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GYNECOLOGICAL CANCER

User Experience With Low-Cost Virtual Reality Cancer Surgery Simulation in an African Setting

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abstract

PURPOSE Limited access to adequate cancer surgery training is one of the driving forces behind global inequities in surgical cancer care. Affordable virtual reality (VR) surgical training could enhance surgical skills in low- and middle-income settings, but most VR and augmented reality systems are too expensive and do not teach open surgical techniques commonly practiced in these contexts. New low-cost VR can offer skill development simulations relevant to these settings, but little is known about how knowledge is gained and applied by surgeons training and working in specific resource-constrained settings. This study addresses this gap, exploring gynecologic oncology trainee learning and user experience using a low-cost VR simulator to learn to perform an open radical abdominal hysterectomy in Lusaka, Zambia.

METHODS Eleven surgical trainees rotating through the gynecologic oncology service were sequentially recruited from the University Teaching Hospital in Lusaka to participate in a study evaluating a VR radical abdominal hysterectomy training designed to replicate the experience in a Zambian hospital. Six participated in semi-structured interviews following the training. Interviews were analyzed using open and axial coding, informed by grounded theory.

RESULTS Simulator participation increased participants' perception of their surgical knowledge, confidence, and skills. Participants believed their skills transferred to other related surgical procedures. Having clear goals and motivation to improve were described as factors that influenced success.

CONCLUSION For cancer surgery trainees in lower-resourced settings learning medical and surgical skills, even for those with limited VR experience, low-cost VR simulators may enhance anatomical knowledge and confidence. The VR simulator reinforced anatomical and clinical knowledge acquired through other modalities. VR-enhanced learning may be particularly valuable when mentored learning opportunities are limited.

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ASSOCIATED CONTENT

Appendix

Data Supplement

Author affiliations and support information (if applicable) appear at the end of this article.

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INTRODUCTION

Surgery plays an important role in cancer treatment, with an estimated 80% of all cancers requiring surgical intervention at some stage. However, only 5% of patients who need surgery in low-income countries and 22% of patients in middle-income countries will receive such care.[1] This care gap can be largely attributed to a dearth of trained cancer surgeons and other barriers to cancer care in low- and middle-income countries (LMICs).[1,2]

Virtual reality (VR) is increasingly recognized as an effective tool for surgical training, improving novice surgeons' operating room performance in a wide range of surgical techniques.[3-6] As an educational tool, VR may be especially effective for training on cognitive skills or control of affect, that is, the ability to emotionally self-regulate in response to ongoing events.[7] Simulations in general promote self-regulated learning, wherein the student's cycle of strategic planning, performance, and self-reflection guide learning; among medical trainees, VR simulations help develop surgical dexterity by creating a virtual environment in which novice surgeons can practice psychomotor skills, sensory acuity, and cognitive planning.[8-10]

Several studies have suggested that these skills can be effectively transferred from the virtual environment to the operating room[4,11]; however, most studies have taken place in developed, high-income countries that can afford expensive and complex VR surgical equipment, typically for minimally invasive and/or robotic surgery, which require significant technical expertise and can cost upwards of $100,000 to procure and maintain.[7,10,12,13] Moreover, surgical simulations designed for higher-income settings that focus on teaching laparoscopic or robotic surgical procedures

CONTEXT

Key Objective

Can a low-cost virtual reality (VR) surgical simulator enhance surgical oncology training in lower-resourced settings? This study based in sub-Saharan Africa suggests that the answer is yes.

Knowledge Generated

After mastering skills to perform a radical abdominal hysterectomy on a VR simulator, gynecologic oncology trainees in Zambia felt more knowledgeable, skilled, and confident in their abilities in the operating room. They also believed that the skills developed within the simulator transferred to other procedures.

Relevance

Low-cost VR surgical simulators may offer an opportunity to provide tailored cancer surgical skill development to trainees in resource-limited settings where the lack of sufficient training and mentorship opportunities may limit surgical oncology skill development and access to cancer surgery care.

instead of open surgical procedures may not enhance the surgical skills needed by cancer surgeons in LMICs.[12] Fortunately, advances in commercial VR gaming equipment may offer a cost-effective alternative suitable for resource-limited settings that can be used to bridge this technologic divide. However, for such training to be effective in LMICs, we must also understand what novice cancer surgeons in such settings are learning when using VR surgical simulators to strengthen their learning and user experience (UX).

UX research often focuses on users' emotions, enjoyment, and experiences of a technology, sometimes emphasizing esthetics over the anticipated purpose, environment, or cultural context in which the technology will be used.[14,15] However, because a user's background and context influence their goals for technology usage, learning outcomes, and overall experience, engineers and designers must seriously consider the needs and realities of users from different cultural, social, and economic contexts.[17] The importance of understanding how these cross-cultural differences may impact the VR learning process is even more pronounced in light of the tremendous need for skilled surgeons in low- and middle-income countries, where VR simulators offer a particularly promising supplement to clinical training.[12]

In Zambia, like many LMICs, women have limited access to early detection and diagnosis of gynecologic cancers, and training in gynecologic oncology has historically been virtually unavailable. This has resulted in a significant need for gynecologic oncology surgeries but few trained specialist providers, coinciding with ongoing difficulties accessing imaging, histopathology, and blood supplies. As a result of recent efforts to train gynecologic oncologists, this study used a semi-structured interview process to evaluate UX and learning within VR radical abdominal hysterectomy (RAH) surgery simulation designed to address the context-specific needs of trainees at a hospital in Zambia.

METHODS

Participants and Design

Eleven surgical trainees in a clinical rotation in gynecologic oncology were recruited from University Teaching Hospital, Women and Newborn Hospital in Lusaka, Zambia, to participate in an evaluation of a VR surgical simulator for RAH. Study participants were Zambian and included eight senior medical students, two resident trainees in obstetrics and gynecology, and a fellow in gynecologic oncology. All participants received an in-person lecture on performing the RAH from a senior gynecologic oncologist, as well as online access to a copy of the lecture and slides. All participants also received VR training on RAH procedures. Six of the 11 study participants were available to be interviewed regarding their experiences using the simulator by trained interviewers in semi-structured interviews. The two residents in obstetrics and gynecology and fellow in gynecologic oncology were interviewed individually, and the three senior medical students were interviewed as a group. All the medical students had rotated to a different clinical service, and five of them were not available to be interviewed.

Semi-structured interviews allow researchers to obtain detailed, qualitative information about participants' lived experiences that cannot be understood through quantitative data alone. This type of interview allows interviewers to probe for additional detail while following a general guide of questions. The interviews primarily focused on factors related to use of and engagement with the simulator, perceived outcomes of simulator training, and recommendations for future development. Guiding questions for the interview are listed in Appendix Table A1. All interviews were audiotaped with participant consent. Interviews were later transcribed by a research assistant (Oswaldo Torres) and verified for accuracy by the interviewers who conducted them (E.G.B. and A.C.) as well as by two research assistants (Oswaldo Torres and Kaitlyn Contreras Castro). Interviews were analyzed using grounded theory.[17,18] Open coding was conducted

TABLE 1. Selected Participant Comments on Opportunity for Learning

"*I really want to gain this experience that is very rare in our environment and this opportunity came. So, when I was asked, I did not hesitate…*"
"*Anything that improves surgical skills is quite welcome for me. I thought it was a good opportunity to learn through simulation. […] Surgical simulation is something relatively new here. We don't do too much of those kinds of simulations.*"

using the constant comparative method, wherein two researchers (E.G.B. and Kaitlyn Contreras Castro) independently coded transcriptions by hand and reviewed the codes until consensus was reached regarding appropriate codes and analytical saturation. Two members of the team (E.G.B. and M.L.B.) then used axial coding to group these inductive codes into a set of key themes via the same consensus-reaching process.

VR Platform

Details on the design of the VR simulator used in this investigation have been previously reported.[16] In brief, participants practiced an RAH on a head-mounted VR platform designed to provide high-quality visuals; generate believable surgical hand interactions; and work efficiently with standard, affordable, and commercially available VR hardware (Oculus Rift; Oculus VR, Menlo Park, CA) and software (Unreal Engine; Epic Games, Cary, NC). Gynecologic oncologists and trainees in the United States and Zambia participated in the VR design process to ensure usability and anatomical accuracy. The virtual human female patient was constructed to scale. The internal pelvic anatomy had realistic three-dimensional organs, peritoneum, connective tissue, and vascular structures, which allowed the surgical trainees to virtually manipulate, clamp, cut, and suture tissue. Internal structures could be moved, allowing the surgeon to receive visual feedback. The simulator did not include haptic feedback. The virtual surgery was performed in a virtual surgical theater typical of a large district hospital in Zambia, with digital replicas of the equipment, instruments, supplies, lighting, and sounds. Virtual surgical instruments were modeled for each of the instruments commonly used in the RAH procedure in Zambia. See the Data Supplement for the video of a user in the surgical simulation.

VR Simulator

The training and procedure used in this study has previously been described in detail.[12] During the virtual surgery simulation, participants were trained to follow five sequential steps in the simulated RAH procedure: (1) exposing the lateral pelvic retroperitoneal spaces; (2) mobilizing the uterine artery over the ureter; (3) mobilizing the ureter from the medial leaf of the broad ligament; (4) unroofing the ureter; and (5) dividing the uterosacral, cardinal, and vesicouterine ligaments. Positive verbal feedback in the voice of the senior surgeon at the hospital was offered upon successful completion of each step. Participants could use the simulator at the hospital during normal business hours as frequently as they wanted until they reached proficiency. They were encouraged to use the simulator as frequently as their schedule permitted and could run the simulation up to six times during each training session. Each session lasted approximately 20 minutes. After each session, participants completed a self-evaluation.

TABLE 2. Selected Participant Comment on Opportunity for Mentorship

"*Prof concentrates on teaching us and I think that's a real privilege, because we don't have many of such high-level kind of trainings around here. We don't have these kinds of gadgets available to us for training. So, the lectures that Prof taught us, the material that he provided us and then this, it's something that is a great value to my name. […] Operating with Prof is a golden opportunity. Because everyone wants to operate with him, so because of this, we're given that spot.*"

RESULTS

At the time of enrollment, participants had an average of 6.7 years of medical training (standard deviation, 2.7 years). Overall, 60% of participants were men and 40% of participants were women. The average age was 35.8 years (standard deviation, 5.8 years). None of the senior medical students had completed or assisted in a hysterectomy, either simple or radical, at the time of study enrollment.

Five key themes were identified in the interviews: the role of goals and motivation; knowledge, confidence, and skill development; skill transfer and applications; barriers to success; and recommendations for the future. The rest of the Results section details findings that emerged in the interviews.

Role of Goals and Motivation

Participants identified several key factors that enhanced their learning and success in the training simulator, including having a clear goal and motivation. Motivation was described both as a reason for participation in the training as well as a product of the training. One important motivating factor expressed by several participants was that the VR simulator offered a rare opportunity for additional training, skill development, and mentorship that they might not ordinarily have access to (Table 1).

The opportunity for mentorship was likewise important. Multiple participants emphasized mentorship as a motivating factor for their participation in the study. Study participants received mentorship and training from the head surgeon, who is greatly revered by medical students at the hospital, and emphasized the value of access to the high-level training, lectures, and materials provided by the head surgeon in addition to the novelty of gadgets (Table 2).

Clear goals were also an important theme addressed by participants. Within the simulator, participants were given clear targets to achieve. Rather than competing with each other, they were told to complete the simulator until they

TABLE 3. Selected Participant Comment on Goals

"*…Knowing the gold standard, I think it's good, 'cause then that gives you a target. So, we're given 80% as a target to achieve. […] I took that as the gold standard. I should reach 80. But looking at the scores… it's more motivating to see your current score compared to your previous score. […] I'm not too competitive. […] It's good to know how other people are doing but that's not always a good measure of your effort. Sometimes, you know, when you are comparing with other people, you… you sort of tend to be satisfied with less. So, if I score 60 and all my friends score 40, I'm thinking, 'Wow, I did so much better than everybody else.' But look, I'm way below the gold standard. So, I would rather compare the gold standard and compete with myself against the gold standard than with other people.*"

could achieve 85% proficiency or higher three times in a row. Having a clear goal was motivating and raised the bar for achievement (Table 3). Having a gold standard to strive for encouraged participants to improve their skills further than they might have otherwise. The role of clear goals as inputs dovetails with the role of opportunities for skill development; a desire to improve, whether in the simulator specifically or more broadly as a surgeon, was an important motivator for several of the participants.

Knowledge, Confidence, and Skill Development

It was expected that the VR simulator would increase participants' anatomical and procedural knowledge, as well as help them develop their surgical skills. All the participants interviewed expressed a belief that the simulator did in fact increase these skills. These improvements in surgical skills were perceived not only by participants but also by others with whom they worked (Table 4). For some, this recognition of improvement translated into additional opportunities in the surgical theater, where the skills they developed in the simulator translated into success in the operating theater, as well as positive feedback from a respected mentor.

One unexpected aspect of this knowledge and skill development reported by participants was that it came not only through practice within the simulator but also through prompting participants to return to their training materials and further review the anatomy. A desire to return to instructional materials was frequently expressed in the self-reflection exercises that participants completed after each session. They described learning not from the VR simulator alone but from the simulator in complement to other modes of learning. These included reading literature, attending lectures, and observing surgeries.

TABLE 4. Selected Participant Comments on Knowledge and Skill Development

"*It [the simulator] has helped me improve my anatomy. Because without that, you really can't know what you are doing. So, it forces me to go through, to revise [review] my anatomy. And it helps me better understand […] more vividly what happens, to relate what happens in theater to what I am seeing.*"
"*My colleagues, my immediate supervisor [… noticed improved] surgical skills […] That procedure, the same hysterectomy, he was the one who was supposed to do it, then he just left me in the deep end. Initially, I was a bit intimidated, but when it was done, [he] was saying, 'I knew you could do it.'*"

Participants also described how practice in the simulator helped them to improve self-confidence, control their affect, and focus on accuracy during the simulator training. With practice, they learned to put aside their fears about the procedure or perceived surgical inadequacies and instead focus on the task at hand, a vital skill in the operating theater. The combination of increased knowledge, confidence, and transferable skills created a positive feedback loop for participants.

Skill Transfer and Applications

Participants believed that the knowledge, confidence, and skills they gained in the simulator transferred to other aspects of medical care and practice. Given that outcomes of interest were not only improved scoring within the VR simulator but also improved outcomes within the surgical theater, the UX for individuals interacting with the VR simulator extends beyond their time using the system itself, particularly because participants invoked their experiences within the simulator as tools to assist them in the operating theater. Participants believed that the anatomical knowledge skills developed within the simulator for RAH transferred to other procedures in which they were involved. They described in detail multiple instances in which the anatomical knowledge reinforced with the simulator helped them manage complications in the operating room and suggested that increased anatomical knowledge improved their ability to treat adverse events in the operating theater (Tables 5 and 6).

Increased confidence following training within the simulator also improved participants' ability to treat patients (Table 6). One participant explained how their increased confidence contributed to both their ability to successfully complete procedures in the operating theater as well as their belief that, with further practice, they would be able to successfully complete complex procedures in the future. This sentiment was based on the success they had treating a case of postpartum hemorrhage following the completion of the simulator training.

DISCUSSION

When designing for constrained health ecosystems, researchers, physicians, designers, and programmers must consider available resources writ broadly to ensure that the technology they are developing is appropriate for the needs and goals of users. Just as survey instruments must be validated in different resource settings and cultural contexts, training tools must be evaluated as well. This means considering not only the feasibility and utility of the technology itself but also factors such as time, noise, lighting, electrical supply, privacy, experience with VR technology, clarity of goals and instructions, and availability of learning opportunities. In their interviews, none of the participants

TABLE 5. Selected Participant Comment on Confidence

"*The very first day I started the sessions, I was so cautious, as if I'm in theater. I thought it would be how exactly the patient would be here. Like, […] it will bleed, and you lose the game. But then with time, I realized, […] it's really concentrating on accuracy of where you put your clamp, some fine hand movements, the way you move your equipment, those things.*"

described aspects of the virtual environment that felt incongruous with the actual surgical theater in Lusaka, perhaps as a result of the significant attention to detail that the design team paid to designing an accurate training environment that reflected the reality of surgeons' experience. The interviews revealed how contextual factors, such as time availability or learning opportunities, affected the UX and impact of the VR surgical system from end to end.

The novelty and rarity of this surgical oncology training and mentorship opportunity was a significant motivation for participation. This raises important questions for researchers and designers about what happens when the novelty wears off and how global programs can ensure sustainability. The emphasis that participants placed on mentorship suggests it may be important to include aspects of mentorship as the program is scaled. It may be possible that mentorship from a respected and admired senior clinician contributed to adherence and success because participants were invested in creating a positive impression for that mentor. Peer relationships may also play an important role in participant success. The gold standard scoring mechanism was specifically selected to not only increase participant aspiration but also mitigate competition between peers; given the positive response participants had to gold standard scoring, supervisors might consider using similar concepts or terminology in evaluating surgical performance. Participants positively described the supportive role colleagues played in their use of the simulator but did not describe other social relationships, such as friends or family.

In this study, motivation was both a resource and a result for participants, that is, it prompted study participation and was a product of the training participants received. In this study, positive feedback within the VR simulator (audio recordings of the head surgeon's voice) as well as guided self-reflection and evaluation following simulator sessions served as mechanisms to reinforce motivation. Creating a positive feedback loop that leverages existing motivation to generate future motivation may be important in developing VR learning systems that participants use consistently and may help one of the most significant issues impacting LMICs: sustaining a learning environment when day-to-day routine patient management dominates because of the huge workloads.[21]

TABLE 6. Selected Participant Comments on Skill Transfer and Managing Complications

"*When you have a clear understanding of the anatomy, even if you have a variation of a hysterectomy, you are more likely to overcome that challenge.*"
"*When a complication arises you actually don't have any problem, because you already know exactly what to expect when you open up those spaces.*"
"*I haven't been brave enough to do stepwise devascularization of the internal iliac, but […] if I go through it mentally over and over again, one day I'll gain that confidence. But one thing I've tried is ligation of the uterine arteries. […] She [a patient] had PPH [post-partum hemorrhage] and she was high parity with bad obstetric history, so there was a need for me to feel like I have to preserve this uterus. Yes, so I tried a B-Lynch. It didn't help much but once I ligated both uterine [arteries], the bleeding just stopped. Yes, so for me, that was really… I felt great, yeah.*"

This study developed not only a VR ecosystem but also a physical ecosystem in which VR technology, mentorship, learning materials, live training opportunities, and guided self-reflection interacted to produce an increase in anatomical expertise, procedural knowledge, cognitive skills, and self-confidence among participants. UX goes beyond direct human-technology interaction and extends into the broader contextual space in which that interaction occurs.[19,20] The UX of participants therefore reflects not only what happens while they are wearing the VR headset but rather everything that happens during and surrounding their participation in the study, including the process of invoking knowledge gained in the virtual surgical theater when operating in the physical surgical theater. This has been a crucially overlooked aspect of building capacity and capability in LMIC.

Quality of UX could be improved in future iterations by allowing participants to take a VR headset home with them, which could reduce feelings of self-consciousness and increase practice time by making the technology more convenient and accessible. The study had a small sample size, and not all participants in the study were available to participate in interviews, so generalized comparisons between qualitative commentary and quantitative outcomes cannot be made. Nor was it feasible to compare perceptions of improvement with outcomes in the surgical theater. However, qualitative data on the lived experience of participants gathered through interviews offer important insights for future VR surgical simulators in resource-limited contexts such as this one and serve as an important research tool when other forms of program evaluation are not feasible.

As cancer surgery training capacities and training needs shift, context-specific VR simulation technology is one strategy for developing responsive learning methodologies for trainees in strained medical systems. It is a particularly useful tool for those aiming to improve access to advanced oncologic and surgical care in low-resource settings, given that it can be used not only to train medical students and residents but also to screen instructors and visiting practitioners prior to departure to ensure they have the appropriate skill sets for the context. Moreover, as access to affordable head-mounted VR technologies increases around the globe, there will be a continued need for research that explores how these technologies can best be used for training and education purposes, especially in resource-limited contexts. This study illustrates not only the technical and methodological challenges of conducting VR training research in resource-limited contexts but also the feasibility of using an iterative, user-centered design process to develop VR training programs that appropriately serves these communities given their specific contextual and clinical needs and resources.

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AUTHORS' DISCLOSURES OF POTENTIAL CONFLICTS OF INTEREST

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APPENDIX

TABLE A1. Guiding Interview Questions

Why did you decide to participate?
Can you tell us about your previous experience with VR or simulations?
What has this experience been like so far?
Can you tell us about your surgical experience before or after participating in this study?
How has this affected your learning or experience in surgery?
Do you have any suggestions for ways to improve or expand this?

Abbreviation: VR, virtual reality.

