Feasibility of Simulation-Based Medical Education in a Low-Income Country

Challenges and Solutions From a 3-year Pilot Program in Uganda

Fred Bulamba, MMed;
Cornelius Sendagire, MMed;
Andrew Kintu, MMed;
Adam Hewitt-Smith, MBBS;
Fred Musana, MMed;
Maytinee Lilaonitkul, MBBS;
Emmanuel T. Ayebale, MMed;
Tyler Law, MD;
Gerald Dubowitz, MB ChB;
Olivia Kituuka, MMed;
Michael S. Lipnick, MD

Summary Statement: Simulation is relatively new in many low-income countries. We describe the challenges encountered, solutions deployed, and the costs incurred while establishing two simulation centers in Uganda. The challenges we experienced included equipment costs, difficulty in procurement, lack of context-appropriate curricula, unreliable power, limited local teaching capacity, and lack of coordination among user groups. Solutions we deployed included improvisation of equipment, customization of low-cost simulation software, creation of context-specific curricula, local administrative support, and creation of a simulation fellowship opportunity for local instructors. Total costs for simulation setups ranged from US $165 to $17,000. For centers in low-income countries trying to establish simulation programs, our experience suggests that careful selection of context-appropriate equipment and curricula, engagement with local and international collaborators, and early emphasis to increase local teaching capacity are essential. Further studies are needed to identify the most cost-effective levels of technological complexity for simulation in similar resource-constrained settings.
(*Sim Healthcare* 14:113–120, 2019)

Key Words: Medical simulation, low-income countries, MakCHS skills and simulation center, BUFHS simulation center, CITA.

Simulation-based education has become increasingly popular as an effective method for teaching and evaluating medical trainees and providers. Simulation is most commonly used in high-income countries despite potential benefits in low-income countries (LICs).[1] Postgraduate medical education in many LICs, including much of Sub-Saharan Africa, relies on traditional education methods such as lectures, bedside teaching, and self-directed learning. Faculty-directed learning, including bedside instruction, is often limited in these settings where provider shortages, high clinical volumes, and the need to rapidly expand the workforce are commonplace.

Although factors such as cost are often anecdotally cited among the many obstacles for implementation of simulation in LICs, few reports exist that describe the feasibility of simulation in such settings. Previous studies and reviews have concluded that simulation has high educational value in multiple facets of medical education, including transfer of knowledge, skills, and behaviors. A small number of studies have also reported effects on patient-related outcomes.[2–4] The case has also been made for the value of simulation for improving patient safety through enhanced task management, teamwork, situational awareness, and decision-making in high-income countries as well as LICs.[5–7] Improved real-world performance has been reported after simulation training for laparoscopy, central line insertion, paracentesis, advanced cardiac life support, and treatment of postpartum hemorrhage among others.[8–13] Some authors would argue that clinical training without simulation is ethically questionable.[14]

A major hindrance to technologically complex simulation is the cost of the fully or semiautomated simulators, applications, and equipment required to simulate different clinical scenarios.[15] Some commonly used simulation mannequins cost approximately US $50,000, and simulation facilities can cost well more than US $1 million.

For many educators and education theorists, there is an assumption that the closer to reality a simulation scenario can appear, the more effective it will be in imparting knowledge.[16–18] Numerous previous studies have indicated that the most important components of simulation-based education are not

From the Department of Anesthesia (F.B., A.H.S., F.M.), Faculty of Health Sciences, Busitema University, Tororo; Department of Anesthesia and intensive care (C.S.), Uganda Heart Institute; Department of Anesthesia (A.K., E.T.A.), College of Health Sciences, Makerere University, Kampala, Uganda; Department of Anesthesia and Perioperative Care (M.L., M.S.L., T.L., G.D.), University of California at San Francisco, San Francisco, California; and Department of Surgery (O.K.), College of Health Sciences, Makerere University, Kampala, Uganda.

Reprints: Fred Bulamba, MMed, Faculty of Health Sciences, Busitema University, PO Box 1640, Mbale, Uganda (e-mail: fredflybulamba@gmail.com; fbulamba@bufhs.ac.ug).

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.simulationinhealthcare.com).

The authors declare no conflict of interest.

This work is attributed to Makerere University College of Health Sciences, Department of Anesthesia, Kampala, Uganda, and Busitema University Faculty of Health Sciences, Department of Anesthesia.

DOI: 10.1097/SIH.0000000000000345

necessarily the advanced technological or expensive features but the psychological experience such tools do offer (ie, does it feel real).[1,6,19,20] This can be achieved through provision of effective feedback, repetitive practice, curriculum integration, a range of difficulty levels, a controlled environment, and clearly defined learning outcomes and benchmarks.[1]

Despite these findings, only a small number of simulation initiatives from LICs have been reported.[7,21–23] In Rwanda, Nigeria, Ethiopia, and Kenya, longstanding international collaborations have been used to establish simulation centers at multiple teaching hospitals.[21,24] Several of these efforts have demonstrated high utilization, positive skills acquisition, and sustained knowledge transfer. One simulation-based training program in Central America, PRONTO, has also demonstrated sustained impact on clinical practice patterns. The program, which focused on training obstetric and neonatal care providers in emergency care, resulted in decreased cesarean-section and neonatal mortality rates.[3,25,26] Although all of these efforts have been well received and demonstrated a range of positive impacts, many have costs that exceed US $100,000. None has thoroughly reported the challenges encountered in setting up simulation education in LICs.

As a first step toward determining the role and impact of simulation-based medical education on learners' competencies and patients' outcomes in a LIC, we sought to characterize the experience and challenges encountered while establishing simulation centers at one urban and one rural teaching hospital in Uganda. Here, we describe the cost implications for varying levels of simulation technology, challenges encountered, and solutions used during a 3-year pilot project to establish simulation centers in a LIC.

Project Scope

This pilot project (2014–2017) established a simulation center at the Makerere University College of Health Sciences (MakCHS), a large urban teaching institution in Kampala, Uganda, and another simulation center at Busitema University Faculty of Health Sciences (BUFHS), a teaching institution in Mbale, Uganda.

The MakCHS campus is adjacent to Mulago National Referral Hospital and includes a medical school with approximately 600 medical students and numerous residency training programs (Masters of Medicine) including surgery, anesthesia, and obstetrics & gynecology programs. The BUFHS campus is adjacent to Mbale Regional Referral Hospital and includes a medical school with approximately 300 medical students, 150 nursing students, and 20 nonphysician anesthesia trainees.

Project planning and funding were a collaborative effort of many departments at the MakCHS and BUFHS, including surgery, anesthesia, orthopedics, and obstetrics & gynecology, as well as multiple visiting international collaborators. During the project period, we collected data on setup costs for the two simulation laboratories and recorded challenges encountered during the pilot period. After reviewing all challenges recorded during the pilot period, we categorized them ad hoc as either equipment, infrastructure, human resource, context, or other. All costs are reported in US dollars.

Challenges and Solutions Used

Two simulation laboratories were established during the project period with simulation incorporated into the MakCHS Masters of Medicine Anesthesia training program (see Figure, Supplemental Digital Content 1A, http://links.lww.com/SIH/A402; which shows the setup of the simulation laboratory at the MakCHS) and the BUFHS Bachelor of Science in Anesthesia program (see Figure, Supplemental Digital Content 1B, http://links.lww.com/SIH/A403; which shows the setup of the simulation laboratory at the BUFHS). During the project period, all equipment remained functional, and both laboratories were used by different users as reported in Table 1. The costs of equipment for the two simulation laboratories are reported in Table 2, and the challenges encountered are reported hereinafter and in Table 3.

Equipment

Limited local availability of equipment, high cost for mannequins, and technical limitations in audio-video setups were the most significant equipment-related challenges encountered. Most clinical equipment, such as the gurney, anesthesia machine, defibrillation unit, airway equipment, intravenous tubing setups, and patient monitor cables were procured cheaply from local medical surplus stores. These pieces of clinical equipment were deemed unusable for clinical care. Other equipment such as mannequins and partial-task trainers were difficult to procure locally and were markedly expensive. To delineate which simulation setup led to student and instructor acceptability and utilization, we trialed several different mannequin configurations with significant range in cost from essentially no cost (donated and repurposed mannequin parts) to US $4500 for a new mannequin. These setups are illustrated in Figures 1 and 2. Initially, a full-length mannequin was assembled from repurposed

TABLE 1. Utilization of the Simulation Laboratories at the MakCHS and BUFHS

	MakCHS Simulation Laboratory (Since 2014)	BUFHS Simulation Laboratory (Since 2017)
User departments	• *Surgery • *Anesthesia • *Obstetrics and gynecology • Accident and emergency • Orthopedics • Internal medicine	• Nonphysician anesthetists • Clinical year medical students
Courses administered	• Basic and advanced life support • Advanced trauma management course • Anesthesia orientation course • Airway management workshop • Regional anesthesia workshop	• †CITA • Medical student simulations

*Frequent users relative to other departments.
†36 nonphysician anesthetists have completed the CITA course.

TABLE 2. Relative Costs and Level of Technology for Various Simulation Laboratory Features

Technology/Cost*	Lower	Intermediate	Higher
Patient	Volunteer student as actor (subtotal $00)	Repurposed parts from used or donated mannequins and partial-task trainers (subtotal US $00)	Mannequin (Laerdal MegaCode Kelly), with homemade customizations for voice and pulse (Fig. 1B) (US $4400) (subtotal US $4400)
Monitors	Manual blood pressure cuff and stethoscope (US $15); vitals reported orally as needed by in-room instructor (subtotal US $15)	2 iPads (US $320) with SimMon software (US $23); Manual blood pressure cuff and stethoscope (US $15) (subtotal US $358)	2 iPads (US $320) with SimMon software (US $23); Manual blood pressure cuff and stethoscope (US $15); 24-inch LCD monitor (US $100) to display iPad screen more visibly for video recording from afar; iPad lightning to VGA adapter (US $44); monitor mount (US $15) (subtotal US $517)
Audio	Patient voice by volunteer; no recording (subtotal US $00)	Mannequin and instructor remote voice: iPad SimMon app custom programed by developer to allow one-way, wireless voice communication from instructor remotely into learning environment Recording audio: built-in microphone on camcorder (US $80) (subtotal US $80)	Mannequin and instructor remote voice: USB 110–240v powered mini portable guitar amp/preamp (US $15) with XLR‡ input placed behind mannequin head and connected to microphone (US $10) in control room Recording audio: condenser microphone (US $85) hung from ceiling and connected to camcorder (US $140); phantom power adapter for camcorder audio input (US $15) (subtotal US $265)
Video	Real-time viewing: done in-room (no video) Recording for playback: none or recorded on personal mobile phone (US $150) (subtotal US $150)	Real-time viewing: done in-room (no video) Recording for playback: Camcorder (US $80) with playback on either TV or via microSD card on LCD monitor (US $100) (subtotal US $180)	Real-time viewing: LCD monitor in adjacent control room (US $100); viewing thru one-way window custom installed (US $200) Recording for playback: camcorder (US $140) with playback via microSD card on computer screen (US $100) or LCD projector (US $300); Miscellaneous cables (US $100) (subtotal US $940)
Power supply	Central (subtotal US $00)	Central (subtotal US $00)	Battery backup system custom built (US $1000) (subtotal US $1000)
Facility	Any available patient room or classroom (subtotal US $00)	Dedicated vacant classroom (subtotal US $00)	Refurbishment of room to include partitions, security bars, one-way windows, and furniture (US $2500–US $10000) (subtotal US $2500-10,000)
Anesthesia equipment	Manual bag-valve for hand ventilation (subtotal US $00)	Surplus, nonfunctioning, closed-circuit anesthesia machine with manual bag-valve for hand ventilation; or surplus, nonfunctioning Oxford miniature vaporizer and bellows (US $200) (subtotal US $200)	Drawover open anesthesia circuit (Diamedica Inc, UK - US $3500); or surplus, nonfunctioning closed-circuit anesthesia machine repaired to allow manual ventilation with tank supply gas (k cylinder + welding regulator US $250); Airway partial-task trainer (Laerdal) (US $1000) (subtotal US $4750)
Total cost†	US $165	US $748	US $8032§

*Select items were purchased preowned from the Internet auction sites.
†Items listed in multiple rows though represent the same one-time cost.
‡The XLR connector is a style of electrical connector, primarily found on professional audio, video, and stage lighting equipment. The connectors are circular in design and have between 3 and 7 pins.
§Refurbishment costs were highly variable and not included in this total.

mannequin parts that had been donated by visiting collaborators. Later in the project period, a new simulation mannequin (MegaCode Kelly – brown skin; Laerdal) was procured without the external controller (SimPad PLUS) that facilitates electrocardiogram interpretation, sounds, and various simulation scenarios. This controller, similar to mannequins

TABLE 3. Challenges to Establishing Simulation Centers in Uganda

Equipment	Infrastructure	Human Resource	Local Context
High cost of mannequins • Limited availability of vendors for local procurement of equipment • High shipping costs for materials not available locally† •Low quality and high cost of audio-video setups • Difficulty of simulation laboratory setup and operation* • Limited availability of 110–240v compatible equipment • Equipment durability and maintenance • Duplication and redundancy of simulation equipment	• High cost and unavailability of facility space • Unreliable electricity • Lack of pressurized gas supply • Security of simulation facility • Time consuming to use video playback for debrief	• Lack of staff to manage simulation laboratory and equipment • Inconsistent local institutional resources for simulation • Lack of local simulation instructors • Limited time for simulation teaching with trainees due to high clinical responsibilities • Limited coordination among visiting international groups.	• Limited availability of simulation scenarios written for the local practice environment • Simulation not formal part of local curriculum • Finding optimal balance between technology, cost, user experience and impact

*Mannequins and partial task trainers.
†Nearly all equipment, including audio-video setups, required significant orientation before instructors were able to operate simulation scenarios independently.

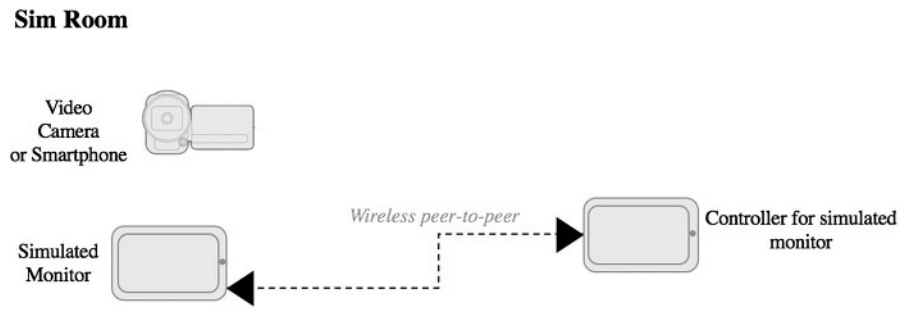

FIGURE 1. Diagram of the first piloted audio/video setup. Outlines the least expensive simulation laboratory setup that was used during the pilot. The setup consists of one room (simulation room) with a video recording device and wirelessly controlled patient monitors

with additional features, would have added significantly to the overall cost, and thus, several workarounds were used. Firstly, low-cost simulation software for iOS devices was piloted (donated by SimMon, Denmark). This software allowed a patient monitor with vital signs to be displayed on a tablet screen, whereas the vital sign parameters could be controlled from a second tablet within wireless range (see Figure, Supplemental Digital Content 2, panel A, http://links.lww.com/SIH/A404; which shows the iPad Monitor that is linked through wireless). Two preowned tablet computers (iPads; Apple Inc) were purchased to run the software at each simulation laboratory. Tablets that support faster Wi-Fi peer-to-peer data transfer speeds, for example, those with lightning ports, performed better than those with only Bluetooth. Another workaround to address the high cost of mannequins was the improvisation of features such as the airway partial-task trainers we created from recycled donated mannequins (see Figure, Supplemental Digital Content 2, panel B, http://links.lww.com/SIH/A404; which shows repurposed airway task trainers) or the creation of a carotid pulse (see Figure, Supplemental Digital Content 2, panel C, http://links.lww.com/SIH/A404; which shows improvised carotid artery setup).

The challenges we faced specific to the audio-video setup (Figs. 1–3) included limited field of view during recording, audio volume and quality, as well as cost and unavailability of this equipment locally. The simplest and lowest cost setup for audio used only the facilitator's voice to directly report vitals orally and to provide verbal prompts from the low-technology mannequin. In an effort to improve the technological experience and move the facilitator outside of the simulation room, a system using a portable, miniaturized, public address speaker and microphone was also installed (Figs. 2 and 3). A forthcoming feature in the SimMon software will allow the facilitator to speak into the controller iPad and have the facilitator's voice projected from the monitor iPad in the simulation room. A beta version of this feature was developed and piloted as part of this project.

The least expensive setup for audio-video recording and playback used a smartphone. Another relatively inexpensive setup used a camcorder to record sessions onto a microSD card and played back these recordings on an external LCD monitor during debriefing (Fig. 2). Both setups functioned, but audio quality suffered because of high ambient noise and distance from the participants, as we were forced to position the camera far away to capture the extent of the simulation room. To address this problem, a different video camera was procured with remote microphone input, and a hanging condenser microphone was hung from the ceiling over the mannequin's head

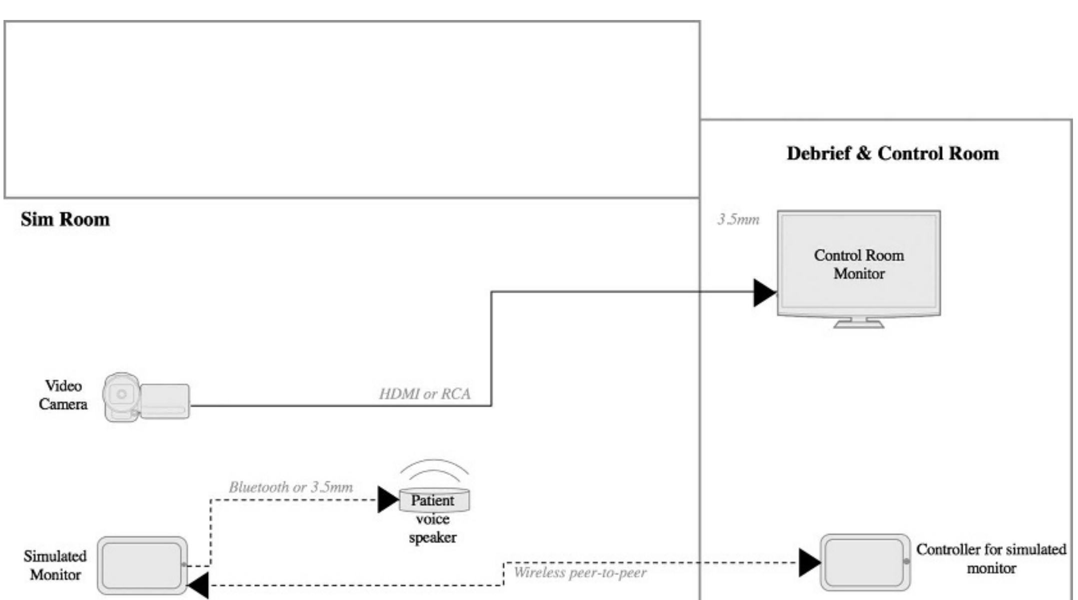

FIGURE 2. Diagram of audio/video setup at the MakCHS. Outlines the simulation laboratory setup used currently at the MakCHS.

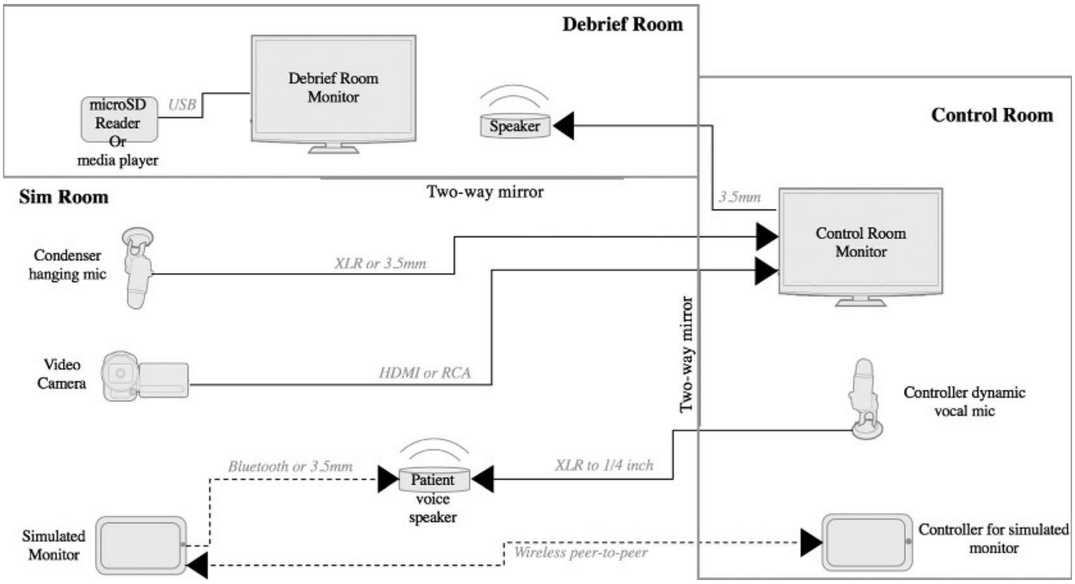

FIGURE 3. Diagram of audio/video setup at the BUFHS. Outlines the most expensive setup deployed during our pilot and is currently in use at the BUFHS.

(Fig. 3). It is important to note that these microphones are "phantom powered" (ie, require power supply directly from the camcorder), and these can cost more than US $500. As a workaround, we procured a US $15 standalone phantom power supply to facilitate use of an inexpensive camcorder and still provide high-quality audio. The current audio-video schematic setups at the MakCHS and BUFHS simulation laboratories are shown in Figures 1 and 2, respectively.

Two additional equipment-related challenges that we routinely encountered included frequent mannequin damage and limited access to maintenance and repair supplies. Airway mannequins and partial-task trainers were frequently damaged because of lack of airway lubrication or inexperienced users and instructors. To address this challenge, relatively inexpensive (recreational) bubble solution was substituted for airway lubrication, and certain pieces of equipment (ie, airway trainers) were restricted to use only in the presence of experienced instructors.

Lessons Learned

1. Simulation can be conducted for extremely low cost and with resources available in many LICs
2. Surplus or broken medical equipment is routinely available in low-resource settings and works well for simulation.
3. The easiest and least expensive simulation laboratory setups to implement may not be well utilized
4. Instructors reported several key simulation features that improved psychological fidelity include the following: presence of a functioning (intubatable airway), capability for ventilation with chest rise, presence of intravenous push line, remotely controlled monitors, and instructor-controlled remote patient voice. Most of these features can be implemented for relatively low cost.

Infrastructure

To create simulation laboratory space at both project sites, we first identified existing rooms that were available and could be converted into simulation laboratories (Table 4). The simulation laboratory at the MakCHS did not require renovation because it was a section of the Canadian Network for International Surgery skills laboratory skill laboratory. At the BUFHS, however, we remodeled a vacant room into a simulation laboratory at a cost of US $5000 (Table 2). A local carpenter constructed insulated, sound-dampening partitions to divide the single space into the following three rooms: a control room, simulation room, and debrief/classroom. Reflective windows,

TABLE 4. Establishment and Evolution of Simulation Laboratories at the MakCHS and BUFHS

Year	MakCHS Simulation Laboratory	BUFHS Simulation Laboratory
2014	• Concept developed • Space identified and remodeled from Canadian Network for International Surgery skills laboratory • Simulation laboratory trialed during anesthesia residents' orientation week • Camcorder-only audio-video system	
2015	• Installation of audio-video system • Hired administrator for the simulation laboratory • Modification of simulation software (SimMon) to include remote patient voice control	
2016	• Procurement of new simulation mannequin to replace preowned and damaged mannequin • Modification of simulation software (SimMon) to include preset vitals and scenarios	• Space identified and remodeled • Installation of backup power • Installation of audio-video system with public address system to control remote patient voice
2017	• Integration of simulation into formal anesthesia curriculum	• Installation of audio-video system with camcorder phantom powered condenser microphone • Open to use by university faculty and students

plumbing with a sink, curtains, and security bars were installed. Tables (with granite tops and metal legs for increased durability) and secure storage cabinets were also built locally.

At the MakCHS, observers (in an adjacent classroom) could view live scenarios by streaming the live video feed from the simulation room onto a projector in the classroom. When power was not available, this setup did not function, and learners who were not participating in the scenario could not observe the scenarios. At the BUFHS, a one-way window was installed to overcome this challenge. This setup facilitated larger groups of trainees (up to 6–8 learners at a time) to be more actively engaged even when not participating in simulation.

Another infrastructural difference between the two sites was the overall room layout. In addition to the one-way window previously mentioned, the BUFHS laboratory had a dedicated control room (with one-way observation window). At the MakCHS, an adjacent room was used as a control room, but because it was shared for other purposes, the instructor's equipment had to be setup each time simulation sessions were held. This created extra work for instructors and additional barriers to implementing simulation.

A significant challenge at both sites (though more frequent at the more rural BUFHS site) was the lack of consistent power supply. To address this challenge, we hired a local electrical technician to make a power backup supply using two large capacity (200 amp-hour) truck batteries and an alternating current-direct current charger with inverter (see Figure, Supplemental Digital Content 2, panel D, http://links.lww.com/SIH/A404; which shows the backup battery). The batteries are able to power the simulation laboratory for up to 2 days. An additional challenge at both sites was the lack of pressurized gas supply that was needed for operating anesthesia machines and conducting scenarios related to oxygen failure. We procured large (size K) compressed oxygen cylinders and secured them in the simulation laboratory (see Figure, Supplemental Digital Content 2, panel E, http://links.lww.com/SIH/A404; which shows the oxygen cylinder).

Lessons Learned

1. Establishing a secure and functional simulation space was associated with significant costs.
2. A one-way window was preferred for observation by learners and instructors over the setup that used a video camera to stream the scenario for nonparticipating learners.
3. The creation of a backup power supply was essential where power failure occurred frequently.
4. Oxygen cylinders and regulators intended for welding applications may be cheaper and more readily available than those designated for clinical use.

Human Resources

Lack of simulation instructors and simulation laboratory managers was a significant challenge at both project sites. Although this is a common challenge for newly established simulation centers regardless of location, the magnitude of the challenge faced in Uganda was compounded by the critical shortage of clinical care providers and medical educators. For example, in Uganda, there are only approximately 84 physician anesthesiologists for the population of 38 million.

In addition, the lack of simulation laboratory managers or administrators made communication among simulation laboratory users difficult. This resulted in duplicated equipment purchases, as well as parallel course development and implementation. To increase utilization, communication, and coordination between different users, a skills laboratory manager was recruited at the MakCHS in the early stage of the pilot. A shared, online Google calendar was created to help coordinate teaching activities of multiple local and visiting groups. The simulation laboratory at the BUFHS is in the process of hiring a manager.

Despite significant interest in simulation among faculty at both project sites, few had experience with simulation education and even fewer had time to dedicate to an additional teaching endeavor. In an effort to increase the number of local educators trained in medical simulation, the University of California San Francisco and the World Federation of Societies of Anesthesiologists created a medical simulation fellowship for trainees from Uganda and other LICs. The program graduated its first fellow in 2017 who plans to lead training of more simulation instructors in the region.

Lessons Learned

1. Lack of adequately trained, local personnel was among the most significant barriers to implemented simulation. This included trained educators to teach the sessions as well as staff to maintain the facility and equipment and to coordinate teaching initiatives.
2. A plan for increasing and supporting local simulation teaching capacity was as important if not more important than creating the facility itself.

Local Context

Relatively few training curricula or equipment is designed specifically for low-resource settings. One minor challenge (relevant to our project location) was the relative lack of dark skin mannequins that were available for local purchase or international donation. In addition, few existing anesthesia simulation scenarios are openly accessible and are explicitly designed for providers in low-resource settings. Most existing scenarios use equipment or drugs that are often not locally available in LICs or omit scenarios commonly encountered in low-resource settings.

Based on input from faculty and trainees in Uganda, we developed 12 clinical scenarios relevant to anesthesiology and the local practice environment. Each scenario contained key elements highlighted by previous studies as critical for effective simulation education, including the following: clearly defined objectives, debrief, repetitive practice, and varying degrees of difficulty. In addition, curricula for partial-task training in airway management and basic life support were also developed. Simulation scenarios were compiled into an instructor's manual. To facilitate easier implementation of each scenario by the instructor, we worked with the manufacturer of the SimMon app (Denmark) to incorporate the preset vital signs corresponding to the different stages for each scenario directly into the beta version of the app. The curriculum scenarios will be published in an open access format.

An additional curricular challenge encountered during this project was the lack of dedicated time for simulation learning because of lack of formal incorporation into the core anesthesia curriculum. For the course of the pilot period, simulation was formally incorporated into the first-year anesthesia curriculum at the MakCHS and incorporated into the formal curriculum for the Bachelor of Science in Anesthesia at the BUFHS.

A final challenge we encountered that was particularly difficult to solve was the harmonization of different local and international groups who were involved in simulation-based teaching. On many occasions, these groups brought in equipment and supplies but did not share or collaborate, leading to duplication of efforts and inefficient use of resources. This specific challenge has not been fully explored in this report or others from LICs, although it is likely to have been experienced in other similar settings.[21] To begin addressing this issue, we recommend investment in a local coordinator.

Lessons Learned

1. Scenarios must be developed to fit locally available resources and the local clinical context.
2. Incorporation of simulation into formal curricula may be critical to ensuring maximal utilization of a simulation laboratory.
3. Investment in a local coordinator can increase facility utilization and increase harmonization of equipment donations and other forms of collaborator support. This position should be supported by the local institution for sustainability.

DISCUSSION

Innovative medical education strategies, such as simulation, may play an important role in LICs where provider shortages and high clinical volumes limit local training capacity. This project successfully created two simulation laboratories in Uganda for relatively low cost and with potential for high utilization, despite encountering several significant challenges. The most commonly encountered challenges were related to equipment and infrastructure (cost and local availability) although the most difficult challenges to address were those categorized as human resource or local context. We found solutions to equipment and infrastructure challenges to be relatively easy and often related to fundraising, resourcefulness, and effort.

This pilot was an initial step toward the ultimate goal of scaling-up simulation as a teaching method in Uganda and assessing the impact of simulation on learners' competencies in a resource-constrained setting. The primary limitation of this pilot report is the lack of data on utilization and learners' outcomes. An electronic registry was maintained during the study period to track facility utilization; however, a large portion of the data was inadvertently deleted, making data analysis and reporting difficult. We are tracking utilization data prospectively at the time of publication and have also begun to collect formal feedback in the form of written surveys from all simulation participants. An additional limitation of this project was the reliance on donated equipment or equipment procured outside the implementation site. Although this mechanism for obtaining equipment may be available at many institutions in LICs, the feasibility of establishing simulation may be significantly more challenging at sites with limited international partnerships or access to supplies.

Despite these limitations, the dearth of published reports on simulation in LICs and growing interest have compelled us to share our experience to assist others seeking to establish simulation training programs in LICs.

CONCLUSIONS

Simulation-based medical education is feasible for institutions in LICs at various price points and may represent a useful and underused learning tool. Workforce shortages pose significant obstacles to implementation.

To help advocate for increased resources for simulation and integration into existing curricula, additional data are needed on outcomes for learners and, ultimately, patients. For other initiatives in LICs trying to establish simulation centers, our experience suggests that several key elements are required for success: careful selection of context-appropriate equipment and curricula, engagement with local and international collaborators, and early emphasis on plans to increase local teaching capacity.

REFERENCES

1. Issenberg BS, McGaghie WC, Petrusa ER, et al. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Med Teach* 2005;27(1):10–28.
2. Cook DA, Hatara R, Brydges R, et al. Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. *JAMA* 2011;306(9):978–988.
3. Fritz J, Walker DM, Cohen S, et al. Can a simulation-based training program impact the use of evidence based routine practices at birth? Results of a hospital-based cluster randomized trial in Mexico. *PloS one* 2017;12(3):e0172623.
4. Seymour MD. Moving the needle: simulation's impact on patient outcomes . *Surg Clin North Am* 2015;95(4):827-838.
5. Khan K, Pattison T, Sherwood M. Simulation in medical education. *Med Teach* 2011;33(1):1–3.
6. Skelton T, Nshimyumuremyi I, Livingston P, et al. Low-fidelity simulation to teach anaesthetists' non-technical skills (ants) in Rwanda. *Can J Surg* 2014;57(3 suppl 1):S8.
7. Taekman JM, Foureman M, Bulamba F, et al. A novel multiplayer screen-based simulation experience for African learners improved confidence in management of postpartum hemorrhage. *Front Public Health* 2017;5:248.
8. Barsuk JH, Cohen ER, Feinglass J, et al. Cost savings of performing paracentesis procedures at the bedside after simulation-based education. *Simul Healthc* 2014;9(5):312–318.
9. Barsuk JH, Cohen ER, Potts S, et al. Dissemination of a simulation-based mastery learning intervention reduces central line-associated bloodstream infections. *BMJ Qual Saf* 2014;23(9):749–756.
10. Butter J, McGaghie WC, Cohen ER, et al. Simulation-based mastery learning improves cardiac auscultation skills in medical students. *J Gen Intern Med* 2010;25(8):780–785.
11. Kanumuri P, Ganai S, Wohaibi EM, et al. Virtual reality and computer-enhanced training devices equally improve laparoscopic surgical skill in novices. *JSLS* 2008;12(3):219–226.
12. Wayne DB, Didwania A, Feinglass J, et al. Simulation-based education improves quality of care during cardiac arrest team responses at an academic teaching hospital: a case–control study. *Chest J* 2008;133(1):56–61.
13. Wohaibi EM, Bush RW, Earle DB, et al. Surgical resident performance on a virtual reality simulator correlates with operating room performance. *J Surg Res* 2010;160(1):67–72.

14. Teteris E, Fraser K, Wright B, et al. Does training learners on simulators benefit real patients? *Adv Health Sci Educ Theory Pract* 2012;17(1):137–144.

15. Cumin D, Merry AF. Simulators for use in anaesthesia. *Anaesthesia* 2007;62(2):151–162.

16. Godden DR, Baddeley AD. Context-dependent memory in two natural environments: on land and underwater. *Br J Psychol* 1975;66(3):325–331.

17. Kneebone R, Kidd J, Nestel D, et al. Blurring the boundaries: scenario-based simulation in a clinical setting. *Med Educ* 2005;39(6):580–587.

18. Hockley WE. The effects of environmental context on recognition memory and claims of remembering. *J Exp Psychol Learn Mem Cogn* 2008;34(6):1412.

19. Maran NJ, Glavin RJ. Low- to high-fidelity simulation - a continuum of medical education? *Med Educ* 2003;37(suppl 1):22–28.

20. Norman G, Dore K, Grierson L. The minimal relationship between simulation fidelity and transfer of learning. *Med Educ* 2012;46(7): 636–647.

21. Livingston P, Bailey J, Ntakiyiruta G, et al. Development of a simulation and skills centre in East Africa: a Rwandan-Canadian partnership. *Pan African Med J* 2014;17(1).

22. Okrainec A, Smith L, Azzie G. Surgical simulation in Africa: the feasibility and impact of a 3-day fundamentals of laparoscopic surgery course. *Surg Endosc* 2009;23(11):2493.

23. Tansley G, Bailey JG, Gu Y, et al. Efficacy of surgical simulation training in a low-income country. *World J Surg* 2016;40(11):2643–2649.

24. Gedlu E, Tedesse A, Cayea D, et al. Introduction of simulation based medical education at addis ababa university college of health sciences: experience and challenge. *Ethiop Med J* 2015;53.

25. Walker DM, Cohen SR, Estrada F, et al. PRONTO training for obstetric and neonatal emergencies in Mexico. *Int J Gynecol Obstet* 2012;116 (2):128–133.

26. Walker DM, Cohen SR, Fritz J, et al. Impact evaluation of PRONTO Mexico: a simulation-based program in obstetric and neonatal emergencies and team training. *Simul Healthc* 2016;11(1):1–9.