings in personal lockers. Hand hygiene should follow after the surface of work shoes is touched. Regular cleaning of work shoes is likewise crucial.

Several studies have already examined through-gown contamination,[7,9] different levels of protection rated to specific facial protective equipment systems,[16] and the difference in self-contamination rates and levels of protection associated with the 2 different types of protective equipment systems.[8] However, limited research is available to show the impact of environmental/bodily contamination during various methods of gown removal. Thus, conducting an experimental study to generate potential data to compare the CDC-recommended method of gown removal with IARM for their level of environmental contamination during procedures is necessary. The results of this study support the notion that the CDC-recommended gown removal method has less impact on environment and bodily contamination (ie, on the hands, shoes, and uniform of the subject). Our results verify the 3 hypotheses presented in the introduction. In summary, when the isolation gown or apron is removed following IARM, the hands, uniforms, and shoes of HCWs, as well as the environment, can be contaminated. The plastic apron and cotton gown carried the highest and lowest contaminative hazards. The CDC-recommended gown removal method can reduce environmental and bodily contaminations. Our findings underscore the importance of the method as follows: (1) choose a proper location when discarding used PPC; (2) following the appropriate procedures for removing PPE; (3) proper PPC is to be selected; (4) proper training and supervision for HCWs in infection control measures should be in place; (5) wash the hands immediately after removal procedures; and (6) separate daily shoes from working shoes, and these shoes should not be mixed with uniform and other belongings in personal lockers.

Future studies can focus on examining more PPC types following the CDC-recommended gown removal method because PPC with different materials exhibits various degrees of protection.

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