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Review Article

Surgical Simulation and Technology-Enabled Learning in Resource Limited Countries: A Review

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Abstract

Objective: The increasing demand for surgical training outside the operating room emphasizes the need for surgical simulators as essential components for skills acquisition and competency. To facilitate psychomotor skills acquisition in surgery, great advancements have been made in simulation technology with wide range of fidelity. Low-income and resource limited countries lack access to simulation facilities due to logistical, financial, and expertise shortage. Our objective is to review the current literature on simulation-based surgical training in low-income and resource limited countries. The secondary outcomes of this study is reach useful conclusions, recommendations, and future directions for simulation-based surgical straining in developing countries.

Methods: A literature search was performed to retrieve relevant studies from electronic databases Pubmed (Medline), and Scopus (Elsevier) for pertinent articles. Studies that reported the use of simulation-based training for surgery in resource-limited countries in the last 10 years were included. In total, 132 articles were retrieved and screened for eligibility, and 21 of those were found relevant for inclusion in this study.

Results: Published evidence for the use of simulation training in developing and low-income countries is extremely limited. The majority of studies done in Africa (80%) and most of the simulation training models used in those studies were low cost and locally sourced materials such as audiovisual modules, lectures, online keynotes, textbooks, or basic task mannequins (90%). About 70% of the studies were conducted on surgical residents. Studies were cross-sectional and observational (95%) and limited by number of enrolled participants. Structured and long-term analysis were lacking in most studies.

Conclusions: There are major challenges impeding the adoption of simulation training in low-income countries including cost, equipment, personnel, and curriculum. Innovative solutions, utilization of local resources, and integration of technology to implement low-cost simulation that is well structured and fits the local needs are essential.

Keywords: Augmented-reality; Developing; Laparoscopy; Low-income; MIS; Resource limited; Robotic; Simulation; Surgery virtual-reality; training

Introduction

Constant developments in healthcare systems and surgical techniques necessitate innovative educational strategies for surgical training to achieve competency and technical skills expertise. The traditional apprenticeship design of surgical residency programs lacks efficiency, cost effectiveness, and jeopardizes patients' safety. The pressure to develop more efficient models in surgical training has led to integration of simulation technologies in medical education and surgical training [1]. The increasing demand for surgical training outside the operating room emphasizes the need for surgical simulators as essential components for skills acquisition. While knowledge can be obtained from textbooks which are usually accessible, psychomotor skills are more challenging to develop due to limited hands-on exposure and operative opportunities [2,3]. Incorporating simulation-based training within the academic surgical curricula have been highlighted in literature and shown to translate into improvements in surgical performance. It allows recreation of clinical scenarios and surgical procedures for trainees to practice repeatedly, refine their skills, and manage complications in a controlled environment [1,4]. To facilitate psychomotor skills acquisition, great advancements have been made in simulation technology with wide range of fidelity. Facilities with cadaveric and animal laboratories, mannikins-based task trainers, and digital simulators like virtual reality or computer-based hybrid simulators offer critical solutions and complement current training structures.

Unfortunately, low-income and resource limited countries lack access to simulation facilities due to logistical, financial, and expertise shortage. The lack of surgical simulation negatively impacts deliberate training needed to obtain proficiency, and ultimately adversely effects surgical care delivery and patient care. In this article we aim to review the current literature on simulation-based surgical training in low-income and resource limited countries. This paper will present current surgical simulation experiences, challenges faced, and outcomes achieved, along with pros and cons of published studies. The purpose of this study is to reach useful conclusions, recommendations, and future directions to inspire cost effective methods for training surgeons in low-income countries.

Methodology

A literature search was performed to retrieve relevant studies from electronic databases Pubmed (Medline), and Scopus (Elsevier) for pertinent articles published until October 2020. The following search terms and keys words were used to retrieve relevant studies; “laparoscopy”, “surgery”, “robotic”, “virtual-reality”, “augmented-reality”, “developing”, “low income”, “resource limited”, “MIS”, “simulation” and “training”. Of the articles retrieved through the above described search strategy, only those that met the following criteria were included to this review: original papers, articles in low-income or resource limited countries, articles conducted in the last 10 years, and those written in English language. Exclusion criteria included non-original articles, those in developed or resource rich countries, those published prior to 2010, and papers in languages other than English. Resulting titles and abstracts were analyzed for relevance and inclusion in this review. Articles were retrieved when their abstracts were judged to meet the inclusion criteria by two independent reviewers (OA, KG). A full text review of the selected articles was made for final inclusion in this review. After full-text review, any discrepancies between the investigators about the inclusion or exclusion of studies were were resolved by a third author (VI). In total, 132 articles were retrieved and screened for eligibility, and 21 of those were found relevant for inclusion in this study (Figure 1).

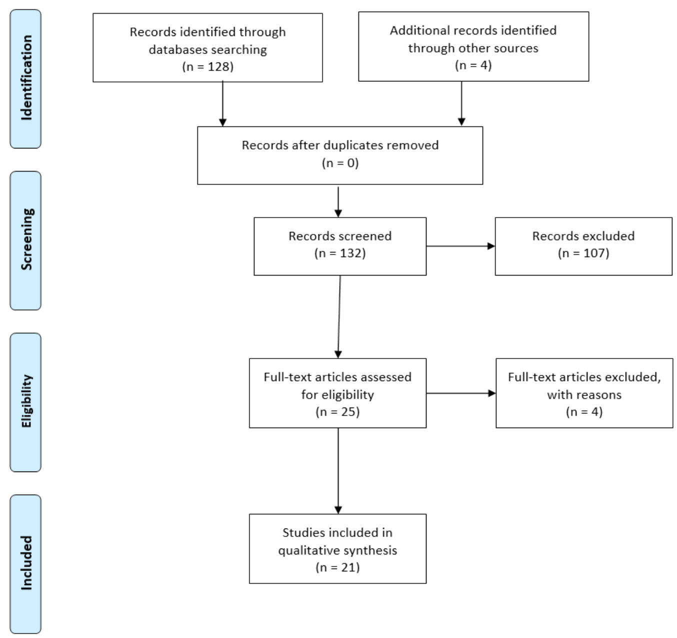

Figure 1: PRISMA flow diagram of selected articles.

Results

Published evidence for the use of simulation training in developing and low-income countries is extremely limited. Our search resulted in total of 21 articles over the past decade (Table 1), with the majority of studies done in Africa (76%). Most of the simulation training models used in those studies were low cost and locally sourced materials such as audiovisual modules, lectures, online keynotes, textbooks, or basic task mannequins (90%). About 70% of the studies were conducted on surgical residents, while remaining participants were surgeons and other healthcare professionals (midwives, anesthetists, nurses, etc.). Studies were cross-sectional and observational (95%) and limited by number of enrolled participants. One randomized clinical trial performed at the University of Rwanda on 27 residents, compared the use of digital application (touch surgery) vs textbook for learning tendon repair surgical technique, and found that digital applications can useful tools to improve both technical skills and knowledge of tendon repair when used in addition to current traditional means of education (textbook) [5].

Study	Year	Country	Primary specialty	Primary Target group	Simulation Type	No. of Participants
Andreatta et al	2014	Ghana	General Surgery	Laparoscopic naive surgeons	Surgical skills	18
Bulamba et al	2018	Uganda	Anesthesiology, General Surgery	Residents	Surgical skills	N/A
Bunogerane at al	2017	Rwanda	Orthopedics	Residents	Surgical skills	27
Clark et al	2019	Uganda	ENT	ENT surgeons	ENT skills	18
Fuller at al	2018	Ecuador	Facial reconstructive surgery	ENT residents	ENT skills	18
Ghesquière et al	2018	Madagascar	General Surgery	OBGYN surgeons	Surgical skills	8
Hasnaoui et al	2019	Tunisia	General Surgery	Surgery residents	Surgical skills	25
Justicz et al	2018	Haiti	ENT	ENT residents	ENT skills	11
Livingstone at al	2014	Rwanda	Various healthcare professionals	Various professionals	Low cost simulation	2,377
Long et al	2014	Kenya	General Surgery	Residents, nurses	Surgical skills	10
Luu et al	2017	Cambodia and Uganda	ENT	Surgery residents	ENT skills	24
Mikrogianakis et al	2011	Botswana	Pediatric Surgery	Residents	Surgical skills	22
Mistry et al	2018	Zambia	Anesthesiology, Pediatrics, Midwifes	Residents and Mid-wives	Resuscitation skills	78
Nataraja et al	2019	Myanmar	Pediatric surgery	Pediatric surgeons	IAE skills	21
Ng et al	2018	Tanzania	Pathology, Radiology	Pathologists, Radiologists, and residents	Fine-needle aspiration biopsy and smear slide simulation	21
Okrainec et al	2010	Botswana	General Surgery	Surgical faculty	Surgical skills	16
Ramirez et al	2018	Rwanda	General thoracic surgery	Surgery residents	Surgical skills	23
Shilkofski et al	2018	Uganda and Myanmar	Pediatrics	Pediatrics residents	Questionnaire	94
Tansley et al	2016	Rwanda	General Surgery	Surgery residents	Surgical skills	26

Wesson et al	2017	Jamaica	Pediatric surgery	Surgery residents	Surgical skills	25
White et al	2018	Madagascar	WHO surgical safety checklist implementation	Various healthcare professionals	Surgical Safety checklist	427

IAE = Infant Intussusception Air Enema, ENT=Ear, Nose, and Throat, OBGYN= Obstetrics and Gynecology

Table 1: Summary of studies and their variables of interest.

Procedure-specific models like an Ear Trainer for endoscopic ear procedures have been developed by the Canadian and British Universities and used for skills training and assessment in Cambodia and Uganda. Despite the lack of previous endoscopic experience and practice time, the Ear Trainer simulator showed to be a useful tool in improving endoscopic ear surgery skills of ENT trainees in low-resource settings. Participants with varying ENT experience were video-recorded performing each task and scored by a blinded expert observer to assess construct validity showed improvements in efficiency of task and performance time [6,7]. An interesting and more comprehensive model for teaching facial plastic and reconstructive surgery was developed in Ecuador and included didactic lectures, surgical simulation, and live surgery. This model was applied to 18 residents who underwent pre- and post-testing including written, oral, and practical examinations and showed successful transfer of both skills and knowledge. The study had a feedback survey from participants who found the course extremely helpful with highest scores given to the simulation workshops [8]. A Tunisian study designed a low-cost laparoscopic trainer box to assess the reliability of a modified MISTELS (McGill inanimate system for training and evaluation of laparoscopic skills) scoring system. The study was conducted on 25 residents and evaluation was based on Cronbach's alpha and Intraclass Correlation Coefficients (ICC). The study highlighted the importance of low-cost simulators which results in significant financial savings and showed that the reliability of a modified MISTELS is not altered using a low-cost trainer box [9].

A Madagascar study used pelvitrainers models for FLS (Fundamentals of Laparoscopic Surgery) training on gynecology residents and evaluations were based on performance-time which showed improvement post training. This study highlighted the need for creativity and demonstrated the potential and educational value of utilizing available local equipment to teach necessary surgical skills and courses, rather than waiting for modern expensive equipment to be available [10]. A comprehensive instructional program for laparoscopic surgery was developed through a collaboration between University of Michigan (USA) and the Kwame-Nkrumah University of Science and Technology in Ghana. Essential equipment was donated but the rest of the course materials were locally sourced in Ghana. The study encourages academic collaboration between high and low-income countries and indicate that a low-cost training program for laparoscopic skills designed for sustainability using locally sourced materials is feasible to implement in resource-limited areas [11]. A low-cost laparoscopic skills curriculum created and validated at the University of Kentucky (USA) was presented to the 10 general surgery residents at Tenwek Hospital in Kenya. The residents had access to simulation materials and curriculum which cost $50 USD/participant and tested on 3 tasks at the initiation of the project and after 3 weeks of practice. Residents showed significant improvement in performance measured by time to complete the tasks and errors. The study proved that academic collaboration and implementation of a low-cost laparoscopic skills curriculum in a third-world setting is feasible and offers much-needed exposure and opportunities for residents with extremely limited resources [12]. This was further proved by another study conducted by University of Virginia (USA), which created low-cost simulation models for teaching general thoracic surgery in Rwanda and showed enhanced confidence and knowledge of participants suggesting simulation surgery could be an effective tool in expanding the resident knowledge base and preparedness for performing clinically needed thoracic procedures [13].

A high-fidelity tissue-based simulation model for end-ileostomy was studied by Dalhousie University (Canada) and University of Rwanda on 26 residents who were assessed at three time points: prior to, immediately following, and 90 days following the simulation training. A single blinded expert reviewer assessed the performance using the Objective Structured Assessment of Technical Skill (OSATS) instrument and showed skills improvement and sustainability over a 90-day period, especially among junior residents. The study supported investment in simulation-based curricula in low-middle income countries [14]. A 2-day workshop offered didactic lectures, demonstrations, and hands-on practice on fundamentals of ultrasound imaging and Fine-needle aspiration biopsy (FNAB) technique was developed by University of California (USA) and implemented in Tanzania resulted in skills enhancement among participating pathologists and radiologists (26 participants). Although those studies were short in duration, they found to be feasible, effective in skills acquisition and improvement, and more importantly generated interest among select participants to pursue additional intensive training [15]. In the pediatrics literature, studies were mostly around cardiopulmonary resuscitation; its status in low-economic regions, and areas of improvements. A Canadian study assessed competencies of clinical practitioners responsible for newborn resuscitation in Zambia and found that midwives lead most deliveries with poor resuscitation skills compared to anesthesia and pediatric residents. The study suggested a multidisciplinary simulation-based newborn resuscitation program with continual clinical reinforcement of best practice [16]. A pediatric trauma course conducted at the Cornwall Regional Hospital in Jamaica included both didactics and hands-on clinical patient simulations was feasible and successful in improving participants skills and confident.

The study advocated collaboration with the regional health authorities to overcome shortage in training and resources [17]. Local needs assessment and evaluation of resuscitation capacity are crucial to refine goals and objectives for the simulation curriculum and to ensure delivery of pragmatic educational content. Johns Hopkins University (USA) performed modified WHO Tool for Situational Analysis to Assess Emergency and Essential Surgical Care in Myanmar and Uganda and implemented their results to enhance the educational benefit with recommendations that were contextualized for local capacity and resource availability [18]. A 3-year pilot program in Uganda described the challenges encountered while establishing two simulation centers which aside from costs included procurement, lack of context-appropriate curricula, limited local teaching capacity, and lack of coordination. Those challenges are usually overlooked; thus the study highly supports careful selection of context-appropriate equipment and curricula, engagement between local and international collaborators, and early investment to increase local teaching capacity [19]. These facts were the core elements and highly stressed-on in a multidisciplinary partnership of Canadian and Rwandan health organizations that created Rwanda's first medical simulation center. They based their training structure on skills acquisition through psychological fidelity (the degree to which the task feels "real") rather than physical fidelity (the specific device used).

Therefore, they capitalized on local experience by teaching surgical-skills with inexpensive locally sourced materials and low-fidelity simulators. Rwandan partners ensured the curriculum was locally relevant and faculty were trained to teach other staff members for continuity of education and sustainability (train the trainer course) [20]. Fundamentals of Laparoscopic Surgery (FLS) tele-simulation course using a low-cost simulator model in Botswana and Columbia showed to be feasible and an effective method of teaching in resource-restricted countries with significant performance improvement in knowledge and skills [21]. Other procedural skills like insertion of interosseous needle was successfully taught remotely using web and low-cost simulators with online scoring system showing improved knowledge, confidence, and comfort level with task performance [22].

Discussion

Studies have demonstrated superiority of simulation-based surgical training when combined to academic curriculum compared to conventional means of education. This revolution in surgical training have shown to improve surgical performance, confidence, reduce time and error, and positively impact patients' outcomes. New-age simulators expanded their use from training novice learners to help expert surgeons maintain complex skills and prepare for unique surgical cases. In fact, several randomized clinical trials assessed parameters such as performance time and ability to complete the procedure and proved that surgical skills acquired by simulation are transferrable to operative settings [23-26]. Despite recent advances in simulation technologies and the invaluable learning experiences offered, surgical simulation is mainly accessible in resource-rich countries and urban cities. Unfortunately, cost, equipment, expertise, and structured curricula are major factors preventing widespread use of simulation training, especially in resource limited countries [2,27-29].

Published literature evaluating simulation-based surgical training in developing or resource limited countries is scarce, and the quality of available evidence is generally poor, with notable limitations to methodologies used and conclusions drawn. Structured curricula were obviously lacking, which has a critical role in learning outcomes. The conduct and methodology of some courses were not didactic or adherent to essential elements of simulation (e.g. briefing, objectives, learning outcomes, debriefing, etc.). Although most studies reported positive impact on performance and overall improvement of knowledge and technical skills, those were mainly self-reported feedback from participants that lack statistical validation. Further, there were no longitudinal data or long-term assessment to evaluate sustainability or skills retention. Facilities and resources to meticulously organize a quality simulation training simply do not exist in low-income countries. On the other hand, general acceptability was reported by majority of learners who valued the simulation experience to gain and practice surgical skills. Overall positive and significant impact on cognitive and technical skills have been reported which emphasize the value of simulation in training in those settings. Feasibility and successful completion of simulation courses and workshops were also reported by most studies, encouraging for more collaborative work and future investments.

Unlike bench-top dry lab models, tissue-based simulation using cadavers and live animals, or animals' tissue offers realistic anatomy and tactile feel, therefore, regarded as "gold standard" in simulation training. Wet lab simulators are superior to other models and can provide an invaluable experience for learners due to their high fidelity and resemblance to human patients. However, the higher cost, poorer availability, cultural issues, and ethical concerns related to tissue models have complicated their widespread adoption and usability. Also, they require extensive time and specialized personnel for preparation and planning. Due to all those reasons, wet labs are mainly accessible in some resource-rich and developed countries. Hybrid simulators which combine cadavers or live animals with other models like laparoscopic box simulators have been designed to enhance surgical skills and replicate complete operations. The downside of these simulators is the significant cost and planning required to develop these complex models, hindering their use in resource limited countries [1].

The innovation of low-cost simulators may facilitate the adoption and implementation of surgical simulation in developing countries. Sharing expertise with local surgeons and development of cost-effective curricula, methods and delivery systems will have a significant impact in resource-restricted areas [30]. To achieve sustainability, such training programs should be focused, clear, easily implementable, and tailored towards the local needs. Furthermore, training local physicians to be future educators and creative utilization of locally sourced materials to achieve desired educational outcomes are crucial for continuity. Academic collaborations with international leading intuitions are necessary for guidance and support.

Technological evolution offers exciting benefits for remote training using virtual reality and augmented reality headsets, and web-based tele-simulation platforms [31]. E-Learning and VR technology offer a unique learning tool and interactive educational platform that can bridge current gaps of surgical training. This cutting-edge technology provides immersive and active learning experience in a simulated safe environment free of location restrictions. The realistic nature of VR based simulation enhances learners' engagement in the educational task and yields a rich environment for experiential learning. The ability to design unlimited scenarios and diverse clinical environments that might not be feasible to implement in a real-world setting makes this educational experience invaluable [28,32,33]. Technology is constantly evolving, getting smarter, compatible, portable, and more affordable and user friendly. Low-cost VR simulators hold promise in helping to ameliorate the shortage in surgical training in underserved communities by overcoming constraints of time, location, cost, curriculum, and expertise. Low-cost VR simulators allows academic collaboration between high-income and resource-restricted countries to develop interactive training platform to acquire the psychomotor skills and cognitive planning required to achieve the surgical dexterity necessary.

There is a desperate need for more research and data to evaluate and improve effectiveness of educational interventions. With global efforts and investments, tele-simulation and newer low-cost high-fidelity models offer potential promise and great applicability in developing countries. Understanding the culture and empowering the local physicians and resources are keys to successful implementation of academic programs and sustainability.

Conclusions

Simulation-based surgical education in resource-limited countries is on demand to improve skills and quality training. There are major challenges impeding the adoption of simulation including cost, equipment, personnel, and curriculum. Innovative solutions and utilization of cutting-edge technology to implement low-cost simulation that is well structured and fits the local needs are essential. Quality research is required to further evaluate the significance of this teaching modality, as well as best relevant methodology and equipment in those settings. Nevertheless, academic collaboration with developed countries and institutions is essential for guidance and sharing resources.

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