PPE in low and middle-income countries during COVID-19

Strategies to protect healthcare workers in resource limited settings

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ABSTRACT

BACKGROUND

Infection prevention and control in health care settings involves, among other measures, the use of personal protective equipment (PPE), which encompasses all of the specialised equipment worn by health care workers (HCWs) for protection against health and safety hazards. In low- and middle-income countries (LMICs), there is a higher incidence of infectious disease, often attributed to the poor hospital environmental conditions and reduced availability of PPE, especially during the COVID-19 pandemic.

AIM

We performed a literature review of proposed methods to prolong the use of PPE and additive measures to protect healthcare workers in resource-limited settings during COVID-19.

METHODS

A search was conducted through several databases, including PubMed, Medline, Scopus, and Google Scholar. Articles were included if they discussed strategies to prolong PPE use for healthcare workers in LMICs.

RESULTS

Although limited evidence-based strategies exist for PPE in LMICs, extended use of PPE may be attained with effective disinfection or sterilisation, proper doffing, and storage techniques. Alternative PPE includes cloth masks, hand hygiene, and use of face shields. Engineering and administration control of healthcare facilities can further minimise viral transmission.

CONCLUSIONS

Several measures have been proposed to optimise current protective measures for HCWs. Extended use and limited reuse of PPE, the use of face shields, proper doffing and hand hygiene, and careful consideration of administrative and engineering controls are all possible strategies to reduce the spread of virus particles to HCWs and patients. However, current studies that show the efficacy of PPE, methods to extend its use, and alternatives to PPE in reducing the transmission of COVID-19 are predominantly conducted in high-income countries. Further research of these strategies in LMICs is required to assess its use in reducing the burden of PPE shortage whilst addressing financial concerns.

1. INTRODUCTION

Transmission of COVID-19 is primarily through droplet and fomite spread. Droplets are particles of body fluid that can travel only short distances through the air before landing on surrounding surfaces. Virus-containing droplets may cause direct transmission from close contacts or contribute to the contamination of fomites. Fomites are surfaces or objects (e.g., clothing, equipment, furniture) that can become contaminated by a virus, where it may remain active for hours to days. In contrast to droplets, aerosols are composed of much smaller fluid particles that can remain suspended in air for prolonged periods. If a virus can remain stable within aerosolised airway secretions, this increases the risk of transmission. Current evidence suggests that, while it is plausible that coronaviruses can survive in aerosol form within fluid particles under certain conditions, this is not the primary mechanism for transmission in the community.[1,2]

Adequate protection against risk infection for HCWs is vital to reduce the burden on health care systems. According to the WHO Guidelines for Infection Prevention and Control, standard droplet precautions are to be applied when in contact with patients with confirmed COVID-19, and airborne procedures must be observed when performing aerosol generating procedures (AGP). According to the Centres of Disease Control and Prevention (CDC), under droplet precautions, PPE must be donned upon entry to the patient’s room; this includes gloves, a gown, and a mask.[3] Airborne precautions require HCWs to don gloves, a gown, and a fit tested N95 or higher level respirator upon entry. Additionally, the CDC has recommended a fundamental framework that all healthcare settings should follow to protect HCWs, which can be represented by a hierarchy of controls, ranked from most to least effective: elimination, substitution, engineering controls, administrative controls, and PPE.[4]

2. METHODS

A literature search was conducted through several databases, including PubMed, Medline, Scopus, and Google Scholar, using the following keywords and MESH terms: (Personal protective equipment OR protective wear OR infection control) AND (COVID-19 OR coronavirus OR pandemic) AND (healthcare worker, front line worker) AND low-middle income countries. Articles were included if they discussed strategies to prolong PPE use for healthcare workers in LMICs. Studies were excluded if they were not published in the English language.

3. RESULTS
3.1 EXTENDED PPE USE

A potential strategy to mitigate challenges associated with PPE in limited resources is to optimise current stores of PPE, particularly N95 respirators. This may be achieved by sterilising respirators or implementing the extended use and/or limited reuse of respirators. Extended use is defined as the continual use of the same respirator across multiple patient consultations without donning and doffing. Limited reuse is the use of the same respirator across multiple consultations with donning and doffing in between. [5] Techniques for increasing the longevity of PPE include proper disinfection, storage, and removal of PPE.

3.1.1 DISINFECTION METHODS

Various disinfection strategies have been suggested to prolong the use of N95 masks. High-income countries and the CDC report that the most promising potential techniques for decontaminating respirators are vaporous hydrogen peroxide, ultraviolet germicidal irradiation (UVGI), and moist heat,[5,6] A summary of each decontamination method and effect on respirator fit performance has been outlined online.[6] However, further research to assess respiratory efficacy post-decontamination for COVID-19 is needed. Studies have shown that UVGI can inactivate coronaviruses, including SARS-CoV and MERS-CoV.[7,8] However, with limited financial flexibility, the use of moist heat incubation (i.e., 15–30 minutes (60°C)) or microwave generated steam (1100-1250 W microwave models (range: 40 seconds to 2 minutes)) could be cost-effective solutions.[6] Another method of N95 mask sterilisation reported by van Straten et al. is as follows: N95 masks were sterilised in a 15 minute procedure at 121°C, using a dry sterilisation process and a regular steam process, with the masks in sterilisation/laminate bags.[10] This method was reported to not influence the functionality of the masks tested. Physical decontamination methods such as moist heat and UVGI are less destructive to the respirator filter than chemical methods, such as alcohol washing or bleach.[9] In addition, reuse of N95 masks may be prolonged with the proper storage of respirators post-cleansing, including hanging respirators to dry or keeping them inside a clean, breathable container.[7,10]

3.1.2 EXTENDED USE AND LIMITED REUSE

There are several factors that must be considered before implementing the extended use or limited reuse of respirators. This includes the efficacy of the filter, HCWs’ tolerance of extended use, and ability for the mask to propagate further transmission of the virus.[11,12]

FILTRATION CAPACITY

Several studies suggest the possible viability of respirator use past the recommended time. Moyer et al. found that intermittent use of N95 respirators for several months resulted in a loss of filtration efficacy after 9-13 hours of cumulative use.[13] Additionally, another study reported the filtration efficacy against inert particles less than 200 nm remained adequate after 5 hours of continuous use, with a maximum recommended extended use period of 8-12 hours. This is suitable against SARS-CoV-2 as it has a diameter of approximately 60-140 nm.[14,15] It has been found that the filtration capacity remained acceptable in respirators stockpiled past their shelf life if stored in manufacturer-recommended conditions.[15] However, the duration N95 respirators remain acceptable past shelf life is unknown.

FIT FACTORS

Respirators can remain adequate for up to 5 successive uses [13,16-17], and failure was avoidable if proper donning procedures were carried out.[12] Moreover, facial perspiration and moisture from exhaled breath has not been shown to significantly impact fit factors.[18]

TOLERABILITY

Several physiological and psychological markers have been evaluated to determine HCWs’ tolerance of extended use. Researchers at the National Institute for Occupational Safety and found that there was no difference between subjects wearing N95 respirators and controls in terms of oxygen saturation levels, core body temperatures, and perceived heat or humidity while performing low to moderate intensity exercise.[19-22] The average duration of respirators worn by HCWs, particularly ICU nurses, is 2.4 to 6.6 hours, with only short interval breaks.[23,24]

FURTHER PROPAGATION OF THE VIRUS

An important consideration of extended or limited reuse of masks is the potential virus particle transmission via the HCW’s hands when donning and doffing, or the re-aerosolisation of trapped particles. Fisher et al. found that a virus containing droplet nuclei of diameter 0.65-7.0 micrometres had a negligible risk of re-aerosolisation.[25] However, this is significantly smaller than the diameter of SARS-CoV-2,[14] and there is no empirical data on the fomite potential of SARS-CoV-2 from respirators. Chin et al. analysed the stability of SARS-CoV-2 on different surfaces and reported that it persisted on the outer layer of surgi-
cal masks for over 7 days.[26] Reassuringly, 2 studies conducted in major tertiary hospitals in Singapore found that no respirators were contaminated after multiple close patient contacts,[27,28] indicating that there may be low contamination potential. Extended reuse of masks needs to be performed with caution to avoid fomite transmission.

3.1.3 PROPER DOFFING AND STORAGE AND PPE COMPETENCY

PROPER DOFFING

During the Ebola virus outbreak, several studies cited the high contamination rates of inner surfaces of PPE and HCWs due to poor handling of PPE,[29] thus illustrating the importance of correct doffing and storage of PPE to reduce rates of self-contamination and further transmission. Several contributory factors were identified, such as inadequate hand hygiene, lack of standardised doffing protocols and training, incorrectly fitting PPE, doffing barriers (e.g., problematic straps on masks), and prioritising doffing efficiency whilst compromising safety, especially when in time-pressed or unfamiliar circumstances.[29] Thus it is clear that the implementation of standardised, safe doffing practices are crucial in maintaining the integrity of PPE and protecting HCWs.

Policy makers may adopt a protocol to reduce the burden of incorrect doffing based on existing recommendations by WHO, CDC, or local guidelines. These include frequent hand hygiene, doffing with the supervision of a trained observer, and just in time training if the standard PPE is replaced with a new model on short notice.[29,30] In LMICs, hands-on training may be a more cost-effective method than computerised training, and this confers the additional benefit of allowing real-time feedback and the development of muscle memory.[29]

PROPER STORAGE

The WHO discourages re-donning of potentially contaminated PPE items without adequate reprocessing and storage, as environmental contamination is a principal source of risk to health care workers.[30] Additionally, the CDC advises that masks should be folded so that their outer surfaces are turned inwards to reduce contamination of the environment, and they are stored in a clean, sealable paper bag or container.[31]

3.2 ADJUNCTS TO PERSONAL PROTECTIVE EQUIPMENT

Techniques for optimising limited reserves of PPE by utilising alternative measures has been suggested to mitigate challenges associated with resource limitation in LMICs. Strategies suggested in the literature include the use of cloth masks in low risk clinical settings, improving hand hygiene compliance, use of face shields, and reducing the risk of exposure for HCWs through well-developed engineering controls.

3.2.1 USE OF CLOTH MASKS

Cloth masks are commonly used in LMICs to prevent the spread of infection.[32] During COVID-19, cloth masks have been used by HCWs in low resource settings as recommended medical face masks when PPE have become exhausted. However, the degree of increased risk of virus exposure for HCWs wearing cloth masks compared with medical face masks remains unclear.[33]

A single RCT assessing the use of cloth masks in a healthcare setting suggested HCWs should not use cloth masks.[34] The risk of exposure was reported to be high during AGPs and in high transmission risk environments, such as emergency and intensive care wards. The study proposes the 3 key characteristics that increase infection risk in cloth masks are moisture retention, sustained reuse, and poor filtration.[34] The study noted the need for innovation of effective cloth mask designs that are evidence-based and low cost for LMICs.[34]

Ma QX et al. [35] found that homemade masks consisting of 4-layer kitchen paper (each layer contains 3 thin layers) and 1 layer of polyester cloth can block 95.15% of SARS-CoV-2 virus. However, the relevant Ct values were not of significant difference, and further research should be performed. Studies have suggested that cloth masks were 5 times more effective than not wearing masks,[36] and common fabric materials may provide marginal protection against virus-sized nanoparticles.[37]

While the current guidelines do not recommend HCWs wear cloth masks in a healthcare setting, wearing a cloth mask in resource-limited settings may provide more protection than wearing no mask at all.

3.2.2 HAND HYGIENE

NOSOCOMIAL TRANSMISSION OF COVID-19

Nosocomial spread is the primary route of transmission through ‘transient’ contamination between HCW activities.[38] The Chinese health system, as of 12 February 2020, accounted for 3.83% of the total number of COVID-19 infections due to nosocomial transmission.[39] Hand hygiene is often neglected by HCWs in both low- and high-income countries, with compliance rates sometimes dipping below
APPLICATION OF WHO HAND HYGIENE STRATEGIES IN LMICS

In resource-limited and overcrowded healthcare environments, hand hygiene is crucial in preventing the spread of viruses. LMICs may be better able to follow WHO’s ‘Multimodal Strategy for Hand Hygiene Improvement’ [44] to maintain optimal hand hygiene behaviour. However, if HCWs in resource-limited countries are unable to adhere to the ‘My 5 Moments for Hand Hygiene’ strategy [44], adaptations such as the “My five moments for hand hygiene” concept for the overcrowded setting in resource-limited healthcare systems should be reviewed.[45]

ALTERNATIVES TO WHO RECOMMENDED ALCOHOL-BASED HAND RUBS (ABHR)

The shortage of PPE has been accompanied with a shortage of ABHR in healthcare facilities, particularly in LMICs.[46] Healthcare facilities that have limited access to ABHR with WHO recommended formulations[42] can use alternatives that remove the SARS-CoV-2 virus. A study found that instant hand wiping using a wet towel soaked in water containing 1.00% soap powder, 0.05% active chlorine, or 0.25% active chlorine from sodium hypochlorite removed 98.36%, 96.62%, and 99.98% of the virus from hands, respectively.[47]

3.2.3 FACE SHIELDS

Face shields are recommended for HCWs when performing aerosol-generating procedures. There is a reported compliance issue surrounding the use of face shields,[48] however, it has been shown to have large potential in reducing the short-term exposure to infectious aerosol particles and preserving face masks and eyewear. Lindsley et al. showed that 0.9% of the initial burst of aerosol from a cough can be inhaled by a worker 46 cm (18 inches) from the patient.[49] During testing of an influenza cough aerosol with a volume median diameter of 8.5 μm, wearing a face shield reduced the inhalation exposure of the worker by 96% in the period immediately after a cough. The face shield also reduced the surface contamination of a respirator by 97%.[49] During the 2009 H1N1 influenza pandemic, the CDC recommended that HCWs consider using face shields to reduce the surface contamination of respirators. Face shields can be made from simple, cost-effective materials, such as plastic film from water bottle cutouts, thermoplastic sheets, A4 acetate sheets, Ziploc bags, and foam for the headpiece.[49] Face shields should be used on top of a respirator mask as an extra protective layer against aerosol transmission.

3.3 ADMINISTRATIVE AND ENGINEERING CONTROLS

Healthcare settings can effectively limit or prevent COVID-19 transmission by implementing administrative controls and using environmental and engineering controls. In conjunction with proper PPE for HCWs, primary prevention strategies should include these controls.[50] Implementation of appropriate controls is dependent on the health facility; however, the general principles have been outlined in Table 1.[51-53]

A simple administration control that can be used in LMICs includes the reduction of staff-to-staff contact. Goh et al. found a significant reduction in virus spread within hospital services by implementing policies of staff segregation and limiting staff-to-staff interaction.[54]

Engineering controls include physical barriers, such as glass or plastic windows that reduce HCW exposure to the virus in locations such as triage and screening areas. Administrative controls may include postponing elective, non-urgent procedures and hospitalisations, as well as the application of telehealth wherever possible to redirect resources, such as PPE and HCWs, to the management of COVID-19 patients. Additionally, staff education on the appropriate use of PPE may help reduce the environmental waste and reserve of PPE.

The effectiveness of refined management (including engineering and administrative controls) in the prevention and control of nosocomial COVID-19 infections in non-isolated areas found that the implementation of such methods resulted in zero hospital-acquired infections (HAI).[55] This is particularly pertinent for LMICs, where hospital patients are exposed to rates of HAI at least 2 times higher than in high-income countries.[55]

4. DISCUSSION

This review demonstrates that there is a robust body of evidence supporting the extended use and limited reuse of N95 respirators, particularly in high-income countries. However, there are some discrepancies regarding specific factors, such as the exact number of cumulative hours that the filtration capacity is sufficient for, duration HCWs can tolerate extended use, and the re-aerosolisation rates of SARS-CoV-2 molecules from PPE.

Furthermore, it is important to note that, whilst ef-
fective and frequent hand hygiene has been shown to minimise viral transmission, persistent handwashing to preserve PPE may increase likelihood of impaired skin integrity to the hands. Lan et al. conducted a survey of 526 front-line COVID-19 HCWs that showed 74.5% of HCWs reported damage to hand skin from enhanced infection prevention measures.[56] HCWs who washed their hands more than 10 times per day reported more damage to hand skin, which increases pathogen routes of entry. To mitigate this, it has been suggested that HCUs use protective gloves if available and regularly moisturise.[57]

As most studies identified in this review were conducted in high-income countries, the ability to translate these proposed strategies to minimise viral transmission amongst HCWs in LMIC needs to be further investigated. Nevertheless, as the COVID-19 pandemic has rapidly affected millions of people in dense populations, research for the efficacy of these strategies may not be possible nor reasonable when there is dire need to protect HCWs. As financial viability in LMICs is a significant barrier for implementing new methods, these strategies may be simple and cost-effective alternatives. Future studies should explore the economic impact of extended use or limited reuse of PPE, with a cost-benefit analysis. We acknowledge that optimal hygiene may not be possible to achieve in many LMIC settings. However, where possible, it should be ensured that doffing and storage policies specific for N95 respirators in the context of SARS-CoV-2 are maintained to preserve the efficacy of PPE in between uses for HCWs.

5. CONCLUSIONS

As this pandemic persists, ensuring sufficient supply of PPE for HCWs remains a major challenge for health facilities around the world. In lower resource settings, this challenge is further exacerbated by financial constraints that underpin the decisions of policy makers. Our review summarises the evidence available for extended use or limited reuse, alternative PPE, and strategic use of engineering and administrative controls as potential solutions to reduce the burden of respirator shortage, without compromising the safety of HCWs. It is important to note that the majority of current evidence is from high-income countries and, thus, careful consideration needs to be taken for the implementation of strategies in LMICs. Further research is required to determine the efficacy of these strategies against SARS-CoV-2 transmission, with cost-benefit analysis to determine the viability in LMICs.

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Conflicts of interests
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Ethical approval
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Table 1. Examples of use of a hierarchy of controls to prevent COVID-19 transmission [51-53]

<table>
<thead>
<tr>
<th>Elimination of sources of infection</th>
<th>Postpone elective visits and procedures for patients with suspected or confirmed COVID-19 until they are no longer infectious</th>
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<tr>
<td></td>
<td>Deny healthcare facility entry to those wishing to visit patients if the visitors have suspected or confirmed to be infected with COVID-19</td>
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<td></td>
<td>Minimise outpatient and emergency department visits for patients with mild COVID-19-like illness who do not have risk factors for complications</td>
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<td></td>
<td>Keep personnel at home while they are ill to reduce the risk of spreading COVID-19</td>
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<thead>
<tr>
<th>Engineering controls</th>
<th>Install partitions (e.g., transparent panels/windows/desk enclosures) in triage areas as physical barriers to shield staff from respiratory droplets</th>
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<tr>
<td></td>
<td>Use local exhaust ventilation (e.g., hoods, tents, or booths) for aerosol-generating procedures</td>
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<td></td>
<td>Use hoods for the performance of laboratory manipulations that generate infectious aerosols</td>
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<td>Point-of-care alcohol-based hand rub (ABHR)</td>
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<td></td>
<td>Install hands-free soap and water dispensers, as well as no-touch waste receptacles for garbage and linen, to minimise environmental contact</td>
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<td></td>
<td>Conduct aerosol-generating procedures in an airborne infection isolation room (AIIR) to prevent the spread of aerosols to other parts of the facility</td>
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<td>Use closed suctioning systems for airway suction in intubated patients</td>
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<td></td>
<td>Use high-efficiency particulate filters on mechanical and bag ventilators</td>
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<td></td>
<td>Ensure effective general ventilation and thorough environmental surface hygiene</td>
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<td></td>
<td>Designated hand washing sinks for HCWs</td>
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<td></td>
<td>A sufficient supply of and ready access to all PPE at point of care for all HCWs</td>
</tr>
</tbody>
</table>

<p>| Personal protective equipment | Wear appropriate gloves, gowns, facemasks, respirators, eye protection, and other PPE |</p>
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<th>Administrative controls</th>
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<tr>
<td>Vaccinate as many healthcare workers as possible (once a vaccine is available)</td>
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<tr>
<td>Identify and isolate patients with known or suspected COVID-19 infections</td>
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<td>Implement respiratory hygiene/cough etiquette programs</td>
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<tr>
<td>Respiratory program for all HCWs (e.g., N95 respirator fit testing)</td>
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<tr>
<td>Use of N95 respirator, in addition to routine practices, as well as droplet and contact precautions for all AGMP</td>
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<tr>
<td>Training, testing, and monitoring for compliance for all HCW education, surveillance, and auditing practices</td>
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<tr>
<td>Set up triage stations, manage patient flow, and assign dedicated staff to minimise the number of healthcare personnel exposed to those with suspected or confirmed COVID-19.</td>
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<tr>
<td>Screen personnel and visitors for signs and symptoms of infection at clinic or hospital entrances or badging stations, then responding appropriately if they are present</td>
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<tr>
<td>Adhere to appropriate isolation precautions</td>
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<tr>
<td>Limit the number of persons present in patient rooms and during aerosol-generating procedures</td>
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<td>Arrange seating to allow 1.8 metres between chairs or between families when possible</td>
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<tr>
<td>Ensure compliance with hand hygiene, respiratory hygiene, and cough etiquette</td>
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<td>Increase availability of tissues, facemasks, and hand sanitizer in waiting areas and other locations in healthcare facility</td>
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<tr>
<td>Establish protocols for cleaning of frequently touched surfaces throughout the facility (e.g., elevator buttons, work surfaces, etc.)</td>
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<tr>
<td>Locate signage in an appropriate language and at the appropriate reading level in areas to alert staff and visitors of the need for specific precautions</td>
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<tr>
<td>Place facemasks on patients, when tolerated, at facility access points (e.g., emergency rooms) or when patients are outside their rooms (e.g., diagnostic testing)</td>
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<tr>
<td>Place facemasks on patients during transport, when tolerated; limiting transport to that which is medically necessary; and minimising delays and waiting times during transport</td>
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<td>Visitor restriction policies</td>
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