ORIGINAL RESEARCH

Ventilator Training through International Telesimulation in Sierra Leone

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ABSTRACT

Background: The coronavirus disease (COVID-19) pandemic resulted in an increased need for medical professionals with expertise in managing patients with acute hypoxemic respiratory failure, overwhelming the existing critical care workforce in many low-resource countries.

Objective: To address this need in Sierra Leone, we developed, piloted, and evaluated a synchronous simulation-based tele-education workshop for healthcare providers on the fundamental principles of intensive care unit (ICU) management of the COVID-19 patient in a low-resource setting.

Methods: Thirteen 2-day virtual workshops were implemented between April and July 2020 with frontline Sierra Leone physicians and nurses for potential ICU patients in hospitals throughout Sierra Leone. Although all training sessions took place at the 34 Military Hospital (a national COVID-19 center) in Freetown, participants were drawn

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from hospitals in each of the provinces of Sierra Leone. The workshops included synchronous tele-education–directed medical simulation didactic sessions about COVID-19, hypoxemia management, and hands-on simulation training about mechanical ventilation. Measures included pre and postworkshop knowledge tests, simulation checklists, and a posttest survey. Test results were analyzed with a paired sample *t* test; Likert-scale survey responses were reported using descriptive statistics; and open-ended responses were analyzed using thematic analysis.

Results: Seventy-five participants enrolled in the program. On average, participants showed 20.8% improvement (a score difference of 4.00 out of a maximum total score of 20) in scores between pre and postworkshop knowledge tests ($P = 0.004$). Participants reported satisfaction with training (96%; $n = 73$), achieved 100% of simulation checklist objectives, and increased confidence with ventilator skills (96%; $n = 73$). Themes from the participants' feedback included increased readiness to train colleagues on critical care ventilators at their hospitals, the need for longer and more frequent training, and a need to have access to critical care ventilators at their hospitals.

Conclusion: This synchronous tele-education–directed medical simulation workshop implemented through partnerships between U.S. physicians and Sierra Leone healthcare providers was a feasible, acceptable, and effective means of providing training about COVID-19, hypoxemia management, and mechanical ventilation. Future ICU ventilator training opportunities may consider increasing the length of training beyond 2 days to allow more time for the hands-on simulation scenarios using the ICU ventilator and assessing knowledge application in long-term follow-up.

Keywords:
COVID-19; Sierra Leone; telesimulation; ICU management; global disparities

Before the coronavirus disease (COVID-19) pandemic, the World Health Organization approximated that 20 million people would need mechanical ventilation and approximately 19 million people would have sepsis in low-resource nations annually (1). The COVID-19 pandemic increased the risk of needing mechanical ventilation and thus increased patient volumes in the intensive care unit (ICU) (2, 3). Yet, critical care providers in low-resource countries often find it challenging to adequately meet such demands because of a lack of standardization of care (4), limited functional equipment, and inadequate training of personnel (5).

In response to the World Health Organization's declaration of a global pandemic in 2020, social distancing, public closures, travel restrictions, mask mandates, and other safety precautions were enforced to help curb the spread of the deadly COVID-19 virus. These restrictions impacted education for healthcare providers, particularly in low-resource settings, where healthcare providers are already in short supply (6) and international partnerships are required to implement train-the-trainer programs (7, 8).

Medical simulation-based training is a form of experiential learning that takes place in a controlled environment with role-playing actors, manikins, and medical equipment to better replicate the clinical context of each case. It creates a high-fidelity scenario with no risk of harm to real patients. Train-the-trainer simulation curricula were successfully implemented in Freetown, Sierra Leone, for the Universal Anesthesia Machine Ventilator course in 2018 and produced significant learning gains at Princess Christian Maternity Hospital (8). Although medical simulation-based training has proved effective for clinical knowledge and skill acquisition (9), and although some studies have included train-the-trainer simulation curricula in a remote video facilitated format (10), little is known regarding its use for critical care training for the patient with COVID-19 in a distance learning format in low-resource countries. The international community advocated for simulation, telemedicine, and online courses for local healthcare workers before the 2020 global pandemic (1). Remote simulation fosters an effective educational environment without the financial and personnel resource exhaustion required for face-to-face simulation training (11). In addition, other studies suggest that remote learning is comparable to in-person, face-to-face learning (12, 13), including in ICUs of low-resource settings (14).

In 2020, the Sierra Leone Directorate of Technology Science and Innovation in Health Care contacted our team to discuss the development of a workshop focused on preparing physicians and nurses from across the country for mechanical ventilation related to patients with COVID-19. This was an urgent request, and, after intense preparations on both the American and Sierra Leone sides, the training program began approximately 2 weeks after establishing an agreement for project execution. In preparation for the anticipated demands for critical care associated with the COVID-19 pandemic, the Sierra Leone Directorate of Technology Science and Innovation in Health Care partnered with Johns Hopkins University to develop, implement, and evaluate a novel workshop addressing the fundamentals of ICU care for general practitioners, using didactics and remote simulation with a special critical care ventilator for the low-resource setting (*see* the METHODS section). The Sierra Leone government made it a priority to choose ventilators that were technologically matched to function well without compressed oxygen (use of oxygen concentrators), low maintenance requirements, a long-lasting backup battery (14 h), and low cost. As a consequence, certain features, such as a pressure-volume screen and an inspiratory feature/plateau pressure feature, were not features that were present on this ventilator model. Course preparation rapidly took place, and simulation-based training started 2 weeks after our agreement to positively respond to this request. The purpose of this study was to evaluate the feasibility, acceptance, and effectiveness of this innovative workshop in Sierra Leone.

METHODS

Ethics

This study was determined to be exempt by our institutional review board (IRB00251989), and the study underwent expedited review and approval by the Sierra Leone Scientific and Ethics Review Committee.

Study Setting

Sierra Leone currently has only two physician anesthesiologists as the primary providers of critical care medicine for its population of 8 million (15). A shortage of anesthesiologists is a barrier to addressing ICU care in low-resource countries (16). Currently, Sierra Leone primarily relies on nurse anesthetists who have completed a United Nations Population

Fund–administered anesthesia training course. Historically, nurse anesthetists are not part of the critical care workforce in Sierra Leone.

In 2017, the Sierra Leone Ministry of Health purchased ICU ventilators to be distributed to hospitals across the country to enable healthcare providers to use the ventilators as needed in the ICU. In conjunction with the rollout of those machines, our international anesthesia education team, along with several U.S. critical care medicine physicians, hosted a course to provide in-person ICU ventilator training in 2018. The Society of Critical Care Medicine's Fundamental Critical Care Support course served as the backbone of instruction, with supplemental mechanical ventilation demonstrations focused on the type of ventilators available in Sierra Leone. The in-person training program, conducted at Connaught Hospital, the main teaching hospital in Sierra Leone, included simulation and didactic training. A unique feature of the simulation included intubatable manikins that were capable of spontaneous ventilation with realistic tidal volumes.

Participants for this workshop were selected from all regions of Sierra Leone by local medical authorities, including the Head of 34 Military Hospital, the anesthesia residency program director at Connaught Hospital, and other anesthesia faculty.

Intervention

We held 13 training sessions over 13 weeks between April 2020 and July 2020. Each session included up to six participants and consisted of two consecutive days of training for 6–8 hours each day. Learners were given a knowledge-based, multiple-choice, 20-question pretest at the beginning (*see* Appendix E1 in the data supplement) to evaluate baseline knowledge of the ventilator. They then received instruction from Johns Hopkins faculty, in parallel with Sierra Leone faculty, on didactic sessions about COVID-19 and hypoxemia management, orientation to the Comprehensive Care Ventilator (CCV) (17) from Gradian Health Systems, and alarm settings. These sessions included live discussion and question-and-answer sessions.

Live hands-on simulation training included clinical scenarios of patients with symptomatic COVID-19 infection. Learners used augmented oxygenation delivery methods to treat patients and demonstrate patient hand-off communication for patients on mechanical ventilation. Participants received immediate feedback using Zoom for tele-education conferencing and Simpl. The Simpl software allowed vital signs to be displayed on a simulated multifunction monitor in real time in Sierra Leone while a Johns Hopkins faculty member controlled the settings. Participants had to voice their simulation actions by speaking into a microphone. An assistant in Sierra Leone discreetly created technical challenges for ventilator troubleshooting exercises throughout the sessions, including high- and low-pressure alarm situations (such as circuit disconnect, circuit kink, breathing circuit valve malposition, ventilator dyssynchrony, and bronchospasm). Participants received a detailed debriefing at the end of the simulation. Participants had to achieve each objective in each segment of the simulation before advancing to the next segment. The training ended with the same 20-question knowledge-based test.

Design

This study used a pre-/posttest design with a multiple-choice test to assess knowledge acquisition. This study also used telesimulation training to assess skill acquisition.

In addition, a survey was used to assess participant satisfaction and confidence levels, which included qualitative data collected from participants' free-text comments.

The knowledge test was developed by Johns Hopkins anesthesiology and critical care medicine faculty and residents after undergoing three drafting processes to reflect the ventilator capabilities, didactics, and simulation curriculum. Questions about mechanical ventilation were based on what is commonly asked of trainees. Questions about the use of the Gradian equipment were obtained from Gradian and modified for this curriculum to reflect the ventilator capabilities for the low-resource setting. There were no questions regarding features that were not accessible with the 2020 model of the Gradian CCV ventilator model. Questions specific to COVID-19 were created with several drafting processes after approval by faculty, because there were no common questions for COVID-19 at the time. Pretest and posttest scores were evaluated for a minimum of 0 points and a maximum of 20 points. The simulation curriculum was developed and revised by the Johns Hopkins University faculty and residents, taking into account the capabilities for a low-resource setting. Situational awareness regarding unfamiliarity with ventilators and with COVID-19 was understood by the Johns Hopkins team. Simulation checklist scores were evaluated for a maximum score of 100%.

Participants anonymously completed a 15-question post-training survey using a 5-point Likert scale ranging from strongly disagree to strongly agree (*see* Appendix E1). Participants were also encouraged to leave comments about the training in the free-response section at the end of the survey. The 15-question post-training survey was developed by Sierra Leone project coordinators and health professionals in line with common questions derived from prior training programs.

Faculty were also welcome to provide formal free-text feedback after each training. Survey ratings, participant survey comments, and faculty comments were included in the analysis.

Data Analysis

Pretest and posttest knowledge scores were both reported descriptively and analyzed using a paired t test for significance with IBM SPSS Statistics software (IBM Corp., 2019). Significance was determined at $P < 0.05$. Survey responses to Likert-scale items were analyzed descriptively as proportions of responses. Thematic analysis was performed inductively by organizing and grouping open-ended responses on the basis of the themes identified (18). Key quotes from the qualitative analysis are presented.

RESULTS

Seventy-three participants enrolled in the program (Table 1) and included doctors and nurses from all regions of Sierra Leone. Workshop faculty included two from Sierra Leone (a nurse anesthetist and anesthesiologist) and six physicians in the United States.

Fifty-five participants completed the pretest and posttest. There was an average improvement in posttest scores of 4.00 (20.8%) from baseline ($P = 0.004$) (Figure 1). Commonly missed questions addressed ventilator determinants of oxygenation ($n = 33$ of 55; 60%), issues specific to modes of ventilation ($n = 27$ of 55 [49%] and $n = 37$ of 55 [67%]), and the specific design of the CCV ($n = 35$ of 55; 64%). All participants completed the simulation through rapid-cycle deliberate practice instruction and achieved 100%

Table 1. Participant demographics

Demographic Variable	n	%
Sex		
Male	51	71%
Female	22	29%
Scope of practice (nurses)	39	53.4%
ICU nurse	5	6.8%
Nurse anesthetist	28	38.4%
Nurse (other)	6	8.2%
Scope of practice (physicians)	33	45.2%
Physician specialist	6	8.2%
Medical officer	21	28.8%
Other house officer	0	0%
Anesthesia resident	4	5.5%
Physician registrar	2	2.7%
Scope of practice (other)	1	1.4%
Province		
Northern	8	11%
Southern	5	6.8%
Eastern	9	12.3%
Western	51	69.9%
Critical care mechanical ventilator access		
Present at their facility	59	80.8%
Not present at their facility	14	19.2%

Definition of abbreviation: ICU = intensive care unit.

of the objectives of the simulation (*see* Appendix E1).

Participant Survey Results and Comments

Survey results totaled 75. Participants were asked to rate their agreement with each response (Table 2), and the mean rating was 4.25.

Qualitative Analysis from Learner Survey Comments

These findings are being reported as a result of our qualitative analysis of learner survey comments. Major themes that emerged from analysis of the participant free-response section reflected acceptability of the workshop and included the need for more training, readiness to train others,

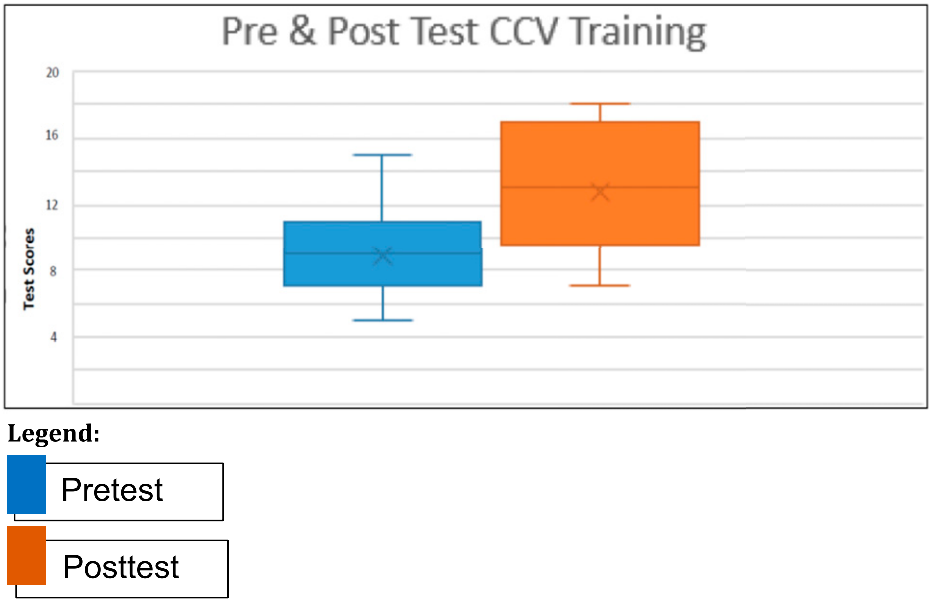

Figure 1. Box plot of pre and posttest results. The training program included a 20-point multiple-choice examination. Program participants' mean pretest score was 8.75, and the mean posttest score was 12.75 ($P = 0.004$).

need for more reading materials, and limited access to ventilators at their facilities.

Participants wanted more training. Some wanted training more frequently, at least every 4 months, and not just to address COVID-19, and for longer than 2 days. For example, one respondent stated, "[T]wo days training was not enough to learn everything about this complex CCV machine. It is a strange machine so it will take time to familiarize ourselves with." Another stated, "I am very much happy for this training and hoping to be having more training from you."

After the training, many participants believed they were ready and equipped to train other colleagues on the critical care ventilator. For example, one participant stated, "I do appreciate this training very much and with the knowledge gained I believe I will be able to help train another healthcare worker to be able to operate the CCV to help save the life of a patient."

Participants requested more pretraining reading materials. One participant mentioned that "more reading materials are needed to increase our confidence level."

Finally, many participants acknowledged the limited access to critical ventilators in their respective health facilities. Participants stated that they "wish to have access to the CCV" to "better improve knowledge" at their various facilities.

Qualitative Analysis of Faculty Comments

These findings are being reported as a result of our qualitative analysis of faculty comments. U.S. and Sierra Leone faculty had to partner to make the program feasible. Both faculty from Sierra Leone and the United States provided feedback to each other after each 2-day session. Response rates from both U.S. and Sierra Leone faculty were 50%. Emerging themes included addressing language and

Table 2. Participant survey results ($n = 75$; 100%)

Survey Question	1 = Strongly Disagree	2 = Disagree	3 = Neutral	4 = Agree	5 = Strongly Agree	Mean (SD)
1. The presentations on day one were easy to follow.	0 (0%)	3 (4%)	15 (20%)	36 (48%)	21 (28%)	4 (0.649)
2. I had a good understanding of how the CCV works by the end of day one.	0 (0%)	5 (6.7%)	19 (25.3%)	38 (50.3%)	11 (14.7%)	3.63 (0.633)
3. I was comfortable with connecting the CCV and doing a machine check by myself by the end of day one.	0 (0%)	3 (4%)	13 (17.3%)	36 (48%)	23 (30.7%)	4.05 (0.646)
4. I was able to understand the various parameters and modes of ventilation by the end of day one	0 (0%)	5 (6.7%)	16 (21.3%)	39 (52%)	15 (20%)	3.65 (0.667)
5. The instructors in this training were clear and easy to understand	1 (1.3%)	0 (0%)	8 (10.7%)	37 (49.3%)	29 (38.7%)	4.24 (0.563)
6. I feel comfortable identifying when a patient with an acute respiratory illness requires ventilator support.	0 (0%)	0 (0%)	9 (12%)	39 (52%)	27 (36%)	4.24 (0.428)
7. I feel comfortable making a plan to safely intubate a patient with hypoxic respiratory failure.	0 (0%)	1 (1.3%)	9 (12%)	39 (52%)	26 (34.7%)	4.2 (0.486)
8. I feel comfortable intubating a patient with hypoxic respiratory failure, e.g., COVID-19 patient.	1 (1.3%)	2 (2.7%)	10 (13.3%)	38 (50.7%)	24 (32%)	4.09 (0.680)
9. I feel comfortable troubleshooting high-pressure and low-pressure alarms on ventilator.	1 (1.3%)	1 (1.3%)	7 (9.3%)	29 (38.8%)	37 (49.3%)	4.33 (0.658)
10. I feel comfortable changing ventilator settings and modes for a patient on the ventilator.	0 (0%)	1 (1.3%)	5 (6.6%)	34 (45.4%)	35 (46.7%)	4.38 (0.453)

Table 2. *Continued.*

Survey Question	1 = Strongly Disagree	2 = Disagree	3 = Neutral	4 = Agree	5 = Strongly Agree	Mean (SD)
11. I feel comfortable identifying when a patient on a mechanical ventilator is ready for extubation and making a safe extubation plan.	0 (0%)	1 (1.3%)	8 (10.6%)	41 (54.7%)	25 (33.4%)	4.2 (0.459)
12. The clinical scenarios have increased my confidence to safely manage a COVID-19 patient using the CCV.	0 (0%)	0 (0%)	5 (6.6%)	41 (54.7%)	29 (38.7%)	4.32 (0.356)
13. I found the additional training material provided quite relevant.	0 (0%)	0 (0%)	6 (8%)	24 (32%)	45 (60%)	4.52 (0.415)
14. I was able to learn effectively in this online training.	0 (0%)	0 (0%)	3 (4%)	32 (43%)	40 (53%)	4.49 (0.334)
15. Overall, I am satisfied with the knowledge and skills gained in this training	0 (0%)	0 (0%)	3 (4%)	25 (33%)	47 (63%)	4.59 (0.327)

Definition of abbreviations: CCV = Comprehensive Care Ventilator; COVID-19 = coronavirus disease; SD = standard deviation.

clarity from U.S. staff and time zone difference and synchronous sessions.

Language and Clarity

U.S. faculty were careful "to avoid abbreviations and colloquialisms that may not necessarily be comprehended by the trainees." In addition, Sierra Leone faculty stated, "At times, the students were confused because they had given the correct answer but this apparently was not heard and so the question was repeated."

Faculty from both the United States and Sierra Leone found it helpful to have parallel setups implemented in Sierra Leone and the United States, where Sierra Leone faculty were "useful by repeating some points while pointing them out on the CCV itself in person" and helped to "facilitate the flow" of the scenarios and monitored "the students for signs of confusion and misapprehension."

Time Zone Difference and Synchronous Sessions

Several faculty respondents reported that this was a feasible method of providing training. Faculty delivered the curriculum overseas across the 4-hour time zone difference between the U.S. Eastern Time Zone and Sierra Leone's time and successfully delivered it through the internet. For example, Sierra Leone faculty stated that the "internet connection was amazing," though U.S. faculty remarked that high-quality "cameras and clip-on microphones may improve" the training. In addition, because of the time zone difference, U.S. faculty thought the program's "hands-on machine check" was most feasible when "Gradian support" was poised "to start earlier than" U.S. faculty did.

The clinical scenarios were implemented for participation from all learners. One U.S. faculty member stated that "each provider should not need more than a half-hour" in each scenario and that having a prerecorded "demonstration" not only was useful for time management and effectiveness of the curriculum but also was an opportunity to "confirm the quality of the recording." Both U.S. and Sierra Leone faculty agreed that instead of having repetition of the same scenarios, it was preferred that the variation offered by "additional scenarios will make it more interesting."

DISCUSSION

On the basis of faculty and learner feedback and results from the knowledge and skill assessments, we believe that our workshop was feasible, acceptable, and effective. On the basis of faculty responses, the didactic session appeared easier to implement than the simulation training because of greater demands on the time of the hands-on simulation portion of the training, as well as real-time machine troubleshooting. Learner ratings and comments suggested that the curriculum was acceptable and that more training and ventilators were desired. Furthermore, participants demonstrated significant improvement in the knowledge and skill assessments, suggesting that the program was effective (19). It is notable that despite the modest improvement from 44% to 64% on the written knowledge test, there was a discrepancy between this score and the perceived comfort and confidence that participants reported in the survey. Improvement on the posttest could have been attributable to the experience of taking the examination and less to the workshop. Having control and intervention groups could have better analyzed this effect. Commonly missed posttest questions include a combination of concepts in mechanical ventilation and specific questions on the various modes of mechanical ventilation. These posttest findings are consistent with participant survey ratings of mastery of the various modes of ventilation. However, we believe that the curriculum was effective in increasing knowledge, as evidenced by the scores, improvement on the simulation, and the survey responses from the entire curricular experience (19). However, a 2-day curriculum may not have been enough to further increase posttest scores.

Several other studies have evaluated the feasibility, acceptability, or effectiveness of telesimulation programs for medical education. Padhya and colleagues (20) addressed a multinational training program for pediatric critical care training. Such training included seven countries, including one in Africa (Congo). Padhya and colleagues (20) employed both pre- and post-training simulation of physicians and nurses, demonstrating improvement after remote training in critical tasks addressing admission to the ICU, thus demonstrating both feasibility and effectiveness. Other successful telesimulation programs have been implemented in developed countries (21, 22). Naik and colleagues used a combination of a video tutorial and telesimulation to educate non-ICU care providers with limited ventilator experience to prepare for patients with COVID-19 in New York City, the U.S. epicenter of the pandemic. However, feedback from the program also suggested a desire to practice troubleshooting mechanical ventilator problems, an activity that was intentionally addressed with our workshop. Another study in Canada focused on low-resource rural areas of Canada (23), where a diverse interprofessional range of learners, including physicians, nurses, respiratory therapists, paramedics, and others, engaged in telesimulation with a focus on personal protective equipment and intubation skills. This contrasts with our innovative program, which was less focused on intubation skills and more intentionally focused on ventilator management of the patient with COVID-19. Shao and colleagues (10) implemented an international virtual simulation curriculum that proved feasible and effective. The authors acknowledged that language and communication barriers can make live telesimulation more time-consuming than initially planned.

In the studies above, only one addressed telesimulation of critical care skills in Africa; the other studies, including the multinational studies, did not include telesimulation in sub-Saharan Africa. However, countries in sub-Saharan Africa, such as Nigeria, have been open to the idea of telesimulation (24). Our study is novel because it targeted the training of highly complex critical care management skills that are necessary for the care of severely hypoxic patients with COVID-19 in Sierra Leone (with known provider shortages) using high-fidelity simulation via a telesimulation format. We successfully implemented parallel equipment setups in the United States and in Sierra Leone. In addition, we achieved this with a rapid ramp-up since the first patients with COVID-19 in Sierra Leone appeared.

A key challenge observed in our workshop was achieving context-appropriate solutions for balancing synchronous and asynchronous curriculums. It is critical to strike a balance between live learner engagement and delivering an asynchronous portion that increases quality and self-paced learning but compromises immediate feedback and live interactions with learners. In our effort to create a sustainable training program, we considered interprofessional, learner-centered, and culturally appropriate methodologies and decided to use synchronous learning because of the benefits, such as increased confidence with skills, feedback, and increased learner satisfaction (25). While maintaining social distancing among learners, we organized multiple trainings with few participants in each session spread out over many weeks to avoid crowding. In this way, we preserved opportunities for live, collective learning.

Our workshop confirmed that what remains most essential in global distance health professions education is that preexisting, ongoing partnerships (7) and voices of local partners in the face of a global health crisis provide a foundation strong enough to enable trust in new initiatives. Such partnerships may endure for a long time and birth impactful global health actions. Participants appeared satisfied with training; yet, they wanted increased access to critical care ventilators and more frequent trainings.

Regardless of the workshop's success, disparities in access to training remain a challenge. Who can travel for live training? Who can access asynchronous training? Who has access to continued training on these ventilators? Not everyone has the privilege to engage in such training in the same way. Even with 100% asynchronous sessions, challenges remain with internet data access, connectivity, or ventilator use. Thus, remote learning with the "essentials" does not necessarily increase outreach, because some populations may disproportionately have less access. Similarly, regardless of where training is offered, or education strategy, or achievement of synchronicity, the post–COVID-19 era will likely reveal the urgent need to create more equal access to training in global health professions education.

Importantly, it is arguable that this training provides a way to continue or augment clinical training in the face of stark physician shortages in Sierra Leone, especially with pandemic-level travel restrictions. However, providing greater access to sustained training of healthcare providers locally will help address shortages for the long term.

Limitations

This workshop did not assess the application of knowledge by the participants in medium to long-term follow-up. Also, with only 2 days available for training each group and limited availability of space and faculty, it would not have been feasible to do a skills pretest and posttest for each participant. Furthermore, in using a critical care ventilator for the low-resource setting, the special features could not coexist with capabilities to display scalar waveforms and inspiratory/expiratory holds. Therefore, having plateau pressure and total positive end-expiratory pressure in the questions and simulations would not be a realistic reflection of the ventilator capabilities necessary for the low-resource setting. Thus, although it was included in the didactics sessions, it was not addressed in the multiple-choice questions or the simulations. This omission does present as a limitation to demonstrating increased safe clinical practice as an outcome. Furthermore, the multiple-choice pretests and posttests alone may demonstrate knowledge acquisition but not necessarily clinical competence or safe clinical practice; further in-person or virtual training would be necessary to achieve clinical mastery and can be a foundation for a change in practice. Regardless, we think that our multimodal methods of training resulted in increased knowledge and skills on ventilator setup and use in treating patients, as was demonstrated with improvement on written assessments, simulation, and responses from the participants.

Future Considerations

Another key observation is the desire for continuous learning and skills training among healthcare providers. This level of engagement and sustainability could provide as much training as a fellowship for general practitioners and other providers who were not in a training program. It is important to note also that in 2018, Sierra Leone started an anesthesiology residency training program, and all the anesthesia residents at that time ($n = 4$) participated in this training. Future workshops can be structured to include more simulation time because the simulations were very well received. More follow-up training can include tracking of the use of the CCV, especially for the anesthesiology and surgery residents as they develop into the perioperative and critical care physicians for Sierra Leone. Other additions to training for participants can include bedside teaching rounds in an actual ICU, teleconsultation, clinical case conferences, or morbidity and mortality sessions.

The COVID-19 pandemic demonstrated the possibility that higher-resource countries could also have a demand for critical care and mechanical ventilation expertise that substantially exceeds supply. Lessons learned from low-resource settings that chronically face this mismatch can have applicability to high-resource countries in disaster planning. This research priority can address training in the context of worker shortages anywhere (26).

In all our efforts with critical care training in Sierra Leone, learner feedback consistently expressed concern that an actual patient may present additional challenges not encountered during the simulated scenarios and concerns regarding a need for further knowledge growth in critical care management. In response to these concerns, a 1-month grant was obtained from the Queen's Commonwealth Trust in the United Kingdom for daily morning rounds of critical care telementoring between frontline COVID-19 healthcare workers at the 34 Military Hospital in Sierra Leone and the Johns Hopkins international anesthesia education team.

Conclusion

Our workshop was a feasible, acceptable, and effective method of teaching healthcare workers about COVID-19, hypoxemia, and mechanical ventilation in a low-resource setting. A more robust curriculum and more sustained engagement are critical next steps to train safe and competent critical care providers in Sierra Leone. Future ventilator training opportunities can address increasing the workshop duration beyond 2 days to optimize knowledge gains and skills improvement with long-term follow-up.

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