ORIGINAL RESEARCH

Introduction of a portable and affordable surgical simulator at a low-resource training programme: A pilot study in western Kenya

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Abstract

Background
Surgical simulation is increasingly recognized as an important adjunct to surgical education. However, high-fidelity models are often unrealistic to replicate in limited-resource settings. The GlobalSurgBox was developed as a portable and modular training platform with the specific goal of creating a low-cost simulator that is adaptable to varying skill sets and training levels. This pilot study aimed to evaluate the initial application and perceptions of the GlobalSurgBox by surgical trainees at a low-resource training programme.

Methods
The usefulness and feasibility of the GlobalSurgBox were assessed following distribution to medical students, junior doctors, surgical trainees, and cardiothoracic surgery fellows at Tenwek Hospital in Bomet, Kenya. Participants were coached on how to perform a variety of common surgical manoeuvres using the GlobalSurgBox and allowed to practise ad libitum for 1 week. Participants were then administered an anonymized, electronic survey.

Results
Twenty-six participants were included. All participants agreed that surgical simulation is an important adjunct to training; however, only 50.0% (n=13) reported access to surgical simulator resources. While 76.9% of participants (n=10 of 13) reported barriers to using currently available simulators, including lack of time and lack of convenient access, only 42.3% of all participants (n=11) cited obstacles to routinely using the GlobalSurgBox. The majority of participants (96.2%) reported that the GlobalSurgBox better prepared them to practise similar skills in the operating theatre.

Conclusions
The GlobalSurgBox represents an important global health equity initiative that provides a novel resource for surgical trainees of all levels and from all types of training environments to supplement their surgical education and operating experience.

Keywords: surgical simulation, surgical education, global health, low- and middle-income countries, Kenya

Introduction

Over the past several decades, surgical simulation has evolved into an increasingly important adjunct to surgical training programmes and trainee education.[1] Unique advantages of simulation training include the ability for trainees to practise and hone their technical skills outside the operating theatre, thus increasing opportunities for repetitive learning and exploration without jeopardizing patient safety. While many United States–based tertiary centres advertise costly, high-fidelity simulation centres as part of their educational curricula, these are largely unattainable to replicate in limited-resource and low-income settings.[2],[3] Moreover, in addition to the significant financial investment, simulated environments often require dedicated personnel to guide such training sessions, again limiting their practicality in resource-poor healthcare settings.

Therefore, despite its potential importance in advancing the field of surgical training, access to affordable, effective, and adaptable simulation tools remains a barrier to the routine implementation of surgical simulation on a global scale. To address this disparity, the GlobalSurgBox was developed as a portable and modular training platform with the specific goal of creating a low-cost simulator that is adaptable to varying skill sets and training levels. This compact, low-fidelity model allows for the creation of any number of different skill modules as well as opportunities to practise in a variety of settings, using materials that can be easily procured for under US $25.

Initial investigation by our group at a United States–based general surgery residency programme found that the GlobalSurgBox provided trainees with a realistic replica of common surgical manoeuvres and promoted increased practising of skills outside the operating theatre.[4] Furthermore, the GlobalSurgBox promotes convenient access to simulation by serving as a portable model that can be used in any location. To evaluate whether these advantages translate effectively to low-resource healthcare settings, we aimed to assess the initial application and perceptions of the GlobalSurgBox at a general surgery and cardiothoracic surgery training programme in Bomet, Kenya. We hypothesized that the GlobalSurgBox would serve as a useful simulation model to supplement operating theatre experience for trainees in low-income countries while circumventing the often prohibitive financial, time, and personnel investments required of preexisting simulation prototypes.

Methods

GlobalSurgBox

The GlobalSurgBox was designed by the senior author as a portable and low-cost surgical simulator, with all of the materials and training platform contained within a 12.5-inch toolbox (Figure 1).[5] The lid of the toolbox stores the necessary materials to use the trainer, including a sponge to hold needles, alligator clips, nails, rubber bands, various-sized suturing threads, and balloons. Inside the toolbox is a removable tray that stores the necessary surgical instruments, including forceps, needle drivers, and scissors. A simple wooden board is located beneath the tray, which serves as the base for all skill exercises. The wooden board contains specifically placed nails to help structure the desired exercises. The board can be removed from the toolbox, or for more challenging practice, the skill can be performed with the board sitting within the toolbox to simulate operating within a cavity. For this study, the GlobalSurgBox trainers were prepared and constructed in the United States and brought to Kenya by a visiting instructor.

All the materials needed for the creation of the box can be sourced from online retailers or local home improvement stores. In parts of the world with limited access to online commerce, locally available materials may be used to replenish supplies. For example, constructing a GlobalSurgBox in Kenya with locally sourced materials costs less than US $10 (Table). While most commercially available simulators use materials that are expensive and difficult to replenish, such

Figure 1. Overview of the GlobalSurgBox

(A) The GlobalSurgBox consists of a 12.5-inch toolbox with (B) the lid containing all the materials to create and perform a variety of different training modules, (C) a removable tray containing the necessary surgical instruments, and (D) the base of the box containing a modular wooden board.

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Table. Cost estimates, in Kenyan shillings (KES), of local materials required to create 1 GlobalSurgBox

Material	Price, KES
Hair ties (×5)	170
Thread	5
Sport mat	32
Shoelaces	17
Balloons (×7)	160
Rubber bands (×5)	55
Pen	55
Ruler	55
Wood and nails	340
Alligator clips	170
Sponge	17
Leather	17
Toilet paper roll	17
Total	**1110**

KES 1110 = US $9.55 as of 22 April 2022

as animal tissue, our model prioritizes the use of inexpensive and universally available materials, such as cotton, rubber, and wood. All such materials can be found at local retailers and purchased in bulk to keep costs low. Surgical instruments and sutures remain the most challenging and expensive items to find, and thus we rely heavily on donations to supply these materials, particularly in resource-limited countries. When available, unused sutures and rejected surgical instruments unsuitable for patient care may be acquired from operating theatre staff and repurposed for the simulator.

Study design

The study was conducted at Tenwek Hospital, a COSECSA (College of Surgeons of East, Central and Southern Africa) and PAACS (Pan-African Academy of Christian Surgeons) training site located in Bomet, Kenya. Participants included medical students, medical officers (individuals who completed medical school but not residency), general surgery residents, and cardiothoracic surgery fellows working at Tenwek Hospital. Participants were provided voluntary access to the GlobalSurgBox and instructed on how to use the trainer via multiple in-person training sessions with a senior cardiothoracic surgery fellow visiting from the United States. Exercises included 2 types of vessel anastomoses commonly performed in cardiothoracic surgery, including an end-to-end anastomosis and end-to-side anastomosis, as well as a vascular patch repair, knot tying, and basic suturing (Figure 2). Residents were allowed to practise exercises of their choosing ad libitum over a 1-week period.

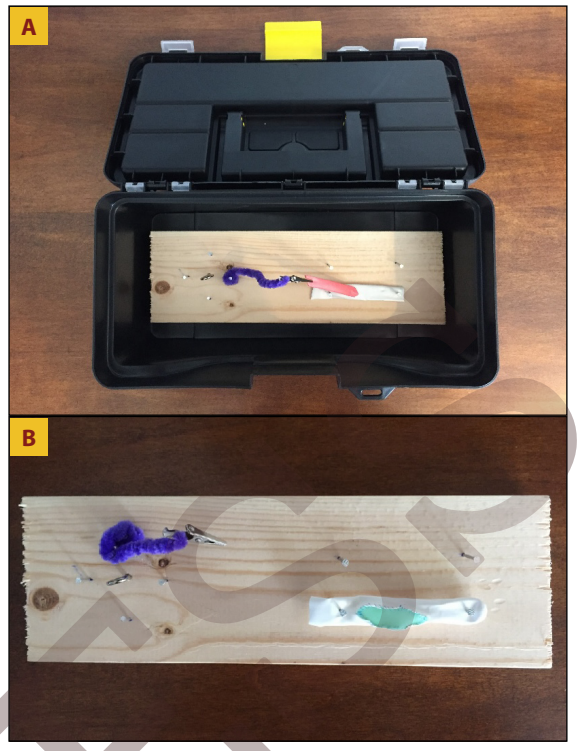

Figure 2. Example modules using the GlobalSurgBox

(A) Initial setup for an end-to-side vascular anastomosis training module; (B) completed vascular patch repair

Following the 1-week trial period, participants were administered an anonymized electronic survey (Supplementary File). The survey sought to evaluate current opinions on surgical simulation models, the usefulness of the GlobalSurgBox, and the feasibility of implementation. This study was approved by the Colorado Multiple Institutional Review Board and Tenwek Hospital Institutional Ethics and Research Committee.

Results

A total of 27 participants from Tenwek Hospital used the GlobalSurgBox and responded to the survey. One participant was excluded from the analysis due to incomplete survey answers. Participants consisted of 7 medical students, 3 medical officers, 14 general surgery residents, and 2 cardiothoracic surgery fellows. Half of the participants (n=13) stated they did not currently have access to surgical simulation resources. The remaining half reported access to a simulation centre through their medical school or surgical training programme, all of which offered simulation training in knot tying, suturing, and laparoscopy. Of the 13 participants with access to a simulation centre, 10 (76.9%) reported barriers to using these resources. The most commonly reported barrier was lack of time, followed by lack of convenient access or desire to practice in a different setting and lack of available personnel to coach the simulation exercises.

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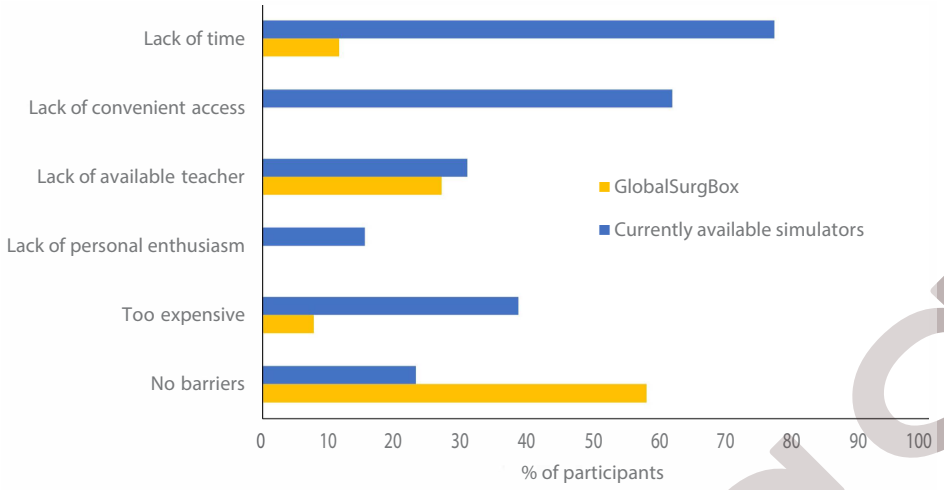

Figure 3. Comparison of reported barriers to using currently available surgical simulators vs the GlobalSurgBox

The GlobalSurgBox provided a less expensive and more accessible simulation model than currently available surgical simulators.

Of the exercises available for practice using the GlobalSurgBox, knot tying was practised by 24 participants (92.3%), suturing by 22 (84.6%), end-to-end vascular anastomosis by 18 (69.2%), vascular patch repair by 8 (30.7%), and end-to-side vascular anastomosis by 6 (23.1%). Sixteen participants (61.5%) used the GlobalSurgBox for practice approximately 1 to 2 times, 8 participants (30.7%) used it 3 to 4 times, and 2 participants (7.7%) used it 5 or more times. Following their use of the GlobalSurgBox, all participants agreed with the statement that surgical simulation is a useful adjunct to their training. Most participants (96.2%) felt better prepared to practise skills in the operating theatre as a result of the GlobalSurgBox. Furthermore, all participants agreed that the GlobalSurgBox encouraged additional practice of surgical skills outside the operating theatre, and they expressed that they would routinely use the simulator for surgical skills practice if given the opportunity.

While 76.9% of participants (n=10 of 13) with prior access to surgical simulation resources initially reported barriers to using them, only 42.3% of all participants (n=11) cited obstacles to routinely using the GlobalSurgBox (Figure 3). Whereas 80.0% (n=8 of 10) reported lack of time as a barrier to currently available simulators, only 11.5% (n=3 of 26) continued to view this as a barrier with the GlobalSurgBox. Furthermore, the issues of not having convenient access and the lack of desire to practise in a different setting were no longer mentioned by participants as barriers to using the GlobalSurgBox. The most frequently anticipated barrier to using the GlobalSurgBox was the absence of available personnel to teach and coach through the simulation exercises (26.9%). Two participants cited prohibitive costs as a barrier to accessing the GlobalSurgBox. Another concern, expressed by 2 participants, was low personal enthusiasm for using existing simulators. However, this latter concern was alleviated after they had the opportunity to use the GlobalSurgBox.

Discussion

Current trends in surgical simulation favour expensive high-fidelity models. Such models are often confined to high-income academic centres and present challenges for widespread adoption, particularly in low-resource settings globally. The development of a simulator that is cost-effective, portable, and modular in design is necessary to evade the challenges associated with simulation training in resource-poor healthcare settings. The GlobalSurgBox was designed to address these challenges, serving as a low-fidelity, durable simulation trainer that can be used in any setting and is adaptable to multiple surgical specialties and skill levels. After distributing the GlobalSurgBox at a resource-limited training centre in Kenya, we observed its positive reception among surgical trainees across different levels of training. It proved to be a practical and affordable surgical simulation tool during an initial trial period.

Simulation in medicine, modelled after aviation and military training principles, is now well established and provides benefits to both students and patients.[6],[7] Although simulation models are commonly employed in Western countries, financial and logistical constraints have hindered their broad implementation in hospitals and training programmes within low-income countries. To bridge this gap, several low-cost surgical simulation models and training programmes have since been designed, demonstrating reasonable success following application in a variety of developing countries.[7]-[11] While high-fidelity systems are widely regarded as offering more authentic depictions of surgical situations and techniques, emerging evidence indicates that the skills acquired from low-fidelity simulators are noninferior to those obtained from their high-fidelity counterparts.[12]-[14] Examples of such low-fidelity models include an ear surgery simulator to practise otolaryngology skills and a penile model to teach male circumcision, both of which have been validated as cost-efficient and useful at training

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facilities in Uganda.[15],[16] Similarly, Nazari et al.[17] developed a low-cost model for open inguinal hernia repair and validated its usefulness, with the goal of enabling local production and distribution of the simulator in low-resource training environments.

The GlobalSurgBox was conceived with a similar intent, albeit with several distinguishing features. First, the GlobalSurgBox was designed to fulfil the training needs of medical students and surgical trainees across the various surgical specialties. The materials, instruments, and wooden platform are interchangeable and adaptable, facilitating the creation of a wide array of exercises tailored to the user's skill level and specific training needs. For example, a medical student can practise knot tying, a general surgery resident can practise vascular anastomoses, and a cardiothoracic surgery fellow can practise suturing an aortic valve, with all participants using the same foundational setup and materials contained within the toolbox. Furthermore, the simulator's complete portability enhances its utility by allowing for the easy transfer of materials between locations, thereby maximizing opportunities for practice in various settings. The findings from this pilot study affirm the GlobalSurgBox's potential as an accessible and practical simulation tool, particularly beneficial in resource-constrained environments for promoting surgical skills practice outside the operating theatre.

Limitations

There were several limitations to this study that warrant mention. First, each simulator must be individually built, requiring an initial time commitment for proper setup. However, once the GlobalSurgBox is constructed, minimal time is required by the user for the creation of individual training modules, given that all the materials are readily available in 1 place. Second, while surveys are imperative for understanding user experiences and perspectives, we recognize that survey administration inherently introduces recall and reporting bias. Additionally, best practices for using the GlobalSurgBox require initial guidance from an experienced surgeon when learning a new skill to ensure proper execution and immediate feedback. This initial coaching session can be followed by independent practice to refine the skill and internalize prior feedback. Recognizing that staff availability may impede consistent use of the GlobalSurgBox, our current efforts are focused on creating a series of video tutorials detailing various exercises, which will be made available online (www.globalsurgbox.com) for global access. These tutorials aim to complement the training process, offering a self-guided approach to learning. However, we continue to encourage intermittent live coaching when available to promote accurate and progressive skills development.

Conclusions

Through its modular, portable, inexpensive, and easily constructible design, the GlobalSurgBox represents an important global health equity initiative that provides a novel resource for surgical trainees from all types of training environments to supplement their surgical education and operating theatre experience. Among other benefits, it is adaptable to all training levels, surgical specialties, and resource settings. Following its introduction at a surgical training programme in Kenya, the GlobalSurgBox shows promise for feasible distribution and application in resource-limited settings. Further, larger-scale studies are needed to validate the benefits of the simulator highlighted by this pilot study and objectively measure its impact on surgical skills development. Future directions are focused on sourcing components and building the simulators locally to enable more practical and immediate implementation, beginning with our partnership at Tenwek Hospital and then extending to partner COSECSA and PAACS training programmes in Kenya. We ultimately hope that increased use and distribution of the GlobalSurgBox will contribute to equity in surgical education on a global scale by providing an affordable and effective way to practise skills needed in the operating theatre.

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