Just-in-Time Simulation to Guide Workflow Design for Coronavirus Disease 2019 Difficult Airway Management

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Objectives: The coronavirus disease 2019 pandemic has required that hospitals rapidly adapt workflows and processes to limit disease spread and optimize the care of critically ill children.

Design and Setting: As part of our institution's coronavirus disease 2019 critical care workflow design process, we developed and conducted a number of simulation exercises, increasing in complexity, progressing to intubation wearing personal protective equipment, and culminating in activation of our difficult airway team for an airway emergency.

Patients and Interventions: In situ simulations were used to identify and rework potential failure points to generate guidance for optimal airway management in coronavirus disease 2019 suspected or positive children. Subsequent to this high-realism difficult airway simulation was a real-life difficult airway event in a patient suspected of coronavirus disease 2019 less than 12 hours later, validating potential failure points and effectiveness of rapidly generated guidance.

Measurements and Main Results: A number of potential workflow challenges were identified during tabletop and physical in situ manikin-based simulations. Experienced clinicians served as participants, debriefed, and provided feedback that was incorporated into local site clinical pathways, job aids, and suggested practices. Clinical management of an actual suspected coronavirus disease 2019 patient with difficult airway demonstrated very similar success and anticipated failure points. Following debriefing and assembly of a success/failure grid, a coronavirus disease 2019 airway bundle template was created using these simulations and clinical experiences for others to adapt to their sites.

Conclusions: Integration of tabletop planning, in situ simulations, and debriefing of real coronavirus disease 2019 cases can enhance planning, training, job aids, and feasible policies/procedures that address human factors, team communication, equipment choice, and patient/provider safety in the coronavirus disease 2019 pandemic era. (*Pediatr Crit Care Med* 2020; XX:00–00)

Key Words: coronavirus disease 2019; critical airway; difficult airway; intubation; pediatric intensive care unit

The coronavirus disease 2019 (COVID-19) pandemic, caused by the rapid global spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), presents logistical challenges. Healthcare institutions face competing priorities to safely care for patients with suspected or confirmed COVID-19 while protecting the health of noninfected patients and frontline healthcare workers, and simultaneously building and preserving critical care workforce capacity. The dynamism of this situation presents ample opportunity for both individual and system error and success.

Numerous groups and societies around the world have convened to conceive (e.g., think through) ideal workflows and best practices. To that end, the International Pediatric Simulation Society currently maintains a collaborative document of ongoing COVID-19 simulation efforts and lessons learned (https://www.ipssglobal.org/community_resources_covid/), for real-time inter-institutional learning (1). Our large urban academic quaternary pediatric hospital in the United States has been quick to establish both system-wide policies, as well as unit-led initiatives, to provide the best and safest care possible for our patients while protecting the health and safety of frontline workers.

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To test the feasibility of executing ideal workflows, our group conducted a series of tabletop and in situ simulation exercises using a systems improvement lens to identify and address potential success and failure points when taking care of the acutely decompensating critically ill patient. These simulations focused on skills necessary for the management of an "unanticipated difficult airway." This approach was intended to demonstrate how "work as imagined" translates to "work as simulated" and "work as done," using a systematic simulation-based approach while applying continuous quality improvement methodology along the entire spectrum from tabletop to in situ simulation to clinical practice. This report also describes the management of an actual patient with a difficult airway, under investigation for COVID-19/SARS-CoV-2, and describes adaptations to our standard practice identified through these experiences.

SIMULATION CASE, DEBRIEF, AND PROCESS CHANGES FROM EXISTING STANDARD

Given the urgent mandate to operationalize a COVID-19 clinical workflow, a series of in situ simulations were conducted related to safe performance of resuscitative procedures. Specific consideration was made for aerosol generating procedures (e.g., tracheal intubation, mask ventilation) which impose a high risk of clinician exposure to COVID-19.

Location and Setting

In situ simulation took place in a fully operational PICU isolation room designated for COVID-19 patient care. For aerosol generating procedures, personal protective equipment (PPE) including powered air-purifying respirators (PAPRs) were preferentially used. Alternatively, N95 masks and eye shields were considered acceptable.

Simulation Goals and Setup

The goal of the simulation was to identify potential patient care and system failure points in managing the unanticipated difficult airway in a child with suspected COVID-19. We used a modified high-technology difficult airway model (Pediatric HAL; Gaumard, Miami, FL) to simulate a 5-year-old who can be ventilated through mask ventilation and supraglottic airway device (SAD) but is difficult for tracheal intubation. The patient vital signs were displayed on a tablet screen at the bedside.

Simulation Scenario

The unanticipated difficult airway scenario (**Appendix A**, Supplemental Digital Content 1, http://links.lww.com/PCC/B382) was developed by two ICU clinicians (A.N., H.A.W.) who were specifically trained as bioresponse team members. Four practicing ICU clinicians (two nurses, one respiratory therapist, one attending intensivist) who were not part of scenario development initially provided direct care to a simulated patient. Once difficult intubation status was recognized, an airway emergency was activated following the institutional protocol, and the anesthesiologist was called to assist at the bedside. The original ICU team placed a SAD while awaiting the anesthesiologist. The Anesthesiologist donned PPE with PAPR prior to entering the room and used hyper-angulated video laryngoscopy (Glidescope; Verathon, Bothell, MA) to successfully place a tracheal tube.

Data Collection for Potential Failure Points

We used Promoting Excellence and Reflective Learning in Simulation framework throughout the simulation (2–4). Simulation participants were briefed with the goal of the simulation, and participant-level system assessment data were collected throughout the debriefing. Two simulation educators, two pediatric intensivists (content experts), and an anesthesiologist observed the simulation in addition to participating in the debriefing. When possible, potential solutions using human factors principles were sought throughout the debriefing (5). Feedback was obtained from all participants and observers during an immediate verbal debriefing process. Summary phase of the debriefing was used to identify the main take home points and action items from our simulation.

CASE REPORT

Within 12 hours of the simulation activity, during the same shift as some of the participating team, a 22-year-old male with an undefined genetic syndrome with multiple medical problems including obstructive sleep apnea requiring nocturnal baseline noninvasive ventilation provided by bi-level positive airway pressure (BiPAP) support with settings of inhaled positive airway pressure 20 cm H_2O, exhaled positive airway pressure 14 cm H_2O, and 0.25 L/min supplemental oxygen presented in respiratory distress to our pediatric emergency department. Upon presentation, he had a temperature of 35.2°C, heart rate of 90 beats/min, blood pressure of 114/57 mm Hg, respiratory rate of 35 breaths/min, and oxygen saturation of 100% on 3 L/min via nasal cannula.

After admission to an isolation unit within the PICU, his work of breathing (WOB) continued to increase with worsening retractions; auscultation revealed coarse breath sounds. A venous blood gas (VBG) revealed a pH of 7.22, P_{CO_2} of 85.4 mm Hg, bicarbonate of 34.4 mmol/L, and base excess of 4.9 mmol/L; lactate was 2.8 mmol/L. Inflammatory markers were elevated (C-reactive protein 23.1 mg/dL, procalcitonin 1.79 ng/dL) and he appeared to have a degree of myelosuppression (hemoglobin 9.9 g/dL, WBC 4.5 K/μL, platelets 36 K/μL). In the setting of increased WOB with evidence of hypercarbic respiratory failure, he was started on his baseline BiPAP support via closed-circuit Dräger Evita V500 (Drägerwerk AG, Lübeck, Germany) to reduce the risk of aerosol generation. He was given broad-spectrum antibiotics through a peripheral IV and nasopharyngeal swabs for influenza A and B, COVID-19, and a respiratory viral panel were sent. After attempts to titrate BiPAP, a repeat VBG showed a worsening respiratory acidosis (pH 7.17, P_{CO_2} 86.4 mm Hg) while on 100% F_{IO_2}. The on-call anesthesiologist was called to the unit to discuss the airway management plan. On-call

otorhinolaryngology—ear, nose, and throat (ENT) team was also made immediately available in the event that a surgical airway was required. The time to assemble and don PPE for the entire team took 30 minutes.

Review of prior airway notes from the electronic medical record documented a Cormack-Lehane grade 4 view with both direct and video laryngoscopy by experienced airway clinicians, a difficult mask ventilation, and difficult SAD placement. This was corroborated by physical examination which demonstrated a small mouth opening, micrognathia, macroglossia, and short neck. Previous success had been achieved with fiberoptic placement of a 5.0 mm cuffed tracheal tube through a size 2.5 air-Q Intubating Laryngeal Airway (air-Q; Salter Labs, Lake Forest, IL). Therefore, 2.0 and 2.5 air-Q SADs, as well as 4.5 mm and 5.0 mm cuffed tracheal tubes and a bronchoscope with suction, were available bedside.

Glycopyrrolate, propofol, and fentanyl were selected to induce anesthesia; rocuronium was available but was not empirically administered in an attempt to maintain spontaneous ventilation should intubation be unsuccessful. The patient was preoxygenated on elevated BiPAP settings with 100% FIO_2.

Sufficient PPE was obtained to allow for a full complement of staff to be donned and in the room for the procedure, including a pediatric intensivist, an anesthesiologist, a pediatric anesthesiology fellow, a pediatric ENT fellow, two PICU nurses, and two respiratory therapists. Following induction, the patient became apneic and hypotensive, requiring intermittent epinephrine boluses for hemodynamic support. Initially, the air-Q 2.5 did not seat and the patient required two-hand mask ventilation with significant jaw thrust and an oropharyngeal airway. After additional lubrication, the same air-Q was easily seated, without peripheral oxygen desaturation. A 5.0 mm cuffed tracheal tube was placed without difficulty via the air-Q with bronchoscopic assistance after visualization and passage through of the vocal cords, but subsequent anatomy was obscured by significant tracheal secretions. The tube was held in place and the patient was ventilated with a Mapleson D circuit with a viral filter in line. Tube placement was confirmed with waveform capnography and auscultation with a Bluetooth stethoscope connected to an external speaker via an in-line amplifier. Bronchoscopy was then performed to clear secretions, collect sputum for analysis, and reconfirm optimal tube placement. Per protocol, a chest radiograph was obtained. Immediately following the case a team debriefing was conducted. Subsequently, clinicians involved in the case also informally debriefed with members of the simulation and workflow development team using plus/delta methods to relay lessons learned.

RESULTS

The specific airway management key points for system improvement were identified through the difficult airway simulation and clinical encounter described above. These key points and mitigation plans were overall similar (**Table 1**). Overall communication challenges and mitigation plans worked well in the clinical encounter, similar to the simulation experience. Equipment (air-Q, emergency medications, and tracheal tubes) was prepared for the clinical encounter based on the simulation experience, which worked well. The clinical encounter required more personnel donned in the room for the anticipated difficult airway. Both simulation and clinical encounter used SADs to maintain ventilation while minimizing aerosolization. Both the simulated team and actual team related that performing the intubation in the PAPR took more concentration and they felt as there was a higher cognitive load given the unfamiliarity of the protective equipment. Although the simulation case used the Glidescope as an intubation device, the clinical encounter successfully employed bronchoscopic-assisted intubation through an air-Q larygeal mask airway based on the patient's known airway history. To provide guidance to bedside clinicians who manage suspected or confirmed COVID-19 patients, an airway bundle with a checklist was generated (**Supplemental Figure 1**, Supplemental Digital Content 2, http://links.lww.com/PCC/B387).

DISCUSSION

Our experience suggests that simulation by experienced practitioners is a useful component in developing optimal airway management workflows pertaining to the COVID-19 population. Our simulation informed practices that were rapidly (same day) deployed during the intubation of a patient with a difficult airway; our practice improved further after feedback from the actual event. The totality of these experiences led to the creation of a patient-specific COVID-19 airway contingency planning bundle, intended to be preemptively completed and available at the bedside for all patients with suspected or confirmed COVID-19.

Traditionally, medical simulation has existed to train clinicians on established standards of care and tends to be conducted for the purposes of assessment, education, maintenance of certification, or research (6). Our group deployed simulation-based methodology to conduct feasibility tests and tests of change during the time-sensitive creation of new workflows. For this purpose, we engaged experienced practitioners as participants to identify stress points in a mission-critical workflow as it was being designed. Incorporating simulation allowed us to be one step closer to demonstrating "work as done" compared to our "work as imagined."

COVID-19 has already posed significant strain on ICU systems worldwide and is likely to continue inflicting increasing pressure, potentially further increasing the risk of morbidity and mortality (7, 8). Here, we propose a method of expedited critical care clinical workflow design that incorporates proxy observation of the workflow in action, in the form of serial simulations. In this capacity, simulation may help assuage the risk that time-sensitive mission-critical policies, procedures, and workflows fail to achieve their intended results. We believe that this process can be undertaken in a timely fashion without significant delay to implementation.

Our group uncovered learning points falling into three broad categories: human factors and communication, equipment, and future considerations. One key theme was

TABLE 1. Simulation and Case Take Home Points for Intubation of Difficult Airway for Coronavirus Disease 2019

Category	Simulation Take-Home	Case Take-Home
Preparation	Have intubating SAD available (outside or in room) for all intubations for coronavirus disease 2019	Intubating SAD used. Equipment available was sufficient in area
	Have all intubation medications and emergency medications available in room and prepared prior to initiation	Plan followed and worked well. Specifically, epinephrine boluses used to treat hypotension after induction
	Team felt that with limited participants in room team should have appropriate size ETT and ½ size down ETT both styletted for intubation	Plan followed and worked well. No stylette necessary as bronchoscopic approach was primary plan
Alert plan	Felt that intubation "heads up" to the backup team not necessary given number and expertise of available staff during daytime for routine intubation. At night when less backup personnel are in the hospital, anesthesiologist ± ENT should be alerted	Plan followed and worked well
Time for team arrival after notification of airway emergency	Allow for 7–10 min from activation of airway team to anesthesiologist arrival and donned in PAPR/PPE	Anesthesiologist was available when patient arrived due to prior conversations
		Time to assemble the entire team and don PPE took 30 min
Personnel	Routine plan: One attending, two nurses, one respiratory therapist	Required more personnel and PPE than anticipated
	Airway team activation: 1 anesthesiologist felt sufficient in simulation	Airway team: Both anesthesiology attending and fellow deemed necessary due to chosen technique. ENT preferred to be in room for first attempt
	Only call in ENT if anesthesiologist fails	
Equipment	Videolaryngoscope with indirect view for first attempt by intensivist	Based on patient history a fiberoptic bronchoscopy through SAD was performed
	Glidescope outside room (second choice for anesthesia team)	
	Bronchoscope third choice	
ETT confirmation	Bluetooth stethoscope, capnography, chest radiograph	Plan followed and worked well
Communication	Difficult to hear in PAPR	Required raised voices and closed-loop communication
	Requires speaking in loud, clear voice	
	Communication from inside room to outside of room was challenging (equipment needs, medications, etc.). Used video conferencing via tablets to communicate from within the room to staff outside	Plan followed and worked well
		Key to plan and anticipate needs prior to start of procedure
	Need clear role assignment and reassignment once additional team members arrive	Reviewed plan prior to induction with additional team members in the room

ENT = otorhinolaryngology–ear, nose, and throat, ETT = endotracheal tube, PAPR = purified air personal respirator, PPE = personal protective equipment, SAD = supraglottic airway device.

the importance of communication at multiple levels; our clinicians agreed that early and clear communication was foundational to our patient's successful outcome. Our unanticipated difficult airway simulation suggests that, in the best of cases, it takes easily seven to 10 minutes for an in-house anesthesiologist to be physically available at the bedside in appropriate PPE, underscoring that early interprofessional discussion and planning should take place if there is any reason to suspect the need for additional help. Increased cognitive load imposed by operating in atypical conditions further supports the importance of clear and directed communication, and the implementation of our airway bundle serves in part mitigate this.

Another important workflow adjustment unveiled in simulation and corroborated by clinical experience is the importance of having primary and backup equipment immediately

available in the room, including additional doses of planned drugs and an adequate supply of emergency drugs. At this time, we have taken the approach that when managing the airway of any COVID-19 suspected or confirmed patient, there should be a cuffed tracheal tube of choice, as well as a second tube 0.5 mm smaller, both open, lubricated, cuff-tested, and styletted. For backup ventilation, we are recommending a low threshold to insert an intubating SAD, which should also be immediately at hand to allow for positive pressure ventilation while minimizing aerosol generation relative to mask ventilation. An intubating SAD specifically allows the option of placing a tracheal tube without having to first remove the SAD, in addition to functioning as a conventional SAD if so desired. Our simulation revealed that, although intubating SADs are readily available at our institution, they did not comprise part of our usual PICU intubation equipment bundle which was subsequently modified for the COVID-19 population.

Depending on the PPE used, additional considerations may be necessary. PAPRs are inherently loud, making it important to have deliberate control of extraneous noise and conversation. Our group found utility in a Bluetooth stethoscope. Given challenges in auscultation, having access to multiple tools for confirmation of tracheal tube placement is critical. For this patient, bronchoscopic visualization was obscured by tracheal secretions; we used a Bluetooth stethoscope, end-tidal capnography, and chest radiography to confirm appropriate placement. Had the patient experienced significant bronchospasm during airway placement, without multiple confirmatory tools, we may have accidentally removed an appropriately positioned tracheal tube.

Although our efforts were conducted in a well-resourced tertiary-quaternary pediatric academic institution, the principles we employed can be applied when faced with a time-sensitive need to alter critical workflows in any environment. That said, our study is not without limitations. This is a feasibility study in which results were collected by unblinded observers involved in the design. The interventions tested were modifications to existing practice, guided by expert opinion on what is likely to be best practice in caring for the COVID-19 population but number of questions remain unanswered. There have been discussions about nasal cannula oxygen flow and risk for aerosolization. Due to this concern, several institutions have avoided to use apneic oxygenation at high oxygen flow and considered high-flow nasal oxygen (HFNO) as an aerosol generating procedure. For now, our group will continue our usual practice of apneic oxygenation with nasal cannula with appropriate PPE on providers, as the risk of hypoxemic cardiorespiratory arrest is high in the pediatric population. We currently believe that noninvasive positive pressure ventilation (NIPPV) is best avoided if possible due to aerosol generation, but a proportion of our population is dependent on NIPPV at baseline, and avoiding NIPPV until tracheal intubation may not be feasible, as was the case in our report. We do advocate for delivery of NIPPV via a closed-circuit ventilator with a high-efficiency particulate air filter on the expiratory limb of the circuit. Of note, the Surviving Sepsis Campaign guidelines adapted for COVID-19 patients support the use of HFNO and, less strongly, NIPPV, as potentially intubation-sparing interventions in adults (weak recommendation, low-quality evidence) (9). At our institution, emergency front of neck airway access (eFONA) is preferentially performed by an otorhinolaryngologist, who is not in the hospital overnight or on weekends. It may be worth considering a protocol and standardized setup for intensivist or anesthesiologist led eFONA should it be inadvisable to wait for the arrival of a surgeon, especially given the additional time incurred in donning PPE.

Although many adult institutions have severely restricted or even prohibited visitors, as a pediatric institution, we still allow parents or legal guardians to stay with their children but do not allow them to leave the room. It remains unclear what the best disposition is for COVID-19–exposed caregivers during invasive procedures.

Further study could help elucidate additional practice improvements. As the clinical and logistical COVID-19 landscape evolves, processes and workflows should continue to be refined in order to provide optimal care to our patients while assuring the highest possible degree of safety to clinicians. We suggest that, while remaining attuned to actual workflows in the ICU and around the hospital, continuing to conduct simulations with the experienced clinicians can provide a low-risk method to identify failure points and validate salient successful practices which might be ignored in routine practice. We suggest a framework of systems-based process improvements (10) in preparing for situations where the risk of failure is incredibly high to both patients and clinicians alike.

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