BMJ Open Quality

How to rapidly design and operationalise PPE donning and doffing areas for a COVID-19 care facility: quality improvement initiative

LaxmiTej Wundavalli, Sheetal Singh, Angel Rajan Singh, Sidhartha Satpathy

To cite: Wundavalli L, Singh S, Singh AR, *et al*. How to rapidly design and operationalise PPE donning and doffing areas for a COVID-19 care facility: quality improvement initiative. *BMJ Open Quality* 2020;**9**:e001022. doi:10.1136/bmjoq-2020-001022

Received 17 May 2020
Revised 27 July 2020
Accepted 3 September 2020

Hospital Administration, All India Institute of Medical Sciences, New Delhi, India

Correspondence to
Dr LaxmiTej Wundavalli;
TEJ.WUNDAVALLI@GMAIL.COM

ABSTRACT

Introduction Effective implementation of standard precautions specific to COVID-19 is a challenge for hospitals within the existing constraints of time and resources.

Aim To rapidly design and operationalise personal protective equipment (PPE) donning and doffing areas required for a COVID-19 care facility.

Methods Literature review was done to identify all issues pertaining to donning and doffing in terms of Donabedian's structure, process and outcome. Training on donning and doffing was given to hospital staff. Donning and doffing mock drills were held. 5S was used as a tool to set up donning and doffing areas. Instances of donning and doffing were observed for protocol deviations and errors. Plan–do–study–act cycles were conducted every alternate day for 4 weeks. The initiative was reported using Standards for QUality Improvement Reporting Excellence (SQUIRE) guidelines.

Results Best practices in donning and doffing were described. Our study recommends a minimum area of 16 m^2 each for donning and doffing rooms. Verbally assisted doffing was found most useful than visual prompts.

Discussion Challenges included sustaining the structure and process of donning and doffing, varied supplies of PPE which altered sequencing of donning and/or doffing, and training non-healthcare workers such as plumbers, electricians and drivers who were required during emergencies in the facility.

Conclusion Our study used evidence-based literature and quality improvement (QI) tools to design and operationalise donning and doffing areas with focus on people, task and environment. Our QI will enable healthcare facilities to rapidly prototype donning and doffing areas in a systematic way.

INTRODUCTION

Personal protective equipment (PPE) use in healthcare involves three phases: donning, while providing patient care, and doffing. Issues during any of these phases can lead to a risk of contamination to the healthcare worker (HCW).[1] Incorrect technique or sequence in donning can expose HCWs during patient care or sets HCW up for a doffing failure.[2] Contamination of HCWs can occur during patient care if PPE is damaged, has design flaws or if HCWs circumvent protection. Risks of contamination during doffing can be due to an incorrect removal technique, improper handling and disposal of PPE, or by damaging PPE to expose HCWs.[1–6]

HCWs endure extreme heat, long periods of standing during patient care and then remove PPE, which requires patience, attention and some unusual movements. Doffing is a physically rigorous task that demands flexibility, balance and constant vigilance.[7] It is a high-risk process[8] that requires a structured procedure and a designated area for removal to ensure protection.[9] However, deviations from recommended doffing protocol are common with self-contamination rates ranging from 13% to 90%.[1–6] Quantitatively, the amount of self-contamination that is clinically meaningful to transmit SARS-CoV-2 during doffing is not yet known. However, SARS-CoV-2 contamination of common objects in the intensive care unit (ICU) and wards, virus aerosolisation in a confined space or spread from asymptomatic infected persons is documented, implying a potentially high infection risk for medical staff and other close contacts even though the amount of viable virus could not be determined.[10 11] Comparatively, despite wearing PPE, 1 in 10 HCWs contracted Ebola during the epidemic.[12–14] Routine breaches in PPE use do not generally result in highly visible disease outbreaks but may contribute to ongoing transmission of nosocomial infection.[4]

Studies describing the layout and design for doffing rooms specific to *Clostridium difficile* and Ebola virus have established that the space and design of built environment for donning and doffing improves HCW safety, influences compliance and has a measurable impact on HCW contamination risk while doffing PPE.[15–18] The coronavirus is not transmitted in the same way and it is not clear if these recommendations translate to

COVID-19. Also, literature is limited on the ideal size for a donning and doffing room and managerial issues of donning and doffing areas.

The aim of our quality improvement (QI) initiative was to rapidly set up PPE donning and doffing areas in a hospital. The objectives were to define the structure (size, layout and design) of an ideal donning and doffing room, identify the process issues pertaining to donning and doffing and take systemic measures to improve the same.

METHODS

The initiative was undertaken at an acute cancer hospital that was converted into a COVID-19 care facility with 400 isolation rooms, 400 beds in wards and 25 beds in ICU. Care was provided to more than 2358 patients for 12 weeks out of which more than 90% had mild to moderate symptoms. A rapid QI event was conducted for 6 weeks. The team comprised hospital administrators, infection preventionists, and supervisors of nursing assistants and environmental service personnel. Inputs were taken from infectious disease specialists as well as the apprehensions, suggestions, comments and feedback of resident doctors throughout.

Our initial literature review identified all issues pertaining to donning and doffing in terms of Donabedian's structure, process and outcome.[19] This was used as a tool to strategise planning and training. Training of trainers was done who later trained HCWs in small groups every day. Physical distancing was maintained between participants during group trainings. Initial training in PPE was done with a commercial PPE ensemble that comprised an impermeable surgical gown, a hood cap, a pair of goggles and a pair each of gloves, arm guards and knee-length impermeable leggings. Ankle-length shoe covers, another pair of gloves, one face shield and one N95 respirator were added separately to complete the full-body PPE. The hospital provided surgical scrubs and slippers to HCWs before donning PPE. Personal clothing was not advised.

The tool, 5S,[20] was used to set up and sustain the structure and process of donning and doffing areas. This tool addresses planning in a structured way: sort, set in order, shine, standardise and sustain. Plan–do–study–act (PDSA) cycles were done to further improvise the structure and process of the areas. The PDSA is a cycle of planning goals and measuring progress during implementation, studying results through careful analysis, and enacting needed changes rapidly to ensure ongoing improvement and assess impact.[21]

RESULTS

Based on literature review, we identified the best practices related to donning and doffing (box 1).

We recommend an area of 16 m^2 each for donning and doffing areas (figure 1). This was calculated based on the best practices which, inter alia, included that there should be space to permit a wide range of movements of the HCW without restricting movement or causing to bump into obstacles. The measurements of range of movements of individuals ranging in height from 152 to 189 cm were calculated. Space required for each step of doffing was

Box 1 Best practices related to donning and doffing[3 15 16 28–31]

- Dedicated room each for donning and doffing.
- The doffing area has a unidirectional flow from contaminated to cleaner areas to the outside in a continuous forward motion.
- The floor demarcation indicates the contaminated areas and clean areas.
- Designated location of key items such as the trash can and chemical mat.
- The size of the doffing area should ensure that all items are always within arm's reach of the healthcare worker (HCW).
- Placing mirrors to assist during shoe cover removal, improve posture and enable self-inspection.
- The HCW is adequately trained regarding proper location and orientation when doffing.
- The HCW is acquainted with available personal protective equipment in advance before donning in practice.
- Defined space to reduce risky behaviours among HCWs.
- Presence of large observational windows to observe the doffing personnel.
- Ensuring good visual and voice contact between the doffing personnel and the observer.
- Minimum 10 air changes per hour for airborne infectious isolation room for doffing.
- The HCW should be able to extend the arms, bend at the wrist and go through a range of motions sufficient for patient care delivery while all remaining correctly covered.
- The height and width of the sink must be at a good working level of HCWs to prevent self-contamination during handwashing.
- Visual cues to enhance provider safety.
- The height of the alcohol-based hand rub dispenser should be mounted at a height of 106–114 cm from the floor.

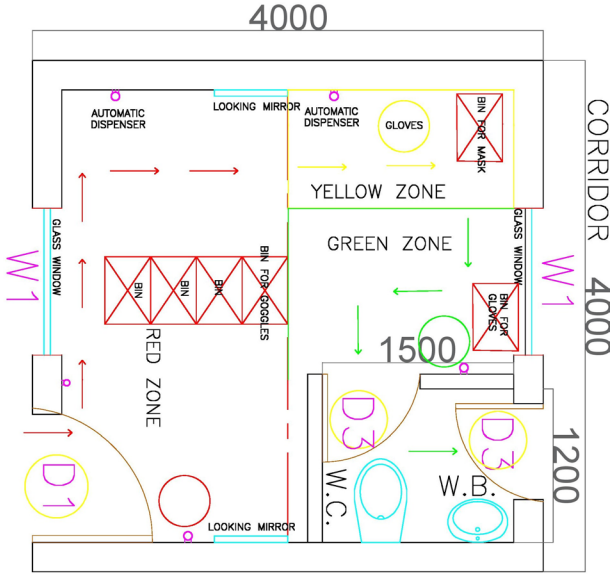

Figure 1 Size, layout and design of the doffing room.

Table 1 Supplies required to set up a donning and doffing area

Sn	Item	Purpose
1	Gloves (assorted sizes)	To don in the donning room and to don before removing face mask in the doffing room
2	Alcohol swabs (cotton and spirit)	To minimise use of alcohol-based hand rubs wherever required, such as cleaning of upper surface of shoes (if not wearing slippers)
3	Hands free ABHR delivery system	For hand hygiene between each doffing step
4	Sodium hypochlorite solution (undiluted)	For disinfection of the room after fresh dilution every time.
5	Biomedical waste bags/liners	To line the biomedical waste bins
6	Tape and scissors	To cover gaps between mask and face if required
7	Marker pens	To label buckets and to prevent mix-up or realignment of reusable PPE and waste bins during cleaning by housekeeping staff
8	Biomedical waste bin, 1	To discard doffed PPE except goggles, face shields, N95 masks and coveralls
9	Biomedical waste bin, 1 (size should be large; otherwise, it gets full quickly and cannot accommodate more PPE)	To discard coveralls that shall be sent for disinfection
10	Buckets, 2	To discard goggles/face shields to be reused after disinfection To discard N95 masks to be reused after disinfection
11	Full length mirrors, 2	To enable viewing of any visible soiling of PPE
12	Graduated mugs	To calculate quantities of sodium hypochlorite needed
13	Graduated buckets	To calculate water required and prepare the final diluted solutions of sodium hypochlorite for placing used goggles and face shields
14	Chairs or stools,* 2 (designated as dirty and clean each)	To sit and remove shoe covers
15	Furniture such as stools/table	To place PPE in donning†
16	Bin‡	To discard worn linen (surgical scrubs) after undressing and before taking shower in the bathroom
17	Mops	To disinfect the surfaces such as floors
18	Multiple small spray bottles filled with freshly prepared sodium hypochlorite or wipes	To spray and disinfect high-touch surfaces in the doffing room
19	Clean towels	Items required during shower and postshower
20	Clean surgical scrubs of different sizes	
21	Individualised toiletries such as soaps and shampoos	
22	Clean slippers: multiple pairs	
23	Sodium hypochlorite-filled damp trays	To be placed at the exit of the doffing room on the floor for HCW to walk through this before walking into clean non-COVID areas
24	Lockers	To store items such as towels, scrubs, soaps, shampoos, masks and clean slippers

All furniture items such as stools and stands should be disinfectable.
*Alternately, grab bars can be installed on walls to minimise contamination.
†Minimise furniture items in doffing area.
‡To be filled with freshly prepared 1% sodium hypochlorite for dipping used linen.
ABHR, alcohol-based hand rub; HCW, healthcare worker; PPE, personal protective equipment; Sn, Serial number.

calculated as the HCW progressively proceeded from a more contaminated to a less contaminated area in a unidirectional manner. Space for various supplies and waste bins that should be within hand's reach was calculated.

We line listed the set of supplies required to operationalise the donning and doffing rooms (table 1).

A doffing area was designed based on the available space (figures 2 and 3) in the hospital.

Based on literature review, the commonly recognised errors in donning and doffing are listed in table 2. These potential errors were highlighted during training. Fifty HCWs were observed for protocol deviations during donning and doffing. They were immediately corrected by a doffing assistant wherever possible.

Figure 2 Layout of the floor in the doffing room.

We used the 5S tool to set up and sustain the donning and doffing areas (table 3). We created a checklist for the donning and doffing areas (table 4).

We performed repeated PDSA cycles to improve compliance to recommended donning and doffing (table 5). We described measures taken to reduce the different aspects of task load pertaining to doffing (table 6)

We used literature review to further refine our PDSA cycles (table 7).

We suggested a theory of change canvas to plan and manage donning and doffing areas (table 8).

DISCUSSION

We designed and operationalised PPE donning and doffing areas for a COVID-19 care facility within a span of 1 week. The biggest challenge was to train the housekeeping staff and environmental service personnel who had no experience in PPE and to translate the training into practice within a short span of time.

There was considerable awareness and interest in COVID-19 among staff due to social media coverage. However, apprehensions related to the disease were also huge. Focus groups, lectures, picture-guided posters, online training videos and demonstrations on donning and doffing were conducted by infection preventionists. Evidence shows that traditional learning methods (eg, watching educational videos and learning PPE guidelines) are inferior to immersive learning methods, including audiovisual devices and active learning involvement using simulation training that includes feedback on performance in guiding the PPE procedures.[22–24] Hands-on practical training should be provided to allow HCWs to develop muscle memory.[6] Though instructional videos were circulated to all HCWs, most did not go through the videos on their own unless under supervised persuasion. The anticipated PPE shortage restricted the staff to practise using PPE extensively. We did a literature review to line list all identified donning and doffing errors and used this as a tool to strengthen training and improvise HCW donning and doffing. Repeated PDSA cycles minimised protocol violations during donning and doffing.

Figure 3 Design of the doffing room.

The PDSA cycles also enabled us to identify practical issues that every healthcare facility must address while operationalising donning and doffing areas in its facility. Limited hospital layouts disrupt space management for PPE use. Since it was not possible to construct an ideal doffing facility or even make major alterations due to constraints of space, time and raw material supply chain logistics due to national lockdown, the identified available space within the ward and the isolation facility was reconfigured optimally.

Initially, items were frequently moved and placed in inconsistent locations when design did not provide standard, convenient locations, leading to errors, frustration and risky behaviours such as retracing into contaminated area to use alcohol-based hand rubs (ABHRs). However, if items such as bins were immovably fixed at identified locations in the doffing room, then this impaired cleaning. Therefore, the floor was marked with coloured tapes to indicate the placement of bins and stools.

Donning was dissected into nine sequential objective steps to reduce cognitive effort. Nine sequential unidirectional stations were created in the donning room. A poster corresponding to each step of donning was pasted on the wall at each station in sequence along with supply of the relevant PPE on tables at that station. Similarly, 11 sequential stations were created in the doffing room corresponding to each step of doffing. At each station, a poster corresponding to the step was pasted on the wall. Automatic no-touch dispensers were provided in each zone (red, yellow and green) in the doffing room to eliminate the risk of contamination and to prevent wastage of ABHRs, which were being used indiscriminately otherwise.

Apart from the errors recognised in literature, the most frequent behaviour was touching the front part of the mask to adjust the positioning of mask at intervals. Individualised seal checks were not possible due to supply of universal size N95 masks. Fogging of goggles occurred

Table 2 Recognised errors in donning and doffing based on literature review that need to be emphasised in training[28–30 32–36]

Donning errors	Doffing errors
Did not perform hand hygiene before entering the room	Did not use proper glove-in-glove technique for glove removal
Did not tie the gown at both the neck and waist	Did not remove gloves first
Selected a procedure mask instead of the N95 disposable respirator	Not doffing gloves inside out
Did not place mask straps properly	Contamination frequently occurred when the contaminated outside surface of gloves was touched with bare hands during removal.
Did not properly seal the mask to the face	The outer gloves were not the first doffing item when untying the outer shoe cover strings first.
Did not conduct a seal check	Gloves and/or masks were not placed in the trash hamper
Did not use eye protection	Removed potentially contaminated eye protection from the room
Glove cuff did not cover gown cuff.	Did not use the foot pedal, but instead touched the hamper lid with bare hand
Did not don equipment in the recommended sequence	Did not place all or part of the gown into the designated hamper
Gloves were not donned last as part of the donning sequence	Did not use proper mask removal technique
Unfamiliarity with PPE items	Touching the outer surface of a gown when rolling it up to reduce its volume after discard
Confusion about the wearing order of multilayered PPE items	Did not use wall-mounted hand sanitiser before exiting the room
Not tying backstrap of gown	Removed other potentially contaminated items from the room
	Did not perform hand hygiene after exiting the room
	Did not doff equipment in the recommended sequence, for example, doffing gloves first and touching other PPE with bare hands
	Touched unprotected areas of the body, which could have resulted in self-contamination
	Adjusted the mask in the room, breaking the seal and potentially resulting in self-contamination
	Touched surfaces in the room that were unnecessary, which could have resulted in greater contamination of the gloved hands
	Difficulty in locating the coverall zipper-slider and pulling it down with gloved hands
	Contacting contaminated PPE with bare hands during doffing
	Doffing the gown with flourish
	Doffing the gown from the front
	Not rolling up the gown before disposal
	Walking between clean and dirty areas of doffing space
	Not completing hand hygiene after each step

often due to poor fit of masks. HCWs used surgical tapes to seal the masks on the face. This carried a risk of contamination during doffing. However, Bell *et al* reported that taping may not present significant contamination risk.[25] HCWs who used prescription glasses perceived risk of contamination of glasses while doffing.

Engineering staff (plumbers and electricians) were required to enter patient isolation rooms to rectify emergency complaints such as seepage of water and faulty drains. Others such as phlebotomists, physiotherapists, radiographers, dieticians, ambulance drivers, laundry personnel and kitchen stewards also required training in PPE use. These were big challenges as it is known that personnel donning and doffing PPE that they are unfamiliar with or have not received training on during emergency situations increase the likelihood of a doffing error.[8] Just-in-time training was provided to them. However, some of these staff doffed expeditiously with less regard to safety and required explicit verbal instructions and prompts by a trained observer on all occasions.

After a few days of regular usage of PPE, some staff exhibited automaticity and reduced compliance to

Table 3 5S tool

5S	Activity
Sort	List all supplies needed.
Set in order	Establish the layout of the donning and doffing room. Design visual prompts on the floor. Place furniture and supplies in identified locations.
Shine	Use freshly prepared 1% sodium hypochlorite every time to disinfect the room. Ensure that the biomedical waste is removed from the bins at defined times. Ensure that coveralls are taken separately out of the room to the disinfection site. Ensure that N95 masks are transported separately out of the room to disinfection site. Ensure that the buckets containing used goggles and face shields are first transported to the disinfection site and then to the donning room for reuse. Ensure that the sodium hypochlorite is periodically replaced in these buckets containing used goggles or face shields.
Standardise	Objective checklist of donning and doffing steps. Standardise placement of items in the donning and doffing rooms. Define and document list of tasks to be performed by each category of staff such as replenishment of supplies, disinfection frequencies, assisting or observing doffing HCW.
Sustain	Reinforcement of activities to housekeeping staff by supervisors once at the beginning of every shift and proactive supervision at random intervals.

HCW, healthcare worker.

doffing sequence even after being explicitly guided by an observer. The presence of a peer guiding the process may have contributed to their reduced compliance. However, in the presence of a senior supervisor, compliance improved. The mean time spent by HCWs in PPE in the wards or isolation facility was 2.4 (±0.04) hours. Some staff (5%) needed to doff within 2 hours of donning PPE due to extreme discomfort or dizziness.

PPE kits should not be changed frequently to minimise errors during donning and doffing.[26] However, PPE supplies changed on four occasions due to unavoidable supply chain logistics and apprehensions regarding

Table 4 Checklist for doffing area

Sn	At the beginning of each shift, tick that the following are available in the doffing room and lockers					
1	ABHR available in automatic dispensers in red, yellow and green zones					
2	Gloves available at designated location in yellow zone (all sizes)					
3	Alcohol swabs available in green zone					
4	Triple-layer masks available in common locker					
5	Surgical scrubs available in common locker (S, M and L sizes)					
6	Soaps available in common locker					
7	Towels available in common locker					
8	Bucket with freshly prepared 1% sodium hypochlorite available in bathroom					
9	Waste bins in designated locations					
10	Waste bins double lined with colour-coded bags					
11	Bins to collect N95 masks labelled and in designated location in the room					
12	Bins to collect goggles or face shields filled with sodium hypochlorite and in designated location in the room					
13	Goggles and face shields collected at the end of each shift and transported safely to a previously identified location for disinfection					
14	N95 masks collected and transported safely to a previously identified location for disinfection					
15	Used coveralls transported from the doffing area to a previously identified location for disinfection (as per the hospital protocol)					
16	Disinfected goggles and face shields transported to the donning area at the beginning of each shift					
		Date Time sign	Date Time sign	Date Time sign	Date Time sign	Date Time sign

ABHR, alcohol-based hand rub; L, large; M, medium; S, small.

Table 5 PDSA cycle for donning and doffing.

Plan the change	What	Who	When
PDSA cycle for donning			
Aim	To ensure that HCW don PPE without any errors or protocol deviations		
Plan	Plan a training programme and schedule for doctors, nurses, nursing assistants and environmental service personnel. Prepare a checklist of donning.	IC team	Week 0 (1 week before start of QI)
Do	Do an awareness and sensitisation lecture for all categories of staff in donning. Identify misconceptions and barriers related to donning in the donning cubicle. Do an extensive literature review on donning practices. Do naturalistic observations of donning in terms of environment, tasks and behaviours and collect informal participant comments.	Hospital administrator, infection control nurses or infection preventionists	Every day in batches
Study	Study aspects of compliance qualitatively. Study misconceptions and wrong practices related to donning using direct observation and with assistance of evidence-based literature.	IC team including hospital administrator	After every third day
Act	Resensitise staff on donning and the need for accurate donning along with clarification of misconceptions, wrong practices and providing solutions to barriers in structure and process.	Hospital administrator and IC team	After every third day until the saturation of training of all staff
PDSA cycle for doffing			
Aim	To ensure that HCW doff PPE without any errors or protocol deviations		
Plan	Plan a training programme and schedule for doctors, nurses, nursing assistants and environmnetal service personnel. Prepare a checklist of doffing.	IC team	Week 0 (1 week before start of QI)
Do	Do an awareness and sensitisation lecture for all categories of staff in doffing. Identify misconceptions and barriers related to doffing in the doffing cubicle. Do an extensive literature review on doffing practices. Do naturalistic observations of doffing in terms of environment, tasks, behaviours and gather informal participant comments.	Hospital administrator, IC nurses or infection preventionists	Every day in batches
Study	Study all aspects of doffing qualitatively. Study misconceptions and wrong practices related to doffing using direct observation and with assistance of evidence-based literature.	IC team, including hospital administrator	After every third day
Act	Resensitise staff on doffing and the need for accurate doffing, along with clarification of misconceptions, wrong practices and providing solutions to barriers in structure and process.	Hospital administrator and IC team	After every third day until saturation of training of all the staff

HCW, healthcare worker; IC, infection control; PDSA, plan–do–study–act; PPE, personal protective equipment; QI, quality improvement.

the quality of PPE among resident doctors due to a few instances of PPE getting torn while donning. The initial PPE ensemble earlier was replaced with an assembled set consisting of a category III protection level tychem coverall, an N95 respirator, a pair of knee length shoe covers and one pair of goggles due to exhausted supplies. Gloves and hood caps had to be obtained separately. This was followed by a supply of two different kinds of coveralls made of spun bound fabric with one layer of microfilm, which differed in their breathability. The other accessories of PPE were separately obtained and assembled. Non-availability of extra-large size gowns or coveralls was an issue of concern for some HCWs due to exposure of the uncovered areas. Due to change in PPE ensemble, the sequence of donning and doffing of shoe covers had to be altered, which led to confusion and errors among HCWs. This required just-in-time training on multiple occasions. Face shields were preferred compared with goggles. However, evidence is limited about the effectiveness of goggles versus face shields.[27]

Another managerial issue that required monitoring was sustaining the practice of discarding used N95 masks, goggles, face shields and coveralls in separate containers in the doffing room by HCWs for reuse after disinfection.

Table 6 Measures taken to reduce task load during doffing (task load parameters derived from Hart and Steveland's NASA Task Load Index)[26]

Sn	Task load	Measures to reduce task load
1	Mental demand	Each step of the doffing was put up as a poster on the wall in a unidirectional flow. Visual prompts were provided on the floor. Verbal prompts were provided by an observer stationed outside the doffing room. All bins that were meant to collect used N95 masks and coveralls were labelled.
2	Physical demand	Grab bars were provided as a balance aid for removing shoe covers. Stools were also provided. Foot-operated trash bins were provided near each doffing step. Full length mirrors were provided to enable visual inspection. No touch ABHR dispensers were provided within easy reach wherever required. The shower room was located right immediately after exit from the doffing room.
3	Temporal demand	In case of an emergency, assistance was given to don PPE. Doffing was assisted and nudged at a comfortable pace. Chairs were placed before entering the doffing room to take rest if required.
4	Performance	Performance was enhanced by a doffing assistant who quickly corrected any protocol deviation or error right at the time of initiation of a deviation.
5	Effort	A donning and/or doffing assistant was provided to reduce individual effort.
6	Frustration	All required PPE supplies and gloves (size-wise), ABHR, alcohol swabs were refilled before the start of donning or doffing. An environmental service personnel was stationed outside the doffing area for any assistance. Towels, soaps and surgical scrubs were provided in the shower room and refilled in every shift. A new set of slippers was provided after exiting from the shower room.

ABHR, alcohol-based hand rub; PPE, personal protective equipment.

Ensuring round-the-clock availability of supplies in the doffing room and postdoffing bathroom was another issue. Direct supervision of the doffing room was comparatively less due to perception of high risk of room contamination and required fresh donning to go inside to check and replenish supplies carefully without contamination. The next issue was to ensure that goggles and face shields were disinfected as per the protocol and transported out from the doffing room safely by the nursing assistants. Ensuring availability of supplies such as towels and scrubs in the lockers always required constant monitoring. A checklist (table 4) was created for the supervisor of environmental service personnel who was made accountable to address these issues in the donning and doffing rooms in every shift.

The availability of all supplies within doffing room, visual prompts and affordances were not sufficient to ensure full compliance with doffing protocols. Fogging of goggles hindered reading doffing posters on the wall for some HCWs. Fatigue also contributed to lack of attention by the HCW during doffing. The presence of a trained observer who provided verbal prompts to the doffing HCW promoted compliance the most. However, some HCWs reported hearing difficulty while in PPE due to which the vocal prompts provided by the doffing assistant during doffing were not heard. This led to the idea of prompting instructions by an observer using a microphone from outside while being able to visualise the doffing process through a glass screen. However, since HCWs doffed at random intervals, ensuring the presence of a doffing assistant always was resource intensive.

Biomedical waste bins for coveralls got filled up faster due to the size of the coveralls. This required more frequent inspection and proactive initiative by environmental service personnel who needed supervisory nudging.

Our experience recommends that water or oral rehydrating solutions should be provided to HCWs at the time of donning and after doffing. There must be space designated for the HCW to sit before entering the doffing room, if the HCW needed to take rest. It was also important to make it known to all the HCWs that these were available for them.

Donning and doffing by different HCWs occurred multiple times due to random arrivals of patients. This caused overcrowding in the doffing room, at times, leading to prolonged waits for other HCW. Some HCWs doffed simultaneously without waiting, which would lead to one of these HCW waiting in the doffing room to enter the bathroom that was already occupied. The waiting in the doffing room without PPE caused apprehensions of exposure to the coronavirus. This was circumvented by preventing simultaneous doffing and by using a set of two rooms, one room to doff and the other room with an attached bathroom to wait if required. Initially, overcrowding happened due to uniform shift timings of staff. We, therefore, staggered the staff duty timings so that at least any one category of staff always remained

Table 7 Lessons learnt from literature review used as a strategic tool to refine our PDSA cycles[27 37–40]

Potential issues identified in literature review	Action taken
Limited hospital layouts disrupted space management for PPE use.	Space was maximally optimised within the available alternatives.
Even when PPE is used, errors in technique may reduce or negate its intended effects.	The right technique of donning was emphasised repeatedly during training and assistance was provided in actual practice.
HCPs were reported to make changed mistakes while avoiding previous mistakes, even after receiving feedback on their PPE contaminations.	Multiple reiterations and trainings were planned and provided.
Lack of assessment of infection control competencies may suggest to learners that these aspects of clinical competency are less valuable than others.	Every training was assessed. Compliance was sought using Hawthorne effect.
Women's experiences wearing PPE found the coverall to be among the worst-fitting PPE types.	Feedback was taken from female HCWs after doffing to improvise the process, if required.
Taping over gaps between hood and coverall	Gaps could not be avoided as it depended on the PPE provided.
With more PPE items, the doffing order became complicated and confusing.	Doffing assistants and observers provided guidance at every step.
Since sitting increases the risk of spreading contamination to other parts of the PPE, installing built-in grab bars was suggested	Handrails were installed at the location where shoe covers are removed.
Layout of the doffing area increases the risk of contamination.	Layout was designed based on best practices cited in literature.
When HCWs are potentially fatigued after hours of providing patient care, removal of PPE has been identified as a high-risk activity for self-contamination and potential acquisition of pathogens. An HCW who is uncomfortable and tired may make mistakes while removing the PPE hastily. Prolonged donning and doffing time may be an issue.	Donning was initiated only based on requirement. Activities were planned in advance before donning to maximise available time after donning. HCW was recommended to take a rest inside the ward/isolation facility at intervals in case of discomfort, uneasiness or heavy sweating. Doffing was initiated only after the HCW was relaxed. Gentle reassurance was provided to them.
In an environment where urgency is evident and employee safety is critical, complex procedures are more accurately followed when written procedures are coupled with visual images to provide guidance to staff. Compliance of staff to the procedure outlined is enhanced when staff can visualise each step as they are completing the process.	Visual posters were put up alongside each instruction in the donning and doffing room.
Some protocols (NC and MSF) recommend rubber boots without boot covers.	We found this recommendation suitable for engineering staff such as plumbers who complained of feet getting soiled or wet during repairs of faulty drains and sewage lines.
Picture-guided posters or visual images enhance staff compliance to donning and doffing procedures when staff is able to visualise each step as they are completing the process.	Full-length posters were made available in the donning and doffing rooms.
Defining specific roles and responsibilities and training the participants to practise core teamwork skills such as closed-loop communication, mutual support, situational awareness and speaking up about safety concerns	PDSA cycles tried to address these issues
HCWs should be given just-in-time training if their standard PPE is replaced with a new style during shortages or vendor changes. Regardless of PPE type, increased access and training to published donning/ doffing guidelines improves HCW ability to don or doff without protocol deviations. PPE protocols must be clear and unambiguous.	PPE protocols were defined. 5S tool was used to standardise and sustain PPE protocols.

HCP, healthcare personnel; HCW, healthcare worker; MSF, Médecins Sans Frontières; NC, North Carolina; PDSA, plan–do–study–act; PPE, personal protective equipment.

Table 8 Theory of change canvas used to create ideal donning and doffing space

Inputs	Activities	Outputs	Outcomes	Impact
Staff: infection control nurses or infection preventionists, engineers, hospital administrators, procurement officer Funds for structural changes in the unit, supply of PPE, dispensers and hand rubs	Designing the structure and layout of the donning and doffing rooms. Training staff on hand hygiene, donning and doffing Making available all supplies such as PPE and ABHR in the donning and doffing rooms and placing them in designated locations in the room.	Improved layout to facilitate donning and doffing that reduces potential for infections (including fomite based) Increase in percentage of hand hygiene compliance among different healthcare workers	No protocol deviations in donning No protocol deviations in doffing Zero contamination	Zero infection rate among healthcare personnel

ABHR, alcohol-based hand rub; PPE, personal protective equipment.

donned inside the isolation facility at any time, PPEs were not used unnecessarily and doffing of all staff at the end of a shift did not occur en masse.

CONCLUSION

Our study used evidence-based literature and QI tools to design and operationalise donning and doffing areas with focus on people, task and environment. Our QI will enable healthcare facilities to rapidly prototype donning and doffing areas systematically.

Contributors LW conceived, designed the work, collected, analysed and interpreted the data, and wrote the draft of the manuscript. SSi analysed and interpreted the data, provided critical feedback on drafts of the manuscript and finally approved the version to be published. ARS and SSi contributed to the analysis of the write up of the study results, provided critical feedback on drafts of the manuscript and finally approved the version to be published. LW, SSa and ARS implemented the planned actions and agreed to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval Our quality improvement (QI) was done as part of the institute's approved plan to set up a COVID-19 care facility. No personal information of any participant was elicited during any part of the study. SQUIRE guidelines were used to report this QI.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article.

ORCID iD

LaxmiTej Wundavalli http://orcid.org/0000-0002-4824-7737

REFERENCES

1 Tomas ME, Kundrapu S, Thota P, *et al*. Contamination of health care personnel during removal of personal protective equipment. *JAMA Intern Med* 2015;175:1904–10.
2 Kwon JH, Burnham C-AD, Reske KA, *et al*. Assessment of healthcare worker protocol deviations and self-contamination during personal protective equipment donning and doffing. *Infect Control Hosp Epidemiol* 2017;38:1077–83.
3 Kang J, O'Donnell JM, Colaianne B, *et al*. Use of personal protective equipment among health care personnel: results of clinical observations and simulations. *Am J Infect Control* 2017;45:17–23.
4 Osei-Bonsu K, Masroor N, Cooper K, *et al*. Alternative doffing strategies of personal protective equipment to prevent self-contamination in the health care setting. *Am J Infect Control* 2019;47:534–9.
5 Casanova L, Alfano-Sobsey E, Rutala WA, *et al*. Virus Transfer from Personal Protective Equipment to Healthcare Employees' Skin and Clothing. *Emerg Infect Dis* 2008;14:1291–3.
6 Baloh J, Reisinger HS, Dukes K, *et al*. Healthcare Workers' Strategies for Doffing Personal Protective Equipment. *Clin Infect Dis* 2019;69:S192–8.
7 Picano JJ, Williams TJ, Roland RR. Assessment and selection of high-risk operational personnel. In: Kennedy CH, Zillmer E, eds. *Military psychology: clinical and operational applications*. New York: Guilford Press, 2006: 353–70.
8 Jinadatha C, Simmons S, Dale C, *et al*. Disinfecting personal protective equipment with pulsed xenon ultraviolet as a risk mitigation strategy for health care workers. *Am J Infect Control* 2015;43:412–4.
9 Centers for Disease Control and Prevention. Guidance on personal protective equipment (PPE) to be used by healthcare workers during management of patients with confirmed Ebola or persons under investigation (PUIs) for Ebola who are clinically unstable or have bleeding, vomiting, or diarrhea in U.S. hospitals, including procedures for donning and doffing PPE, 2015. Available: https://www.cdc.gov/vhf/ebola/healthcare-us/ppe/guidance.html
10 Cai J, Sun W, Huang J, *et al*. Indirect virus transmission in cluster of COVID-19 cases, Wenzhou, China, 2020. *Emerg Infect Dis* 2020;26:1343–5.
11 Guo Z-D, Wang Z-Y, Zhang S-F, *et al*. Aerosol and surface distribution of severe acute respiratory syndrome coronavirus 2 in hospital wards, Wuhan, China, 2020. *Emerg Infect Dis* 2020;26:1583–91.
12 MacIntyre CR, Chughtai AA, Seale H, *et al*. Respiratory protection for healthcare workers treating Ebola virus disease (EVD): are facemasks sufficient to meet occupational health and safety obligations? *Int J Nurs Stud* 2014;51:1421–6.
13 MacIntyre CR, Chughtai AA, Seale H, *et al*. Uncertainty, risk analysis and change for Ebola personal protective equipment guidelines. *Int J Nurs Stud* 2015;52:899–903.
14 MacIntyre CR, Chughtai AA, Seale H, *et al*. Response to Martin-Moreno et al. (2014) surgical mask or no mask for health workers not a defensible position for Ebola. *Int J Nurs Stud* 2014;51:1694–5.
15 Herlihey TA, Gelmi S, Cafazzo JA, *et al*. The impact of environmental design on doffing personal protective equipment in a healthcare environment: a formative human factors trial. *Infect Control Hosp Epidemiol* 2017;38:712–7.
16 Wong MF, Matić Z, Campiglia GC, *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.

17 Garibaldi BT, Kelen GD, Brower RG, *et al*. The creation of a biocontainment unit at a tertiary care hospital. The Johns Hopkins medicine experience. *Ann Am Thorac Soc* 2016;13:600–8.
18 Drews FA. Adherence engineering: a new approach to increasing adherence to protocols. *Ergonomics in Design: The Quarterly of Human Factors Applications* 2013;21:19–25.
19 Donabedian A. *Explorations in quality assessment and monitoring: the criteria and standards of quality volume 2*. Health Administration Press: The University of Michigan, 1980.
20 Jimmerson C. *Review: realizing exceptional value in everyday work*. 3rd edn. Bozeman, MT: CareOregon Inc, 2014.
21 Langley GJ, Moen RD, Nolan KM, *et al*. *The improvement guide: a practical approach to enhancing organizational performance*. 2nd edn. San Francisco, CA: Jossey-Bass publishers, 2009.
22 Lim SM, Cha WC, Chae MK, *et al*. Contamination during doffing of personal protective equipment by healthcare providers. *Clin Exp Emerg Med* 2015;2:162–7.
23 Clay KA, O'Shea MK, Fletcher T, *et al*. Use of an ultraviolet tracer in simulation training for the clinical management of Ebola virus disease. *J Hosp Infect* 2015;91:275–7.
24 Poller B, Hall S, Bailey C, *et al*. 'VIOLET': a fluorescence-based simulation exercise for training healthcare workers in the use of personal protective equipment. *J Hosp Infect* 2018;99:229–35.
25 Bell T, Smoot J, Patterson J, *et al*. Ebola virus disease: the use of fluorescents as markers of contamination for personal protective equipment. *IDCases* 2015;2:27–30.
26 Hart SG. NASA-Task load index (NASA-TLX); 20 years later. *Proceedings of the Human Factors and Ergonomics Society annual meeting*, Los Angeles, CA: Sage Publications, 2006.
27 Chughtai AA, Chen X, Macintyre CR. Risk of self-contamination during doffing of personal protective equipment. *Am J Infect Control* 2018;46:1329–34.
28 Herlihey TA, Gelmi S, Flewwelling CJ, *et al*. Personal protective equipment for infectious disease preparedness: a human factors evaluation. *Infect Control Hosp Epidemiol* 2016;37:1022–8.
29 DuBose JR, Matić Z, Sala MFW, *et al*. Design strategies to improve healthcare worker safety in biocontainment units: learning from Ebola preparedness. *Infect Control Hosp Epidemiol* 2018;39:961–7.
30 Zimring CM, Matić Z, Wong Sala MF, *et al*. Making the invisible visible: why does design matter for safe doffing of personal protection equipment? *Infect Control Hosp Epidemiol* 2018;39:1375–7.
31 McLaws M-L, Chughtai AA, Salmon S, *et al*. A highly precautionary doffing sequence for health care workers after caring for wet Ebola patients to further reduce occupational acquisition of Ebola. *Am J Infect Control* 2016;44:740–4.
32 Mulvey D, Mayer J, Visnovsky L, *et al*. Frequent and unexpected deviations from personal protective equipment guidelines increase contamination risks. *Am J Infect Control* 2019;47:1146–7.
33 Beam EL, Gibbs SG, Boulter KC, *et al*. A method for evaluating health care workers' personal protective equipment technique. *Am J Infect Control* 2011;39:415–20.
34 Andonian J, Kazi S, Therkorn J, *et al*. Effect of an intervention package and teamwork training to prevent healthcare personnel self-contamination during personal protective equipment doffing. *Clin Infect Dis* 2019;69:S248–55.
35 Phan LT, Maita D, Mortiz DC, *et al*. Personal protective equipment doffing practices of healthcare workers. *J Occup Environ Hyg* 2019;16:575–81.
36 Alhmidi H, Gonzalez-Orta M, Cadnum JL, *et al*. Contamination of health care personnel during removal of contaminated gloves. *Am J Infect Control* 2019;47:850–2.
37 Swanhorst J, Boulter K, Vasa A, *et al*. A detailed instructional process for donning and doffing level C personal protective equipment in a healthcare setting. *Am J Infect Control* 2014;42:S93–166.
38 Mumma JM, Durso FT, Ferguson AN, *et al*. Human factors risk analyses of a doffing protocol for Ebola-level personal protective equipment: mapping errors to contamination. *Clin Infect Dis* 2018;66:950–8.
39 Hambraeus A. Lowbury Lecture 2005: infection control from a global perspective. *J Hosp Infect* 2006;64:217–23.
40 McKinley RK, Strand J, Ward L, *et al*. Checklists for assessment and certification of clinical procedural skills omit essential competencies: a systematic review. *Med Educ* 2008;42:338–49.