Robotics in Simulated COVID-19 Patient Room for Health Care Worker Effector Tasks: Preliminary, Feasibility Experiments[a]

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Abstract

The coronavirus disease 2019 (COVID-19) pandemic has strained health care systems and personal protective equipment (PPE) supplies globally. We hypothesized that a collaborative robot system could perform health care worker effector tasks inside a simulated intensive care unit (ICU) patient room, which could theoretically reduce both PPE use and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) exposures. We planned a prospective proof-of-concept feasibility and design pilot study to test 5 discrete medical tasks in a simulated ICU room of a COVID-19 patient using a collaborative robot: push a button on intravenous pole machine when alert occurs for downstream occlusion, adjust ventilator knob, push button on ICU monitor to silence false alerts, increase oxygen flow on wall-mounted flow meter to allow the patient to walk to the bathroom and back (dial-up and dial-down oxygen flow), and push wall-mounted nurse call button. Feasibility was defined as task completion robotically. A training period of 45 minutes to 1 hour was needed to program the system de novo for each task. In less than 30 days, the team completed 5 simple effector task experiments robotically. Selected collaborative robotic effector tasks appear feasible in a simulated ICU room of the COVID-19 patient. Theoretically, this robotic approach could reduce PPE use and staff SARS-CoV-2 exposure. It requires future validation and health care worker learning similar to other ICU device training.

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The global pandemic of coronavirus disease 2019 (COVID-19) rapidly emerged and caused considerable workflow stress on existing health care resources. A relative shortage of personal protective equipment (PPE) from the surge in COVID-19 patients strained the system along with a rate of 20% to 30% cross-infection of health care workers[1,2] (HCWs) and resultant deaths.

In health care, robotics holds the promise of automating many tasks. Yet, its use in health care lags behind many other industries[3-7] because of various barriers. These include concerns about safety and costs; fear of replacing HCW jobs; and adoption factors of other stakeholders, including clinicians, nonclinicians, caregivers, technologists and researchers (robotic makers), administrators, policymakers, insurers, and advocacy groups.[8] Predominant use of health care robotics in hospitals is largely confined to the operating room, where robots perform complex or minimally invasive surgery with nearby surgeons (eg, da Vinci surgical system, Mazor guidance system).[9]

Some persons argue that the COVID-19 pandemic was a wake-up call for more extensive use of robotics in health care.[10] Furthermore, it became abundantly clear that our hospital needed rapid and creative solutions to solve the dueling issues of PPE use reduction and decreased HCW exposure. If HCWs become infected, they ironically can become

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consumers of health care resources and be unable to help other COVID-19 patients. The COVID-19 patients at high risk should ideally be in a negative pressure room and wear a surgical mask to minimize aerosolization and the viral water droplets known to spread the infection.[11] Up to 10% of patients with COVID-19 require care at the intensive care unit (ICU) level and represent individuals at highest risk medically for deterioration and death[12] because of greater use of a high-flow nasal cannula for oxygen delivery and need for intubation and mechanical ventilation. This high-risk group potentially can infect multiple HCW teams, including nurses, respiratory therapists, nurse practitioners and physician assistants, and physicians.

We hypothesized that use of a collaborative robot system inside an ICU simulated room for a COVID-19 patient could perform some human effector tasks or use cases, such as pushing buttons and turning knobs in the patient room, and could have downstream potential to reduce the donning and doffing of PPE. A collaborative robot (ie, Cobot) system is defined by the Robotic Industries Association[13] as one that is designed for direct interaction with humans within a defined collaborative workspace. Most hospitals have different types of medical ICU equipment (eg, ICU monitors, ventilators, oxygen flow rate regulators, intravenous [IV] pump machines) that do not integrate or communicate with each other. In addition, many hospital and ICU machines require analogue or human interface design for the HCW to push buttons and program manually as effectors. Because many of these machines differ in design and do not integrate or communicate with each other, they cannot be controlled or programmed remotely from outside the patient room. This requires an HCW to enter a COVID-19 patient's room for otherwise human-level button-pushing tasks that could be performed robotically.

We saw these capabilities, or features, as design gaps in COVID-19 ICU care and as potential variables to model and solve with use of a robotic arm. Effectively, the robotic arm would perform tasks of the HCW's hand as an effector to push buttons and to turn knobs in the current ICU room design. The robot could save HCW PPE for when it is absolutely needed to perform high-complexity tasks, such as medical procedures and functions that require higher level skills not currently possible robotically (eg, intubation, bronchoscopy, central line placement).

The COVID-19 pandemic has exposed a critical unmet health care need to test relatively simple effector capabilities with collaborative robotics and potentially to be applied more broadly at other hospitals around the globe with the ongoing pandemic or future ones.

METHODS

Mayo Clinic Institutional Review Board approval was not required for this pilot work because it did not involve human participants and occurred in the Mayo Clinic Medical Simulation Center with only robotics, inanimate objects, and a manikin simulating a human with COVID-19. This 2-phase pilot was designed as a prospective proof-of-concept feasibility construct to test several discrete medical tasks inside a simulated COVID-19 patient ICU room. Phase 1 was a collection of the tasks from medical staff that might be feasible and helpful clinically in COVID-19 patient rooms to unburden staff from PPE donning and doffing and from patient room entry risk. Phase 2 was a feasibility assessment of the final effector tasks robotically in the Mayo Clinic Medical Simulation Center ICU room.

Phase 1: Collection and Classification of Common COVID-19 Robotic Effector Tasks

We collected a list of medical tasks or use cases to be performed robotically, polling various nursing and physician staff involved with the COVID-19 team at Mayo Clinic. The main feedback targeted simple tasks that a robot could complete without medical provider entry into a simulated COVID-19 patient room that requires donning and doffing of PPE and without safety compromise. We reviewed the available literature (National Library of Medicine and Google Scholar) around similar topics. We could not find particular examples of the use of robotics to reduce PPE wear and HCW exposure. Yet, the literature contained calls for this kind of experimental work. Of note, we believed that each use case chosen by the team might prevent room entry and thus prevent PPE donning and doffing.[14] Because these experiments were focused on feasibility of the task, we did not measure simulated PPE use, an assessment that could be performed in a follow-up study.

In retrospect, before the COVID-19 pandemic, many of these HCW tasks appeared mundane to our nursing and physician staff but were manageable because there was adequate supply of PPE. HCWs practice basic hand hygiene before and after room entry; however, since COVID-19, there have been considerable changes in baseline PPE requirements over time. For example, a single COVID-19 patient requires extensive PPE use by HCWs, including gowns, gloves, and protective facial masks (N95 or equivalent), which all became in short supply because of a rapid increase in demand.[15] After this work was completed, patients and HCWs were asked to wear surgical masks at all times. Therefore, the most feasible tasks that emerged from our COVID-19 group discussions included common effector tasks that require entry into the COVID-19 patient room to silence ICU alarms and call buttons (false alerts) and other button-pushing and knob-turning activities. Robotic performance of these effector tasks was believed to cut down on unnecessary room entry and thus PPE use simultaneously as an overarching goal.

Our team estimated that among the hypothetical robotic effector functions, we could save at least about half of all HCW entry into COVID-19 rooms, an estimate based on our early experience in February and March 2020 to save PPE and to avoid unnecessary HCW viral exposure. Before COVID-19, these same effector tasks inside the room were executed largely by nursing staff who responded to alarms on ICU machines. For most patients without COVID-19, only simple hand hygiene with alcohol-based foam is required before and after being in a patient room. In retrospect, many of these common HCW effector tasks were manageable before COVID-19 because they did not require a large amount of time or effort per task and donning and doffing of PPE.

For example, dialing up and down of oxygen flow rates for COVID-19 patients reflects the Mayo Clinic COVID-19 care team's observation as a use case that if it were to be performed robotically could prevent entry into a room. This task was derived from the observation by one of the pulmonary critical care physicians (J.M.M.) that the oxygen saturation of COVID-19 patients receiving supplemental oxygen by nasal cannula often decreases when they walk to the bathroom and back (arterial oxygen saturation on pulse oximeter, <90%). To prevent this desaturation, a countermeasure is for a nurse to enter the room and manually dial up the oxygen level (eg, from 6 L/min to 15 L/min) for the patient to get out of bed and to the bathroom and dial down the oxygen level in reverse manner. If this simple task were performed by a robot, it would effectively prevent using 2 rounds of PPE for entry and reentry and potentially 2 viral exposures. This COVID-19 multidisciplinary team of coauthors generated the final prioritized list of effector tasks and what was deemed theoretically feasible (Table 1).

Robotics Platform

Sawyer is a 7-axis robot with flexible joints, a 4-kg payload, and tolerance of up to 0.1 mm. It includes an integrated camera (Cognex Corp) and is power and force limited by inherent design as described in ISO 10218-1:2011 to work safely around people. The Sawyer Black Edition arm components include sealed actuators that provide high-reliability high-quality components for uninterrupted operations and gears with smaller tolerances for uniform and harmonious movement.

The Mayo Clinic Medical Simulation Center ICU room has the same size and proportions as a typical ICU patient room at Mayo Clinic Hospital in Jacksonville, Florida. A computer laptop was interfaced with the robot through the Sawyer software (Intera Studio; Rethink Robotics GmbH), which allows laptop- and PC-based programming as well as physical programming on the robot or a combination of physical and web-based programming. Intera has intuitive icon-based programming for ease of operations and can integrate with voice activation and voice response.[16] To program the robotic arm, staff used a PC laptop to create tasks in Intera. The PC laptop with Intera worked off a local secure Wi-Fi on the robot arm that could be reviewed, and programs could be executed

TABLE 1. Description of Final Health Care Worker Robotic Task List to Reduce the Use of Personal Protective Equipment and to Prevent Viral Exposure

1. Push a button on the IV pole machine when an alert occurs for "Downstream occlusion," which prevents IV infusion of critical medications until this button is pushed to continue medication infusion.
2. Adjust a ventilator knob used for critically ill machine-ventilated patients (eg, to increase FIO_2 oxygen, to adjust tidal volume). The knob task can be used singly or in combination with task No. 1 because ventilators often have an LCD screen to push first and to select the mode on the knob second.
3. Push a button on an ICU monitor to "Silence alarm" false alerts.
4. Adjust the level of oxygen (L/min) from wall fixtures to allow the patient to walk to the bathroom and back (dial-up oxygen).
5. Push the nurse call button to "Off" on the wall to acknowledge that the patient's request has been responded to verbally or in person (as needed).

FIO_2 = fraction of inspired oxygen; ICU = intensive care unit; IV = intravenous; LCD = liquid crystal display.

outside the room with the same laptop on Wi-Fi. The voice response feature was not used in the experiments.

All staff involved in this study had online access to educational information about the Intera Studio platform and had short instruction videos to maximize their learning about the robotic system before the experiments. The Cobot Team staff provided real-time video conferencing support from Portland, Oregon, to Jacksonville, Florida, during the robotic health care experiments to provide guidance on operations and programming to the medical team (similar to medical in-service training).

Feasibility Design

Feasibility was defined as completion or incompletion of each robotic task and was gauged successful or not successful by one of the medical team (D.K.S., M.S.S., M.S.K., S.M.B., and J.M.M.) and compared with human task equivalency. Safety was observed from the robotic movements for any potential damage to the simulated manikin (ie, the patient), to other machines or objects, or to the HCW in the ICU room. Potential damage to the manikin was defined in 3 categories: superficial injury (simulated skin), crush injury (eg, if the robotic arm dropped or moved into and deformed the manikin head or parts), and penetrating injury. Twice a week, real-time virtual meetings (Zoom Video Communications, Inc) were arranged. The meetings occurred in 4 sessions during 3 weeks.

The first session (March 31, 2020) was an overview and the setup of the robotic system. Session 2 (April 2) conducted the first experiment; session 3 (April 7), the second and third experiments; and session 4 (April 9), the fourth and fifth experiments. At each session, a briefing or overview was done, then the experiments for task execution were performed and feasibility was assessed, followed by a debriefing at the end of the experiments. A summary was written after each session and was provided for shared learning. Secondarily, time in minutes was measured for the overall experiments with virtual conferencing that included hands-on training. Time was not a primary aim of the feasibility.

Phase 2: Execution of Robotic Effector Tasks

The 5 effector tasks necessary to accomplish the task list (Table 1) were (1) IV pole machine button pushing without landmark, (2) ventilator knob adjustment feasibility, (3) ICU monitor button pushing to "Silence alarm" for false alerts, (4) oxygen flow rate knob adjustment, and (5) nurse call button pushing to "Off."

Each effector task was constructed from the multidisciplinary task list (Table 1). The COVID-19 team suggested that these tasks would reduce PPE use and HCW exposure on the basis of clinical experience of the coauthors who cover that clinical ICU service (D.K.S., M.S.S., M.S.K., and J.M.M.).

RESULTS

In less than 30 days, the team completed 5 robotic health care COVID-19 tasks or feasibility experiments. All experiments were performed robotically with human training time similar to HCW in-service training less than 1 hour for most health care devices and other machines. Phase 1 actions (Table 1) completed HCW tasks that ranged from simple to highly aspirational and complex. Some tasks were too complex to complete in this short time and could be experiments to focus on in the future (Table 2). The phase 1 simple tasks were defined a priori before implementation of phase 2.

Phase 2 Feasibility Results

The 5 experiments achieved feasibility in each session (Table 3). All tasks tested the

TABLE 2. Stakeholder List of Future Robotic Tasks Performed for Health Care Workers[a,b]

Reposition or boost a patient in bed: RN or PCT
Bring meds in a med cup to the patient to administer: RN
Conduct oral care for patients with COVID-19 who are too weak to do this care: RN or OT
Act as the personal assistant, helping patients with basic tasks that they usually ask their families to do (eg, lights on and off, TV channel change): PCT or RN
Replace oxygen saturation sensor on the fingertip: RN or RT
Conduct chest physiotherapy: RT
Do range of motion (basic or passive) activities with patient: PT or OT
Tip or empty the Foley catheter and empty the urinal: RN
Help take SCD on or off (for DVT prevention): RN
Place a peripheral IV line: RN
Perform glucose checks, especially for patients receiving an insulin drip: RN
Visualize an IV site or a wound: RN, MD, APRN, or PA
Visualize chest tube output in the chest drainage system (Pleur-evac; Teleflex Inc): RN, APRN, PA, or MD
Apply a warm blanket: PCT or RN

[a] APRN, advanced practice registered nurse; COVID-19, coronavirus disease 2019; DVT, deep venous thrombosis; IV, intravenous; MD, medical doctorate (physician); med, medicine; OT, occupational therapist; PA, physician assistant; PCT, patient care technician; PT, physical therapist; RN, registered nurse; RT, respiratory therapist; SCD, sequential compression device (used to prevent DVT caused by immobility).

[b] Stakeholders involved in these specific use cases included ICU nursing staff, ICU physicians, APRNs, and PAs and discussions with RTs, PTs, OTs, and PCTs.

repeatability and reliability of the robotic attempts. Four tasks had quick response codes that served as computer vision landmarks near the target (ie, ventilator, oxygen knob, ICU call button, and ICU monitor screen). The ICU ventilator and monitors were moved backward several centimeters in those experiments to test the quick response code–like landmark reorientation of the robot, which was successful. The 2 experiments involving the ICU wall were not movable (oxygen knob and ICU call button). The IV pole machine was moved and the task repeated but without a landmark.

A learning curve of 30 to 40 minutes occurred in each session about task-specific robotic programming or the online software systems. No safety concerns were observed in any experiment. Of note, the robot has safety features that disengage movement with high object resistance, and all its movements were slowed from express mode to the slowest global speed of operation.

Experiments

The experiments were performed with the collaborative Black edition robot named Sawyer (Rethink Robotics GmbH) with personnel of Cobot Team LLC (T.S., J.D., and B.B.)[17,18] by conference call along with a Mayo Clinic (Jacksonville, Florida) multidisciplinary medical team inside the Mayo Clinic Medical Simulation Center ICU room. The role and function of the Cobot Team were to help train the Mayo Clinic HCW team on accomplishing the experiments. This included providing an overview of the system and its basic operations and the programming and executing of the effector tasks. The Sawyer collaborative robot is safe, easy to program, and approachable, with a programming screen that shows friendly eyes during its operation (which helps social acceptance of employee and staff to consider the robot a supporting coworker).[8] No safety issues occurred with the Sawyer robot, with human interactions, or with the manikins that served as simulated patients.

No. 1: IV Pump Button. After the IV pump device was secured onto a stationary pole as is common practice, the Sawyer was programmed physically with the zero gravity feature to move the robotic arm with a finger

TABLE 3. Results of Feasibility Robotic Experiments on ICU Effector Tasks[a]

Robotic ICU effector task[b]	Other	Figure or Supplemental Video
1. IV pump device continue button	No landmark	Figure 1
2. Ventilator knob adjustment	Landmark	Figure 2
3. ICU monitor silence	Landmark	Supplemental Figure 1
4. Oxygen knob adjustment	No landmark	Supplemental Figure 2; video at https://youtu.be/z6yiWsdzPjg?t=10 (360-degree camera view of the experiment)
5. Call button deactivation	Landmark, PC control, robot moved farther back	Supplemental Figure 3; video at https://www.youtube.com/watch?v=ghs3pOV-UJw (360-degree camera view of the experiment)

[a] ICU, intensive care unit; IV, intravenous.
[b] All tasks were deemed feasible.

gripper (Zimmer Group) and 2 rubber fingertips (Swingline) and to touch the button of interest repeatedly (Figure 1). This experiment achieved success because these IV pumps often sound an alarm when the patient moves the arm, creating a "Downstream occlusion" alarm. Patients can be told verbally from outside the room through a telecommunications system to straighten the elbow and arm, but the button still requires a physical touch to allow the infusion to continue. This experiment was one of the first sessions; video recording was not optimized until later experiments. Programming of several IV pump buttons was discussed (eg, programming IV infusion medication drip rates up and down) but was outside the scope of this experiment. Figure 1B shows the ICU room in perspective and the scale of objects in the room as they pertain to the other experiments.

FIGURE 1. Robotic experiment 1 and the intensive care unit room. A, Intravenous pump device. The objective of the robot was to touch the "Run stop" button, which often alarms when a downstream occlusion occurs. B, Perspective and layout of the intensive care unit room, with the intravenous pump device on the far side behind the bed and near the ventilator.

No. 2: Ventilator Knob Adjustment. A ventilator (Maquet Servo-i; Siemens)[19] was locked in place with its 4-wheel brake mechanism, and a landmark was placed near the ventilator adjustor knob specifically for the effector task of a 10-degree clockwise turn. This particular knob-turning task on a ventilator can increase the fraction of inspired oxygen for patients who are intubated and receive mechanical ventilation and can adjust other ventilator settings by turning them up or down.

The robotic arm and finger gripper system was able to find, grab, and turn a knob precisely (Figure 2). This proof of concept was an important first step to demonstrate one of the more complicated effector ICU room tasks. This task could theoretically be combined with other features, such as touching a button followed by turning a knob (ie, combinatorial tasks). The ventilator knob was physically programmed by team members, and the robotic system performed the task effectively. For showing the reorientation of the landmark system, the ventilator wheels were unlocked and

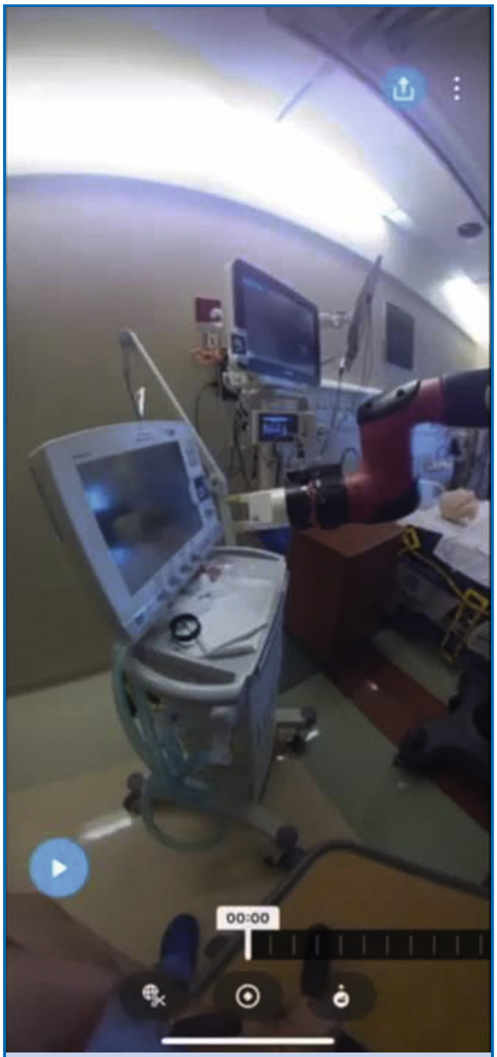

FIGURE 2. Robotic arm grasping knob, turning it 10 degrees, releasing knob, and retracting from the ventilator.

moved back 5 cm, then relocked in place. The robot was able to reexecute the same task after reorienting itself using the landmark. This was considered a feasible task.

No. 3: ICU Monitor Silencing. An ICU touch screen monitor (Koninklijke Philips NV) was chosen to push the "Silence alarm" button on the bottom left of the monitor (Supplemental Figure 1A, available online at http://mcpiqojournal.org). The robot was positioned to the left of the patient's bed and near the monitor, ideal for the other experiments of ventilator and the ICU headboard, which house the oxygen knob and the call alarm button (Supplemental Figure 1B). The ICU monitor often alarms from various vital sign false alerts (as well as real alarms).

Unfortunately, the ICU monitor touch screen "Silence alarm" button cannot be engaged from outside the room and requires physical touch to be activated. Presumably, this alarm was engineered for the dual purpose of confirming that a human has both checked in on the patient when an alarm occurs and silenced the alarm. ICU monitors have other touch screen points for adjustments.

The robotic system was physically programmed to touch the button, and a landmark was placed nearby. The robot was successful in touching the ICU monitor "Silence alarm" button repeatedly and after the monitor was moved back slightly. It used the landmark system successfully. Of note, the monitor is mobile, and without much force, it can move. We did not test these motions repeatedly until failure, but it is possible for monitor movement to happen. This robotic task was deemed feasible.

No. 4: Oxygen Knob Adjustment. This task helps turn up the oxygen flow for a patient with a nasal cannula. A landmark was not applied because the ICU headboard wall is immovable and Sawyer was not moved. The robot was physically programmed, and it physically completed an impressive and precise approach to the oxygen knob. The robotic arm and gripper were able to grasp and rotate (turn up oxygen flow) and repeat this function (Supplemental Figure 2, available online at http://mcpiqojournal.org). This ICU effector task was deemed feasible.

No. 5: Call Button Silencing. COVID-19 patients in hospitals have a call button they can push on the bed or on a remote control that comes with the hospital bed. This action generates a signal that notifies the nurse. The deactivate button is located above the patient's head—a particularly unsafe area for high-risk aerosolization of COVID-19 because of higher concentrations of viral particles, even in a negative pressure room and with PPE (Supplemental Figure 3, available online at http://mcpiqojournal.org).

This experiment was conducted with both physical and laptop software programming by an ICU nursing team member (M.S.K.).

Similar safety parameters were used, including a slower speed of the robot. The robotic arm can move at various speeds. Given the preliminary nature of this robotic health care simulation and the proximity of other human HCW team members, the Mayo Clinic team was advised by the company to start at a lower speed. In industrial robotics, speeds can be increased after a task is perfected to improve assembly line production. Because these were preliminary feasibility experiments, a slower speed was believed to be reasonable for the start. The robot was placed to the left of the patient's bed. The base of the robot was moved farther away from the simulated COVID-19 patient after an initial attempt showed that the robotic elbow came closer than a distance with which most patients might feel comfortable (<2 feet from the patient's head). After this placement was set up, the robotic system completed the tasks perfectly on several repeated attempts. This task was deemed a feasibility success.

We noted during this experiment the importance of positioning the robot relative to multiple effectors (on the left side of the bed in the room or at the patient's right side), when possible. This placement optimizes both the ergonomics and space limitations inherent to the ICU room and the location of other objects in the way when the effector tasks are being completed.

DISCUSSION

The proof-of-concept robotic experiments showed preliminary feasibility of a collaborative robot system used with an HCW team to accomplish simple simulated ICU room effector tasks. The uncomplicated robotic effector tasks represent important capability functions inside the medical simulated ICU room design of a simulated COVID-19 patient.

We acknowledge numerous limitations inherent in this work. We learned a great deal about hospital room and device design in doing the actual experiments that could generate more futuristic all-in-one hospital robotic designs, with integrated medical devices to optimize both patient care needs and HCW needs. We found only 1 area regulated by the US Occupational Safety and Health Administration regarding safe patient lifting by an HCW to reduce musculoskeletal injuries.[20] (Patient-lifting musculoskeletal injuries account for more than 18,000 days away annually from work and considerable downstream health care costs to employers and patients because of the removal of HCWs from the workforce.[20]) Although the Occupational Safety and Health Administration and the Centers for Disease Control and Prevention recommend PPE for an HCW caring for patients with COVID-19, we could not find any guidance on the issue of multiple nonintegrated machines and ergonomics for the health care workforce. This is likely to be due to the various manufacturers and models involved and the choice each hospital makes on the basis of its own needs and costs. This relative weakness could be changed to a strength through the application of ICU room redesign toward a converged-systems approach that protects not only patients but also HCWs.

These simulated COVID-19—related experiments exposed a design limitation inherent in many ICU devices in that they lack interconnectivity inside and outside the room. Therefore, our experiments should be interpreted with caution regarding scalability and diffusibility to other ICU settings. We recognized during these use case—based experiments that various ICU equipment is made by different companies (eg, ventilators, ICU monitors), and the different types are not designed to communicate with each other. However, we learned that these case experiments were important because they have potential to reduce physical entry into a COVID-19—simulated patient room and to reduce some HCW effector tasks.

Another limitation of the study is the preliminary nature and relative speed of our robotic experiments and the estimated PPE usage rate observed from our team experience. However, a relative strength of this work is that the preliminary knowledge we gained could be tested by other HCWs, roboticists, and engineering teams to share ideas and potentially to problem solve for their own health care system needs.

Many other barriers to the adoption of robotics in the health care arena exist that are not addressed in this work. Only a few are noted in this Discussion section. Barriers to more broad health care robotics include demonstration of the capability and reliability of robotic function, patient safety, clinical effectiveness, and cost-effectiveness (Supplemental Figure 4, available online at http://mcpiqojournal.org). These challenges require potential solutions before decision makers in hospitals and the health care system understand the true value of robotic assistance over the potentially lower cost HCWs doing the same effector functions.

Robotics use in health care must show a high standard of safety, similar to the flight industry, and an affordability compared with existing HCW models. Cost-efficacy is not analyzed in this report because we performed only a robotic patient simulation. However, if we assume that a similar robotic system costs at least about $40,000 (ie, higher cost with addition of specialized accessories, grippers, vision system, and mobility platforms) but saves an equivalent amount in prevention of a few serious infections of HCWs, requiring hospitalization of $13,297 or ICU-level care estimated at about $40,218 per patient,[21] the robotic model starts to pay for itself. This simple cost estimate also does not factor in the 14 days of quarantine if an HCW becomes infected and misses time from work (a paid leave of absence due to illness). The case-fatality rate in Lombardy, Italy, for example, was higher than expected because of several factors, including an older population with more comorbidities[22] and a patient care surge that overwhelmed HCWs, hospital and ICU resources, and systems logistics (eg, a shortage of PPE to prevent spread, running out of ventilators).[1]

Other limitations of this work include the lack of experimentation of other potential medical tasks that might help medical teams. This pilot did not have enough time, given the rapid deployment and experimental design needed before the patient surge at Mayo Clinic in Florida, which was expected to hit our hospital around late April 2020. We also did not have time to test the many other health care–centered design and medical device robotic effector solutions. Examples include programming of the IV pole machine for the ICU medications, such as a propofol sedative drip administration up or down. However, we believe these experiments share key technical insights for other hospitals and systems to apply potential collaborative robotics for similar HCW benefits. We also acknowledge that the hardware and software used in these experiments are likely to require redesign specific for each case of health care environment and use.

Despite these limitations, we believe that the strengths of this proof-of-concept work include a generalized outline for global health care systems to consider redesign of their medical device systems, integration of robotics into their health care teams, or both. Each of the 5 experiment tasks represents potential for hospitals to develop their own innovative approaches to reduce mundane effector tasks, to save PPE, and to lower infection risks. In addition, we acknowledge that other approaches are likely—both high-tech and low-tech workarounds—to address some of these challenges and perhaps to address them through wireless computing, hardware and software redesign, future Internet of things interconnection, use of smaller robotics, or other effector options during the COVID-19 pandemic.

CONCLUSION

We report robotic feasibility of performing 5 ICU-level effector tasks for HCW teams that could potentially reduce PPE waste and decrease COVID-19 patient exposures. These findings are preliminary, but they can be considered by global health care systems for a health care redesign and planning of response to ongoing and future infectious disease pandemics to reduce PPE use and to mitigate HCW exposure of entry into the rooms of patients with a highly infectious disease.

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SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://mcpiqojournal.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **COVID-19** = coronavirus disease 2019; **HCW** = health care worker; **ICU** = intensive care unit; **IV** = intravenous; **PPE** = personal protective equipment

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