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Major Article

A novel personal protective equipment coverall was rated higher than standard Ebola virus personal protective equipment in terms of comfort, mobility and perception of safety when tested by health care workers in Liberia and in a United States biocontainment unit



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Key words:

Infection prevention
Health care worker safety
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Background: During the 2014–2016 Ebola virus epidemic, more than 500 health care workers (HCWs) died in spite of the use of personal protective equipment (PPE). The Johns Hopkins University Center for Bioengineering Innovation and Design (CBID) and Jhpiego, an international nongovernmental organization affiliate of Johns Hopkins, collaborated to create new PPE to improve the ease of the doffing process.

Methods: HCWs in Liberia and a US biocontainment unit compared standard Médecins Sans Frontières PPE (PPE A) with the new PPE (PPE B). Participants wore each PPE ensemble while performing simulated patient care activities. Range of motion, time to doff, comfort, and perceived risk were measured.

Results: Overall, 100% of participants preferred PPE B over PPE A ($P < .0001$); 98.1% of respondents would recommend PPE B for their home clinical unit ($P < .0001$). There was a trend towards greater comfort in PPE B. HCWs at both sites felt more at risk in PPE A than PPE B (71.9% vs 25% in Liberia, $P < .0001$; 100% vs 40% in the US biocontainment unit, $P < .0001$).

Conclusions: HCWs preferred a new PPE ensemble to Médecins Sans Frontières PPE for high-consequence pathogens. Further studies on the safety of this new PPE need to be conducted.

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BACKGROUND

During the Ebola virus outbreak in West Africa in 2014–2016, health care workers (HCWs) were almost 30 times more likely to become infected with Ebola virus compared with non-HCWs. More than 800 HCWs contracted the disease, and more than 500 died.¹ One

of the most important factors in protecting HCWs from Ebola virus and other viral hemorrhagic fevers is the availability of personal protective equipment (PPE), as well as proper training to appropriately put on (don) and take off (doff) that equipment.² For example, in a survey of returning HCWs to the United Kingdom, 8% reported direct contact with patients with confirmed Ebola virus disease (EVD) while not wearing PPE. Even with proper training and equipment, up to 17% of HCWs reported an intermediate- to high-risk exposure while providing care for patients with EVD. Intermediate risk was defined as potential contact of mucous membranes or broken skin with bodily fluids of a patient with EVD. High risk was defined as definite exposure of mucous membranes or broken skin with the bodily fluids of a patient with EVD (eg, a needlestick injury through visibly soiled

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gloves).³ Some HCWs became infected without a known exposure, raising further questions about the effectiveness of current PPE and PPE protocols.⁴ The doffing process is believed to be a particularly high-risk time in terms of self-contamination and subsequent infection. Hand hygiene and the removal of powered air-purifying respirator hoods have perhaps the highest level contamination risk.^{5–8}

In response to the recognized need to improve current PPE, the Johns Hopkins University Center for Bioengineering Innovation and Design (CBID) and Jhpiego, an international nongovernmental organization affiliate of Johns Hopkins University, organized the “Johns Hopkins Emergency Ebola Design Challenge” in October of 2014, with support from Clinvue, a health care design consultancy. During this weekend hackathon, a spiral model design process was used to create innovative features for a novel PPE design.^{9,10} More than 80 individuals from multiple disciplines (eg, engineering, fashion design, infection control) participated in the event. The top challenges with standard Médecins Sans Frontière (MSF) Ebola PPE were identified, and the team chose the most feasible and impactful challenges on which to focus. These included fogging of eye protection, difficulty with HCW identification and communication, comfort, and the complexity of the doffing process.

The design process centered on 4 key elements, including clinical performance, technical performance, commercialization potential, and team organization. The best design elements from the challenge were incorporated into a single PPE ensemble. A combined team from CBID and Jhpiego then traveled to West Africa multiple times to gain feedback on all elements of the design from frontline HCWs. More than 200 HCWs from both West Africa and the United States provided comments on the ensemble. Each change to the ensemble was tested by HCWs who would potentially wear the suit. The PPE was also subjected to technical evaluations and critical vetting from experts in the PPE industry, global health, and programmatic implementation.

In this study, HCWs in a mock Ebola treatment center (ETC) in Liberia and a US biocontainment unit compared standard MSF PPE (PPE A) to the new CBID/Jhpiego PPE (PPE B) to test the comfort, ease of doffing, perception of risk, and preferences for each PPE ensemble.

METHODS

MSF PPE ensemble (PPE A)

The MSF PPE ensemble includes a coverall or gown, a hood to cover the head, goggles to protect the eyes, a surgical mask or N95 respirator for the nose and mouth, a double layer of gloves, rubber boots, and an outer apron (Fig 1).^{9,11}

CBID/Jhpiego PPE ensemble (PPE B)

The main design innovations featured in the final CBID/Jhpiego PPE include a rear zipper protected by a rigid double flap, finger loops to secure gloves and protect hands and wrists from contamination, a high neck collar, and doffing tabs that are secured to the shoulder. These tabs are used during the doffing process and allow the user to pull the coverall off while folding the contaminated outside of the suit into itself.⁹ These features were designed to improve the ease of doffing, as well as the comfort and safety of the provider. The initial design also included a hood with an integrated facemask and isolated inhalation and exhalation pathways to provide head coverage, respiratory protection, infusion of fresh air, and reduction in fogging. The design process of the hood, mainly to reduce cost, is still ongoing within CBID and DuPont. The remainder of this manuscript focuses only on the coverall component of the novel design (Fig 2).



Fig 1. Standard Médecins Sans Frontière ensemble. Adapted from: <http://www.bbc.com/news/health-29518703>.



Fig 2. Center for Bioengineering Innovation and Design/Jhpiego personal protective equipment ensemble.

Study location and participants

Once the final CBID/Jhpiego design was completed, the study team identified 2 sites to compare the usability of standard MSF Ebola PPE (PPE A) to the novel coverall (PPE B). The first site was a conference room of a private rented facility in Monrovia, Liberia. Many of the participants from the Liberian site were experienced with standard MSF PPE and had provided care for patients with EVD during the 2014–2016 outbreak. The second site was The Johns Hopkins Hospital (JHH) Biocontainment Unit (BCU) in Baltimore, Maryland.

The JHH BCU is a state of the art infectious diseases unit that was built in 2014 to provide care for patients infected with high-consequence pathogens such as Ebola virus. It is 1 of 10 federal Regional Ebola and Special Pathogen Treatment Centers funded by the Office of the Assistant Secretary for Preparedness and Response to enhance US preparedness for highly infectious diseases.¹² HCWs on the BCU undergo extensive training in the donning and doffing of PPE, and participate in quarterly trainings and drill activities. The BCU has not yet provided care for patients with confirmed EVD or other high-consequence pathogens, but it has been activated for persons under investigation for EVD. BCU HCWs have limited experience with an ensemble similar to standard MSF PPE. The current PPE for BCU HCWs includes thigh-high boots, an Association for the Advancement of Medical Instrumentation level 4 surgical gown, double gloves, and a powered air-purifying respirator with a fluid-impermeable shroud. Because the intent of the study was to compare the new PPE ensemble with what was currently available in the field in developing countries, the standard BCU PPE was not included in the study design.

Participants at both sites were recruited through convenience sampling. In Liberia, participants were recruited via word of mouth, as well as posting of fliers at local health care facilities. In the United States, participants were recruited by emailing all rostered staff of the JHH BCU. All adult HCWs over the age of 18 were eligible for participation. The only exclusion criterion was exposure to a patient with known EVD in the 21 days before enrollment. Informed consent was obtained to participate in the study. Participants at each site were required to complete a respiratory assessment to ensure that they could safely wear each PPE ensemble. The study took place from June 14–17, 2016, in Liberia, and from June 28–July 15, 2016, in the Johns Hopkins BCU. Participants at the Johns Hopkins BCU did not receive any compensation or incentives for their involvement in the study. Participants in Liberia were reimbursed for transportation and meals on the day of the study.

Study protocol

At each study site, 5 stations were created to simulate clinical scenarios and test various elements of each PPE ensemble. Temperature and humidity were recorded at each site on the days of the study. Participants rotated through the 5 stations wearing 1 type of PPE and then repeated the same 5 stations wearing the second type of PPE. PPE A was worn first at each site, followed by PPE B. Because the majority of participants in Liberia were familiar with PPE A, the decision was made not to randomize the order of the PPE ensemble and to have participants complete tasks in PPE A first, in order to be able to then compare performance with PPE B. Stations 1, 4, and 5 focused specifically on the overall and will be the focus of the remainder of this article.

Station 1 focused on the donning process. Each participant donned appropriate PPE with the assistance of a donning partner. After the donning process, study participants were asked questions about how the PPE they had just donned compared with their standard PPE ensemble. The donning protocol for PPE A is available at <http://msf-seasia.org/16369>.¹¹ The donning protocol for PPE B is available in the Appendix.

Station 4 assessed the comfort of PPE during routine use. Participants were asked to perform movements they might use while working in an ETC (eg, walking, squatting, bending over, lifting arms). They were also given specific activities to perform in PPE, including helping a mock patient to sit up, administering 2 tablets and a glass of water to the patient, and cleaning up simulated vomit. Participants were observed during these tasks and then self-reported their comfort while performing each activity.

Station 5 focused on the doffing process. Participants were observed while they doffed the 2 types of PPE. Each step of the doffing process was timed by an observer. Participants provided feedback on the doffing process related to the ease of doffing, as well as their perceived risk of self-contamination. The doffing protocol for PPE A is

available at <http://msf-seasia.org/16369>.¹¹ The doffing protocol for PPE B is available in the appendix.

After station 5, participants completed a final survey. The survey asked participants to rank order the novel features of PPE B. The survey also asked participants about their overall PPE preferences, including whether they would recommend PPE A or PPE B, and whether they thought it would be worth spending additional money on PPE B if the costs were higher.

Statistical analysis

The results at each station were compared for PPE A and PPE B within the Hopkins BCU and within the Liberian simulated setting. Comparisons were not made between the Hopkins and Liberian sites because the demographics and clinical experience across both sites with regard to EVD were different. Statistical significance was determined using Fisher's exact, χ^2 , and Mann-Whitney U tests on R statistical software (Free Software Foundation, Inc., Boston, MA). Values were considered statistically significant at $P < .05$.

Ethical approval

Ethical oversight was provided by the Johns Hopkins University School of Medicine institutional review board (Protocol no. 00080031) and the National Research Ethics Board, Ministry of Health, Liberia (Protocol NREB-004-16).

RESULTS

Conditions at each study location

Average temperature and humidity levels in Monrovia over the course of the study were 81.6°F and 80.3%, respectively, whereas temperature and humidity levels at the JHH BCU in Baltimore were below 70°F and 50%.

Baseline characteristics of the study population

Thirty-four participants enrolled in Liberia, and 20 participants enrolled in Baltimore (Table 1). All participants completed the study wearing both PPE ensembles. Each participant spent approximately 6–8 hours completing the protocol.

The 2 populations were almost equally split between the males and females. The median age of the participants was 30–39. However, there was a slight difference in the age distribution, with more participants over 50 years of age in the JHH BCU group. Although the BCU participants were split between clinicians and nonclinicians (nonclinicians include trained clinical laboratory staff and paramedics), two-thirds of the Liberia participants were clinicians who cared for patients with EVD during the 2014 outbreak. None of the JHH BCU participants had provided care for patients with EVD during the outbreak. Standard doffing procedures differed between sites. Eighty percent of participants in the BCU reported using a doffing partner as part of their standard doffing procedure, compared with only 32.3% of Liberia participants. The Liberia participants had more experience (79.4%) with the MSF PPE (PPE A) than the BCU participants (26.3%).

Comfort while wearing each PPE ensemble

Participants were asked to undergo a simulated situation that might occur while caring for patients with EVD. Their comfort levels were recorded in both PPE A and PPE B (Table 2). Any indication of discomfort, even minor, was counted as discomfort. The 2 sites were compared independently as indicated above. BCU participants were significantly more comfortable while walking in PPE B compared

Table 1
Basic demographics and PPE experience of the study population

	Liberia	BCU	P value
Sex			.5798
Male	41.2% (14/34)	50% (10/20)	
Female	58.8% (20/34)	50% (10/20)	
Age			.0058*
20–29	0% (0/34)	25% (5/20)	
30–39	53% (18/34)	40% (8/20)	
40–49	29.4% (10/34)	10% (2/20)	
50–59	17.6% (6/34)	15% (3/20)	
60–69	0% (0/34)	10% (2/20)	
Occupation			.0457*
Clinician	73.5% (25/34)	45% (9/20)	
Nonclinician	26.5% (9/34)	55% (11/20)	
Clinician with experience treating EVD patients?			<.0001*
Yes	66.7% (22/33)	0% (0/20)	
No	33.3% (11/33)	100% (20/20)	
Use of partner to doff PPE in actual clinical practice?			.0014*
Yes	32.3% (10/31)	80% (16/20)	
No	67.7% (21/31)	20% (4/20)	
Time (min) spent in PPE continuously according to clinical protocols			.002*
0–30	3.2% (1/31)	6.5% (2/18)	
31–60	48.4% (15/31)	3.2% (1/18)	
61–90	19.4% (6/31)	3.2% (1/18)	
91+	29% (9/31)	45.2% (14/18)	
Experience using PPE A			.0003*
Yes	79.4% (27/34)	26.3% (5/19)	
No	20.6% (7/34)	73.7% (14/19)	

BCU, biocontainment unit; EVD, Ebola virus disease; PPE, personal protective equipment.

A total of 34 participants were eligible for the Liberia site and 20 participants were eligible for the BCU site. The table indicates the percentage of the population with the number/the total number for which an answer was recorded.

*Statistical significance as determined by Fisher's exact, χ^2 , $P < .05$.

with in PPE A (94.7% vs 50%, $P = .0033$). The overall trend was for more comfort in PPE B during all types of movements across both sites.

The doffing process

Participants were asked for feedback on the doffing process. PPE B had novel doffing pull tabs that the majority of participants at both sites felt were intuitive to use. The majority of the participants at both sites also believed that doffing PPE B would be feasible in an ETC. Participants at both sites felt significantly more at risk while doffing PPE A compared with PPE B. In Liberia, where the majority of the participants had worn PPE A while treating patients with EVD, 71.9% reported feeling at risk in PPE A, whereas only 25% reported feeling at risk in PPE B ($P < .0001$). One hundred percent of BCU participants reported feeling at risk in PPE A, whereas 40% felt at risk in PPE B ($P < .0001$) (Table 3). Much of the perceived risk in PPE A revolved around concerns that the face and neck area might become contaminated while removing the coverall. Most concerns about PPE B centered around the possibility that the inner glove would come off with the outer suit and lead to hand contamination. Despite the self-doffing tabs, 20%–25% of participants in both groups

believed they would still need a partner to doff PPE B. Several individuals at both sites were concerned that reaching for the self-doffing tabs without a mirror might lead to contamination.

Time to doff the apron, outer gloves, coverall, and inner gloves were measured for PPE A, and the time to doff the apron, first hand, second hand, and stomping out of PPE were measured for PPE B. BCU participants doffed PPE B almost 2 minutes more quickly than PPE A (4:35 vs 6:45, $P = .0815$). In Liberia, participants doffed PPE A in a shorter amount of time than PPE B (6:41 vs 7:07, $P = .6786$).

PPE preference

At the end of the study, participants were asked questions about their PPE preferences (Table 4).

In all cases and across both sites, participants significantly preferred PPE B for donning, doffing, removal of outer gloves, and the overall experience. Moreover, participants at both sites said they would recommend PPE B for their facility even if the cost was greater (Table 5).

Table 2
Comfort during PPE use

	Liberia			BCU		
	PPE A	PPE B	P value	PPE A	PPE B	P value
Bending over	46.6% (13/28)	53.6% (15/28)	.1203	55.6% (10/18)	95% (19/20)	.1274
Lifting arms	54.5% (18/33)	75.8% (25/33)	.1203	45% (9/20)	75% (15/20)	.1053
Squatting	60.6% (20/33)	70.6% (24/34)	.4469	50% (10/20)	75% (15/20)	.1908
Walking	69.7% (23/33)	78.8% (26/33)	.5743	50% (10/20)	94.7% (18/19)	.0033*

BCU, biocontainment unit; PPE, personal protective equipment.

Participants were asked how comfortable they felt while accomplishing tasks during a simulated care exercise. Table shows the % of participants who felt completely comfortable (no report of even minor discomfort) with the number answering versus the total number of participants who provided an answer.

*Statistical significance as determined by Fisher exact, χ^2 , $P < .05$.

Table 3
PPE doffing

	Liberia	Hopkins BCU
Is it intuitive to pull the tabs of PPE B in the correct direction?		
Yes	87.5% (28/32)	95% (19/20)
Is it feasible to carry out the doffing of PPE B in an ETC?		
Yes	96.8% (30/31)	94.4% (17/18)
Participants who feel at risk doffing specific PPE		
PPE A	71.9% (23/32)	100% (20/20)
PPE B	25% (8/32)	40% (8/20)
P value	<.0001*	<.0001*
Do you feel you need a partner to maneuver out of PPE B?		
Yes	20.7% (6/29)	25% (5/20)
Time to doff		
PPE A	6:41	6:45
PPE B	7:07	4:35
P value	.6786	.0815

BCU, biocontainment unit; ETC, Ebola treatment center; PPE, personal protective equipment.

Participants were asked a series of questions related to the doffing process. A statistical comparison was made on the perceived risk of doffing PPE A or PPE B by Fisher's exact χ^2 . Median time to doff is reported and comparison by time is done using a Mann-Whitney U test.

*Statistical significance ($P < .05$).

Table 4
Overall preferences of participants in all situations tested

Preference	PPE A	PPE B	P value
While donning			
Liberia	0% (0/34)	100% (34/34)	<.0001*
BCU	5.6% (1/17)	94.4% (17/18)	<.0001*
While doffing			
Liberia	0% (0/34)	100% (34/34)	<.0001*
BCU	0% (0/20)	100% (20/20)	<.0001*
While taking off outer gloves			
Liberia	0% (0/31)	100% (31/31)	<.0001*
BCU	38.9% (7/18)	61.1% (11/18)	.372
Overall			
Liberia	0% (0/34)	100% (34/34)	<.0001*
BCU	0% (0/20)	100% (20/20)	<.0001*

BCU, biocontainment unit; PPE, personal protective equipment.

Participants from both sites were asked their preference for PPE A versus PPE B during donning, doffing, taking off outer gloves, and overall. Percentage and number shown only for participants who provided an answer.

*Statistical significance as determined by Fisher's exact, χ^2 , $P < .05$.

Participants were also asked to rank the features of the PPE B with a numerical value from best to worst. The rear entry and exit seam, rear zipper with secured flap and adhesive, and the over-the-shoulder pull-tabs were ranked roughly equally as the best features among the participants from both Liberia and the BCU (Table 5). The finger loops were consistently ranked as the worst feature both in Liberia and the BCU. Several users felt that the finger loops were constricting and made it difficult to get the outer gloves off.

DISCUSSION

This study shows that a novel PPE coverall with unique design features was preferred over traditional MSF PPE in terms of comfort and perception of risk. Participants in Liberia, as well as at a biocontainment unit in the United States, overwhelmingly preferred the novel PPE design and would recommend it for their facility even if it cost more than their current PPE. The novel PPE was preferred during both donning and doffing and took less time to doff than MSF PPE among users who had not previously used either style of PPE. Although the time to

Table 5
Questions about adopting PPE B and feature ranking

	Liberia	BCU
Would you adopt PPE B?		
Yes	97.1% (33/34)	94.4% (17/18)
No	2.9% (1/34)	5.6% (1/18)
P value	<.0001*	<.0001*
Would you recommend PPE B to your facility?		
Yes	97.1% (33/34)	100% (19/19)
No	2.9% (1/34)	0% (0/19)
P value	<.0001*	<.0001*
Do you pay more for PPE B?		
Yes	87.1% (27/31)	100% (18/18)
No	12.9% (4/31)	0% (0/18)
P value	<.0001*	<.0001*
Feature ranking		
Feature 1: Rear entry and exit		
Best feature	28% (5/18)	17% (3/18)
Worst feature	6% (1/18)	0% (0/18)
Feature 2: Rear zipper secured with flap and adhesive		
Best feature	28% (5/18)	6% (1/18)
Worst feature	6% (1/18)	0% (0/18)
Feature 3: Over-the-shoulder doffing pull-tabs		
Best feature	22% (4/18)	61% (11/18)
Worst feature	6% (1/18)	0% (0/18)
Feature 4: Finger loops		
Best feature	6% (1/18)	11% (2/18)
Worst feature	22% (4/18)	28% (5/18)
P value feature comparison		
Feature 1 vs 2	NS	NS
Feature 1 vs 3	NS	.2667
Feature 1 vs 4	.0801	.1667
Feature 2 vs 3	NS	NS
Feature 2 vs 4	.0801	.3750
Feature 3 vs 4	.2063	.0025*

BCU, biocontainment unit; NS, not significant; PPE, personal protective equipment.

Participants were asked about their feelings on adopting PPE B and the cost. Percent and numbers only shown for participants who provided an answer. The P value is a Fisher exact χ^2 comparing yes to no at both sites. Ranking of the features as best or worst. Shown are the percentage and number of participants who gave answers for all. The P values are Fisher exact χ^2 comparing best to worst at each site, and each feature at each site.

*Statistical significance ($P < .05$).

doff a PPE ensemble is not a marker of safety, the fact that the novel PPE ensemble did not take longer to doff than standard PPE suggests that the new ensemble would not place an unreasonable time burden on HCWs. The rear entry and exit seam, the covered zipper, and the over-the-shoulder pull tabs were the most highly rated aspects of the design. The unique finger loops that aid in removing the outer glove were the least highly rated aspect of the design but were more highly rated by providers in Liberia than in the JHH BCU.

This study suggests that features designed to improve the ease of the doffing process are favored by HCWs in the context of highly infectious diseases. The over-the-shoulder tabs in PPE B allow a provider to potentially self-doff the PPE ensemble without having to rely on the assistance of a partner during this critical step. This feature was particularly attractive to providers in Liberia who often use protocols that lack a doffing assistant. The rear entry and covered zipper were also attractive features to both groups. This was possibly owing to the known risk of contamination of the chest area of PPE, even while wearing an outer apron.⁵

There are a number of limitations to this study. There was a difference in clinical experience between the US and Liberian providers in terms of actual clinical care of patients with high-consequence pathogens. Liberian providers were more likely to have provided care for patients with EVD and had more experience with PPE A before the study. This difference in experience probably affected participants' views of the 2 PPE ensembles. However, the fact that Liberian clinicians with experience in providing care for patients with EVD

preferred PPE B suggests that the novel design features were an improvement over existing PPE options.

Differences in heat, fogging, and the amount of time an HCW is able to comfortably remain in PPE may be partly attributed to differences in temperature and humidity between Monrovia and Baltimore. Other factors, such as the availability of human resources at each location, also influence donning and doffing protocols for HCWs. These differences likely affected participants' opinions of the 2 PPE ensembles.

The PPE CBID/Jhpiego PPE ensemble tested in this study included a hood with an integrated respirator. That aspect of the design is still under development. It is unclear whether the use of the integrated hood in the current experiment influenced the overall opinions of HCWs in favor of the CBID/Jhpiego PPE.

Participants at both sites felt safer in PPE B and would recommend its use independent of cost. However, perceptions of risk do not always match objective measures of performance.¹³ Further studies are needed to evaluate whether the risk of contamination is truly lower using PPE B. We are in the process of optimizing a protocol that uses fluorescent microbeads to track simulated infectious particles through a clinical space during HCW activities. This method has been used to test the air-handling and environmental safety features of the JHH BCU and is currently being modified to be able to detect HCW contamination, particularly during the doffing process. This could provide safety data to better understand the potential advantages of PPE B compared with PPE A.¹⁴

PPE A was tested first at both sites. The lack of randomization of PPE order in the study protocol may have introduced unintended biases toward one of the PPE ensembles.

Although most providers across both sites indicated they would pay more for the CBID/Jhpiego PPE, we were unable to conduct specific cost analyses to compare the price difference of standard MSF PPE with the CBID/Jhpiego PPE. After the study was completed, Johns Hopkins University licensed both the coverall and hood PPE design patents to DuPont, a leader in the production of PPE and materials such as Tyvek and Tychem that are routinely used in PPE. DuPont has placed these new PPE designs in their internal product development process. Market and commercialization factors, including improved value and performance of the new design, cost to manufacture, costs associated with the recent increased involvement of the US Food and Drug Administration in regulating PPE, and market demand, all impact the timeline for large-scale availability of these new designs in the market.

CONCLUSIONS

A new PPE coverall designed to improve comfort and ease of the doffing process was preferred over MSF PPE by HCWs in Liberia and in a US BCU. An iterative-spiral health care design process effectively identified problem areas with current PPE and directed the design team to innovative solutions. HCWs felt more comfortable and safer in the new PPE and would recommend its use in their home units, even if it cost more than standard PPE. Further studies are needed to address the efficacy of this design in preventing HCW infection when providing care for patients infected with high consequence pathogens.

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APPENDIX. STEPS FOR DORNING AND DOFFING NEWLY DESIGNED COVERALL AND INTEGRATED HOOD AND MASK

Steps for donning newly designed coverall

- Step 1: Ensure that you have the right size coverall for you. They are available in small (S), medium (M), large (L), extra-large (XL), and double extra-large (XXL).
- Step 2: Put inner examination gloves on both hands.
- Step 3: Unfold the coverall and unzip the rear zipper.
- Step 4: Hold the coverall from the waist line, step into the coverall, and pull it up to the waistline.
- Step 5: Insert arms in the sleeves one by one while sliding fingers into the loops attached to the distal end of the sleeve placing each loop between two adjacent fingers and thumb.

The trained assistant:

- Step 6: Zips the rear zipper up to the neck.
- Step 7: Covers the zipper with the left storm flap.
- Step 8: Removes the cover on the left storm flap to expose the adhesive.
- Step 9: Places the right storm flap over the left flap to ensure it aligns and attaches completely on the left flap.
- Step 10: Adjusts the collar flap as needed.
- Step 11: Removes the cover to expose the adhesive and attaches pull tabs to the upper part of the chest on both sides.

The health care worker:

- Step 12: Puts on the outer long-cuff gloves on both hands.

Steps for doffing coverall

- Step 1: Disinfect outer gloves with 0.5% chlorine solution or ABHR.
- Step 2: Detach the pull tabs and hold one in each hand behind the neck.
- Step 3: Slowly but firmly pull the tabs away from the body by extending the forearms to begin unzipping.
- Step 4: Continue to pull the tabs laterally and forward by bringing both arms in the front as you allow the coverall to slide off the shoulders.
- Step 5: Release the tab from your left hand.
- Step 6: Hold coverall at the elbow of the right arm and gently pull the right arm out of the sleeve and the outer gloves.
- Step 7: Use the right hand with inner glove to hold on the inner side of the coverall and to pull the left arm out of the sleeve and the outer glove.
- Step 8: Let the coverall drop on the floor. Remove legs one by one by fixing the gown on the floor with the other foot.
- Step 9: Stomp on the coverall to doff and step out.
- Step 10: Gently fold the coverall and drop it in the contaminated waste container.

Steps for donning integrated hood and mask

- Step 1: Hold the hood with the back of the hood facing you.
- Step 2: Turn the back side of the hood upside down so that the mask is visible.
- Step 3: Hold the mask and fit it over the nose ensuring the upper side of the mask covers the bridge of the nose.
- Step 4: Pull the rubber band and pull it over to the head to secure it.
- Step 5: Pull the lower flap of the mask under the chin to ensure that it covers the mouth and nose completely.
- Step 6: Adjust the rubber band over the head so that it stays in the front of the ears and rests on the head.
- Step 7: Using the fingers of both hands, adjust the upper part of the mask to the bridge of the nose to ensure a good fit and seal.
- Step 8: Breathe in and out to check that air is not leaking and mask fits well on the nose and the chin.
- Step 9: Pull the hood over the head to completely cover the face and the head.
- Step 10: Adjust the mask and the hood as needed.
- Step 11: With both hands, hold the ties attached to the hood on the back.
- Step 12: Cross over the ties so that the tie on the right is on the left-hand side and vice versa. This will result in the flaps on the hood completely overlapping each other to fully cover the back.
- Step 13: Bring the ties in the front of the body.
- Step 14: Tie knots to fully secure the ties underneath the shroud of the hood.

Steps for doffing integrated hood and mask

- Step 1: Disinfect outer gloves with 0.5% chlorine solution or ABHR.
- Step 2: Slide your hands underneath the front of the shroud and untie the knots to release the ties and let them drop on the back.
- Step 3: Move your hands behind to locate the ties and hold left tie in the left hand and right tie in the right hand (trained assistant may guide the health care workers in locating the ties).
- Step 4: Hold the ties from behind and raise your hands above the head.
- Step 5: Hold both ties in your nondominant hand.
- Step 6: Holding ties in nondominant hand, with your dominant hand locate the raised area on the rubber band underneath the hood.

(continued)

(Continued)

Steps for donning newly designed coverall

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- Step 7: Bend forward with head below the shoulder level.
 Step 8: Remove the hood by pulling the rubber band of the mask away from the head so that both hood and the mask come out as a single piece.
 Step 9: Let the hood and mask fall on the floor.
 Step 10: Immediately after removing the hood, disinfect the inner gloves with 0.5% chlorine solution or ABHR.
 Step 11: Gently lift the hood off the floor and dispose of it in a contaminated waste container.
 Step 12: Disinfect the inner gloves with 0.5% chlorine solution or ABHR.
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ABHR, alcohol-based hand rub.

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