Process-Oriented In Situ Simulation Is a Valuable Tool to Rapidly Ensure Operating Room Preparedness for COVID-19 Outbreak

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Summary Statement: Process-oriented in situ simulation has been gaining widespread acceptance in the evaluation of the safety of new healthcare teams and facilities. In this article, we highlight learning points from our proactive use of in situ simulation as part of plan-do-study-act cycles to ensure operating room facility preparedness for COVID-19 outbreak. We found in situ simulation to be a valuable tool in disease outbreak preparedness, allowing us to ensure proper use of personal protective equipment and protocol adherence, and to identify latent safety threats and novel problems that were not apparent in the initial planning stage. Through this, we could refine our workflow and operating room setup to provide timely surgical interventions for potential COVID-19 patients in our hospital while keeping our staff and patients safe. Running a simulation may be time and resource intensive, but it is a small price to pay if it can help prevent disease spread in an outbreak.
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Key Words: Coronavirus disease, pandemic, preparedness, in situ simulation, operating room workflow.

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The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causing coronavirus disease 2019 (COVID-19)[1] was first reported in Wuhan, China, on December 31, 2019. At the time of writing, SARS-CoV-2 has infected more than 3 million people globally and caused more than 200,000 deaths.[2] Given the rapid domestic and international spread, the World Health Organization declared COVID-19 a pandemic on March 11, 2020,[3] triggering rapid escalation of outbreak response measures worldwide. The mechanisms of human-to-human transmission of SARS-CoV-2 are likely contact, droplet, and possibly airborne, especially in high-risk aerosol-generating procedures.[4] Data suggest that the transmissibility of SARS-CoV-2 is moderate to high, with a basic reproduction number (R0) ranging between 2 and 3[5–7] and a mortality rate estimate of 5.7%,[8] this number varying widely across different geographical regions and patient characteristics.[9,10] In Singapore, we saw our first confirmed imported case of COVID-19 on January 23, 2020.[11] Given the high infectivity and subsequent rapid community spread, hospitals nationwide under the leadership of a multiministerial task force formed by the Singapore Government rapidly implemented measures aimed at containing and mitigating the risk of imported cases and community transmission. In hospitals, these included enhanced surveillance, administrative and environmental controls, environment hygiene, correct work practices, and appropriate use of personal protective equipment (PPE), in keeping with recommendations from the World Health Organization[12] and Centers for Disease Prevention and Control.[13]

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As anesthesiologists, we identified the urgent need to change our clinical practice and operating room (OR) workflow to minimize risk of spread among staff, patients, and the public, while continuing to deliver safe and competent patient care. Drawing from lessons learned during the outbreaks of severe acute respiratory syndrome (SARS),[14–16] influenza A (H1N1), and the middle east respiratory syndrome (MERS), and practical recommendations based on current understanding of COVID-19,[4,6] our department embarked on disease outbreak response efforts in coordination with surgical, nursing, and other allied health staff to address the different phases of this evolving pandemic. These included engineering controls, administrative measures, introduction and intensive training on the use of PPE and powered air-purifying respirators (PAPRs), and, finally, formulation of clinical guidelines for anesthetic management.[17]

The role of simulation to assist and amplify preparedness during disease outbreaks is increasingly being recognized worldwide. This was especially borne out during the Ebola virus disease epidemic, with simulation used both at the hospital[18–21] and national levels to enhance operational readiness.[22,23] Traditionally, pandemic preparedness tended to focus on the emergency departments and critical care facilities as these are areas that will experience a surge in patients first. Although surgery is rarely mentioned in the literature surrounding the previously mentioned outbreaks, it had been described in COVID-19 patients,[24] prompting organizations such as the American College of Surgeons to develop best practices and guidance that specifically target the concerns and challenges surgeons face.[25] In addition, as there have been unconfirmed reports of transmission before symptoms show and develop, it may be challenging to identify and isolate patients carrying the virus before deciding to institute appropriate OR precautions. To the best of our knowledge, there is no prior work published on the use of simulation in preparing the OR for urgent/emergent surgical cases during outbreaks. Our article aims to

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highlight important learning points from our proactive use of in situ simulation to ensure OR facility preparedness. These may be beneficial for hospitals and simulation communities across the world, as we systematically prepare ourselves to deal with this COVID-19 pandemic or other highly communicable disease outbreaks in the future.

METHOD

Background of Isolation OR Arrangement and Workflow

Our hospital, Singapore General Hospital (SGH) is the oldest and largest academic and tertiary acute care hospital in Singapore, with 1700 beds and 55 ORs. As part of engineering controls, a single OR located in a standalone urology OR complex was designated the dedicated OR for COVID-19 patients requiring surgery. This location was selected to reduce exposure and cross infection of other elective patients as it is situated at one corner of the hospital campus away from the main OR complex and areas of high human traffic flow. The urology OR complex also houses 2 other larger ORs. The chosen COVID-19 OR shares an induction room with its neighboring OR, where elective urologic surgery is performed. Although a negative pressure OR is ideal, the standard OR is usually designed to be a positive pressure room with laminar airflow. Because of lack of time for major structural changes and other engineering constraints, it was not possible to change our ORs to be negative pressure rooms. As such, we recommended that personnel not needed for intubation remained outside the OR until anesthesia induction and intubation were completed, re-entering only after the air changes in the OR have filtered out as much viral load as possible.[25,26] In our instance, the high frequency of air changes (25 per hour) would rapidly reduce the viral load within the OR by 99% in less than 14 minutes,[27] so our workflow allowed personnel to safely reenter the OR 15 minutes after intubation if the patient was stable. Along with this, we formulated an activation workflow incorporating the administrative, logistics, and infection control measures that should be undertaken when this COVID-19 OR is activated. This included coordination of staff, movement of elective urology cases in neighboring ORs to other ORs, transport of surgical and anesthetic equipment, infection prevention practices, and decontamination after the procedure. However, this proved to be challenging because it involved a location and setup unfamiliar to most surgical disciplines, untested logistics, new intrahospital patient transport process, multidisciplinary coordination, and new staff mix. Our workflow also had to keep up with the rapidly changing infection control, containment and mitigation measures whenever new epidemiological data surfaced as the pandemic situation evolved. We felt that process-oriented in situ simulation, examining the process of care rather than the outcome,[28] would be a powerful and rapid tool to help enhance both individual (training the health care worker to effectively deliver care while minimizing risk to self and others) and system preparedness (identifying potential deficiencies and latent threats in our workflow) so that these can be addressed before a COVID-19 patient presents for surgery. In situ simulation has been used in a variety of clinical contexts, including preimplementation testing of clinical services[29] and in formulating operating protocols to mitigate outbreaks.[30,31] The use of in situ simulation has been shown to improve patient safety,[32,33] clinical skills, teamwork, and observed behaviors,[34,35] prompting our use for this purpose.

Simulation Objectives

The objectives of our in situ simulations were manifold. Firstly, we wanted to identify latent safety threats in our workflow and potential breaches in infection control before they could result in clinical harm. This is especially important when dealing with an infectious disease outbreak where virus spread can be rapid and deadly. Secondly, we sought to test preparedness of the outbreak OR facility, focusing on domains which we thought were key determinants of facility preparedness: (1) readiness and responsiveness (response time), (2) adaptability and suitability to cater to a variety of cases, (3) adherence to infection control measures, and (4) capability to deal with perioperative crisis. Lastly, we wanted to ensure individual preparedness, both in terms of technical familiarity and proficiency in the use of PPE/PAPR, and psychological readiness in delivering care to patients with an infectious respiratory viral disease.

Simulation Design

Our hospital-based simulation program, accredited by the Society for Simulation in Healthcare, consists of interdisciplinary staff trained as simulation faculty, some of whom are Certified Healthcare Simulation Educators with many years of experience as educators in their own fields. These faculty were responsible for simulation design, implementation, and debriefing. We conducted all simulations in situ in the COVID-19 OR. To achieve the previously mentioned objectives, simulation scenarios were conducted as part of plan-do-study-act (PDSA) cycles for rapid improvement. They were designed and planned based on needs expressed by the various surgical departments and cases that we thought would be resource intensive with potential for breach in workflow and safety. In addition, input was sought from hospital and nursing leadership and administration. Key stakeholders including the OR nursing team, isolation ward nurses, anesthesiologists, surgeons, infectious disease specialists, infection prevention and epidemiology (IPE) specialty nurses, OR technicians, security officers, and environmental services staff were involved right from the start. Having long recognized the value of simulation in developing collaborative programs to enhance patient safety, health care delivery, and operational readiness, our hospital administration was fully supportive of this simulation initiative to help achieve timely pandemic preparedness. All participants were excused from clinical duties to participate in these simulation exercises. No additional funding was required as we had enough equipment and consumables to address both educational and operational needs. In our institution, quality improvement projects, such as ours, where participants are not subject to additional risks or burdens beyond usual clinical practice, do not require review by the institutional review board.

Stages of Implementation

We conducted the simulations in 2 stages for 12 days to achieve our objectives, with each simulation session representing the "do" component of the PDSA cycle. Each simulation session tested the entire workflow covering all 3 phases of operations—

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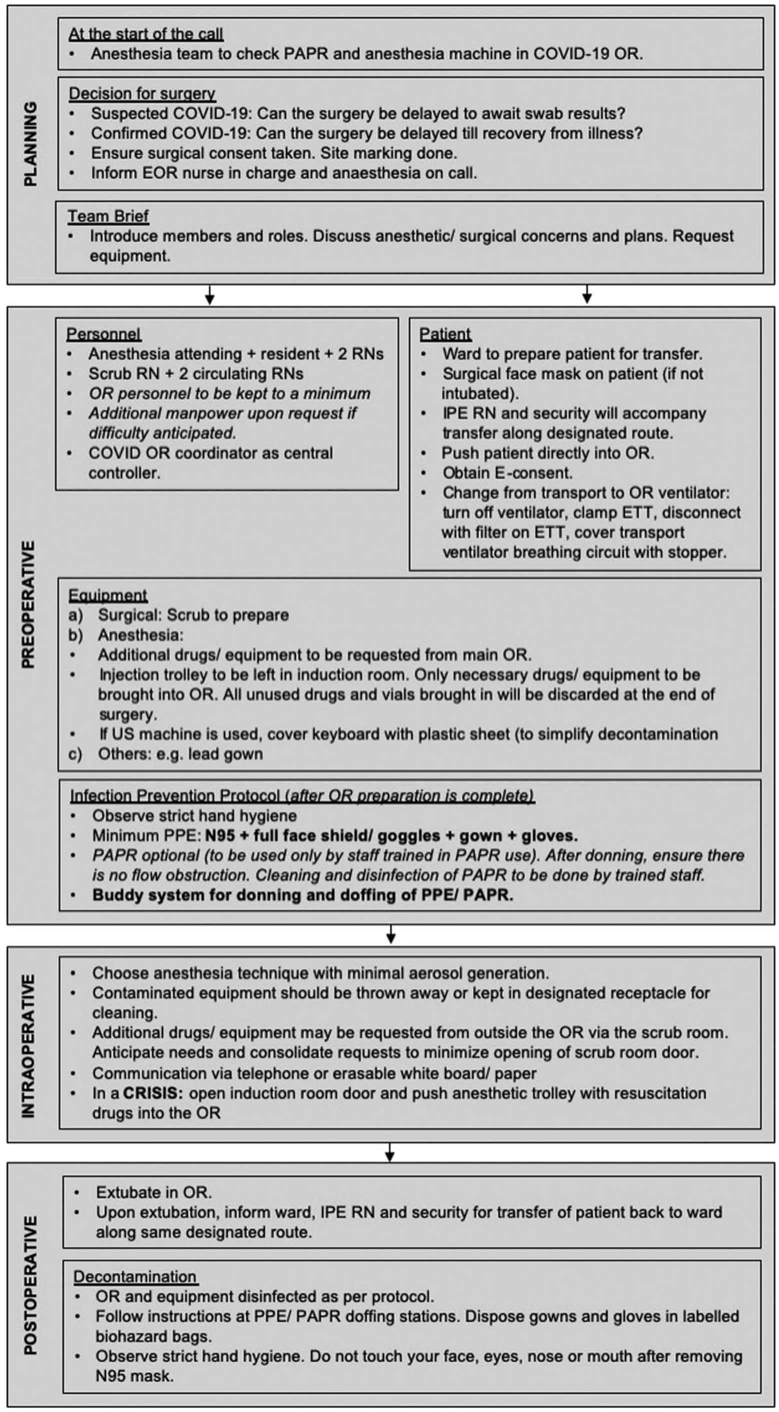

FIGURE 1. Activation workflow and concept of operations for COVID-19 OR. EOR, emergency operating room; ETT, endotracheal tube; RN, registered nurse; US: ultrasound.

preoperative (activation and setup of COVID-19 OR and transfer of patient from isolation ward/intensive care unit [ICU] to OR), intraoperative, and postoperative/decontamination (Fig. 1). At least 2 simulation faculty members with experience in identifying latent threats were present during each simulation session to observe and take notes. In stage 1, there were 2 scenarios involving the use of a simulated patient. The first scenario involved the obstetric and neonatal teams managing a parturient with COVID-19 requiring emergency lower segment cesarean section (LSCS). In our hospital, all operative deliveries are performed in the obstetric OR located in the main OR complex, next to the labor and delivery suite. We do not have an OR within the labor and delivery suite. Hence, this scenario was designed to deliberately focus on the challenges of transfer of parturient and neonatal resuscitation equipment to the COVID-19 OR, isolation of neonate postdelivery, and coordination between teams unaccustomed to working in this new environment. In this case, the neonate would need to be isolated and brought to the adjacent induction room/anteroom to be cared for by a dedicated neonatology team in PPE because of possible vertical transmission of SARS-CoV-2.[36–38] The second scenario involved the interventional

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TABLE 1. Summary of Simulation Sessions

	Objectives	Added Rationale Behind Choice of Simulation Scenario	Location of Simulation (Progression)	Simulation Participants	Simulators Used	Length of Session
PDSA 1 (scenario 1: emergency LSCS)	1. To identify latent safety threats (classified into process, infection control, and equipment/PPE-related threats) in our COVID-19 OR activation workflow. 2. Test preparedness of COVID-19 OR facility*. 3. Improve individual preparedness (including technical proficiency in use of PPE/PAPR).	• Challenges of transfer of parturient and neonatal resuscitation equipment, isolation of neonate postdelivery, and coordination between obstetrics and neonatal teams unaccustomed to COVID-19 OR.	Isolation ward → *OR* → isolation ward	• Isolation ward RN • IPE RN • Security officers •Anesthesia attending + resident +2 RNs • Scrub RN + 2 circulating RNs • Attending surgeon/ proceduralist +1 or 2 assistant surgeons •COVID OR coordinator • Environmental Services staff	Standardized patient	4.5 H
PDSA 2 (scenario 2: IR)		• Challenges of moving equipment and personnel out of their traditional care area.	Isolation ward → *OR* → isolation ward		Standardized patient	4 H
PDSA 3 (scenario 3: GI hemorrhage with crisis)		• Need to rapidly mobilize resources, engage multiple disciplines, and maintain integrity of infection control measures during resuscitation.	Isolation ward → *OR* → isolation ICU		SimMan 3G high-fidelity manikin	5 H

*In testing the preparedness of the COVID-19 OR facility, we focused on the following domains: (1) readiness and responsiveness (response time), (2) adaptability and suitability to cater to a variety of cases, (3) adherence to infection control measures, and (4) capability to deal with perioperative crisis.
RN, registered nurse.

radiology (IR) team performing percutaneous transhepatic biliary drainage on a COVID-19 patient with biliary obstruction. The IR team had to move and set up their imaging equipment to work in the COVID-19 OR. Such an arrangement was made to protect people and spaces in the IR facility from contamination in the context of an airborne threat as other elective procedures were still ongoing there. Hence, this scenario focused on the challenge of moving equipment and personnel to the COVID-19 OR as opposed to moving the patient to the usual IR facility. Both simulation scenarios took place during office hours. Security personnel were stationed at strategic entry points to cordon the area off and direct people away from the COVID-19 OR to minimize personnel exposure.

In stage 2, we introduced a resuscitation scenario using a high-fidelity manikin. The scenario involved the general surgeons needing to emergently operate on a COVID-19 patient who developed massive hemorrhage from a bleeding stress ulcer, complicated by a brief period of pulseless electrical activity after induction of anesthesia. The participants were expected to apply the Advanced Cardiac Life Support algorithm, call for help, send for blood products, check blood products, and initiate massive blood transfusion using a rapid infuser. This scenario challenged the need to rapidly mobilize resources, engage multiple disciplines, and maintain integrity of infection control measures during a resuscitation.

At the end of each simulation scenario, debriefing was conducted by simulation faculty members and served as the "study" component of the PDSA cycle. Senior staff from hospital and nursing administration, IPE, environmental services, and biomedical engineering served as subject matter experts during these debriefs. The findings and recommendations were documented in postsimulation reports that were then shared with the various stakeholders and hospital and nursing leadership in a timely manner. Some of these deficiencies were corrected on the spot during the simulation. Follow-up actions ensued for the rest, and process improvements were made to our OR workflow after each simulation. These constituted the "act" component of the PDSA cycles, with changes made in time to be re-evaluated in the subsequent simulation session.

Details for each simulation session, including rationale behind each scenario, location, staff involved, duration, and resources used can be found in Table 1.

TABLE 2. Number of Threats Identified, Classified Into Process Threats, Infection Control Threats, and Equipment/PPE Issues

	Process Threats	Infection Control Threats	Equipment/PPE Issues
PDSA 1 (scenario 1: emergency LSCS)	15	7	4
PDSA 2 (Scenario 2: IR)	11	8	5
PDSA 3 (Scenario 3: GI hemorrhage with crisis)	8	6	1

RESULTS

Issues Identified and Rectifications

We identified a large number of latent threats within the initial system and setup that can be classified into process threats, infection control threats, and equipment/PPE issues (Table 2). The cumulative number of threats was observed to decrease with each simulation/PDSA cycle despite different surgical disciplines and personnel involved, indicating that the solutions were effectively integrated into the system and sustainable. Additional threats were identified with each PDSA cycle despite implementation of proposed solutions from the previous round, indicating the usefulness of PDSA cycles to assess for results or unintended consequences of these solutions. Activation time reduced from 46 minutes in PDSA 1 (scenario 1: emergency LSCS) to 22 minutes in PDSA 3 (scenario 3: gastrointestinal [GI] hemorrhage with crisis). Table 3 gives a summary of major issues identified under the various domains important for isolation OR facility preparedness (readiness and responsiveness, adaptability and suitability to cater to a variety of cases, infection control measures, and capability to deal with perioperative crisis), and solutions for these individual aspects to augment facility preparedness.

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TABLE 3. A Summary of Major Issues Identified Under the Various Domains Important for Health Care Facility Preparedness and Rectifications Done

Issues	Rectifications
1. Readiness and responsiveness	
The process of transporting the COVID-19 patient from isolation ward to OR was complex.	We clarified and streamlined the transport process with relevant parties involved.
There was severe lack of space in the COVID-19 OR vicinity.	The entire urology operating complex containing 3 ORs was made the dedicated OR facility for COVID-19 patients, increasing the space available.
There was no identified backup OR should the single COVID-19 OR be used by another case.	With the urology OR complex dedicated to COVID-19 cases, there will be 3 ORs available.
Activation time was unacceptably long if the cases had to be done emergently. Staff were unfamiliar with the multistep activation process.	We streamlined the OR activation process. Role and task allocation were clarified. An overall COVID-OR coordinator was appointed. A team brief will be done with all involved parties upon activation.
2. Adaptability and suitability to cater to a variety of cases	
Each time the COVID-19 OR was activated, equipment specific to each surgical discipline had to be pushed over from the major OR complex. This resulted in a delay in getting the OR ready to receive the patient.	Some of the equipment can be parked at the dedicated COVID-19 OR complex so that setup time can be significantly reduced.
3. Infection control measures	
There was a lack of familiarity with PPE/PAPR among hospital staff.	Educational videos were made available on the hospital and department intranet. Posters were placed at each PPE/PAPR station to serve as visual and cognitive aids. Deliberate practice was intensified.
There were no designated PPE/PAPR donning/doffing stations	With increased space from the takeover of the urology OR complex, we set up designated and clearly demarcated PPE/PAPR donning and doffing stations.
Some PAPR units malfunctioned during the exercises.	Defective sets were replaced. Powered air-purifying respirator units are checked at the start of each shift to ensure functionality.
There was inappropriate donning and doffing of PPE/PAPR. Several areas of the body were still exposed after donning the PPE.	We introduced a buddy system so that staff could help guide one another and ensure no breaches in infection control. We also assigned spotter roles to 2 nurses in the team who will ensure that staff are properly protected.
The patient may contaminate the paper consent form when he/she is signing it.	We introduced electronic consent taking to remove the possibility of contaminated forms.
4. Capability to deal with perioperative crisis	
It was difficult to recognize people when fully gowned in PPE and goggles.	We used role stickers stuck on scrub caps to facilitate role identification.
It was difficult to communicate clearly when one was wearing the PAPR hood.	We relied on nonverbal methods such as hand signals and eye contact to achieve closed loop communication.
Wearing the PAPR impaired the vision and hearing of the anesthesiologists, resulting in reduced situational awareness	We reminded the leader to position himself/herself to gain clear oversight of the situation and turn up the volume of the monitors.
There was hesitation in pushing the crash cart into the OR for fear of contaminating unused supplies.	We provided a scaled-down resuscitation trolley that would contain enough drugs for initial use in a resuscitation, with early activation of help to obtain more drugs/equipment.
There was significant delay in the arrival of help in a crisis, as responding staff would require time to don PPE/PAPR.	We emphasized that the call for help must be made at the first sign of trouble. If the case is expected to be potentially unstable or complex, increased manpower should be anticipated before the start and activated from the beginning.

First, the most pertinent process threat identified was that the limited physical space of the single designated COVID-19 OR would not allow us to achieve our dual aims of timely surgical care for the COVID-19 patient while maintaining staff and public safety. There was inadequate space for proper donning and doffing of PPE and PAPR. The space constraint may also lead to potential inadvertent cross-contamination of surroundings during movement of patient, OR personnel, and additional bulky equipment such as the neonatal transport incubator, or an extracorporeal membrane oxygenation machine.

During the LSCS scenario, neonatal resuscitation and aerosol-generating procedures, such as airway suctioning and intubation, were performed in the induction room/anteroom. The available space in the induction room was limited and would not be able to accommodate a twin delivery. There may also be inadvertent cross-contamination of other equipment stored in the cabinets of the induction room. Only 1 of the 3 ORs in the urology operating complex was designated the COVID-19 OR. The other 2 were still being used for elective surgeries for noninfected patients. If an additional patient with COVID-19 were to require emergency surgery while the existing COVID-19 OR was in use, elective patients in the neighboring OR will need to be urgently transferred back to main OR complex, posing a safety threat. Furthermore, postsurgery decontamination with either hydrogen peroxide vaporization or ultraviolet-C irradiation meant that the sole COVID-19 OR will be rendered unavailable for up to 4 hours. This would delay timely patient care. Given the space constraints and operational considerations identified, the simulation team therefore proposed that all elective urology cases be shifted to the main OR complex so that the entire urology operating complex housing 3 ORs can be used as a dedicated facility for COVID-19 cases. This would allow multiple ORs to be always in a ready-to-use state for rapid deployment in the event of 2 concurrent urgent/immediate priority cases, obviating the need to urgently transfer elective patients back to the main OR. There would also be more space for movement of personnel and equipment and for proper PPE/PAPR donning

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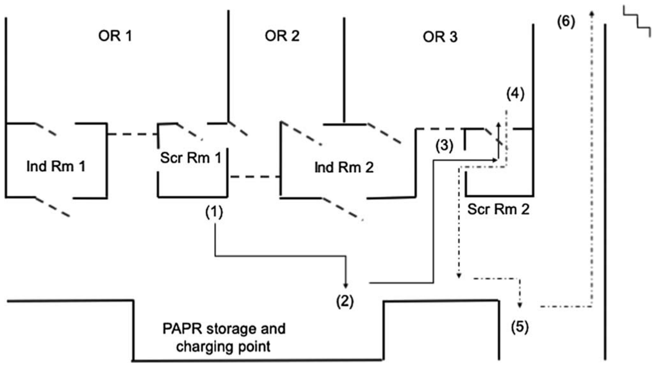

FIGURE 2. Floor plan of the urology OR complex. Initially only OR 3 was designated the COVID-19 OR. Subsequently, the entire urology OR complex was adapted to be a dedicated facility for COVID-19 cases, allowing proper PPE/PAPR donning/doffing areas and multiple ORs in a ready-to-use state for rapid deployment. Solid arrows show ingress into OR 3. (1) N95 respirator station → (2) PAPR and PPE donning station → (3) enter OR 3 via scrub room door. Dotted arrows show egress from OR 3 at the end of surgery. (4): PPE doffing area → exit via scrub room → (5) PAPR doffing station → (6) personnel exit staircase to change room to shower. During the surgery, personnel in the OR are not allowed to step out. Two runners wearing PPE are stationed outside the OR and can obtain additional drugs or equipment. These will be placed on a trolley in the scrub room for the OR team to retrieve. The process is reversed if the OR team needs to send out specimens such as blood samples. The blood tubes will be cleaned with disinfectant wipes and left on the trolley for the runners to retrieve. Communication is via telephone or erasable white board/paper. All doors leading to the OR, except the scrub room door, are locked during surgery to minimize environment contamination. Ind Rm, induction room; Scr Rm, scrub room.

and doffing areas to be setup (Fig. 2). This proposal was quickly approved by the hospital leadership and setup was completed within 3 days. In addition, as part of hospital surge capacity planning, elective surgeries were reduced, hence freeing up manpower and rotatable OR spaces.

The second process threat identified related to hospital staff being unfamiliar with the multistep COVID-19 OR activation workflow as it involved coordinating multiple disciplines, movement of equipment, setup of OR, infection control measures and patient transport, on top of having to care for the patient, and protecting themselves and one another at the same time. We recognized that the cognitive load would be immense. Hence, we saw the need to appoint an overall COVID-OR coordinator who would be familiar with the entirety of the workflow and would not be directly involved in the care of the infected patient. The senior anesthesiologist may be preoccupied with the clinical care of the patient and may not have the mental bandwidth to fulfill this coordinating role. The COVID-OR coordinator's main role was to help coordinate, direct, and guide the anesthesia, surgical and nursing teams coming in who may be unfamiliar with the COVID-19 OR setup and advise on infection prevention measures specific to them. A single coordinator in OR worked for us as we adopt a decentralized command and control structure. Other care areas had their own coordinators and these coordinators maintained close communication to orchestrate the overall process. We introduced a team brief into the workflow, to be done by the anesthesia, surgical, and nursing teams before they started preparing the OR so that role clarification, task allocation, and appropriate equipment could be requested and prepared beforehand to minimize personnel movement in and out of the rooms after the infected patient arrived. To help this process further, an activation checklist was devised to serve as a memory aid during activation. Finally, because it was difficult to train all of the department's staff to be familiar with the COVID-19 OR workflow, we focused on training a subset of anesthesia residents and attendings as these personnel formed the core group doing shifts in the emergency OR who would be caring for the COVID-19 patients should they present for surgery.

Before this, a comprehensive program for the use of PPE/PAPR had been enforced. Subject matter experts from the Department of Occupational and Environmental Medicine conducted hospital-wide training for PPE donning and doffing, including the initial train-the-trainer sessions for a cross-section of key clinical members in our department. However, during our simulation exercises, we identified many instances of inappropriate donning and doffing of PPE/PAPR and found that it was difficult to ensure that the perioperative management team was properly protected by their PPE, especially when pressed for time in an emergency situation. In response to this, we encouraged staff to regularly review the educational materials and videos that were easily accessible on the hospital intranet. Deliberate practice of PPE/PAPR donning and doffing was also intensified for the select perioperative teams to attain both knowledge and skills competency. With the entire urology OR complex dedicated for COVID-19 cases, we now have the space to designate central PPE/PAPR donning and doffing areas, putting up pictorial guides as cognitive aids to guide the individual through the process. Powered air-purifying respirators sets are prechecked by the on-duty anesthesia team at the start of each day and individually packed and labeled to facilitate rapid donning. We reinforced the concept that a buddy system should be used whenever staff don PPE/PAPR so that they can look out for each other. In addition, specific members in the care team have been appointed to act as spotters to help identify any potential or actual breeches during the donning/doffing process, adding an additional layer of safety and assurance that everyone on the team would be appropriately protected. At the end of the case, the scrub nurse runner would supervise the proper doffing of PPE by the surgical team so that the surgeons will not inadvertently contaminate themselves or the environment.

The process of consent taking was identified as a key infection control threat in PDSA 1 and 2 (Table 2). Our hospital uses paper consent forms, which raised the question of how to prevent the paper consent form and pen from being contaminated for this group of patients. To get around this, we introduced electronic consent taking on the PDF version of the consent form with a laptop with touchscreen capabilities. This allowed the addition of free texts and signatures by signing or typing on the screen itself. The laptop was protected with a clear plastic sheet that allowed for easy cleaning and decontamination at the end of the case. Should a hard copy consent form be required for filing subsequently, it can be printed out by wireless connection to a nearby printer.

Finally, the resuscitation simulation scenario allowed us to identify difficulties with perioperative resuscitation in PPE and PAPR. These constituted most process and infection control

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threats in PDSA 3 (Table 2). The team faced mobility limitations, challenges in communication (both internally within the OR care team and externally with "runners" stationed in the "clean" area outside) and reported impaired situational awareness because of reduced peripheral vision and auditory input. Communication difficulties in PAPR were compounded by our efforts to minimize flow of contaminated air by locking all doors to the OR during surgery, such that there was only one possible route for entry/exit via the scrub room. In addition, there would be an inevitable delay in arrival of help as these additional personnel would require time to come in because of the distance of the COVID-19 OR from the main OR complex, as well as the need to don PPE before entering the OR. Finally, bringing an entire resuscitation cart into the OR would lead to inadvertent contamination and wastage of unused equipment and supplies. During the debriefing, we discussed the need to rely on other nonverbal methods to achieve closed loop communication such as eye contact and hand signals to seek acknowledgement. An erasable white board and an additional cordless phone were provided as means of external communication with personnel in "clean" areas outside of the OR. Help should be activated early as time is needed for additional personnel to be appropriately protected with PPE/PAPR before entering the resuscitation.[4] Small prepacked resuscitation kits or a scaled down resuscitation trolley containing standard advanced cardiac life support resuscitation drugs such as epinephrine and amiodarone (as adopted in our case) can be prepared to reduce wastage.

DISCUSSION

We describe the use of process-oriented in situ simulation in a series of PDSA cycles to both refine our OR activation workflow and test our OR preparedness to manage COVID-19 patients presenting for surgery. Simulation-based training (whether conducted in situ or in simulation centers) can help with several aspects of disease outbreak preparedness, including proper use of PPE,[31,39] understanding of what the protocols are and how to follow them,[31] testing the local environment to make sure local teams and environment are in compliance to the PPE and protocol adherence,[18] and opening it up to human factors and resilience engineering. Baers et al[30] described a collaborative approach with specialists in infection prevention and control and human factors, combining the strengths of both person-specific and systems-level approaches in the process of identifying hazards leading to potential contamination of health care workers with Ebola. Finally, Biddell et al[18] described the rapid deployment of a multimodality simulation approach within 12 hours to assess hospital preparedness for ebola virus disease in the emergency department, transport team, pediatric ICU, and interdepartmental transfers. They concluded that an organization's investment in a robust simulation program allowed for swift action and was crucial to appropriate disaster preparedness, whether it is related to an infectious disease or a mass-casualty event.[18]

Many latent threats and operational challenges were identified during our simulations, leading to implementation of many useful changes by the end of the third PDSA cycle. The team brief immediately after activation allowed role clarification and clear task allocation. Operating room responsiveness was further amplified by the appointment of a COVID-19 OR coordinator who acted as a central controller. Clearly designated and sequentially labeled PPE/PAPR donning and doffing stations ensured staff protection and safety. Infection control measures were further safeguarded by the introduction of a buddy system and spotters. Most importantly, in situ simulation allowed us to identify and address novel problems that were not apparent in the initial planning stage, the most significant being the lack of space in the original designated COVID-OR area. Results of the in situ simulation revealing multiple hazards resulting from this lack of space had a significant impact on influencing the executive decision to dedicate the entire urology OR complex to COVID-19 cases. This was a significant step forward and allowed the implementation of many downstream interventions that further enhanced facility preparedness. Prepacked surgical instruments and anesthetic equipment can now be stored there, such that the OR is in a ready-to-use state. Previously, all equipment had to be moved over from the main OR complex upon activation and the COVID-OR set up from scratch. Three ORs are now available for rapid mobilization should there be more than 1 COVID-19 patient requiring emergency surgery simultaneously.

Next, the resuscitation scenario allowed us to identify additional barriers to effective crisis management during a resuscitation such as difficult communication, impaired situational awareness, fear of being infected during high-risk resuscitation, and delay in arrival of help. The urgency of the clinical situation may result in inadvertent breaches of infection control measures, and participants were made cognizant of these by the infection prevention nurse during the exercise.

All in all, through our simulation exercises, we were able to improve OR responsiveness and readiness by streamlining the ward transport process and refining the OR activation workflow. By the third PDSA cycle, COVID OR was set up by 22 minutes, and the case arrived in OR within 30 minutes. With this response time, it would be possible to perform virtually all types of emergency surgery in the revamped COVID-OR complex. The final workflow for COVID-19 OR, which was re-engineered based on findings from our simulations, is presented in Figure 1. It is important to recognize that the process of emergency preparedness and facility level preparedness is multifaceted. As expounded by Lum et al,[23] requirements for hospital preparation encompasses in house evaluations using "table-top" (theoretical) exercises, quality and process improvement "walkabouts," and department-specific simulation exercises to test and facilitate enhancement of systems. Just like in cases described, in situ simulation is one component in containment and mitigation, as described in more detail in our preceding work.[17]

In the organization of these in situ simulations, we faced several challenges. The conduct of simulation-based training is time and resource intensive, requiring dedicated simulation faculty and technologists. We needed to find time when all stakeholders were available to conduct these exercises, which was challenging in a busy hospital like ours. Particularly, we involved security personnel and staff from environmental services early so that the processes related to their roles could be developed early on, especially with regard to handling contaminated waste and instruments. Our sessions were often lengthy and stretched 4 to 5 hours because of the need to address and follow up on the various threats identified with the multiple

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stakeholders involved. We also had to tailor our in situ simulations to avoid disruption of ongoing patient care duties and causing unnecessary anxiety with our PPE/PAPR and escorted patient transfers. In centers without an established and robust simulation infrastructure with hospital funding support, cost incurred from engaging the relevant expertise and use of nonreusable consumables during the simulation sessions would have to be factored in during planning. Finally, we cannot emphasize enough the importance of buy in and support from hospital leadership who shared our goal of pandemic preparedness, allowing us to rapidly organize and conduct these simulation exercises.

The OR workflow and clinical care guidelines are institution and department specific. Furthermore, designing and conducting in situ simulation require faculty formally trained in simulation for it to be impactful. Hence, our findings, learning points, and resulting interventions may not be generalizable to other institutions where such expertise and simulation infrastructure are lacking. We could have incorporated human factors engineering into formulating our OR layout and setup to improve task and workflow efficiency, and influence compliance to infection prevention measures.[40] Lastly, although there were observed improvements in workflow, response time, and OR facility preparedness, actual clinical outcomes in COVID-19 patients presenting for surgery will need to be explored as the situation progresses.

CONCLUSIONS

Process-oriented in situ simulation has been gaining widespread acceptance in recent years as a valuable tool in the evaluation of the safety of new healthcare teams and new facilities, proactively identifying latent threats before delivering patient care. Best-laid plans can often go awry, as practical challenges and potential pitfalls are often only revealed during simulation, with more granularity compared with just a "walk through" or "table-top" exercise. Running a simulation may be time and resource intensive, but it is a small price to pay if it can optimize individual and system preparedness to prevent disease spread in an outbreak, safeguard physical and mental well-being of staff, and give everyone involved psychological reassurance. With each simulation exercise, we have repeatedly refined our workflows and OR setup such that we are now confident that we can provide timely surgical interventions for a COVID-19 patient in our hospital while keeping our staff and other patients safe.

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