Rapid cycle system improvement for COVID-19 readiness: integrating deliberate practice, psychological safety and vicarious learning

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ABSTRACT

Introduction In the face of a rapidly advancing pandemic with uncertain pathophysiology, pop-up healthcare units, ad hoc teams and unpredictable personal protective equipment supply, it is difficult for healthcare institutions and front-line teams to invent and test robust and safe clinical care pathways for patients and clinicians. Conventional simulation-based education was not designed for the time-pressured and emergent needs of readiness in a pandemic. We used 'rapid cycle system improvement' to create a psychologically safe learning oasis in the midst of a pandemic. This oasis provided a context to build staff technical and teamwork capacity and improve clinical workflows simultaneously.

Methods At the Department of Anaesthesia and Intensive Care in Prince of Wales Hospital, a tertiary institution, in situ simulations were carried out in the operating theatres and intensive care unit (ICU). The translational simulation design leveraged principles of psychological safety, rapid cycle deliberate practice, direct and vicarious learning to ready over 200 staff with 51 sessions and achieve iterative system improvement all within 7 days. Staff evaluations and system improvements were documented postsimulation.

Results/Findings Staff in both operating theatres and ICU were significantly more comfortable and confident in managing patients with COVID-19 postsimulation. Teamwork, communication and collective ability to manage infectious cases were enhanced. Key system issues were also identified and improved.

Discussion To develop readiness in the rapidly progressing COVID-19 pandemic, we demonstrated that 'rapid cycle system improvement' can efficiently help achieve three intertwined goals: (1) ready staff for new clinical processes, (2) build team competence and confidence and (3) improve workflows and procedures.

INTRODUCTION

It is difficult for healthcare teams to both adopt new skills and adapt clinical care pathways in a clinical care environment for COVID-19 that includes uncertain pathophysiology, pop-up care spaces, ad hoc teams, unpredictable personal protective equipment (PPE) supply and evolving infection-control protocols and guidelines. The problem is twofold: first, in the skills domain, the psychological and cognitive demands of providing care are heavy. This means that 'simple' skill practice and acquisition is unlikely to be sufficient to help clinicians

practise at their best. This is because infection-control measures increase workload and disrupt familiar work patterns. Workload problems are compounded when providers become ill and staff capacity to provide patient care is reduced.[1] The negative psychological impact during the severe acute respiratory syndrome epidemic was well known and seems to be resurfacing in the current COVID-19 pandemic. Uncertainty and unfamiliarity with frequently changing infection-control measures as well as isolation and constant fear for their own personal safety can be psychologically demanding and depleting.[2 3]

Second, within the clinical domain, hospital systems and processes have to be both proactively tested in preparation of clinical care demands that will stress existing workflows, and iteratively revised as they are implemented. Protocols and guidelines in such times are often developed based on official recommendations such as WHO or Centers for Disease Control and Surveillance (CDC), without adapting to local needs and situations, and systems are strained without adequate integration. The systems around front-line healthcare workers caring for patients with COVID-19, if not well tested and developed, can potentially increase the threat of their exposure, particularly during aerosol-generating procedures associated with high risk of transmission of viral infections.[4–6] A corollary is that if the systems are not perceived by clinicians' to be well-thought out, practical and tested, this can worsen their anxiety and reduce confidence in leaders and the health system. Like rock climbers who depend on their ropes and anchor systems to climb, healthcare workers need to be able to depend on the systems around them to care for patients. Clinicians stepping into care roles in 2020 were likely aware of statistics from Wuhan showed that 1716 (3.8% of confirmed cases in a cohort in China) healthcare workers were infected.[7] Or that in Italy, at least 2026 healthcare workers have been infected by 16 March 2020.[8] Other healthcare workers in Europe and the USA and worldwide are facing similar concerns. As of 6 July 2020, there have been 92 957 healthcare workers infected with COVID-19 according to the CDC.

Simulation-based education, and translational simulation in particular[9] via both diagnostic and interventional functions, can play a critical role in

staff preparedness for personal protection and infection control.[10 11] Translational simulation was instrumental in previous epidemics[12] and was effectively deployed in a few health systems in 2020 to transform services rapidly for COVID-19 readiness.[13] However, not much has been reported on the specific educational theory and training steps of translational simulation to build staff capacity, system robustness and relational aspects of working as a team in face of a rapidly progressing pandemic, as in the current situation with COVID-19. While methods that enhance mastery learning using simulation have been described,[14] to achieve mastery in its true sense is challenging under extreme time pressure, particularly given the rapidity of the evolving outbreak. In addition, means to achieve psychological safety in normal simulation contexts is well understood[15]—how to do so under the generalised anxiety of a pandemic is less clear. Moreover, system integration and clinical care process testing[16 17] often take time to set up, and change process is usually slow. Lastly, if clinical process testing is done poorly, it can exacerbate healthcare workers' anxiety when they perceive that policies and procedures designed for staff and patient safety are flawed.

With these learning and system design challenges, we reasoned that supporting the psychological resilience, technical and system readiness for front-line providers was a practical and ethical responsibility. To do this, we built on findings that translational simulation—simulation directly connected to health system priorities, patient outcomes and clinician safety—might also enhance relational aspects of care,[18] teamworking skills[19 20] and a sense of collective competence.[21] Working as a team to mutually support each other could improve learning and performance, and serve as a buffer against the mental and emotional demands of constantly changing workflows and personal safety. We sought to amplify this effect by developing a progression from vicarious to direct learning that allowed staff to inch their way into the newly implemented infection-control procedures about which they were anxious. Moreover, by engaging them in active participation in the evaluation of workflows and encouraging input for system improvement, there would be a dual benefit of enhancing both the system and confidence in it. The aim was to use 'rapid cycle system improvement', to achieve three intertwined goals: (1) build staff readiness for new clinical care pathways and processes, (2) build competence and confidence in working as a team and (3) improve workflows and procedures.

Pressed by time and by the exigencies of protecting staff from exposure to COVID-19 in the early days of the pandemic in February 2020, the Department of Anaesthesia and Intensive Care at Prince of Wales Hospital, a tertiary teaching hospital affiliated with the Chinese University of Hong Kong, designed and deployed a rapid cycle deliberate practice (RCDP)[14] approach to staff upskilling and system testing that also built the teams' collective ability to manage these challenges. The specific challenges we addressed were as follows: (1) how to prepare staff both technically and psychologically to perform aerosol-generating procedures, such as tracheal intubation, non-invasive ventilation, tracheostomy, cardiopulmonary resuscitation, manual ventilation before intubation and bronchoscopy in the operating theatre and the intensive care unit (ICU)[22] for suspected or confirmed cases of COVID-19 in the operating theatre and intensive care unit; and (2) how to achieve care process improvement based on system integration principles[16 17] and refine infection-control protocols and workflow at the institution.

This article describes a translational simulation approach that effectively achieves these two goals using an iterative process we describe as 'rapid cycle system improvement'. To illustrate the possible impacts of this programme for others, we describe the self-reported impact of the programme on learners as well as a sample of the system improvements that resulted.

METHODS
Conceptual framework
The central challenge in the current pandemic is the time pressure and the staff anxiety in imminently facing patients with COVID-19: staff capacity needs to be enhanced to manage infection control both safely and efficiently but in a psychologically safe learning environment. Therefore, educational methods must be crafted to engage learners who were already stressed by workload and the anxiety of treating patients who may put them personally at risk. We integrated the principles of meaningful learning,[23] deliberate practice[24] and psychological safety[15] to develop a learning process that combined vicarious and direct experiential learning,[25] for rigorous yet efficient progress towards mastery of key airway management skills in the context of infection control for COVID-19.

First, to propel meaningful learning,[23] our design assumed that healthcare workers would relate new information on infection-control principles for COVID-19 to pre-existing knowledge, and through a process known as *elaboration*, use their prior knowledge to embellish new information such that it can be further consolidated, and form a new mental model. As all healthcare workers have been exposed to infection-control training or measures in their career, they have a certain extent of prior knowledge of such procedures, though it may not be within the current context. By using staged videos of well-done and poorly done infection-control practices and subsequent rating of the videos along with facilitated discussions, learners enriched their existing mental models through acquisition of new criteria for personal protection, infection control, pitfalls and facilitators of good practices. This process allowed them to draw on prior knowledge and *elaborate* upon it,[23] and use these gains to strengthen technical and teamwork skills in the subsequent hands-on portion of the training. In the high anxiety context of a pandemic, this method of building on vicarious learning (before the hands-on portion) allowed learners to inch their way into readiness. First, they observed infection-control processes vicariously, discussed them with their peers (building connections with each other in the process) and had the opportunity to process them mentally without the added cognitive load and anxiety of planning and coordinating clinical actions, speaking and regulating their emotional responses.[25]

Second, to help staff integrate and apply new and existing knowledge and skills for airway management for COVID-19, we adapted the RCDP approach pioneered by Hunt *et al*.[14] The goal was to move staff towards mastery[26] through recurrent small cycles of practice with feedback. Deliberate practice using short recurrent cycles can be achieved easily in a high-fidelity simulation setting and can accelerate improvement by repeating particular infection-control tasks. Combined with vicarious learning via video we hypothesised that these repeated opportunities for problem-solving, self-evaluation and repeated performance would both reduce anxiety[27] and enhance automatisation.[24] Within this context, staff performed infection-control tasks for COVID-19 repeatedly in a high-fidelity in situ simulation setting with immediate feedback—until the teams were able to achieve a high level of coordination and reach target performance goals. Given the limited time for deliberate practice in face of the rapidly spreading pandemic, it would be challenging to achieve full mastery—nonetheless, the learners and instructors were highly motivated to use these pedagogical methods to bring learners closer to it.

Third, given the anxiety associated with exposure to pathogens, we sought to build psychological safety for the learners so that they could focus on the learning at hand. In the current pandemic, healthcare workers suffer from anxiety and stress,[28 29] and are under extreme pressures in making tough clinical decisions, balancing their own safety and duty to patients, while facing heavy workload.[30] It is well known that learning and psychological and emotional states are intricately intertwined; thus, well-constructed pre-briefings, learner interconnections with each other,[18] instructor reassurance and peer affirmation are vital to creating a 'safe container' in which learners feel able to take social risks for the sake of enhancing their skills, knowledge and behaviours.[15] The COVID-19 pandemic poses a very real threat to psychological and physical safety of staff. The ultimate aim is to provide a 'learning oasis' for staff to proverbially doff their anxieties and stress and focus on learning and improving skills so that they can competently take care of patients and themselves.

Yet, using educational strategies to enhance the capacity of the front-line staff will not suffice in a pandemic if the system, environment and processes which they work in do not ensure patient and staff safety.[31] System-focused simulation, particularly in the in situ setting (ie, in the actual clinical workplace), is instrumental to identify system gaps and latent safety threats—system-based threats that could lead to medical errors.[32] System integration is subsequently carried out to ensure coordination of work processes to ensure safety,[16 17] but such processes may take time to materialise into actual changes. When the situation is rapidly evolving, such as in a rapidly propagating epidemic, the lag time between system testing, change and implementation must be shortened, and iterative testing must be in place to ensure the robustness of the system modifications.[16] Another anticipated benefit of such system-focused simulation in the COVID-19 pandemic is that staff will have first-hand experience in rapid system improvement, including influencing it themselves, and be able to trust that the organisation that they are working in is constantly improving to ensure patient, as well as their own safety.

Simulation design

To achieve the educational and system goals, careful consideration was given to the instructional design of the simulation. The simulations were carried out in situ—within airborne infection isolation rooms (AIIR) in the operating theatre and ICU. The scenario design was based on the need for airway management of confirmed patients with COVID-19. The participants were interprofessional, intact teams working in their respective settings (operating theatre: anaesthetists, nurses, patient care assistants/technicians; ICU: intensive care doctors, nurses and other essential staff). In keeping with infection-control principles in COVID-19, there were no more than three to four staff in each managing team to minimise the risk of contamination. After obtaining institutional support, staff of all ranks were recruited to engage in the simulation.

A prebriefing script (online appendix 1) was developed to orientate participants to the goals of the simulation, including the educational purposes in infection control, as well as purpose of system testing. Specifically, participants were asked to give feedback on the processes in infection control within the respective settings after the simulation that were enablers or barriers to patient and staff safety.[17] The pre-briefing script was also crafted to build psychological safety to enhance learning.[15]

Prior to engaging in the simulation scenario, participants viewed two videos of teams conducting airway management for a confirmed patient with COVID-19—one with ideal performance and other with behaviours that could be improved. The participants were then guided through a discussion of the videos by a trained facilitator on the behaviours of the team in the video using a Plus/Delta technique. This process used accepted observational rating methods[33] to activate prior knowledge, and consolidate knowledge through elaboration and forming a mental model of the relevant infection-control principles.[23]

Based on principles of RCDP[14] the tasks of donning and doffing of PPE, preparing the AIIR and equipment, assessing the airway, conducting the intubation were chunked and practised, along with the associated teamwork and communication skills. The focus was on rapid acquisition of procedural and teamwork skills and building trust for infection control in aerosol-generating procedures. Direct feedback as well as providing opportunities to repeat the process was emphasised rather than focused facilitation approach.[14 34] A rubric (online appendix 2) and video recordings were used to guide feedback. The simulation scenarios were deliberately designed to be different from the sample presimulation videos, such that staff were not simply replicating performance but challenged to apply the infection-control principles appropriately. In addition, facilitators used sticker labels and video reviews during the debriefing to demonstrate areas of contamination by the team within the clinical workspace—since visualisation of contamination is a powerful learning aid for infection control.[35]

To achieve goals of process testing and system integration, the participants were orientated at the beginning of the simulation to the system testing purposes of the simulation, and also be given the opportunity of expressing their thoughts and concerns about the processes in infection control within the respective settings.[17] Close collaboration and communication were maintained with the infection-control team, which was responsible for the development of guidelines and workflow processes for infection control within operating theatre and ICU. Results from system testing were documented and fed back to the infection-control team for modification of the workflow processes iteratively, and retested in the simulation setting until saturation was reached.[31 36]

Outcome measurement

A convergent mixed methods design[37] is used to provide a comprehensive analysis of the outcomes of the simulation. Both quantitative and quality data were collected and integrated for the overall interpretation of the results. The aim was to triangulate multiple data sources to provide a richer picture of the effects of the simulation design and instructional method of deliberate practice.

Evaluations were distributed electronically to gather demographic data, feedback on the simulation and instructional methods, as well as self-perceived comfort and confidence with handling patients with C OVID-19before and after the simulation (table 1). Qualitative and written feedback were also encouraged and were analysed using the steps of thematic analysis described by Boyatzis.[38] Open coding was performed to create a comprehensive list, followed by distillation into emerging themes. The themes were subsequently revised iteratively until agreement was reached on the classification. We pursued free text answers to learners' experience because we wanted to understand the subjective experience of clinicians attempting to prepare themselves for care about which they were very anxious. We reasoned that quantitative ratings would report learners' assessment of variables we deemed important but might miss nuances

Table 1 Combined summary of evaluations of in situ simulation training for management of patients with COVID-19 in operating theatre and ICU

Demographics*			
Role	Physician 53 (36.3%)	Nurse 73 (50%)	Other staff 20 (13.7%)
Years of experience	0–10 90 (61.6%)	10–20 34 (23.3%)	≥20 22 (15.1%)
SARS experience	Yes 40 (27.3%)	No 106 (72.7%)	
Self-assessment (with relation to infectioncontrol management of patients with COVID-19)†	Presimulation	Postsimulation	P value
How comfortable are you in handling a patient confirmed with COVID-19 infection?	5 (4–7)	8 (7–8)	<0.001
How confident are you in your ability to protect yourself from getting infected?	6 (5–7)	8 (7–9)	<0.001
How confident are you in your ability to protect other staff from getting infected?	6 (5–7)	8 (7–9)	<0.001

*Demographics reported as frequency (% of total respondents).
†Self-assessment Likert score reported as median (IQR).
ICU, intensive care unit; SARS, severe acute respiratory syndrome.

that mattered to them. Including reports of their subjective experience would allow us to adapt and improve later training and system testing designs.

The raw qualitative feedback data can be made available upon request. As researchers bring their own backgrounds and assumptions to the study, reflexivity is crucial to understand how the qualitative analysis may be subsequently affected. In light of reflexivity, the following contextual information is provided: the lead author AC is an anaesthetist with significant experience in simulation-based medical education; JR is an organisational behavioural scientist with significant experience in simulation-based medical education and qualitative research; GMJ is an intensivist-anaesthetist engaged in undergraduate and postgraduate medical education; VNML, HKNW, RSLW are anaesthetists, and GYSC is an intensivist—all with experience in medical simulation.

Descriptive data were reported as frequency (%) or median (IQR). Questions that were evaluated with a 10-point Likert scale (1=least comfortable/confident disagree, 10=most comfortable/confident) were analysed individually as ordinal variables. Normality of data was tested using the eyeball test, skewness and kurtosis, as well as formal normality tests including Shapiro-Wilk test. To detect changes in scores before and after simulation, Wilcoxon signed-rank test was used for non-normal data. Level of significance was set at $p < 0.05$. All statistical analyses were carried out using SPSS version 22.0. The qualitative feedback was coded and thematically analysed.

Identification of workflow and system issues was documented, as well as the subsequent modifications of the guidelines and processes. The number of iterations to achieve saturation of modifications was also recorded.

RESULTS

In the operating theatre, 51 in situ simulation training sessions were carried out over 7 days in the AIIR, involving 205 staff (84.7%)—31 specialist anaesthetists (93.9%), 24 anaesthetic registrars (100%), 110 nurses (78.6%) and 40 patient care assistants (88.9%). In the ICU, 11 in situ sessions were carried out in the AIIR involving 44 ICU staff—11 intensivists and 33 nurses

and supporting staff. The utility of the simulation in the ICU for system improvement has been reported elsewhere,[39] but not the evaluation results.

Seven to eight sessions were carried out each day depending on staffing, carried out by an average of two facilitators experienced in simulation debriefing. One simulation technician provided support. Each session lasted 60 min for ICU and 70 min in the operating theatre (difference due to manpower availability), with 15 min allocated in the beginning of the OT simulation for viewing of two videos of teams managing patients with COVID-19, followed by facilitator-led discussions. Subsequently, participants practised donning of PPE, engaged in management of a confirmed patients with COVID-19, followed by debriefing with RCDP and finally doffing of PPE. Efforts were made to conserve PPE—particulate respirators were reused for clinical care, and face shields and gowns were reused within the simulation.

Programme evaluations were completed by 58.6% (146/249) of participants. Combination of operating theatre and ICU results is summarised in table 1. Overall, 139 (95.2%) respondents felt that RCDP was useful in consolidating knowledge and skills for infection control for patients with COVID-19. The full results of the evaluation can be found in online supplemental file 1.

Self-reported comfort levels for managing cases with COVID-19 were significantly improved after the simulation as were self-perceived confidence in protection of self as well as fellow staff (table 1 and online appendix 3).

The following themes were identified from the qualitative feedback in response to the question 'what was the best part of the workshop?' (table 2): improved familiarisation with infection-control workflow and procedural steps for airway management in patients with COVID-19 through in situ simulation; enhancement of team communication, confidence and competence, through interprofessional training, for management of similar cases in the future; enhancement of awareness to contamination pitfalls, and identification of practices that may put staff at risk through visualisation and debriefing; and a recognition of the positive effect of learning via video and discussion prior to simulation, as well as the process of RCDP.

Key system issues and latent safety threats in management of patients with COVID-19 from both operating theatre and ICU[39] were classified into following domains: equipment, tasks, environment, people, organisation, processes[40]; these are listed in table 3. These were communicated repeatedly with the infection control and operation teams, which resulted in system and workflow changes that were re-tested in the simulation (table 3). In both the operating theatre and ICU, eight iterations were required before saturation for system changes was reached.

DISCUSSION

In preparing for COVID-19 patient care during the early stages of a pandemic, the challenge healthcare systems faced was how to shorten the improvement cycles that optimise both staff and patient safety, psychological resilience and staff readiness all within the short time frame. Simulation-based education undoubtedly has played an important role in previous epidemics and current pandemic,[12 41] yet in a critical period when organisations are mobilising all available resources to focus on patient care, building staff capacity is not solely about skills and knowledge but also about the mutual support, collective competency and psychological resilience. Combining teamwork skills practice and system testing allows iterative improvement to be done in a timely and effective manner. At

Table 2 Themes identified through analysis of qualitative feedback of surveys

Theme	Examples
Familiarisation with infection-control workflow and procedural steps for airway management in patients with COVID-19 through in situ simulation	► 'Standardised the procedure to minimise the unnecessary communication and hiccup during the intubation.' ► 'Realising how our usual workflow is readily interrupted to facilitate adherence to infection control.' ► 'Simulation part. It reminds all of us what we should do to minimise the risk of getting infected.'

Enhancement of team communication, confidence and competence, through interprofessional training, for management of similar cases in future	► 'The need for constant and clear communication between the team caring for the simulated patient with COVID-19.'
	  ► 'Make us (*able*) to prevent infection in OT (operating theatre) (*with*) more confidence.'
	  ► 'Encourage teamwork with participation of anaesthetist, nurses and operating theatre assistants (OTAs).'
	  ► 'Involvement of different parties like nurses and OTA with reinforcement on important points.'
	  ► 'Being able to interact with the other (*interprofessional*) participants during the simulation, and sharing experience in the debriefing.'

Enhancement of awareness to areas of contamination and practices that may put staff at risk through visualisation and debriefing	► 'It helps me to find out my weak point in infectious control measure and helps me to reduce the chance of making mistake in real situation.' ► 'Sticking (attention) labels to allow participants to be more visually aware of dirty/contaminated areas.' ► 'Labelling the parts that are contaminated helps raise awareness of staff in different positions. (*Also providing*) tips on reducing infectious risks.' ► 'Reinforce memories which area inside theatre will easily be contaminated.'
Facilitation of learning via video and discussion prior to simulation	► 'It was interactive with immediate direct feedback and discussion. The video before the simulation also made learning more effective.' ► 'The demonstration videos were good as it explicitly illustrated the good example and bad example to all team members including OTA and nurses, and it served as a +ve and -ve role model for all. Its sort of 'standardised' how things should be done and we all have an understanding as to what should and should not be done before the simulation, making the simulation more meaningful.' ► 'The pre-sim video helps me to have mental preparation for both of the drill and in real situations.'
Facilitation of learning via rapid cycle deliberate practice	► 'Making us redo what was done sub-optimally was an effective way of learning too.' ► 'Feedback and repeat are useful in consolidating the knowledge through the process.' ► 'Able to practise again after feedback'.

our institution, we developed an in situ simulation programme in the operating theatre and ICU based on sound educational and relational principles and provided 'just-in-time' training for over 200 staff in 7 days. Staff showed significant improvement in comfort level and confidence for managing cases with COVID-19 after taking part in the in situ simulation training. Moreover, iterative systems testing and improvement resulted in refinement of guidelines and workflow to manage suspected and confirmed cases. Interestingly, in both the operating theatre and ICU, eight iterations resulted in saturation of system changes pertaining to infection control for aerosol-generating procedures in the respective locations.

In essence, the simulation design served a dual purpose: (1) enhance staff capabilities and confidence in management of cases with COVID-19 and (2) system improvement in preparation for the pandemic. In the true sense of mastery learning,[24 26] it is difficult to achieve it within the short time frame available with a rapidly progressing viral pandemic. Typical 'just-in-time' training may not necessarily result in performance and outcome improvements.[42] Nonetheless, evaluation of qualitative feedback demonstrated that video[43 44] with discussion was positively received, and participants verbalised that the video preparation prior to engaging in simulation likely made learning more effective. This process aligns with the theory of activation of prior knowledge and elaboration of mental models[23] of airway management,

actualised in the context of infection control. This stepwise process that includes vicarious learning[25] via video was a time-efficient adjunct to RCDP.[14] We showed that this combination resulted in enhanced staff comfort and confidence in managing cases with COVID-19, as well as increased awareness of practices and workflows to prevent infection. Moreover, in situ interprofessional training may further enhance teamwork and communication, and collective ability to manage high risk-infectious cases.

Psychological safety has been shown to play a pivotal role in learning when professionally relevant skills are at play,[15] but in the face of pandemics where concerns and stresses for personal safety are well documented,[2 3 45] it is of paramount importance to build a 'safe container' for staff, including by enhancing relational aspects of teaming during practice.[46] We achieved this in multiple ways— involving all stakeholders, especially front-line healthcare staff in the simulation and system improvement, to demonstrate the institution's commitment to their safety; providing a detailed prebrief to align learners with the goals of the simulation in preparedness for COVID-19 and the basic assumption (online appendix 1); and using videos to provide staff with knowledge basis to practise and improve upon infection-control measures in the simulation.

With regards to system testing and improvement, we applied well-documented principles[16 17 31] and performed it in a rapidly iterative manner. Previous studies have demonstrated that five to six iterations were required to fulfil system testing

Table 3 Summary of system issues and latent safety threats identified for management of patients with COVID-19 and subsequent system improvements, specifically related to operating theatre (OT), as well as common to OT and ICU[39]

Domain	Issues identified	System improvements
Equipment and drugs	Unavailability of closed suction system and incompatibility with disposable masks and circuits (OT)	Acquisition of compatible equipment and ensure availability (OT)
	Unavailability of dedicated equipment for confirmed cases, including disposable video laryngoscopes, viral filters on expiratory limb of circuits (OT)	Dedicated trolleys and equipment for confirmed cases, as well as development of equipment preparation checklists (OT)
	Inability to rapidly provide key drugs or equipment for urgent use in the AIIR—particularly those requiring patient identification and/or special registration (ICU)	Guideline amendment that additional gowned personnel, airway equipment and drugs should be immediately available in the anteroom (ICU)
	High risk of contamination of extra equipment in AIIR, may result in cross-contamination or wastage (OT)	Streamline equipment and limit unnecessary disposables in the AIIR (OT)
	Stethoscopes have high risk of contamination (OT)	Acquisition of electronic stethoscopes, as well as dedicated location for stethoscope in AIIR (OT)
	Contamination of environment with used equipment such as laryngoscopes, intubating aids, suction devices (OT/ICU)	Designated 'dirty' trolley for disposal of contaminated equipment (OT/ICU)
	Some personal protective equipment (PPE), including certain models of N95 were not immediately available in the gown up room (OT)	Ensure regular checks and availability of PPE in gown up room outside AIIR (OT)
	Connections between the bag valve mask (BVM) resuscitator, PEEP valve, mainstream CO_2 monitor, bacterial/viral filter and face mask were frequently incorrectly placed (ICU)	Additional mainstream end-tidal CO_2 sensor made available for use in ventilator circuit accompanied by guideline amendment (ICU)
Tasks	Staff were unfamiliar with donning and doffing procedures of PPE, and enter AIIR with inadequate self-protection (OT/ICU)	Provision of visual aids in the gown up and gown down areas, and emphasis placed on buddy system to cross check. Also, established on-duty 'patrol' nurse to monitor donning and doffing procedures. (OT/ICU)
	Personal belongings such as mobile phones were not taken out before donning of PPE, with risk of contamination, as well as inability to communicate with staff outside AIIR (OT/ICU)	▶ Provision of visible signage in the gown up and anteroom to remind staff to put down personal belongings in the AIIR, as well as disposable plastic bags for hospital phones/pagers if needed to be brought into AIIR (OT). ▶ Extra dedicated hospital mobile phone available inside and outside the AIIR, with use of speakerphone to allow easy communication and forwarded calls (ICU).
	Inadequate airway and equipment planning, and allocation of tasks during intubation within the AIIR (OT/ICU)	Establishment of equipment and drug checklists for intubation in AIIR, as well as visible cognitive aids for pre-intubation checks within the AIIR (OT/ICU)
	Rapid cycle deliberate practice to enhance muscle memory and cognitive processes for circuit disconnection, as well as frequent cross-checking to maintain situation awareness as a team (OT)	Failure to pause or standby ventilator before circuit disconnection, due to cognitive overload during stressful induction (OT)
	Gas leakage around endotracheal tube due to inadequate cuff insufflation upon commencement of positive pressure ventilation, as well as leakage during cuff pressure checking (due to intrinsic problem of cuff pressure monitor (OT/ICU)	Modification of guidelines to recommend confirmation of correct endotracheal tube position by the observation of end-tidal carbon dioxide and ensure cuff inflation prior to commencement of mechanical ventilation; as well as standby of ventilator during cuff pressure monitoring (OT/ICU)
Environment	Staff are unfamiliar with the location of the donning and doffing rooms for the AIIR in the OR, and often breach the interlocking doors between the ante room and the AIIR (OT)	Provide signage that clearly points out the donning and doffing rooms, as well as physical barriers around the handles that can manually override the interlocking doors (OT)
	Lack of clear signs to indicate the presence of a high-risk patient within the AIIR in the OT, which at other times may be used for non-infectious cases (OT)	Clear signs that indicate high risk patient (COVID-19) within the AIIR in the operating theatre (OT)
	It is unclear to staff which surfaces are clean and which surfaces are contaminated during management of patients with COVID-19—some surfaces are inevitably contaminated such as the ventilator on the anaesthetic machine as well as the control knobs (OT)	Development of 'contamination grid' to identify clean versus contaminated surfaces, and provision of 1:49 chlorine wipes to readily clean contaminated surfaces (OT)
	Confusion as to where doffing should take place, particularly in the operating theatre design of the AIIR is different from wards. (OT/ICU)	Clear signs to indicate where to gown down, as well as education of staff of the design of the AIIR (OT/ICU)
	Proximity of staff during doffing of PPE, resulting in possible cross contamination (OT/ICU)	Clear signs to indicate that only one person should be in the gown down room at a time (OT/ICU)
People	There were physical barriers to support and additional equipment during patient management, especially in operating theatre where the AIIR is far from other rooms. (OT/ICU)	Dedicated standby backup/runner (with PPE protection) immediately outside AIIR to provide timely support and acquisition of equipment if needed (OT/ICU)
Processes	Unclear workflow for transfer and handover of cases with COVID-19 to AIIR, including risk of cross-contamination of non-infected patients, and when doffing should occur when transferring a patient out of the AIIR for the operating theatre (OT)	Revision of the guidelines to ensure clarity of the workflow of handover and transfer of patients with COVID-19 (OT)
Organisation	Only 55% of staff working in the operating theatre had updated N95 leak test performed, with some staff up to 10 years outdated (OT)	Plan for liaison with hospital infectioncontrol team for provision of timely N95 fit test for staff protection (OT)
	Staff unclear as to criteria for utilisation of isolation theatre for suspected or confirmed cases (OT)	Clarification in the guidelines and protocol for criteria for use of isolation theatre (OT)

ICU-specific system issues and improvements are published elsewhere.[39]

AIIR, airborne infection isolation rooms; ICU, intensive care unit; PEEP, positive end-expiatory pressure.

requirements.[36 47] For us, the eight iterations required to reach saturation for system improvement were comparable, and the higher number of repetitions required could be explained by the complexity of combining the needs of individual learning and system improvement. This finding may be useful for future system integration studies, and certainly in the current time-sensitive climate, it shows that system improvement can be accomplished within an achievable time frame.

Limitations

Despite the promising findings for the 'just-in-time' simulation training for COVID-19 preparedness in our institution, it is unclear whether staff are able to translate the knowledge, skills and attitudes to clinical practice, and whether there is knowledge retention in the immediate and long term. Particularly since the time frame for preparedness is short, mastery learning may not be fully attained despite efforts to use RCDP to enhance knowledge and skill development. Moreover, we focused our training and system improvement on the highest risk procedure in our department, yet there are other workflow and processes that need to be tested in such an iterative manner in the current pandemic.

CONCLUSION

It is difficult for healthcare institutions preparing for the pandemic to improve staff capacity and system readiness under the immense time pressure. The uncertain pathophysiology of the disease, continually changing clinical care pathways and infection-control measures, new teams and unfamiliar spaces—all combined with heightened anxiety—make the development of both psychological and technical readiness a challenging task. This study provides empirical support for the idea that building technical and team skills, improving systems and workflows, and providing psychological support can be done simultaneously. We used a process that incorporated vicarious learning paired with rapid skill and interprofessional team relationship building, as well as concurrent system testing to optimise both staff and patient safety within the short time available. We found that building healthcare workers' technical skills in the context of team tasks helped them function as a competent collective that supports and assists each other. We think this process may help bridge the gap between individual skills and vigilance, and ideal practice.[20]

This study describes how we prepared staff who were going to perform high-risk aerosol-generating procedures while minimising exposure, both technically and psychologically. This translational simulation-based healthcare training played a critical role in staff readiness and allowed staff to gain confidence in personal protection and infection control before treating actual patients. We reported how, pressed by time and by the exigencies of protecting staff from exposure to COVID-19 in the early days of the pandemic, the Department of Anaesthesia and Intensive Care at Prince of Wales Hospital in Hong Kong, designed and deployed 51 learning sessions for over 200 clinical staff in 7 days. Our approach effectively and efficiently achieved success in the domains of staff capacity and confidence building, teamworking and system improvement using an iterative process we dub 'rapid cycle system improvement'.

What is already known on this subject

► Translational simulation can be used to diagnose and improve health system processes, patient outcomes, as well as relational coordination among clinicians.
► In the rapidly advancing pandemic of COVID-19, translational simulation is instrumental in effectively transforming health systems for pandemic preparedness.
► In simulation-based medical education, vicarious and direct perspectives, rapid cycle deliberate practice, psychological safety and knowledge elaboration can enhance learning.

What this study adds

► Focusing on 'rapid cycle system improvement' provides a unifying structure for translational simulation that simultaneously supports individual skill building, collective and team competence, and process improvement.
► Employing educational strategies to provide a 'learning oasis' for staff in a rapidly progressing pandemic is important, such that they can 'doff' their stress and anxieties, and focus on learning and improving skills to face clinical and infection control challenges.
► Engaging staff in systems improvement in the COVID-19 pandemic may enable them to trust that the organisation that they are working in is constantly improving to ensure patient, as well as their own safety.

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