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Floor and environmental contamination during glove disposal

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SUMMARY

Background: Evidence suggests that doffing and possibly disposal of used personal protective equipment (PPE) can lead to environmental contamination.
Aim: To ascertain the potential for site and floor contamination when medical gloves are inappropriately disposed.
Methods: Fifteen healthcare workers (HCWs) disposed of gloves inoculated with bacteriophage and a chemical dye into a wastebasket, located 1.22 m away. Following each trial, designated sample areas were visually inspected with a blacklight for fluorescent dye stains and swabbed with a 3M Letheen Broth sponge to quantify the bacteriophage.
Findings: The area closest to the participant (<0.30 m) had the highest bacteriophage concentrations (geomean: 6.9×10^3 pfu/100 cm^2; range: 8.07 to 3.93×10^7 pfu/100 cm^2). Bacteriophage concentrations were significantly higher ($P < 0.05$) in areas ≤0.61 m compared to >0.61 m from the HCWs. Although the farthest distances (1.22–1.52 m) resulted in 14% bacteriophage- and 4% fluorescent dye-positive occurrences, there was no significant difference ($P = 0.069$) between the tracers. The bacteriophage and chemical dye indicate highest environmental contamination nearest the HCWs and both tracers could be appropriate for PPE disposal training.
Conclusion: HCWs use gloves every workday and potentially could contaminate surrounding surfaces and floors, during improper disposal practices. Therefore, proper disposal techniques are required to minimize pathogen transmission by establishing industry-wide policies, adequate training, and education to HCWs.

Introduction

Infectious diseases that occur three days after admission to a healthcare facility are considered healthcare-associated infections (HCAIs) [1]. According to a 2011 HCAI surveillance survey across 10 states, one out of every 25 inpatients contract at least one HCAI every day in US acute care hospitals [2]. Annually, 1.7 million Americans suffer from an HCAI, spending between three and 23 extra days hospitalized and costing from $10,000 to $40,000 per case [3]. About 99,000 of these Americans die, making HCAIs higher than several leading causes of death in the USA [4,5]. To reduce the number of HCAIs, research is needed to investigate the sources, transport, and fate of pathogenic micro-organisms in healthcare environments.

Personal protective equipment (PPE), such as gloves, gowns, goggles, and masks are known to reduce the exposure of highly infectious diseases to healthcare workers (HCWs) [6]. However,

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there was more environmental contamination when doffing gloves (52.9%) compared to doffing gowns (37.8%), and a significant increase in environmental contamination when HCWs used their personal doffing method compared to Centers for Disease Control and Prevention (CDC) protocols ($P < 0.001$) [7,8]. Several studies have identified barriers to appropriate PPE use in the healthcare industry which include a lack of training, constantly changing industry PPE protocols, difficulty with PPE use (e.g. donning gloves when hands are swollen and moist), the lack of pathogen transmission knowledge, and improper PPE disposal practices [9–11].

Whereas infected patients are the main source of environmental contamination within healthcare environments [12–14], HCWs' gloves also contribute to pathogen transmission after touching patients or contaminated objects [15–18]. One study found 53% of HCWs' hands contaminated with pathogenic bacteria from occupied patient rooms, whereas 24% were contaminated from cleaned patient rooms [16]. Since previous HCW surveys identified gloves as the most commonly used PPE, the precedence relies on personnel being trained and aware of proper glove doffing and disposal and hand hygiene, so as not to increase pathogen transmission [19,20].

The purpose of this study was to quantify environmental contamination when gloves are inappropriately disposed. Here we describe inappropriate glove disposal as flinging, tossing, or throwing used gloves, rather than appropriately placing them into a wastebasket. The objectives of this study were: (i) to measure the overall spread of contamination from glove disposal to the surrounding environment; (ii) to quantify the contamination along the glove flight path and the distance from the HCW; and (iii) to evaluate the use of a fluorescent dye tracer as a teaching tool for PPE disposal scenarios.

Methods

Study protocols were approved by the University of Arizona Institutional Review Board. Study participants were recruited from public health professional fields to ensure a basic knowledge of doffing PPE. There were 15 HCWs with experience in a range of fields, such as clinical, hospital, laboratory, or fire/emergency medical technician occupations. The survey and glove disposal portions of the study were performed at the Environment, Exposure Science, and Risk Assessment Center (ESRAC) laboratory at the University of Arizona (Tucson).

Public health professionals survey

The Qualtrics system survey (Qualtrics, Provo, UT, USA) was used to collect participant information on their years of experience, field experiences, PPE proficiency, soiled PPE disposal method, contaminated glove disposal method, and whether they ever witnessed co-workers dispose of PPE inappropriately. This study was under the umbrella of a larger study to verify CDC Ebola PPE doffing protocols for emergency responders, which the public health professionals survey was also used for. The survey was given to the HCWs before starting each glove disposal experiment.

Glove disposal experiment

HCWs sanitized their hands with alcohol-based hand rub (ABHR) (Purell hand gel; Gojo Industries, Inc., Akron, OH, USA) following the manufacturer's recommendations before donning nitrile gloves. Similar to a previously published study, 1.0 mL of bacteriophage PR772 (concentration: 9.20–9.57 $\log_{10}$ pfu/mL; mean: 9.37 $\log_{10}$ pfu/mL) followed by 1.0 mL of fluorescent dye (GloGerm, Moab, UT, USA) was then applied to both gloved palms [21]. As this project fell under a larger CDC Ebola study, bacteriophage PR772 was used as an Ebola surrogate due to its internal lipid-containing structure, similar size, and reductions from chlorine disinfection [22–24]. Yet bacteriophage PR772 is innocuous to humans, the environment, and only requires a BioSafety Laboratory 1 host [23,24]. HCWs rubbed their hands together for 15 s to spread both bacteriophage and fluorescent dye evenly over gloves. Trials started within 1 min while gloves were still visibly wet. Participants, each evaluated individually, were instructed to doff and dispose of their gloves into the wastebasket but were restricted to stand 1.22 m in front of the wastebasket (Figure 1). Eight tiles (each measuring 30.48 cm^2) (A–D2 sample areas) were laid out along a path from the HCW to the wastebasket, one tile attached to the front of wastebasket (D3), two tiles on either side of wastebasket (F1–F2), with eight tiles (F3–F10) attached to a wall behind the wastebasket, and one tile (E1) 1.07 m adjacent to the HCW.

After glove disposal, the room was darkened, and a black light was used to observe the presence/absence of fluorescence on sample areas. Fluorescent stains outside of the tiled area, including on the participant, were noted but not recorded. At the conclusion of the study, participants were given the opportunity to perform hand hygiene with ABHR or soap and water.

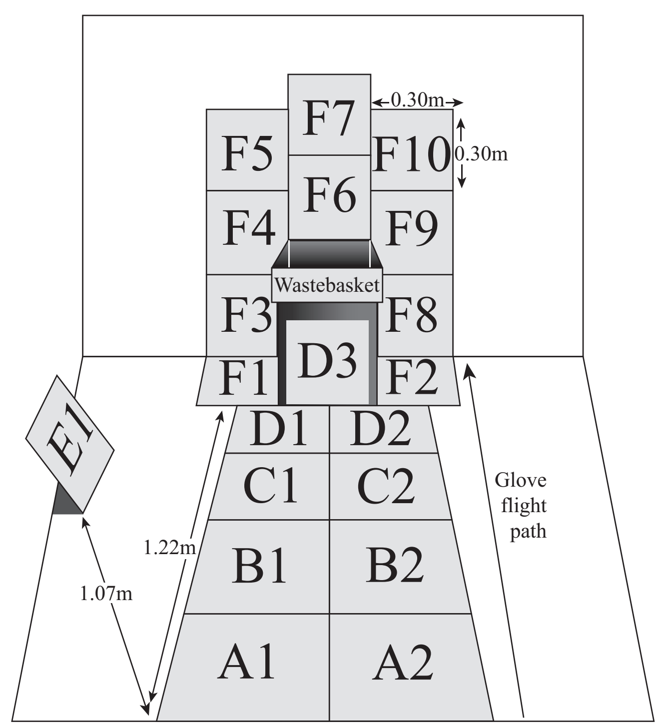

Figure 1. Sample area = 30.48 cm^2 areas in increments of 0.30 m: A = 0–0.30 m; B = 0.30–0.61 m; C = 0.61–0.91 m; D = 0.91–1.22 m; E = 1.07 m to left of participant; F = 1.22–1.52 m. D3 = 1.22 m, attached to front of wastebasket.

Each sampling area (A1–F10; Figure 1) was swabbed with a Letheen Broth sponge-stick (3M, St Paul, MN, USA), then held on ice until processed that same day. Sampled areas were cleaned after each trial with 70% ethanol for a 30 s contact time, repeated, and allowed to dry. After trials, sampled areas were inspected for any residual fluorescent stains. Sample area tiles were cleaned with soap and water to remove fluorescent stains to be used again.

Laboratory methods

Bacteriophage PR772 (HER 221) (ATTC: BAA-769-B1) and its host *Escherichia coli* strain K12J53-1 (ATCC: BAA-769) was acquired from American Type Culture Collection (ATTC) as well as performing propagation methods according to ATTC. Bacteriophage PR772 propagation was titrated to 10^9 concentration per mL, then 1.0 mL of 0.22 µm filtrated aliquots were stored in cryovials at −80°C until use on trial day.

Each sponge-stick was agitated by hand within its transport bag for 30 s, then pipetted, measured, recorded, and transferred into sterile vial sample containers. A modified EPA method 1601 double agar layer protocol was used [25]. Specifically, a volume of 0.5 mL of *E. coli* strain K12J53-1 and 10-fold bacteriophage dilutions with sterilized phosphate-buffered saline (PBS) were added to 5 mL of top agar. Samples were incubated at 37°C for 20 h. All serial dilutions were averaged and then calculated to plaque-forming units per millilitre (pfu/mL). Concentrations were converted to pfu/100 cm^2 using extracted eluent (mL) volumes and size of tile (30.48 cm^2) with the following equation: ((pfu/mL * Eluent (mL)) ÷ 30.48 cm^2) * 100 = x pfu/100 cm^2.

Data analysis

Descriptive statistics of the data were performed using Microsoft Excel (version 2016). The R computing program (R Core Team version 3.4.1) was used to perform geomean, geomean standard deviation, *t*-tests, and correlations to assess differences in contamination by distances and McNemar's test for comparing the presence of tracers in sampling areas.

Results

Public health professionals survey

Twelve out of the 15 HCWs participating in the glove disposal experiment had more than five years of PPE use experience (Table Ia). More than 50% of HCWs reported witnessing a peer perform improper PPE disposal in the previous 12 months (Table Ia). None of the current study participants indicated use of the flinging method to dispose of PPE. However, 40% and 0.07% reported tossing or throwing PPE, respectively.

Glove disposal experiment

Three disposal methods were observed: underhanded throw into/towards the wastebasket (toss, $N = 8$); overhanded throw into/towards the wastebasket (throw, $N = 2$); pulling on the gloves to stretch and launch into/towards the wastebasket (fling, $N = 5$). During the glove disposal experiment, 47% of participants had at least one glove land on the floor. Bacteriophage geomean concentration across all sites for each glove disposal method were 6.35×10^6 pfu/100 cm^2 (throw), 3.94×10^5 pfu/100 cm^2 (toss), and 1.29×10^5 pfu/100 cm^2 (fling).

Following disposal of gloves, bacteriophage concentrations in all sample areas ranged from below the detection limit (≤8.07 pfu/100 cm^2) to 3.93×10^7 pfu/100 cm^2 (geomean: 78.32 pfu/100 cm^2). No fluorescent dye or bacteriophage was detected in area F4, the tile located along the wall 0.3 m above the floor and on left corner of the wastebasket.

The fluorescent dye was detected in every sampling area along the glove flight path except F1–F5 and F8–F9 which were located on the wall behind the wastebasket (Figure 1). Fluorescent dye stains were visible outside the designated sample areas, within a 0.61 m circumference of the HCW, but bacteriophage was not measured at these spots.

Table Ia
Healthcare workers' survey in glove experiment

Question/answer	No. of healthcare workers ($N = 15$)
Over the last 5 years, where has the majority of your personal protective equipment (PPE) use been?	
Emergency medical technicians	2
Allied health	1
Physicians	4
Nurses	2
Laboratory	6
No. of years of experience using PPE	
≥5	12
3–5	1
1–2	1
<1	1
Have you ever seen someone else not follow PPE disposal protocol? If so, how many times?	
Too many times to count	2
Frequently	1
Often	5
Seldom	6
Never	1

Table Ib
Healthcare workers' survey results in glove experiment

Question/answer	Survey results	Observation results
How do you commonly handle disposal of soiled gloves?		
Throw	1	2[a]
Toss	6	8[b]
Fling	0	5[c]
Place	8	–

Success of both gloves into wastebasket from throw: [a]100%; toss: [b]50%; fling: [c]40%.

Environmental contamination by distance

Within the first 0.61 m from the HCW, up to 80% tallied positive for bacteriophage (Table II). Bacteriophage geomean

Table II
Contamination from glove disposal along the glove flight path

Distance from healthcare worker (m)	Bacteriophage					Fluorescent dye
	Geomean ± SD (pfu/100 cm^2)	Median (pfu/100 cm^2)	Min (pfu/100 cm^2)	Max (pfu/100 cm^2)	Positive occurrence (%)	Positive occurrence (%)
≤0.30	6.90×10^3 ±81.22	9.28×10^3	8.07	4.15×10^7	80	87
0.30–0.61	3.34×10^3 ±91.86	9.28×10^3	8.07	4.36×10^6	70	77
0.61–0.91	1.32×10^2 ±45.44	8.07	≤8.07	1.98×10^5	40	43
0.91–1.22	4.88×10^1 ±28.18	8.07	≤8.07	2.12×10^7	29	31
1.07 to left	3.52×10^1 ±13.24	8.07	≤8.07	8.07×10^3	27	0
1.22–1.52	1.68×10^1 ± 6.73	8.07	≤8.07	1.86×10^4	14	4

Distance areas starting from healthcare worker (HCW): A ≤ 0.30 m; 0.30 m < B ≤ 0.61 m; 0.61 m < C ≤ 0.91 m; 0.91 m < D ≤ 1.22 m; E = 1.07 m; 1.22 m < F ≤ 1.52 m. Glove flight path consisted of an area of two side-by-side 30.48 cm^2 tiles in front of the HCW along with a 1.22 m path to the wastebasket. One 30.48 cm^2 tile was placed 1.07 m left of HCW, to display contamination outside glove flight path. Surface area = plaque forming units (pfu) per 100 cm^2).

concentrations binned by distance were 6.90×10^3 pfu/100 cm^2 (0–0.30 m) and 3.34×10^3 pfu/100 cm^2 (0.30–0.61 m) (Table II). As distances increased farther than 0.61 m from the HCW, the overall geomean decreased from 132 pfu/100 cm^2 (0.61–0.91 m) to 48.8 pfu/100 cm^2 (0.91–1.22 m) to 16.8 pfu/100 cm^2 (1.22–1.52 m) (Table II). Consistent with bacteriophage concentrations, positive occurrences decreased from 80% to 14% as distances increased (Table II). Bacteriophage concentrations were significantly greater at distances ≤0.61 m than at distances >0.61 m away from the HCW ($P < 0.05$).

Glove disposal practices: fluorescent dye and bacteriophage comparison

Positive occurrences of fluorescent dye stains (Figure 2) were compared to bacteriophage (Figure 2) on all sample areas across all trials. Similarities between positive fluorescence and bacteriophage detection occurred mostly within areas A, B, C, and D which were along the glove flight path. Differences occurred more frequently within areas surrounding the wastebasket (e.g. areas E and F). Fluorescent dye occurred on four out of 10 tiles between 1.22 and 1.52 m and bacteriophage occurred on eight out of these 10 same tiles (Figure 2). No positive fluorescent dye occurred on the tile 1.07 m left of the HCW (Figure 2) yet bacteriophage contaminated this tile (E), during four out of 15 participants (Figure 2). Areas between 1.22 and 1.52 m recorded the lowest positive occurrences for both bacteriophage and fluorescent dye, 14% and 4% respectively (Table II). Area E1, symbolizing surfaces or equipment outside the glove flight path, recorded 27% positive occurrence for bacteriophage and 0% for fluorescent (Table II). A decrease in both fluorescent dye and bacteriophage presence by area was measured with increased distance from the HCW.

Approximately 83% of the 299 sampled areas (F18 sample area is missing due to loss of bacteriophage sample during laboratory analysis) were positive for both fluorescent dye and bacteriophage contamination, 6.4% were positive for only bacteriophage, and 10.7% positive only for fluorescent dye. McNemar's test concluded no significant difference between bacteriophage and fluorescent dye contamination ($P = 0.069$), indicating that the fluorescent dye, which is almost immediately visible and requires fewer resources, was a reasonable surrogate for bacteriophage during the PPE disposal experiments.

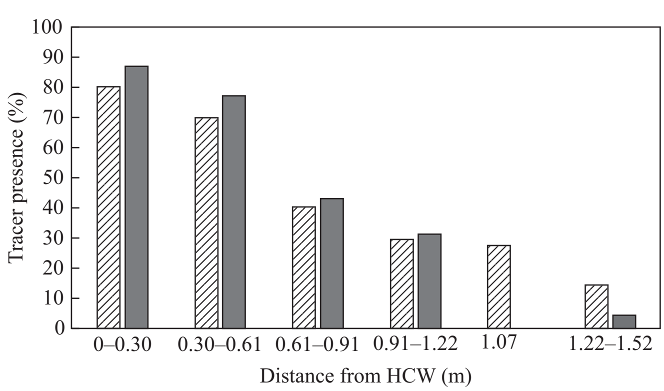

Figure 2. Tracer presence by distance from healthcare worker (HCW). Both tracers (bacteriophage: hatched bars; fluorescent dye: grey bars) present occurrence by distance in metres from HCW disposing gloves. Distances in relation to Figure 1 areas: A: 0–0.30 m; 0.30 m < B ≤ 0.61 m; 0.61 m < C ≤ 0.91 m; 0.91 m < D ≤ 1.22 m; E = 1.07 m outside glove flight path; 1.22 m < F ≤ 1.52 m.

Discussion

Gloves are the most utilized type of PPE in healthcare; however, the CDC and World Health Organization (WHO) have no detailed PPE disposal protocols for used gloves — only doffing methods [19,20]. Studies have shown that gloves are frequently contaminated and can end up on the floor during disposal practices [26,27]. Similar to the results of this study, improper glove disposal can contaminate floors and the surrounding environment. Transfer from contaminated floors to wheels and cords of medical mobile units, TV remotes, or dropped items may then lead to microbial spread throughout the healthcare facility. This project stemmed from conversations with multiple HCWs claiming to fling, toss, or throw used gloves during the disposal process. This is the first study to our knowledge that explores inappropriate glove disposal practices and quantifies the potential contributions to environmental microbial contamination.

Existing literature has evaluated contamination from various PPE doffing protocols such as gloves, gowns, and aprons but lacks information on disposal contamination, which this study confirms [7,8,10,19,20,28–31]. In the current study, environmental contamination stemming from inappropriately disposing seeded gloves towards a wastebasket was found throughout the vast majority of sampled areas with a maximum concentration of 3.93×10^7 pfu/100 cm^2 (Table II). Fluorescent dye was also observed outside of the sampling areas (primarily within a 0.61 m circumference of the participant) and on HCWs' wrists, fingers, and forearms. The presence of both tracers on surfaces and skin, within the inappropriate glove disposal vicinity gloves, indicates the potential for improper disposal of contaminated gloves to spread micro-organisms through an environment. To reduce surface contamination in healthcare settings, facilities should adopt and enforce surface cleaning practices and enhancement of CDC- or WHO-recommended glove doffing methods.

Experimental sampling distances were determined based on expected contamination potentials along the flight path and with higher concentrations expected around the wastebasket. However, bacteriophage and fluorescent dye indicated that the highest contamination occurred around the HCW (<0.61 m). This matches previous studies finding that contamination falls within 0.61–0.91 m of HCWs using personally devised glove doffing methods, rather than CDC glove doffing methods [8,31].

In areas beyond 0.61 m from the HCW and up to the wall at 1.52 m, bacteriophage concentrations were found as high as 1.90×10^7 pfu/100 cm^2. Area E1 represented surfaces and equipment beyond the direct line of glove disposal. The current study identified bacteriophage presence in this area 27% of the time following glove flings. Based on this information, environmental contamination may reach objects and surfaces such as medical equipment, bedrails, tables, and floors outside the glove flight path which may become a reservoir for pathogens [14,16,18,28]. The bacteriophage concentrations on surfaces, in this study, represent a potential hazard to people within the glove disposal area and those outside the immediate area who may come into contact with contaminated surfaces or objects [16,18]. Based on this spatial analysis, environmental cleaning protocols should include doffing areas, especially floors, and all mobile equipment used on patients.

Recent floor studies demonstrated that hospital floors are 'under-appreciated reservoirs for pathogens' [32] and considered a potential principal transmission site for HCAIs [17,18,32,33]. Another study found that 41 out of 100 hospital rooms had one to four high-touch objects (e.g. cell phone chargers, call buttons, and blood pressure mobile units) that touched the floor leading to pathogen transmission to adjacent rooms [32]. This current study found that inappropriate glove disposal may contribute to contaminating floors which then come into contact with high-touch objects, leading to the spread of HCAI-associated pathogens throughout the healthcare environment [17,32].

Fluorescent dye results in this study were not significantly different from bacteriophage contamination, suggesting that the fluorescent dye is an appropriate surrogate when demonstrating contamination from inappropriate glove disposal. Use of fluorescent dyes can provide rapid visualization of contamination and may need fewer resources compared to other biological surrogates. This may more readily assist in behaviour awareness and educate HCWs on pathogen transmission while enforcing a need to follow PPE disposal protocols [7,8,28,29,31]. The suitabilities of the fluorescent dye and bacteriophage were tested as surrogates for Ebola-like viruses. Future studies should focus on these surrogates to act as indicators for bacterial pathogens to improve environmental tracer studies.

Behaviour studies state that mixed policies from institutions, hospitals and/or government, policy ambiguity, and a lack of in-depth training lead to workplace non-compliance with PPE protocols [10,11,20,34,35]. From our survey, >50% of HCWs reported observing their peers improperly disposing of PPE. This non-compliance behaviour could lead to additional pathogenic transmission and self-contamination [9,20,36]. However, there is evidence that, with more training, HCWs increase compliance with policies [35]. Although participants were restricted to a distance at which they disposed of used gloves, overall inappropriate disposals successfully landed in the wastebasket (Table Ia and b). Of the participating HCWs, 53% successfully flung their gloves into the wastebasket, without any awkward execution in doffing gloves, suggesting previous experience with such disposal methods. During the glove disposal experiment, one HCW stated that flinging gloves into the wastebasket is a 'cool trick to show patients' and stated that they [the patients] 'love it.' Behaviour and compliance must integrate in practice to lower potential pathogen transmission within the healthcare industry.

Glove disposal protocols should entail the following steps: (1) ensure wastebasket is at least 1.52 m away from equipment, (2) doff gloves over wastebasket, (3) doff away from patients and those within the room, (4) place (don't fling, toss, or throw) used gloves into the wastebasket, (5) include areas outside the 0.61 m disposal site in routine cleaning practices, and (6) provide accessibility to sanitation wipes within doffing area for any portable equipment left in the room during doffing and if gloves accidentally land on the floor. Studies have shown reduction in environmental contamination when increasing cleaning of surfaces and floors; therefore, these areas farther than 0.61 m should be incorporated into infection control cleaning policies [8,37,38]. Further training of CDC- and WHO-recommended doffing methods during schooling and recurrent job training could also minimize environmental contamination [10].

Future research studies should elaborate on these results by comparing environmental contamination through inappropriate glove disposal with a more appropriate method such as gently placing gloves into the wastebasket. Whereas fluorescent dye suitably represented transmission and is user-friendly, bacteriophages are beneficial to further evaluate pathogen survival and susceptibility to disinfectants.

A limitation in this study was the assumption that all HCWs participating knew the CDC protocol for removing used gloves [39]. The significant difference of contamination between the two distances of ≤0.61 m and >0.61 m might be due to the differences in CDC doffing methods and personally devised doffing methods rather than the disposal method of flinging gloves into the wastebasket [39]. Studies have shown that CDC-recommended PPE removal methods significantly decreased environmental contamination compared to personal doffing methods, after a video demonstrating CDC removal methods was shown to participants [8,31].

In conclusion, proper doffing and disposal techniques are required to minimize pathogen transmission from used, contaminated gloves. Lack of continuing education on pathogen transmission and training on PPE use might encourage flinging gloves and other inappropriate disposal methods. Inappropriate disposal of used gloves may lead to floor and environmental surface contamination and possible transmission, infecting HCWs and other patients. Establishing industry-wide policies and ensuring adequate training and education on possible transmission pathways and appropriate glove disposal can help to improve practices.

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Conflicts of interest statement

None declared.

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