

## Design Strategies To Improve Healthcare Worker Safety In Doffing Units: An Evidence Based Study In Bio secure Mobile Doffing Unit

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### ABSTRACT

**Back ground:** Removal of personal protective equipment (PPE),” Doffing” is identified as a high-risk activity for self-contamination to health care workers (HCWs). The environmental design of doffing area can impact the contamination risk to HCWs. However, the data regarding the design of the doffing area for the safety of HCWs are limited. With the wide spread of this pandemic, the need for treatment centre is rapidly increasing day by day, and setting up a doffing area is furthermore challenging.

**Objective:** To assess the impact and effectiveness of design changes in the Biosecure mobile doffing unit on improving the HCW performance and safety.

**Methodology:** The study was done by a mixed-method approach – evidence based microbiological analysis to assess the doffing environmental hygiene and user feedback collection by questionnaire

**Results:** Environmental designs in the mobile doffing units were found to impact HCW safety. The four disinfection methods inside the unit- Ultraviolet-C (UVC), high efficiency particulate air

(HEPA) filter, mist sanitization and pedal operated hand sanitization kept the doffing environment sterile and enhanced safety to HCWs while doffing. **Conclusions:** Mobile doffing unit is a replacement for conventional fixed doffing stations in hospitals, where new wards need to be set up on the go, because of the advantages of mobility, less cost, ease of use, touch free entry and different disinfection methods.

**KEYWORDS:** Doffing; Personal Protective Equipment; Health Care Worker; Design Modification; High Efficiency Particulate Air Filter; Ultraviolet C; Fog Mist Sanitization

### INTRODUCTION

The COVID-19 pandemic is considered to be one of the most globally impacted health calamities of the century. In December 2019, a new infectious respiratory disease emerged in Wuhan, Hubei province, China and was named by WHO as COVID-19. The causative agent is a novel corona virus known as severe acute respiratory syndrome corona virus 2 (SARS-CoV-2). The pandemic seems to have affected the entire globe both physically and finan-

cially. With the emergence of mutant strains, it continues to be challenging for entire population.

HCWs are the ones who encounter the infected people in the first instance and to secure them PPE is used. PPE kit involves masks, gloves, gown, feet covers, face shield, head cap etc. Donning is the process of wearing all these gears before entering a patient zone. Similarly, doffing is the process of removing these gears under proper sanitization in a secure and enclosed environment and disposing them to avoid any spread of the virus.

## DESIGN THINKING

Conventional methods for doffing involve preparing a secure room for this procedure and performing the steps under supervision. But with the wide spread of this epidemic, the need for treatment centres is rapidly increasing day by day, and setting up a doffing area is furthermore challenging [1]. The time to setup a doffing area is more, as most of the times it involves civil work to split an existing room. Thus, comes the idea of an enclosed area that can be setup easily and can be placed anywhere in no time.

Bio secure mobile doffing unit is a replacement of these conventional fixed doffing stations in hospitals, where new wards need to be set up on the go. These units have the advantages of mobility, less cost, ease of use, touch free entry and can be disinfected very fast with a higher disinfection rate than a fixed doffing station.

The initial design considerations were a cage structure, which should be mobile in nature, be enclosed and sterilized continuously, has secure PPE waste disposal, has touch free access and has sterilization inventory in the unit following the basic doffing procedure mandates. A prototype was developed with these considerations in 2-week time. That was a great success and met all the basic design considerations. But there was still room to improvise. Changes were made to the design to include fogging machine, exhaust with HEPA filter for ventilation, auto door closers and easy disposal of PPE waste.

## SALIENT FEATURES

The salient features of the unit included mobility – unit having wheels with brakes, split design, pedal operated doors with auto closure, pedal operated sanitizer dispensers, sensor operated UVC, exhaust fan ventilation with HEPA filter, portable fogging machine for sanitizing, full size mirror for self-review, demarcation zone and PPE kit disposal duct.

### Detailed Description

There are lots of limitations in setting up doffing stations in hospitals, which were not designed for COVID care. Hence, we developed this idea of having a mobile platform for doffing purpose which is known as Bio secure mobile doffing unit. We have developed four steps for disinfection for the unit and the HCW- UVC, HEPA filter, fog mist sanitizer and pedal operated hand sanitizers.

HCW will enter the unit using pedal operated door. The door will close automatically once the person enters. They can sanitize hands using the foot-operated sanitizer. The doffing process can be started after that. A full size mirror is provided, so that the worker can do doffing without any help. The PPE kit can be disposed into the duct, which is provided on the side of the unit. The waste material from the duct is collected in a bucket and removed later. Once the PPE kit is removed, the worker can sanitize hands again and use the exit door to come out of the unit.

## DESIGN

### Structure

The unit is made up of a split design, to provide better mobility. These two sections will be bolted together in the ward itself and can be dismantled easily (Figure 1).



**Figure 1:** Mobile doffing Unit: (a) Exterior view with pedal operated entry door, PPE disposal unit and fogging machine (b) Interior view depicting the line of demarcation between clean and dirty zone, long mirror and automated hand sanitizers.

### Panels

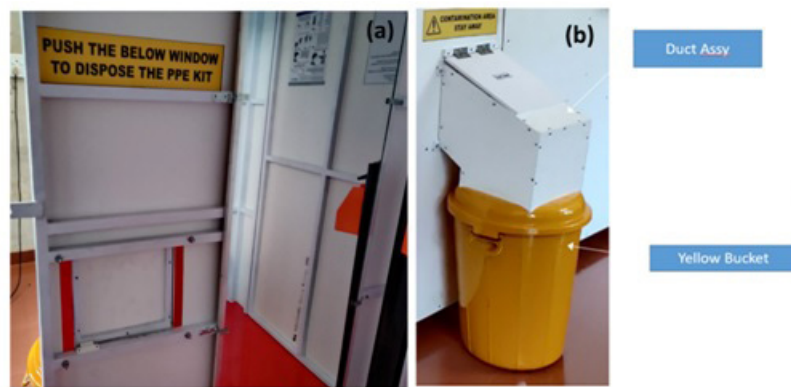
The base, side and top panels are made up of Green wood having required strength and good corrosion properties.

### Doors

There are two doors, one for entry, and another for exit. The door is made up of GI bars panelled with Green wood. The entry door will be opened using a foot pedal. Once the HCW enters the unit, the door will close automatically with the help of auto door closures. The exit door can be pushed opened from inside. It will be closed automatically with the help of auto door closures.

### Kit Disposal Unit

The waste disposal unit consists of duct assembly and yellow bucket to collect PPE kits. HCW disposes off the PPE kit through the waste disposal unit door inside the unit. The PPE kit is collected in the yellow bucket through the duct assembly (Figure 2). The kits from the bucket are removed later safely. This unit can be dismantled and assembled easily to provide better mobility.



**Figure 2:** PPE kit disposal unit: (a) PPE disposal window inside the unit (b) detachable duct assembly and yellow bucket outside the unit.

### Mirror

A full size mirror is provided in the unit which helps to inspect oneself while doffing.

### Hand Sanitizers

Two hand sanitizing stands with sanitizers are provided near the entry and exit doors. The HCW can use this during the entire PPE kit removal process.

### UVC

UVC is used to sanitize the unit. Its sensor controlled light will be

on, once the worker enters, and will be turned off automatically after few minutes of the departure of the worker. It is placed near the exit door, so that the direct exposure to the health worker is minimized.

### HEPA Filter

HEPA filter is used in line with the exhaust fan. It will filter approximately 99.9% of the virus, which makes sure that only clean air will come out of the unit. This unit is placed near the exit door (Figure 3)



**Figure 3:** UVC and HEPA filter are two gadgets inside the unit for disinfection. Both are placed in the clean zone of the unit near the exit door.

### Fog sanitizer

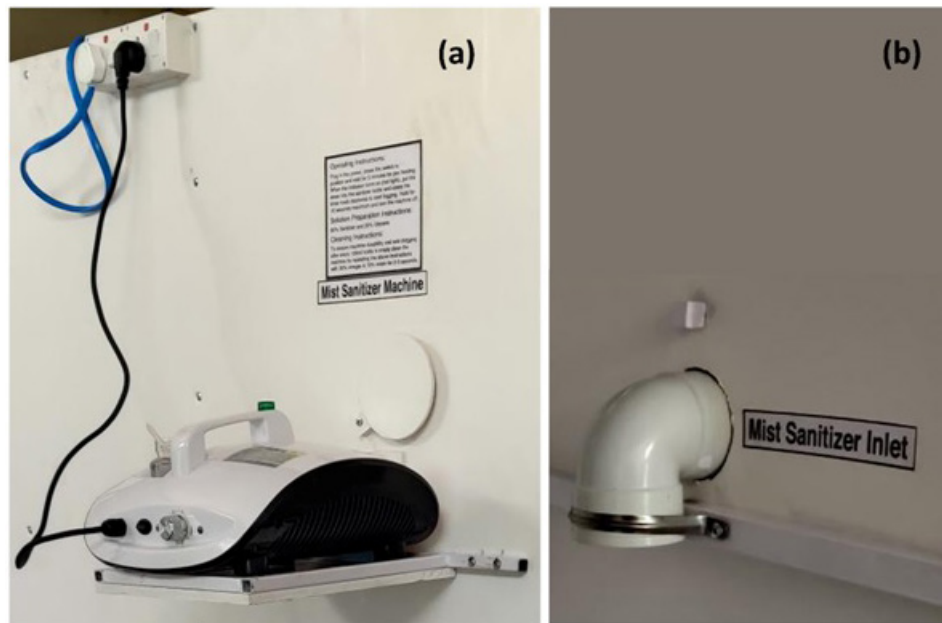
It consists of a portable fogging machine, which is placed outside the unit and a mist sanitizer inlet (Figure 4). This spray a mixture of 70% alcohol and glycerine in a mist form, so that all difficult to clean areas in the unit are sterilised at respective times. The portable fogging machine and stand can be dismantled and assembled for better mobility.

Fig: 4 (a)detachable fogging machine outside the doffing unit (b) mist sanitizer inlet inside the unit.

Recent studies suggest that environmental design of the doffing

area impact the contamination risk of HCWs during doffing process and increases Health Care Associated Infections(HCAI). Also studies related to the size, design and layout for an ideal doffing room is limited.

Objective of our study was to explore the impact of design changes in the Bio secure mobile doffing units in providing safety to HCWs compared to the conventional doffing area. The effects and proper functioning of the gadgets meant for disinfection inside the doffing units were also assessed.



**Figure 4:** (a) detachable fogging machine outside the doffing unit (b) mist sanitizer inlet inside the unit.

## METHODOLOGY

The impact of environmental design in the Bio secure mobile doffing unit was tested by mixed method approach- 1) evidence based microbiological analysis to assess the hygiene in the doffing unit and 2) a questionnaire method for the evaluation of the concept, facility and design of these units by users.

### Microbiological Assessment

Environmental hygiene in these doffing units was assessed by taking surveillance samples by air sampling and surface sampling method. Air sampling was done by settle plate method. Surface sampling was done by taking samples from high touch area using sterile cotton swab moistened in liquid media. These swabs were inoculated onto blood agar and Mac Conkey agar.

Both air sampling plates and inoculated culture plates were incubated for 48 hours. Assessment was done based on colony count in the air sampling plates and from the growth obtained in the inoculated plates of surface samples. Since contamination by viruses in the environment cannot be assessed directly by this method and by using these culture media, presence of bacteria and fungus in the doffing environment was used as a method of indirect assessment for presence of virus.

### Performance Assessment

Questionnaire responses were collected to elicit feedback from the users. The questionnaire contained questions and information regarding various design features in the Bio secure units. Participants had to follow their own institutional doffing protocol within the constraints of the doffing unit. At the end doffing procedure, participants had to complete a questionnaire in the google. docs form.

User evaluation form on the concept, facility and design of Bio Secure Mobile Doffing Unit

Is the pedal operated door entry easy to use? Yes/No

Is the doffing space inside the unit adequate? Yes/No

Is the demarcation zone between Clean and Dirty area useful? Yes/No

Is the pedal operated sanitizing dispensers positioned conveniently? Yes/No

Is the automated ABHR dispensing system working properly? Yes/No

Is the sensor and UV light working properly? Yes/No

Is the biomedical waste disposal outlet easily accessible and easy to use? Yes/No

Does the position of mirror help in avoiding contamination and gives confidence while doffing? Yes/No

Does the long mirror provided act as a virtual buddy and help in self inspecting during the process of doffing? Yes/No

Is general cleanliness inside the doffing unit adequate? Yes/No

Is the waste disposing system outside the doffing unit useful? Yes/No

Is the waste being disposed from bin at timely intervals Yes/ No

## RESULTS

The doffing environmental hygiene was assessed by taking surveillance samples with and without functioning the gadgets meant for disinfection. Assessment was done based on the growth obtained in culture media.

Assessment of environmental hygiene



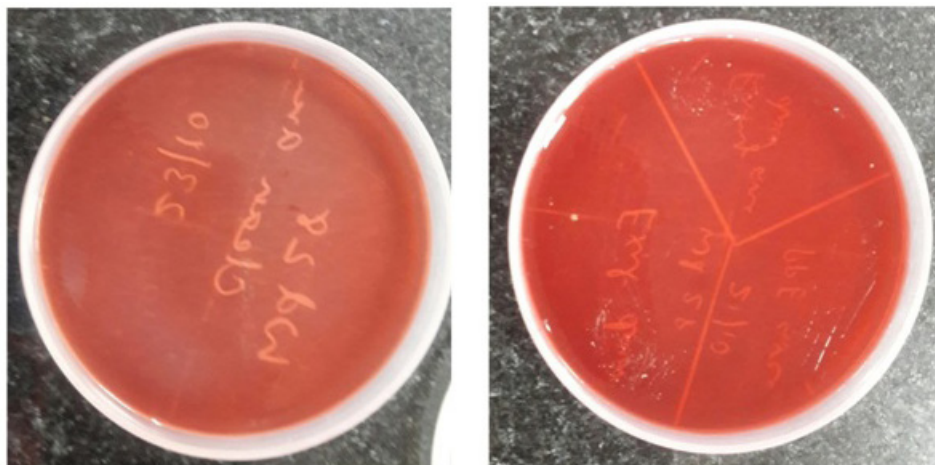
Environmental samples were taken from three Bio secure units at frequent intervals. Both air sampling and surface sampling, taken from these Bio secure units showed no growth on proper functioning of all the three gadgets –UVC, HEPA filter and fog mist sanitizer (Figure 5). The doffing units were sterile.

The environmental samples taken from Biosecure units without working of these gadgets showed growth of pathogenic microor-

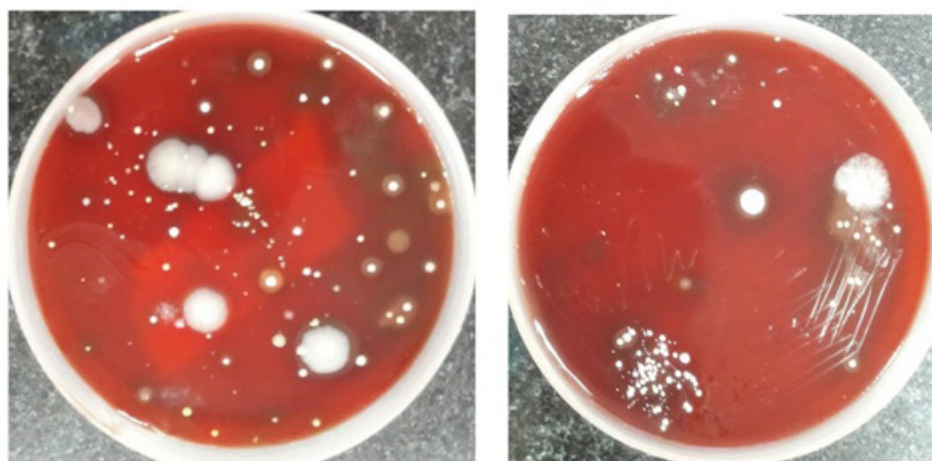
ganisms including fungus (Figure 6).

In addition to this, samples were taken from conventional doffing area in the wards which also yielded mixed bacterial growth.

From these findings, we can conclude that the risk of contamination to the HCW and chance of getting nosocomial infection while doffing will be less in mobile doffing units.



**Figure 5:** Culture plates showing no growth indicating the proper functioning of gadgets for disinfection.



**Figure 6:** Culture plates showing growth of microorganisms without functioning of the gadgets.

### Assessment of Feedback from Participants

The responses obtained by the users of the doffing unit were analyzed. 91.7% responders were nursing staff, and 8.3% were doctors.

90.9% of the responders were satisfied with the pedal operated entry door and had the opinion of easy use, while 9.1% disagreed. Regarding the doffing space 41.7% had the opinion of adequate space inside the doffing unit, while 58.3% had the opinion of inadequate space.

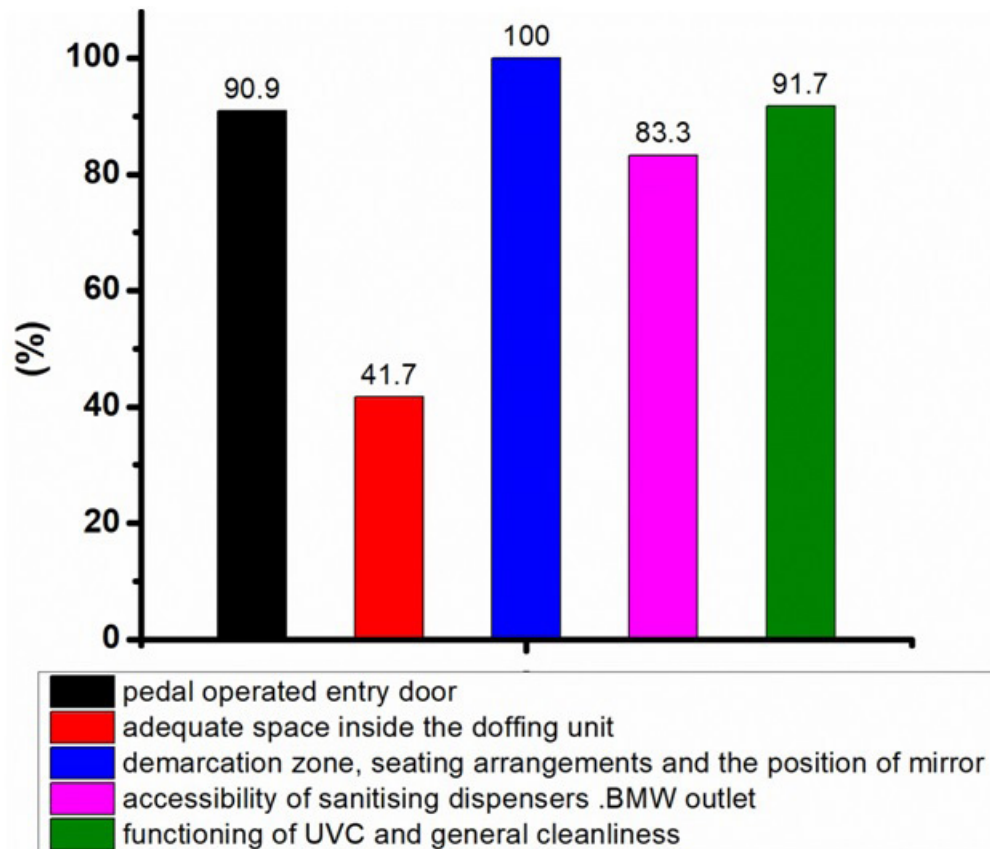
All the users responded were in favor of the demarcation zone between clean and dirt area, the position of the mirror and the seating arrangements with an opinion that the mirror helps in avoiding

contamination and gives confidence while doffing. Moreover, the mirror act as a virtual buddy and help in self-inspecting during doffing process.

83.3% users opined that the pedal operated sanitizing dispensers positioned conveniently, easily accessible and worked properly. They also felt that the PPE disposal outlet inside the doffing unit is easily accessible and comfortable.

Regarding the waste disposing system outside the doffing unit, disposal of waste from bin at timely intervals, general cleanliness inside the doffing unit and the proper functioning of sensor and UVC, 91.7% had favorable opinion and 8.3% disagreed.

The responses on the questionnaire from the respondents were analyzed and presented in the bar chart (Figure 7).



**Figure 7:** Percentage of satisfaction from the user response.

## DISCUSSION

We demonstrated that design modifications in doffing units have measurable impact on HCW contamination risk. The design strategies like pedal operated entry door, demarcation zone, long mirror, automated hand sanitizer and various disinfection methods provides the unit safe and comfortable to HCWs.

Effective use of PPE is an important aspect of infection prevention and control (IPC) in healthcare setting. PPE effectiveness is also influenced by how HCWs don and doff PPE. Risk of self-contamination while doffing PPE, rates as high as 46%–90% [2, 3]. Self-contamination is a frequent problem associated with incorrect doffing performance and likely contributes to the spread of viral infections [4].

Laxmi Tej et al in their study noted that the layout, space and design of environment for donning and doffing improve HCW safety (1). Various researchers in their study noted doffing as a high-risk activity for nosocomial infection by the exposure to contaminated body fluids on the outside of used PPEs [5, 6].

The study conducted by Maria F Wong et al in 2019 observed that the environmental design of the doffing area in a bio containment unit can have a measurable impact HCW safety during doffing performance [7]. They also emphasized the importance of the design and layout of doffing area in HCW safety.

The data regarding the design and layout for an ideal doffing area are limited. Some studies have recommended 16m<sup>2</sup> as the needed space for doffing area [1], but mobile doffing area can be designed at much less area. The limitation is that only one person can do doffing at a time. The presence of HEPA filter and conveniently positioned exhaust fan helps to ensure unidirectional air flow and adequate air exchange within the unit.

In the study conducted by Jennifer R Du Bose et al in 2018, they observed that if there were no clear demarcation zones between clean and dirty area, HCWs would inadvertently step back into the contaminated area after doffing [8]. Another study conducted by Tracey et al. in 2016 highlights the use of high-contrast coloring in doffing area which made it easier for the users to move in a unidirectional flow inside doffing area without looking at the floor [9].

Herlihey TA et al in 2017 in their study, mentioned the importance of having a mirror for self-inspection while doffing [10]. The mirror allows the HCWs in self inspection easily without having to turn or bend. In some doffing areas mirrors were placed not at eye level, so there will be more chance of self-contamination [4, 7, 8]. The long mirror provided in the mobile doffing unit act as a virtual buddy and help in self inspecting during the process of doffing.

Design changes like high-contrast coloring between clean and dirty area, accessible position of hand sanitizer and provision of

mirrors to detect contamination were tested by Tracey et al in 2017 and reported as very effective for HCWs in their study (10).

UVC radiation has been found to be very effective in destroying Corona virus. UVC is dangerous to humans and can cause allergic reactions such as photo dermatitis and conjunctivitis. So direct exposure to skin and eyes should be avoided. Appropriate dose of UVGI exposition effectively decontaminate viral agents [11]. UVC devices can reduce healthcare-associated infections by decreasing environmental contamination [12].

HEPA filters have been discussed as an adjunctive means for decontamination of SARS-CoV-2 aerosols in health care settings [13]. This confers filtration capacity which is effective to 99.97% of 0.1 micron particles. Most air purifiers employ HEPA, which is efficient to remove such virus-laden aerosols [14]. Although research on HEPA filtration of SARS-CoV-2 is not yet published, their efficacy and containment of diseases of similar particle size is well documented [15].

Our study highlights the importance of the doffing environment in a healthcare setting and the design strategies in the mobile doffing unit. The split design of the doffing unit provides better mobility and can be transported to any patient care area through elevator/ramp. The entry door is pedal operated and touch free, so there is less chance of contamination of the door by the HCWs. The other features in the doffing units like seating arrangements in the clean and dirty area and the doffing steps pasted inside the unit helps in proper doffing.

The disinfection methods like UVC, HEPA filter, mist sanitizer which are the unique features in this mobile doffing unit makes the unit sterile and reduces HCAI. The automated hand sanitizer and the mirror are the other features which make the doffing units' user friendly.

The mobile doffing unit with the unique features emphasize the importance of the environmental design of the doffing space as a strategy for enhancing HCW safety.

## CONCLUSIONS

Our healthcare workers, the frontlines of battling the COVID-19 are at a greater risk of infection than the general population due to contact with patient's contaminated body fluids. The contaminated PPE is an important source of infection and can cause self-infection to the HCWs.

The doffing environment also has an important role in preventing HCAI in a healthcare setting. The design and layout of our mobile doffing units improved doffing performance of HCWs. Disinfection methods like UVC, HEPA filter, mist sanitization and pedal operated hand sanitizers inside the mobile doffing units impart HCW safety. Mobile doffing unit is a replacement of conventional fixed doffing stations in hospitals, where new wards need to be set

up on the go, because of the advantages of mobility, less cost, ease of use, touch free entry and different disinfection methods.

Our findings emphasize the importance of the design strategies of the doffing space for enhancing HCW safety. Simple and low-cost environmental design modifications can improve HCW safety. The HCW performance can be improved and the risk for self-contamination can be reduced by following the PPE protocol and providing safe doffing area.

## REFERENCES

1. Wundavalli LT, Singh S, Singh AS, Satpathy S. How to rapidly design and operationalise PPE donning and doffing areas for a COVID-19 care facility: quality improvement initiative. *BMJ Open Qual.* Sept. 2020; 9: e001022
2. Baloh J, Reisinger HS, Dukes K, da Silva JP, Salehi HP, Ward M, et al. Healthcare Workers' Strategies for Doffing Personal Protective Equipment. *Clin Infect Dis.* 2019; 69: S192-8.
3. Osei-Bonsu K, Masroor N, Cooper K. Alternative doffing strategies of personal protective equipment to prevent self-contamination in the health care setting. *Am J Infect Control.* 2019; 47: 534-9.
4. Barycka K, Torlinski T, Filipiak KJ, Jaguszewski M. Risk of self-contamination among healthcare workers in the COVID-19 pandemic. *Am J Emerg Med.* 2021; 46: 751-2.
5. Casanova LM, Teal LJ, Sickbert-Bennett EE, Anderson DJ, Sexton DJ, Rutala WA, et al. Assessment of self-contamination during removal of personal protective equipment for Ebola patient care. *Infect Control Hosp Epidemiol.* 2016; 37: 1156-61.
6. Tomas ME, Kundrapu S, Thota P, Venkata C K, Sunkesula VC, Cadnum JL, et al. Contamination of health care personnel during removal of personal protective equipment. *JAMA Intern Med.* 2015; 175: 1904-10.
7. Wong MF, Matic Z, Matic Z, Zimring CM, Mumma JM, Kraft CS, et al. Design strategies for biocontainment units to reduce risk during doffing of high-level personal protective equipment. *Clin Infect Dis.* 2019; 69: S241-7.
8. DuBose JR, Matic Z, Sala MFW, Mumma JM, Casanova LM, Erukunakpor K, et al. Design strategies to improve healthcare worker safety in biocontainment units: learning from Ebola preparedness. *Infect Control Hosp Epidemiol.* 2018; 39: 961-7.
9. Herlihey TA, Gelmi S, Flewwelling CJ, Hall TN, Bañez C, Morita PP, et al. Personal protective equipment for infectious disease preparedness: A human factors evaluation. *Infect Control Hosp Epidemiol.* 2016; 37: 1022-8.
10. Herlihey TA, Gelmi S, Cafazzo JA, Hall TNT. The impact of environmental design on doffing personal protective equipment in a healthcare environment: a formative human factors trial. *J. Infect Control Hosp Epidemiol.* 2017; 38: 712-7
11. Yang H, Hu J, Li P, Zhang C. Ultraviolet germicidal irradiation for filtering face piece respirators disinfection to facilitate reuse during

- COVID-19 pandemic: A review. Elsevier public health emergency collection 2020; 31: 101943.
12. Boyce JM, Donskey CJ. Understanding ultraviolet light surface decontamination in hospital rooms: A primer. *Infect Control Hosp Epidemiol.* 2019; 40:1030-5.
  13. Christopherson DA, Yao WC, Lu M, Vijayakumar R, Sedaghat AR. Efficiency Particulate Air Filters in the Era of COVID-19: Function and Efficacy. *Otolaryngol Head Neck Surg.* 2020; 163: 1153-5.
  14. Zhao B, Liu Y, and Che C. Air purifiers: A supplementary measure to remove airborne SARS-CoV-2. *Build Environ.* 2020; 177: 106918.
  15. Yeo S, Hosein I, McGregor-Davies L. Use of HEPA filters to reduce the risk of nosocomial spread of SARS-CoV-2 via operating theatre ventilation systems. *Br J Anaesth.* 2020; 124: e361-3.