The Journal of Education in Perioperative Medicine

Original Research

Evaluating Rapid-cycle Deliberate Practice Versus Mastery Learning in Training Nurse Anesthetists on the Universal Anaesthesia Machine Ventilator in Sierra Leone

Oluwakemi Tomobi, MD, MEHP
Serkan Toy, PhD
Michelle Ondari, BA
Sabair Lee, MD, MS
Howard Nelson-Williams, MD, MPH
Michael Koroma, MBCHB
John B. Sampson, MD

Introduction

Low-income and middle-income countries in sub-Saharan Africa have 0.1 to 1.4 anesthesia providers per 100 000 citizens,[1] well below the Lancet Commission's target of 20 per 100 000 citizens needed to provide safe surgery. Most countries in this region have a shortage or even absence of anesthesia physicians, and thus they rely almost entirely upon nurse anesthetists, who have limited postgraduate training and no supervision or anesthesiologist collaboration when providing anesthesia care for surgical procedures.

Sierra Leone currently has only 2 physician anesthetists serving its population of 6 million.[2] Whereas the United Kingdom has 17 physician anesthetists per 100 000 residents, Sierra Leone has a mere 0.03 per 100 000.[2] Currently, the country relies on nurse anesthetists who complete a United Nations Population Fund (UNFPA)-administered anesthesia training course that is meant to improve maternal mortality. In 2017, the Sierra Leone Ministry of Health purchased 41 anesthesia machines to be distributed to 21 hospitals across the country in an effort to enable nurse anesthetists to administer general anesthesia. In conjunction with the rollout of those machines, the Johns Hopkins University international anesthesia education team hosted a course to provide nonventilator anesthesia machine training in 2017. In the current study, which was carried out in 2018, we returned to Sierra Leone to train practitioners in using the anesthesia machine with a ventilator. We chose a simulation-based educational approach.

Medical simulation-based training is a form of experiential learning that takes place in a controlled environment with role-playing actors, mannequins, and equipment to better replicate the clinical context of each case.[3-5] It creates a high-fidelity scenario with no risk of harm to real patients. Although medical simulation-based training is proven effective for clinical knowledge and skill acquisition, little is known regarding which of its 2 methods—rapid-cycle deliberate practice (RCDP) or mastery learning (ML)—leads to greater clinical competence in low-resource settings.

RCDP emphasizes immediate, directed feedback at the point of error, and requires that following this feedback, the participant repeat the clinical training scenario either from the instant before the error was made or from the beginning of the scenario.[6] It cycles between *deliberate practice* and *directed feedback* until the participant masters the scenario from beginning to end without error. This methodology enables the trainer to provide debriefing throughout the session while participants work through the scenario multiple times until they have mastered both basic and complex tasks.[7] Studies in the United States show that RCDP has been effective in improving pediatric resuscitation skills for pediatric residents, and that improvement in neonatal resuscitation skills were observed after RCDP.[6,7] However, the benefits of RCDP in low-resource settings is unknown.

In ML, learners are tested at baseline before practicing scenarios that proceed with clear learning objectives and increasing difficulty. They engage in educational activities that are focused on the learning objectives and continue to practice until they complete a set minimum passing standard, such as a checklist score, for each education unit.[8] ML is not a *time-based* curriculum. Simulation-based ML has been shown to improve the clinical skills of interns as compared to those of historical controls[9] and to improve paracentesis skills and thoracentesis skills in internal medicine residents.[10,11]

The aim of this study was to determine whether RCDP or ML is more beneficial to nurse anesthetists learning to use a new intraoperative ventilator in Freetown, Sierra Leone. We hypothesized that both techniques would increase participants' performance scores but that RCDP would be more effective than ML in simulations of 3 scenarios: general anesthesia, postoperative pulmonary edema, and intraoperative power failure.

Materials and Methods

Ethics

This study was granted exempt status by our local institutional review board and was

continued on next page

continued from previous page

approved by the Research Ethics Committee of Princess Christian Maternity Hospital (PCMH) as being in full compliance with the institutional guidelines, rules, and regulations set forth by Sierra Leone. Participants were deidentified, and informed consent was obtained from each.

Setting

The Universal Anaesthesia Machine (UAM) training sessions took place at PCMH, in Freetown, Sierra Leone. The study was conducted over a 2-week period in June 2018. PCMH is the sole government-operated tertiary hospital and training center for maternal health services in Sierra Leone, where the main type of anesthesia administered for Cesarean sections was spinal anesthesia, with occasional procedures done with general anesthesia.[12] It has also been the site of an UNFPA-sponsored anesthesia training program aimed at decreasing national maternal mortality rates.

Participant Selection

All nurses recruited were required to have received a 1-year nursing diploma and to have undergone the UNFPA Nurse Anesthesia Training Program. Anesthesia technicians who completed additional UNFPA training were eligible and were also recruited to be part of the study. In addition, participants in the 2018 program must have completed the previous year's Fundamentals of General Anesthesia training program implemented in Sierra Leone. However, the anesthesia machines used in that program were not equipped with a ventilator. Foreign-trained nurse anesthetists and physician anesthesiologists were excluded from the program. Participants were recruited to represent the 4 geographic regions of Sierra Leone: West, North, South, and East. The local project coordinator contacted all 25 participants from the previous year's training by phone. The sampling strategy was influenced by clinical availability and the ability of the participant to travel to the central location of the simulation sessions. Twenty nurse anesthetists (87%) and technicians agreed to participate, and 17 (74%) completed the study.

Materials

The UAM and ventilator were from Gradian Health Systems, Inc (New York, New York). The lung simulators used were QuickLung Breather and Respitrainer Advance (each from InMar Medical Inc, Pittsburgh, Pennsylvania). Other equipment used in the simulations included an auxiliary oxygen tank for the UAM, a laryngoscope with Macintosh-3 and Miller-2 blades, a size 7.0 endotracheal tube, and an oral airway. Computer-simulated vital sign monitoring required an iPAD vital sign simulation app (Apple, Cupertino, California), a desktop computer monitor, and a cable connector between the 2.

Study Design

For this 2018 study, we conducted a pretest and posttest experimental study with 2 intervention groups: one that received training via RCDP and the other with ML. The simulations were designed to depict a routine General Anesthesia scenario, a postoperative emergency, and an Intraoperative Power Failure scenario that leads to loss of oxygen delivery. We chose the routine General Anesthesia scenario and checklist items because this was the first opportunity for learners to use the ventilator with an uncomplicated elective surgical case, and because it was a direct application of the basic science portion of the curriculum (for example, learners were exposed to concepts of preoxygenation). Thus, we demonstrated the most basic skills of how to use the ventilator in a common General Anesthesia case. We chose the Postoperative Pulmonary Edema scenario as an opportunity to determine if certain training strategies were advantageous to emergency situations in which learners must think quickly. The Intraoperative Power Failure scenario was similar to one used during the 2017 training program and was chosen because the learners' practice environments were prone to frequent power outages. This scenario served as refresher training on how power failures affect anesthesia management priorities, such as identifying alternate sources of oxygen and maintaining the fully anesthetized patient on room air anesthesia if the power failure (oxygen concentrator will stop) occurs concurrently with oxygen tank depletion. New to the 2018 Intraoperative Power Failure scenario was the use of the ventilator. Critical decision-making events that would occur during these scenarios were outlined by anesthesiology faculty and formed the basis of the checklists.

Participants were randomized to the RCDP or ML training group by picking a number from a hat. Nurses with even numbers were assigned to ML simulation training and those with odd numbers to RCDP simulation training. For each scenario, the participants took a clinical scenario simulation pretest that served as a baseline, and the number of checklist items achieved was documented. Participants also took a simulation posttest, during which time was recorded in minutes and the number of completed checklist items documented. The differences in checklist item completion between pretest and posttest were determined in both intervention groups and were compared. Two data collectors independently recorded the time and the number of steps completed.

Variables and Data Measurement

Each participant randomized to the ML group received a simulation pretest followed by a group debriefing. They then had additional unlimited and uninterrupted simulation opportunities to achieve mastery of the clinical scenarios, before debriefing and a simulation posttest.

Each participant randomized to the RCDP group received a simulation pretest and then undertook the scenarios with RCDP intervention. In this intervention, participants were stopped at specific points when they made critical mistakes. They then received a demonstration of the task, feedback, and an opportunity to redo the task within the simulation. The participant moved on to the next segment of the scenario only after objective standards were met. A simulation posttest was administered thereafter. The number of times the participant was stopped at each item was also recorded for this group.

Curriculum

The curriculum consisted of 3 checklists, 1 for each scenario. Each of these checklists included a list of essential steps, which varied depending on the scenario (see Supplemental Online Material, Appendix A). The list of steps for each scenario made up the simulation curriculum that would

continued on next page

continued from previous page

be taught to the nurse anesthetists during the training. The checklists were tested and modified by faculty before being used in the simulation training. The Intraoperative Power Failure checklist from the previous training was used again for the current training. The other two checklists were evaluated based on the anticipated content of the lectures and were tested with learners who did and did not have anesthesiology experience. Our anesthesiology faculty suggested modifications to include a preoxygenation step and incremental steps for transitioning between spontaneous and mechanical ventilation.

Participant Evaluation

The same checklists used for training were used during the pretraining assessment to evaluate baseline skills and during the posttraining assessment to measure performance improvement. Participants were evaluated based on a 5-item General Anesthesia checklist, a 7-item Intraoperative Power Failure checklist, and a 5-item Postoperative Pulmonary Edema checklist (see Supplemental Online Material, Appendix A). Each checklist item was scored as 0 if it was not completed or 1 if it was completed. Two data collectors evaluated each participant, and agreement between them was compared. Data collectors were not blinded to participants' group assignment because the data collection sheet is designed differently for each group assignment; thus data collectors needed to be aware to collect different data based on group assignment. Data collectors had no prior knowledge of participants in the study, nor did the data collectors participate in the teaching modalities used in the study.

For each participant, time elapsed in the scenarios and checklist completion scores were recorded for the pretest and posttest simulations. Pretest and posttest differences in number of steps completed represented learning gains and constituted the primary outcomes. We compared the means and medians of these scores in the 2 intervention groups to assess for significant differences between the groups.

Simulation Setup

At least 5 simulation personnel were involved with execution of the scenarios: 1 who served as the facilitator, 1 who controlled the vital signs and other machine settings, 2 who served as data collectors, and 1 who played the role of surgeon. Each participant was allowed 2 minutes to review the available written scenario and then was instructed to commence anesthesia care. Based on a simulation script, each participant was given verbal cues on the progress of the case.

Analysis

We performed a test of comparability between groups to ensure that participants in the RCDP and ML groups had similar baseline characteristics. The mean differences in the number of checklist items completed between pretest and posttest were computed for each intervention group. A Mann-Whitney *U* test was used to determine statistical significance. Interrater reliability was determined by using Cohen kappa coefficient. We performed a combined group analysis with the Wilcoxon signed rank test to determine the overall effectiveness of simulation-based medical education training. Finally, as a group, the high-frequency problem areas in the checklists were gathered. The total percentage of all participants who achieved the checklist items at baseline was computed and displayed with the number of times a participant in the RCDP group was stopped for that same checklist item. The statistical analyses were carried out with statistical package for the social sciences (IBM SPSS Statistics for Mac, version 25.0, IBM Corp, Armonk, New York), and significance level was set at $P < .05$.

Results

Seventeen nurse anesthetists who met the inclusion criteria participated in this study (Table 1, Figures 1 and 2). Most practiced in locations that previously had no functioning anesthesia machine, in which case a bag-valve-mask or similar resuscitation bag with intravenous ketamine would be used for general anesthesia. However, those who practiced at PCMH and Connaught Hospital did have access to anesthesia machines. None of the participants had any previous training on the UAM Ventilator.

The data for the General Anesthesia, Intraoperative Power Failure, and Postoperative Pulmonary Edema scenarios, as illustrated in Table 2, reveal nonsignificant elapsed time differences in pretest and posttest between the groups: (General Anesthesia: $P = .51$; Intraoperative Power Failure: $P = .89$; Postoperative Pulmonary Edema: $P = .85$). A set of Mann-Whitney *U* tests showed no difference in the number of steps completed between the 2 groups for any scenario (General Anesthesia, $U = 31.5$, $P = .73$; Intraoperative Power Failure, I = 25, $P = .58$; Postoperative Pulmonary Edema, $U = 27$, $P = 0.43$). In comparing average total simulation curriculum time in minutes, participants spent significantly more simulation time in RCDP than in ML for the General Anesthesia scenarios (RCDP: mean [M] = 52.3 min, SD = 14.8; ML: M = 34.4 min, SD = 13.1; $P = .02$) and slightly more simulation time in the Postoperative Pulmonary Edema scenarios (RCDP: M = 21.3, SD = 10.1; ML: M = 14.1 min, SD = 4.5; $P = .07$). In contrast, for the Intraoperative Power Failure scenario, participants spent slightly more time in ML than in RCDP (RCDP: M = 25.4 min, SD = 9.7; ML: M = 27.8 min, SD = 11.7; $P = .68$).

In addition to evaluating the intervention groups separately, we evaluated the participants together as one group. A set of Wilcoxon signed rank tests showed that simulation-based training, regardless of the technique used, helped participants significantly improve their scores on the outcome measure in all 3 scenarios (General Anesthesia: $Z = -3.621$, $P < .001$; Intraoperative Power Failure: $Z = -3.51$, $P < .001$; Postoperative Pulmonary Edema: $Z = -3.354$, $P = .001$).

Table 3 is a compilation of the checklist items from all 3 clinical scenarios that correspond with life-threatening gaps in real clinical situations. Each checklist item includes the percentage of all participants who achieved the task at baseline, and for the RCDP group only, the total number of times a participant was stopped to get feedback and to redo the task before the posttest. The highest frequency problem area for participants was switching from spontaneous ventilation to mechanical ventilation (35.3%, 11 stops). The next highest frequency problem areas were preoxygenation (41%, 6 stops) and identifying appropriate treatment recommendations in a postoperative emergency (32.4%, 6 stops).

continued on next page

continued from previous page

Interrater reliability for the data collectors was assessed with Cohen kappa coefficient, and was unweighted for 2 raters, where kappa = 0.737, z = 12.2, and *P* = 0.

Discussion

The purpose of this study was to evaluate whether RCDP was more effective than ML for training nurse anesthetists on the UAM. In the process of doing this we also identified high frequency problem areas for ventilator course participants. Checklist items on our simulation scenarios revealed life-threatening gaps in the performance of safe anesthesia in Sierra Leone. Both simulation-based ML and RCDP training led to increased proficiency and accuracy of nurse anesthetists who completed our clinical scenarios. We also wanted to address the benefit of RCDP vs ML for simulation facilitators and other educators.

During the General Anesthesia scenario, certain checklist items were time-sensitive and could lead to life-threatening gaps if missed. Preoxygenation and switching from spontaneous ventilation to mechanical ventilation were 2 such items. Preoxygenation is recommended to create a reservoir for oxygen when periods of apnea are anticipated.[13] Switching between spontaneous ventilation and mechanical ventilation is important to improve patient breathing and to prevent patient-ventilator dyssynchrony and its complications. These checklist items were the most frequent problem areas for both the RCDP and ML groups. Improvement in these areas did not differ significantly between the groups; therefore, RCDP did not appear to have an advantage in the General Anesthesia scenario. In comparing total simulation instructional time, participants in the RCDP group used significantly more simulation time than participants in the ML group used for the General Anesthesia scenarios (*P* = .02). These findings suggest that while ML is not a time-limited curriculum strategy, RCDP may actually require significantly more time investment for simulation, with higher numbers of RCDP participants requiring more curricular time in simulation than in ML.

In the Intraoperative Power Failure scenario, the most common problem areas for both groups were in recognizing the decreasing oxygen flowmeter level after the power outage, identifying the sources of oxygen during power failure, identifying a machine breathing circuit disconnect, and developing a systematic approach to correct the disconnect. The difference in performance scores between the 2 groups, however, was not statistically significant. Participants in the RCDP group were not stopped as frequently in the intraoperative power failure scenario as they were stopped in the other scenarios. Therefore RCDP did not appear to have an advantage, even when accounting for the amount of time per step. The lack of difference between the RCDP and ML groups could potentially have been because the Intraoperative Power Failure scenario was also part of the 2017 Fundamentals of Anesthesia training program (unpublished study). Thus, all participants had received prior exposure to this part of the curriculum. Owing to the need for frequent training in the setting of power failure, the previous checklist was determined to be useful for the current training. Unlike the General Anesthesia scenario, participants spent slightly more time in ML than in RCDP for the Intraoperative Power Failure scenarios, but it was not statistically significant (*P* = .68). A possible explanation could be that these participants spent more time refreshing knowledge and skills that have been identified in prior trainings.

For the Postoperative Pulmonary Edema scenario, the most common problem area for participants in both groups was identifying and responding to this postoperative emergency. Upon extubation, learners must immediately recognize when laryngospasm develops, monitor oxygen saturation, and prevent (or manage) postoperative pulmonary edema, which is a complication of laryngospasm. These items in the scenario are the most time-sensitive and require much intuition to react to the emergency. Based on the advantage of reflection-in-action in time-sensitive segments of the clinical scenarios,[14] we predicted that RCDP would be especially beneficial in the Postoperative Pulmonary Edema scenario. In emergency, time-sensitive, life-threatening situations, RCDP has an advantage in role play, communication, and teamwork.[6,7] These skills are particularly crucial in the Postoperative Pulmonary Edema scenario, as learners are dealing with postoperative emergencies and transitions between care teams. Despite our expectations, the differences in performance scores were not statistically significant. RCDP had no clear advantage for training nurse anesthetists in the technical skills required to master the ventilator. Because of the limitations of small sample size and statistical insignificance, any predicted advantage of RCDP was not demonstrated. In comparing total simulation time, participants spent more time in RCDP than in ML for the Postoperative Pulmonary Edema scenarios, but the difference was not statistically significant. These findings suggest that while ML is not a time-limited curriculum strategy, RCDP may actually require more time investment for simulation, with higher numbers of RCDP participants requiring more curricular time in simulation than in ML.

However, when all participants were evaluated as 1 simulation group, the results indicated a statistically significant increase in skills after simulation-based training for all 3 scenarios. These results confirm that either form of simulation is a useful method to train nurse anesthetists on the UAM Ventilator, and that all participants benefitted from the simulation-based training. These findings also support literature that simulation is a useful education strategy in low-resource environments.[15,16]

We are not aware of any literature that compares RCDP simulation to ML in either high-resource or low-resource settings. Rosman et al[17] compared RCDP with traditional simulation for pediatric residents in Rwanda and found no significant differences in performance scores or confidence ratings. Traditional simulation, as defined in their study, is different from ML in that traditional simulation is limited to 1 scenario with a debriefing session. ML, on the other hand, is not time-based and participants can repeat the scenarios and debriefing sessions to achieve a minimum passing standard.[8] Our study compares RCDP and ML in a low-resource setting. A pilot study by Lemke et al[18] compares RCDP to traditional simulation in the United States and detected significant improvement in team-based resuscitation skills, revealing that RCDP is more advantageous over traditional simulation. Another study enrolled US fourth year medical students in an airway

continued on next page

continued from previous page

management course and compared RCDP to traditional simulation, and found RCDP to significantly improve scores in procedural airway management skills when compared to traditional simulation,[19] with immediate feedback and opportunity to demonstrate skills as highlights of the findings. Finally, Chancey et al[20] conducted a qualitative study of learners' perceptions of RCDP after they completed a pediatric emergency medicine rotation. Findings revealed positive perceptions towards learning quickly from the interruptions, learning in a safe environment, learning information in small chunks, and preventing cognitive overload. Together, these findings[18-20] indicate several benefits of RCDP in high resource settings that could have suggested benefits for learners in our study, and, along with studies by Hunt et al[6] and Magee et al[7] led to our hypothesis that RCDP would be more effective than ML in this ventilator training program.

Studies suggest that refresher trainings may benefit more from ML than from RCDP. One study[21] used ML as "booster sessions" to prevent skill decay in pediatric residents while another study[22] used ML to update incoming medical interns in a "bootcamp" before starting residency. This use of ML was something that we saw in our study, as simulation time for the Intraoperative Power Failure scenario was similar in both the RCDP and ML groups ($P = .68$), suggesting that this scenario was a refresher training for both groups of participants; there were fewer stops in the RCDP group; thus, less feedback and demonstration of skills was needed to progress through this scenario. Taken together, these findings[21,22] support the literature on both RCDP and ML in high resource settings. Our study helps to fill in a gap in comparing the effectiveness of RCDP to ML in both high-resource and low-resource settings and also addresses the time investment required for each instructional strategy. Thus, our study has implications for comparing instructional strategies for health professionals in low-resource settings, where resource limitations, regardless of learner sample size, may determine the optimal educational strategy that is more impactful.

As discussed above, small sample size was a limitation. Sierra Leone is medically underserved, with limited numbers of anesthesia providers available to participate in training programs. While increasing the sample size may provide enough power to clarify differences between the ML group and the RCDP group, and could support or refute our findings, the reality is that the numbers are below the Lancet Commission's recommendation for safe surgery, and it would have been difficult to recruit high numbers of anesthesia providers for this study.[1,2] Another limitation was the lack of follow-up training. It may be a challenge to retain the same participants for a follow-up study in which we could determine if RCDP shows an advantage in long-term learning gains. Such a challenge can be an opportunity for a future study. Also, a case could be made for comparing time-sensitive transitions in the scenarios between the RCDP and the ML group, and this can also be an opportunity for a future study. An additional limitation was in the design, which consisted of 2 intervention groups and no control group. This design may compromise external validity. Nevertheless, we thought it would be a poor use of time and resources to limit some participants to a control group that would not have the opportunity to master all of the learning objectives.

Overall, participants in both groups benefitted from the training. Both groups exhibited a decrease in mean elapsed time in the scenarios, and though baseline performances varied, both groups were able to achieve 100% completion of the checklist on the posttest. Collective participant feedback did not distinguish between RCDP or ML groups but revealed that the majority of participants "liked the clinical scenarios," because it allowed them "to think on [their] feet about critical decisions in the operating theater." The majority wanted even more clinical simulation scenarios, with some wanting more pediatric and obstetric scenarios. Majority of respondents cited the opportunity to go through the ventilator settings as a crucial part of the course; they found this process very helpful. They especially found the intraoperative moments of dealing with oxygen desaturation as a great learning opportunity. The majority of participants wanted to decrease the time lapse between trainings, with no more than 6 months between training sessions. Feedback from instructors, however, indicated increased fatigue with RCDP simulation when compared to ML simulation.

In future studies, we hope to explore the type of learners and curricula to benefit most from RCDP and investigate whether early career trainees gain more than advanced learners do from RCDP. In low-income and middle-income countries, the limiting factor in safe surgical care is often anesthesia care. By implementing best educational strategies, training of anesthesia providers at any level can become more impactful in Sierra Leone. Our findings may have implications for increasing surgical safety in Sierra Leone and other low-income and middle-income countries in sub-Saharan Africa.

Acknowledgments

The authors thank Tamba Ansumana for coordinating the training program; Sahr Lamin, for leading the data collection process; Johns Hopkins School of Education's Masters in Education of the Health Professions (MEHP) program for approval of this study, in partial fulfillment of the MEHP requirements; the Johns Hopkins Center for Global Health for assistance with international travel preparation; and the Johns Hopkins Global Alliance of Perioperative Professionals for support throughout all the phases of this project.

References

1. Dubowitz G, Detlefs S, McQueen KA. Global anesthesia workforce crisis: a preliminary survey revealing shortages contributing to undesirable outcomes and unsafe practices. *World J Surg.* 2010;34(3):438-44.
2. Vaughan E, Sesay F, Chima A, et al. An assessment of surgical and anesthesia staff at 10 government hospitals in Sierra Leone. *JAMA Surg.* 2015;150(3):237-44.
3. Cook DA, Hatala R, Brydges R, et al. Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. *JAMA.* 2011;306(9):978-88.
4. Cook DA, Brydges R, Hamstra SJ, et al. Comparative effectiveness of technology-enhanced simulation versus other instructional methods: a systematic review and meta-analysis. *Simul Healthc.* 2012;7(5):308-20.
5. Steadman RH, Coates WC, Huang YM, et al. Simulation-based training is superior to problem-based learning for the acquisition of critical assessment and management skills. *Crit Care Med.* 2006;34(1):151-7.
6. Hunt EA, Duval-Arnould JM, Nelson-McMillan KL, et al. Pediatric resident resuscitation skills improve after "rapid cycle deliberate practice"

continued on next page

continued from previous page

training. *Resuscitation.* 2014;85(7):945-51.

7. Magee MJ, Farkouh-Karoleski C, Rosen TS. Improvement of immediate performance in neonatal resuscitation through rapid cycle deliberate practice training. *J Grad Med Educ.* 2018;10(2):192-7.
8. McGaghie WC, Siddall VJ, Mazmanian PE, et al. Lessons for continuing medical education from simulation research in undergraduate and graduate medical education: effectiveness of continuing medical education: American College of Chest Physicians Evidence-Based Educational Guidelines. *Chest.* 2009;135(3 Suppl):62S-8S.
9. Cohen ER, Barsuk JH, Moazed F, et al. Making July safer: simulation-based mastery learning during intern boot camp. *Acad Med.* 2013;88(2):233-9.
10. Barsuk JH, Cohen ER, Vozenilek JA, et al. Simulation-based education with mastery learning improves paracentesis skills. *J Grad Med Educ.* 2012;4(1):23-7.
11. Barsuk JH, Cohen ER, Williams MV, et al. Simulation-based mastery learning for thoracentesis skills improves patient outcomes: a randomized trial. *Acad Med.* 2018;93(5):729-35.
12. Koka R, Chima AM, Sampson JB, et al. Anesthesia practice and perioperative outcomes at two tertiary care hospitals in Freetown, Sierra Leone. *Anesth Analg.* 2016;123(1):213-27.
13. Benumof JL. Preoxygenation: best method for both efficacy and efficiency. *Anesthesiology.* 1999;91(3):603-5.
14. Schön DA. *The Reflective Practitioner. How Professionals Think in Action*. New York, NY: Basic Books; 1983.
15. Chima A, Koka R, Lee B, et al. Medical simulation as a vital adjunct to identifying clinical life-threatening gaps in austere environments. *J Natl Med Assoc*. 2018:110(2);117-23.
16. Turkot O, Banks MC, Lee SW, et al. A review of anesthesia simulation in low-income countries. *Curr Anesthesiol Rep*. 2019;9(1):1-9.
17. Rosman SL, Nyirasafari R, Bwisa HM, et al. Rapid cycle deliberate practice vs. traditional simulation in a resource-limited setting. *BMC Med Educ.* 2019;19(1):314.
18. Lemke DS, Fielder DK, Hsu DB, et al. Improved team performance during pediatric resuscitations after rapid cycle deliberate practice compared with traditional debriefing: a pilot study. *Pediatr Emerg Care*. 2019;35(7):480-6.
19. Gross IT, Abrahan DG, Kumar A, et al. Rapid cycle deliberate practice (RCDP) as a method to improve airway management skills - a randomized controlled simulation study. *Cureus.* 2019;11(9):e5546.
20. Chancey RJ, Sampayo EM, Lemke DS, et al. Learners' experiences during rapid cycle deliberate practice simulations: a qualitative analysis. *Simul Healthc*. 2019;14(1):18-28.
21. Matterson H, Szyld D, Green B, et al. Neonatal resuscitation experience curves: simulation based mastery learning booster sessions and skill decay patterns among pediatric residents. *J Perinat Med*. 2018;46(8):934-41.
22. Cohen E, Barshuk J, Moazed F, et al. Making July safer: simulation-based mastery learning during intern boot camp. *Acad Med*. 2013;88(2):233-9.

The following authors are in the Department of Anesthesiology & Critical Care Medicine, Johns Hopkins School of Medicine, Baltimore, MD: ***Oluwakemi Tomobi*** *is a Research Fellow;* ***Serkan Toy*** *is an Assistant Professor;* ***Sabair Lee*** *is a Clinical Instructor;* ***Howard Nelson-Williams*** *is a Senior Research Coordinator; and* ***John B. Sampson*** *is an Associate Professor.* ***Michelle Ondari*** *is a MSPH Candidate at Johns Hopkins School of Public Health, Baltimore, MD.* ***Michael Koroma*** *is the Director of the Nurse Anesthesia Training Program, Department of Anesthesiology, Princess Christian Maternity Hospital, Freetown, Sierra Leone.*

Corresponding author: *John B. Sampson, MD, Department of Anesthesiology & Critical Care Medicine, Johns Hopkins School of Medicine, 600 North Wolfe Street, Phipps 415, Baltimore, MD 21287-7840. Telephone: (410) 955-2611*

Email address: *John B. Sampson: jsampso4@jhmi.edu*

Funding: *This work was supported by a Johns Hopkins Center for Global Health Travel Grant and an unrestricted educational grant from Gradian Health Systems, Inc.*

Abstract

Background: Underserved sub-Saharan countries have 0.1 to 1.4 anesthesia providers per 100 000 citizens, below the Lancet Commission's target of 20 per 100 000 needed for safe surgery. Most of these anesthesia providers are nurse anesthetists, with anesthesiologists numbering as few as zero in some nations and 2 per 7 million in others, such as Sierra Leone. In this study, we compared 2 simulation-based techniques for training nurse anesthetists on the Universal Anaesthesia Machine Ventilator—rapid-cycle deliberate practice and mastery learning.

Methods: A 2-week Universal Anaesthesia Machine Ventilator course was administered to 17 participants in Sierra Leone. Seven were randomized to the rapid-cycle deliberate practice group and 10 to the mastery learning group. Participants underwent baseline and posttraining evaluations in 3 scenarios: general anesthesia, intraoperative power failure, and postoperative pulmonary edema. Performance was analyzed based on checklist performance scores and the number of times participants were stopped for a mistake. Statistical significance to 0.05 was determined with the Mann-Whitney *U* Test.

Results: Checklist performance scores did not differ significantly between the 2 groups. When the groups were combined, simulation-based training resulted in a statistically significant improvement in performance. The highest-frequency problem areas were preoxygenation, switching from spontaneous to mechanical ventilation, and executing appropriate treatment interventions for a postoperative emergency.

Conclusion: Both rapid-cycle deliberate practice and mastery learning are effective methods for simulation-based training to improve nurse anesthetist performance with the Universal Anaesthesia Machine Ventilator in 3 separate scenarios. The data did not indicate any difference between these methods; however, a larger sample size may support or refute our findings.

Keywords: Medical simulation, low-resource environment, anesthesia training, Sub-Saharan Africa, rapid-cycle deliberate practice, mastery learning

continued on next page

continued from previous page

Figures

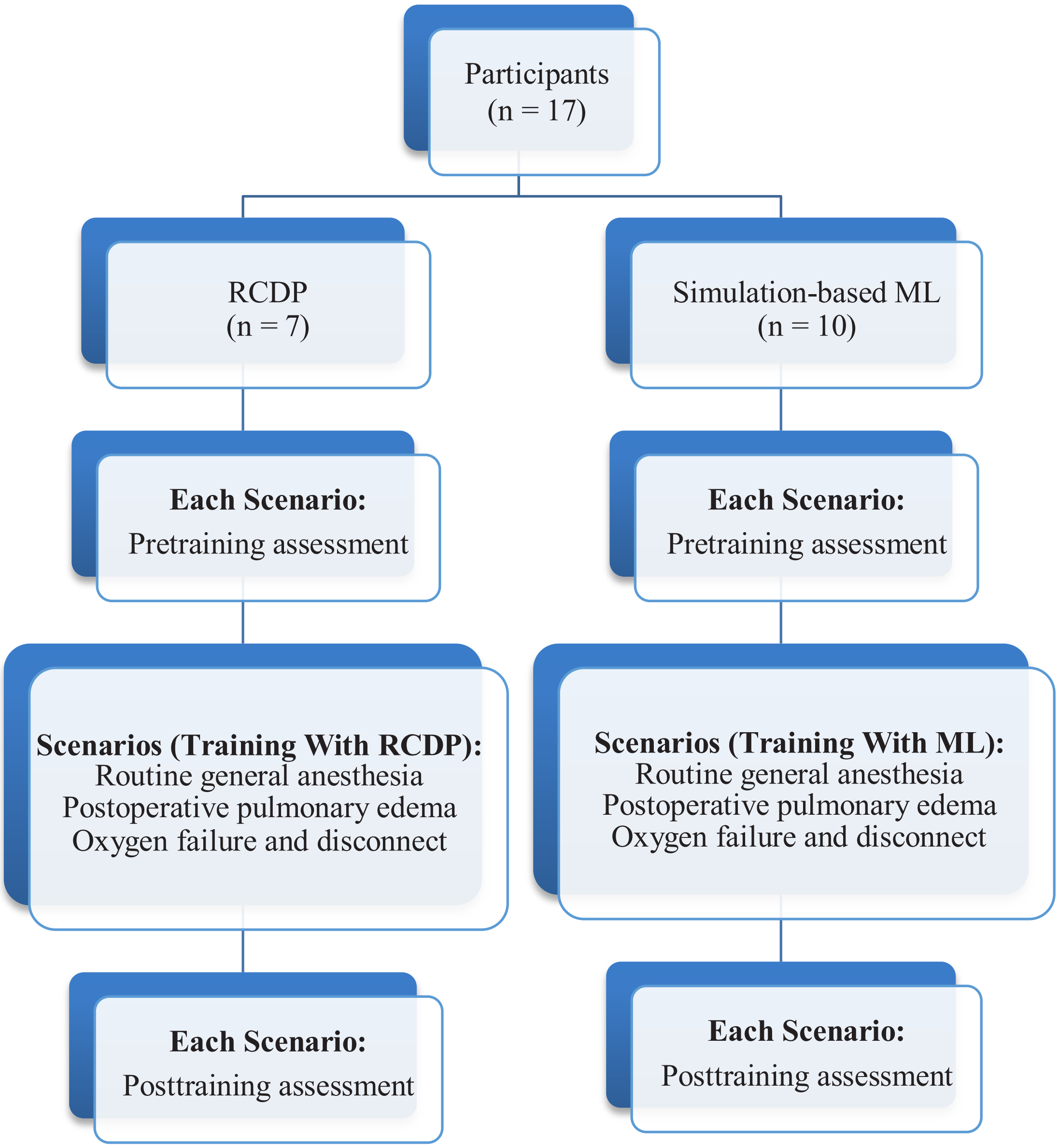
Figure 1. *Participant demographics. Participants were recruited from each of the 4 provinces of Sierra Leone. The training was implemented at Princess Christian Maternity Hospital, a teaching hospital in Freetown, Sierra Leone. (Attribution: Author: NordNordWest. License: Creative Commons by-sa-3.0 de: https://creativecommons.org/licenses/by-sa/3.0/de/deed.en.)*

continued on next page

continued from previous page

Figures *continued*

Figure 2. *Participant allocation. Abbreviations: ML, mastery learning; RCDP, rapid-cycle deliberate practice.*



continued on next page

continued from previous page

Tables

Table 1. *Participant Demographics*[a]

Demographics	All Participants (N = 17)	RCDP Group (n = 7)	ML Group (n = 10)
Sex			
Male	10 (58.9)	3 (42.8)	7 (70)
Female	7 (41.2)	4 (57.1)	3 (30)
Region			
North	6 (35.3)	3 (42.9)	3 (30)
South	3 (17.6)	2 (28.6)	1 (10)
East	3 (17.6)	0 (0)	3 (30)
West	5 (29.4)	2 (28.6)	3 (30)
Type of hospital			
Academic teaching hospital	4 (23.5)	2 (28.6)	2 (20)
Community hospital	13 (76.5)	5 (71.4)	8 (80)
Previous training on UAM ventilator	0 (0)	0 (0)	0 (0)
Clinical position			
Anesthesia technician	2 (11.8)	2 (28.6)	0 (0)
Nurse anesthetist	15 (88.2)	5 (71.4)	10 (100)

Abbreviations: ML, mastery learning; RCDP, rapid-cycle deliberate practice; UAM, Universal Anaesthesia Machine.

[a] All data are given as n (%).

continued on next page

continued from previous page

Tables *continued*

Table 2. *Descriptive Statistical Summary of Participants' Checklist Scores and Time in the Clinical Scenarios*

Scenario	ML (n = 10)				RCDP (n = 7)[a]			
	Mean (SD)	Median	Min	Max	Mean (SD)	Median	Min	Max
General anesthesia								
Baseline time (min)	17.15 (9.68)	13.75	7	36	21.07 (14.62)	17	5	40
Baseline steps	2.65 (1.56)	2.5	0	5	2.29 (2.36)	2	0	5
Posttraining time (min)	6.8 (2.06)	7	4	11	6.71 (3.29)	6.5	2	11
Posttraining steps	5 (0)	5	5	5	5 (0)	5	5	5
Intraoperative power failure								
Baseline time (min)	11 (6.88)	9	5	26.5	7.25 (3.24)	6.25	5	13.5
Baseline steps	2.8 (2.44)	3	0	7	2.25 (2.64)	1.75	0	7
Posttraining time (min)	7.85 (4.72)	6.25	2	16	4.58 (0.92)	5	3	5.5
Posttraining steps	7 (0)	7	7	7	7 (0)	7	7	7
Postoperative pulmonary edema								
Baseline time (min)	4.05 (1.01)	4	2	6	5.93 (3.91)	6.5	1.5	12
Baseline steps	2.6 (2.16)	3.25	0	5	1.93 (1.84)	1	0	4
Posttraining time (min)	3.95 (1.76)	3.75	2	7	5.86 (3.17)	5	2.5	10.5
Posttraining steps	5 (0)	5	5	5	5 (0)	5	5	5

Abbreviations: ML, mastery learning; RCDP, rapid-cycle deliberate practice.

[a] Intraoperative Power Failure scenario data are available for only 6 participants in the RCDP group.

continued on next page

continued from previous page

Tables *continued*

Table 3. *Table of Checklist Items that Correspond to Life-Threatening Emergencies*[a]

Checklist Item	Percent of Participants Who Achieved Checklist Item	Number of Stops for Checklist Item (RCDP Group Only)
Preoxygenation	41.2	6
Switch From Spontaneous to Mechanical Ventilation	35.3	11
Switch From Mechanical to Spontaneous Ventilation	35.3	2
Identify Postoperative Emergency	52.9	1
Identify Appropriate Treatment Interventions	32.4	6
Recognize Breathing Circuit Disconnect	21.2	2
Systematic Approach to Identifying and Correcting the Source of Disconnect	21.2	0
Recognize Decreasing Oxygen Flowmeter	59.3	2.5
Recognize Depletion of Tank	50	3

Abbreviation: RCDP, rapid-cycle deliberate practice.

[a] Data are shown as the total percentage of participants who achieved the checklist item at baseline and the total number of times that participants in the RCDP group were stopped.

continued on next page

continued from previous page

Supplemental Material

Supplemental Online Material

Appendix A. Checklists

Routine General Anesthesia Scenario Checklist

Mrs Laura Kayombo is a 30-year-old woman that presented to your emergency department with right lower abdominal pain for one day. Her temperature is 37.9°C. Her last meal was 6:00 PM yesterday. She has no previous medical complaints and no known drug allergies. The surgeon that examined her suspects that she has appendicitis and intends to do an open appendectomy. Her BP is 120/75 mmHg, pulse rate 90, and SaO_2 98%. She has a respiratory rate of 24 cycles per minute. She was just brought into the operating room. She has a well running 18 gauge IV. Please proceed with providing anesthesia care for this patient.

Name of Recorder:

Name of Participant:

Date:

Location:

<u>Routine General Anesthesia Pretraining Assessment</u>

Time at the start:

Routine Anesthesia Case Learning Objectives

❐ Not placing the flow-sensor between patient and breathing circuit

❐ Not placing a bacterial filter in the circuit prior to the flow-sensor

❐ Not preoxygenating patient

❐ Not transitioning the patient to mechanical ventilation via one of the 3 methods:

- ☐ Moves the ventilator switch (to ventilator)
- ☐ Confirms that the ventilator settings are appropriate
- ☐ Starting the ventilator

❐ Not transitioning the patient to spontaneous ventilation prior to extubation

Time at the end:

<u>Training Cycle</u>

Time at the start:

❐ Not placing the flow-sensor between patient and breathing circuit: ____

❐ Not placing a bacterial filter in the circuit prior to the flow-sensor: ____

❐ Not preoxygenating patient: ____

❐ Not transitioning the patient to mechanical ventilation via one of the 3 methods:

- ☐ Moves the ventilator switch (to ventilator): ____
- ☐ Confirms that the ventilator settings are appropriate: ____
- ☐ Starting the ventilator: ____

❐ Not transitioning the patient to spontaneous ventilation prior to extubation: ____

Time at the end:

continued on next page

continued from previous page

Supplemental Material *continued*

Routine General Anesthesia Posttraining Assessment

Time at the start:

- ❐ Not placing the flow-sensor between patient and breathing circuit: ____
- ❐ Not placing a bacterial filter in the circuit prior to the flow-sensor: ____
- ❐ Not preoxygenating patient: ____
- ❐ Not transitioning the patient to mechanical ventilation via one of the 3 methods:
  - ◻ Moves the ventilator switch (to ventilator): ____
  - ◻ Confirms that the ventilator settings are appropriate: ____
  - ◻ Starting the ventilator: ____
- ❐ Not transitioning the patient to spontaneous ventilation prior to extubation: ____

Time at the end:

Pulmonary Edema Scenario Checklist

Pulmonary Edema Scenario

The patient is semiconscious, starts struggling for air and is not able to inhale a breath. The patient's oxygen saturation starts to rapidly fall and the blood pressure/HR rapidly rises. Accessory muscle respiration are being used and paradoxical respiration motions are seen. Name of Recorder:

Name of Participant:

Date:

Location:

Pulmonary Edema Pretraining Assessment

Time at the start:

Pulmonary Edema Learning Objectives

- ❐ Identify the need for acute postintubation airway management
- ❐ Identify the need for reintubation
- ❐ Identify pulmonary edema
- ❐ Appropriate treatment interventions
- ❐ Appropriate postoperative recommendations (wean oxygen/PEEP in operating room or arrange for ICU bed with ventilator)

Time at end:

Training Cycle

Time at the start:

Pulmonary Edema Learning Objectives

- ❐ Identify the need for acute postintubation airway management

Duration to identify need:

- ❐ Identify the need for re-intubation

continued on next page

continued from previous page

Supplemental Material *continued*

Duration to identify need:

❒ Identify pulmonary edema

❒ Appropriate treatment interventions

❒ Appropriate postoperative recommendations (wean oxygen/PEEP in operating room or arrange for ICU bed with ventilator)

Time at end:

<u>Pulmonary Edema Posttraining Assessment</u>

Time at the start:

Pulmonary Edema Learning Objectives

❒ Identify the need for acute postintubation airway management

Duration to identify need:

❒ Identify the need for re-intubation

Duration to identify need:

❒ Identify pulmonary edema

❒ Appropriate treatment interventions

❒ Appropriate postoperative recommendations (wean oxygen/PEEP in operating room or arrange for ICU bed with ventilator)

Time at end:

Power/Oxygen Failure and Ventilator Disconnect Scenario Checklist

Mr James Lukala is a 26-year-old who presents to your hospital with severe left lower abdominal pain that started 6 hours ago. He reports that for the last 11 months there has been a bulge in his left groin whenever coughs or laughs hard especially when standing, and it disappears when laying in bed. He has no significant past medical history and no known allergies. Upon examination the surgeon discovers a tender swelling 6 cm in diameter, above the area of the inguinal ligament, that does not reduce in size. The surgeon makes a diagnosis of a strangulated inguinal hernia and plans to do a herniorrhaphy. The patient has just been wheeled into the OR and you are the only anesthesia provider on duty. His blood pressure is 130/80 mmHg, respiratory rate 16 cycles per minute, pulse rate 85, and SaO_2 96%. The hospital power supply in the past week has been irregular and there was power failure 4 times yesterday. Please proceed with providing anesthesia care for this patient.

Name of Recorder:

Name of Participant:

Date:

Location:

continued on next page

continued from previous page

Supplemental Material *continued*

Power/Oxygen Failure and Ventilator Pretraining Assessment

Time at the start:

Power Failure Learning Objectives

- ❒ Number of times the person needed to be stopped due to failure to recognize decreasing O_2 flow on flowmeter (say out loud):
- ❒ Number of times the person needed to be stopped due to failure to open O_2 tank:
- ❒ Number of times the person needed to be stopped due to failure to recognize depletion of tank (say out loud):
- ❒ Recognition that there is a breathing circuit disconnect:
- ❒ Number of repeats before a systematic method of disconnect location is used:
- ❒ Number of repeats before correction of disconnect is instituted:
- ❒ Number of times the person needed to be stopped during maintenance of room air anesthesia:

Time at end:

Training Cycle

Time at start:

- ❒ Number of times the person needed to be stopped due to failure to recognize decreasing O_2 flow on flow-meter (say out loud):
- ❒ Number of times the person needed to be stopped due to failure to open O_2 tank:
- ❒ Number of times the person needed to be stopped due to failure to recognize depletion of tank (say out loud):
- ❒ Recognition that there is a breathing circuit disconnect:
- ❒ Number of repeats before a systematic method of disconnect location is used:
- ❒ Number of repeats before correction of disconnect is instituted:
- ❒ Number of times the person needed to be stopped during maintenance of room air anesthesia:

Time at end:

Power/Oxygen Failure and Ventilator Posttraining Assessment

Time at start:

- ❒ Number of times the person needed to be stopped due to failure to recognize decreasing O_2 flow on flow-meter (say out loud):
- ❒ Number of times the person needed to be stopped due to failure to open O_2 tank:
- ❒ Number of times the person needed to be stopped due to failure to recognize depletion of tank (say out loud):
- ❒ Recognition that there is a breathing circuit disconnect:
- ❒ Number of repeats before a systematic method of disconnect location is used:
- ❒ Number of repeats before correction of disconnect is instituted:
- ❒ Number of times the person needed to be stopped during maintenance of room air anesthesia:

Time at the end:

Abbreviations: BP, blood pressure; HR, heart rate; ICU, intensive care unit; IV, intravenous.