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Research Article

A Critical Review of Simulation-Based Medical Education: An Advanced Opportunity for Next Generation of Medical Education

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Abstract

Mistakes made by medical personnel may cause numerous medical errors and accidents, resulting in the death of patients. Therefore, it is imperative to increase overall medical knowledge and to improve the medical skills of caregivers during their education and training. Simulation-Based Medical Education (SBME) is a compelling method for medical training; it not only improves medical education quality and trainee confidence but also reduces medical error risk and keeps patients safe, increasing patients' satisfaction. SBME provides valuable tools to address realistic, challenging problems in medical education. Multiple factors are carefully evaluated and incorporated into the simulator design to most accurately mimic the real clinical situation and to measure the teamwork competency and learning objectives. Those practices include performance designs, a virtual platform for invasive medical procedures and noninvasive medical operations, psychology simulation, the combination of simulation and live/replayed surgery observation, and platform real force feedback. Simulation is the key element for SBME. The use of simulation in education ensures compliance with the established norms for clinical diagnosis, treatment, and some specific emergency cases. Trainees can repeatedly practice and learn from SBME without the risk of medical accidents. Improving the design of simulators with sufficient fidelity to the clinical events, in reality, will improve the quality of SBME.

Keywords: simulation-based medical education (SBME); performance design; virtual system; platform real force feedback

Introduction

Simulation-Based Medical Education (SBME) is a widely accepted method to effectively improve the skills and knowledge of medical professionals and an approved, risk-free method during medical education[1, 2]. With the increased requirements for patients' safety during medical procedures and the need to improve the quality of healthcare education, it requires SBME to incorporate the most updated data on medical performance[3, 4]. SBME was considered to be a milestone in remedial education, training, research and evaluation[5].

SBME provides valuable tools to address realistic, challenging problems in medical education. Multiple factors are carefully evaluated and incorporated in the simulator design to most accurately mimic the real clinical situation and to measure the teamwork competency and learning objectives [6-8]. These factors include but are not limited to simulation-based doctrine and practice, new science and technology, and new instruments and tactics.

It is noteworthy that plenty of medical errors are caused by mistakes made by healthcare providers or unskilled clinical technicians. According to the statistical analysis result from the Institute of Medicine, 44,000 to 98,000 deaths of patients are caused by the medical errors made during inpatient hospitalization every year[9, 10]. This number is even bigger than the number of persons who died from traffic accidents [11, 12], breast cancer[13], and AIDS[14-16]. Therefore, qualified clinical skills are closely associated with the survival rate of patients[17]. It is true for both in-hospital treatments and medical emergencies[17]. SBME provides opportunities for caregivers to practice, thus enhancing their clinical skills without touching real patients. Through repeated practice, healthcare providers could improve their clinical skills in both restorative procedures and emergency situations, therefore assuring the safety of patients during medical treatment [18].

Currently, most of the necessary medical knowledge acquisition still relies on traditional learning methods such as textbooks and discussions. Most of the first clinical experiences of medical students or trainees come from the actual practice on patients supervised by mentors, which imposes the patient a potential safety risk[19]. Therefore, a practice platform that simulates actual medical situations with high fidelity is in urgent need of technical training in medical procedures. In summary, how to improve the fidelity of simulators in SBME becomes an important issue to address, and SBME would be an advanced opportunity for the next generation of medical education.

A fidelity performance design

Medical education, as it stands now, is an education system that continuously embraces new technologies to enhance the learning experiences of students and have them better trained. The application of virtual experiences to improve the clinical training experience is not new to the medical field [20, 21]. The idea of imitation teaching in medical education, which uses a discrete simulation model for teaching and testing, is aimed to provide an initial practice experience to participants [20, 21]. It would be beneficial for participants to have a simulation experience that mimics symptoms of specific syndromes or side effects of various treatments [20, 21]. More importantly, simulation-based teaching conforms to the standards of clinical diagnosis, treatments and sometimes specific emergency scenarios [22]. One of the essential characteristics of SBME is simulation. It requires the simulators to react like a real patient. The result of such training depends heavily on the simulators' fidelity [23]. In high-technology simulations, like Virtual Reality (VR), the simulated human model has been set up by using the trackball, HMDS (Head Mounted Display systems), feeling gloves, etc., allowing trainees to better understand the structure of internal organs. In addition, VR(Virtual Reality) technology has to determine advantages in some particular cases, such as long-distance remote surgery, complicated operation schedules, surgical result prediction, and even the development of new drugs [1]. The immersion practice environment ensures trainees a realistic environment and unique learning experience that could enhance traditional schooling results without risking the safety of any real patients.

Virtual platform in noninvasive medical operation

Medical history collection is the first step in diagnosis and treatment decisions. Medical students could improve their clinical interviewing and physical examination skills through a simulation teaching program. A widely used medical history training system includes a professional case library and realistic 3D models, providing simulation models for dozens of diseases in various organs or systems such as circulation, respiratory, urinary, endocrine, digestive, and obstetrics and gynecology [24-26]. These virtual human models and human-computer interactions encourage students to observe the "patient" from different angles. Virtual patients have vivid facial expressions as well as "sit and stand" positions. Additionally, they can answer questions, participate in the physical examination, and respond to different diagnostic instruments.

In order to help trainees build their habit of critical thinking, current simulators are designed to create clinical scenarios that encourage trainees to do problem-solving. The simulating system automatically asks trainees to analyze the data presented to them and to draw specific conclusions for a given scenario [9, 13, 22]. It encourages trainees to imagine themselves in an office or ward. As trainees are learning the basics of physical diagnosis, it also requires them to integrate other factors such as disease etiology, pathology, physiology, and clinical manifestations to efficiently and accurately obtain a complete medical history and physical examination result[27]. It further develops through laboratory findings and imaging results to accurately diagnose the disease and make an appropriate treatment plan [27]. Practicing with this simulation system would help trainees acquire the medical skills in a stepwise way [27].

Psychology simulation

Sensory perception is one of the vital components of psychology. It is an abstract, psychological phenomenon that is not easy to contribute to. Simulation of sensory perception through a series of psychological instruments and equipment creates a platform for perceptual psychology experiments [28]. The stroboscope is an example of such an instruments. It decelerates a fast-cycled movement into a slowly moving one. Such an intense flashing/pulsing light at various frequencies can trigger epileptic seizures in people who are impacted by photosensitive epilepsy [29]. An experiment-specific project could include multiple instruments such as a stroboscope, reflector, stabilizer and multiple reaction condition testers to investigate certain target manifestations such as attention span [28]. Trainees would get trained and evaluated by operating the instruments and analyzing the results. Those above practices would not only make students get familiar with the abstract psychological phenomenon of sensory perception but also broaden the students' understanding of the underlying mechanisms involved [28]. This simulation system will help trainees build a solid foundation of clinical diagnosis and research in psychology.

Virtual platform for invasive medical procedures

A successful design of a medical simulator is based on multiple components, including thoroughly investigated medical background information, medical data collection and post-production data integration [30]. In general, designing a medical simulation model comprises two steps: raw digital data importing and medical image collection, including CT scans, MRI and ultrasound screening to accumulate sufficient tomography data, and image preprocessing, segmentation, registration, and complete digitalization of a whole human body or an organ. Specific tools and software are available for complete image processing [31].

Compared to traditional training with animal models, the simulation-based training models are safer, more intuitive, and more accurately reflective of real clinical situations. Yoshida summarized the trainees' initial impressions of a new virtual reality hysteroscopy trainer after they completed a hysteroscopy myomectomy and compared it to that of a widely used traditional training using animal models [32]. The trainees rated the training effects of the two different imitation methods, and it turned out that the simulation method scored significantly higher than the training using animal models for "a variety of training cases" and "performance assessment," with the exception of "hysteroscopy myomectomy", for which the simulation-based training tightened to the "gold standard" demonstrated by the training using animal model [32, 33].

Predictably, simulation-based training will partially replace animal-model-based training due to its outstanding advantage in data collection and reorganization [32, 34]. Data reception hardware with a 3D platform system is capable of connecting to the server to transmit data[32, 34]. Therefore, the system can give the command to the workstation to run the equipment in a virtual environment, and the system in a virtual environment can generate feedback to the trainee during the force-force feedback. The force feedback process allows the system server to generate force feedback instruction after receiving data processing information (force feedback, virtual touch) [30, 32, 34]. This process also enables the digital/analog (D/A) converter to adapt digital quantity feedback to analog and controls the workstation output force feedback to the trainee.

Data reception processing equipment (force feedback, virtual touch) can prevent action delay and jitter, especially in the process of simulating endoscopic operation. The 3D medical model processing server is connected to a 3D platform system server, providing access to a huge amount of medical data, including medical diseases, complications, and emergency models[35-37]. A virtual environment can be generated through the 3D platform system server, giving rise to the virtual instruments and virtual organs, among many other features. The display device comprises a platform system that is connected to the server, which is capable of casting the images during the training to a variety of devices (such as monitors, projectors, etc.), enabling the vision of each detailed medical scenario [37].

In the early '90s, a virtual surgical training platform was invented with the leg and abdominal surgery simulation at the forefront. Now, this virtual platform further includes a surgical lamp, virtual surgical instruments (such as scalpels, syringes, forceps, etc.) and virtual organs, etc. With the aid of feeling gloves, trainees can operate on a virtual human model [30, 38-40]. Moreover, with the help of silicon images and a virtual operating table, NASA's biological computer center rebuilt a virtual patient for facial plastic and reconstructive surgery [41]. By wearing specially-made feeling gloves, surgeons are able to restructure the patient's organs and bones by using the energizing track scanning pen and slime-relevant software. Physicians can clearly realize the prognosis of the disease and the outcome of the treatment. Without this system, it was difficult to explain the procedure to patients using layman's terms [42]. Reconstitution of the virtual stereo image allowed patients to understand the process more clearly.

The faithful simulator could also be used in the clinic in reality. Surgeons can repeatedly simulate operations on screen, move the organs, search for the best operation procedures, and improve surgical proficiency with the help of virtual reality technology. Furthermore, it could help surgeons in remote surgeries in the future by planning cooperating plans, providing instructions in the operation process, predicting operation results, and improving living conditions for those who are physically challenged [43-45].

In reality, medical professionals are not in the situation of "fighting alone". It is more complicated than in the simulating situation and often requires team responses. In order to be prepared for this situation, trainees are required to operate more than three advanced medical simulators[46]. Computer-operated, physiological function parameters such as heart rate, respiratory rate, blood pressure and temperature will adequately respond to any medical interventions such as artificial ventilation, chest compression, and induced hibernation in CPR (Cardio Pulmonary Resuscitation). This program emphasizes the collaboration of physicians and nurses, the prescription and implementation of medical orders, and the recording of clinical events in real-time [34, 47]. It is able to simulate many other parameters. VR simulator trainees are educated surgeons and doctors in many other medical subspecialties (e.g., interventional cardiologists) who work heavily in intricate and invasive procedures that may put real patients at risk. It should be kept in mind that such a medical situation can be complicated and volatile. Thorough data analysis and consideration of such situations should be practiced for future simulator designs and future SBME technology selection [45].

Platform real force feedback

The nervous system is a complex, highly organized network that allows the transmission of signals throughout the body to control movements, sensations, thoughts and feelings [48]. During an operation, the nervous system works at many different levels. For instance, the operator's fingers have susceptible receptors connected to the nerves that transmit information to the operator's brain, the photoreceptors in the operator's eyes perceive not only light but also the organ position, active bleeding sites, suture position and other pertinent information [49-54]. The operator's brain is constantly sending out commands to control the fine movements of the fingers and wrist, which are particularly critical in such a vulnerable environment[50]. For a simulator, visual information is obtained through the virtual scene, and tactile information is obtained through force feedback devices. It would, in many senses, feels like a real operation because of the realistic resistance when cutting through muscles and bones. An US group employed a virtual surgery system named Haptic Workbench for training purposes [55]. It is a 3D imaging system that utilizes glasses and a mechanical arm with the integration of detailed human anatomy data to simulate realistic, high-resolution 3D virtual scenes [55]. In accordance with different training purposes, trainees can adapt the mechanical arm to various surgical tools, such as a scalpel or hemostatic forceps [56]. The system also has a tactile reflection through force feedback or cutting resistance.

Highly restored simulation systems, such as ophthalmology operation simulation systems, which can create 3D images according to the structure of eyeballs, are capable of providing real-time tactile feedback. This would be an excellent educational resource for students, allowing them to simply observe or be more actively involved in different simulated activities, i.e., removing the lens of the eye, manipulating blood vessels, and observing various anatomical structures of the orbit [30, 32, 57-59]. The advanced simulator for the artery stent system has been applied on levels as high as vascular surgeons' training [57]. The endovascular simulator provides an incredibly realistic feel to trainees [57]. Additionally, the simulator can measure and record the movement of multiple guidewires and catheters, as well as distinguish between proper and improper tip placement [34]. Trainees can receive objective feedback in a simulated surgery to enhance their skills and to provide an opportunity to obtain valuable experience. By practicing with the simulation system, the performance of the trainee can be scored[25, 26]. The score doesn't merely depend on an arbitrary evaluation index, such as the time duration to finish the procedure. A certain amount of unique skills can be evaluated objectively. If an experienced trainee completes a technique training and gets a score, the score can be used as a benchmark of proficiency in this simulation system. To achieve this goal, a high level of simulation fidelity is a requirement for the system. A very precise simulation experience can ensure fewer variations among trainees and eliminate any remaining subjectivity throughout the process of training [37].

By using a simulator, almost all medical scenarios can be reconstructed, and various aspects of many medical procedures can be mimicked, including cutting, sewing, knotting, the use of titanium clips, and even bleeding. During the surgery, trainees can utilize the virtual instruments (clamps, ultrasonic knives, electric coagulation hooks, etc.) to practice minimally invasive endoscopic surgical procedures. From the data received from feedback signals to workstation output feedback force and virtual touch, these simulation activities continue to transform into an even more realistic experience.

Combination of simulation and live/replayed surgery observation

Yoshida and his collaborators indicated that a combined virtual reality endoscopy and colonoscopy simulator, in addition to the alternate laparoscopy surgical training, could significantly improve the effect of training [32, 34]. It was also shown to shorten the trainees' initial learning curve, reduce the safety risk of patients, and lower the occurrence of complications related to the operation.

It would be beneficial for trainees to engage in repeated virtual reality simulator training of laparoscopy for one week. This is especially true for training in specialized areas such as the hand. Such training achieved through a training module could improve the training efficiency. Training efficiency could also be improved by watching video demos of operations that encountered unexpected circumstances [32, 34]. The training should be focused on explanations of any unexpectancies and how to avoid them or deal with them [32, 34]. At the end of the sixth week, trainees participated in clinical surgery practice training [7, 8]. As a result of such training, the operation accuracy and speed of trainees regarding the surgical instruments were improved dramatically, as well as the basic skills of suture and knotting and a marked strengthened hand-eye coordination [32, 34].

Designer/trainee feedback

Designer/trainee feedback is one of the key components of the evaluation standards for simulation fidelity. It is very critical for SBME to design and plays important roles in medical education through SBME [9, 10]. The core elements of SBME are varieties, sources and impact. The variety lies in the summative and formative forms of performance feedback. The outcome of SBME does not require summative judgments, and simulation schooling increases learners' clinical skills. A prime example of the medical simulation is the four-step model presented by Rudolph and his colleagues comprising of 1. observing the gap between desired and actual performance; 2. commenting on the performance gap; 3. investigating deeper into the basis for the performance gap, and 4. helping to close the gap through discussion and didactics [60]. However, some problems still remain even after the collection of feedback, including how to evaluate the quality of each feedback and how to translate the feedback to match the ultimate goal [20, 21, 61]. If the SBME equipment involves video or digital recordings, the question remains on how to train participants and instructors to adapt to the novel environment. As of today, feedback still has limits, and it is understood that performing a composite analysis is helpful in achieving a better training result.

Previous studies that focused on simulators have reported an evaluation of available technologies as supplementing training methods. Berridge et al. tested two training simulators, the endoscopic retrograde cholangiopancreatography (ERCP) mechanical simulator (EMS) and ex-vivo porcine stomach model (PSM), in ERCP training [62, 63]. It turned out that endoscopists who practiced with both models had a better understanding of the surgical performance and reported increased confidence during a real ERCP procedure. Because both PSM and EMS simulators were designed to be equipped with many accessories and to serve a broad range of training purposes, the training procedure using these two simulators was more authentic than other training using full computer-simulated platforms. Endoscopists who were trained with PSM and EMS expressed a preference for these training over traditional medical education methods [63].

Recently, more and more studies reported the benefits of engaging in simulation-based training in medical education. Farcas and his colleagues reported a remarkable improvement in technical skills, patient safety and overall performance in a group of medical students trained under the SBME program [59]. The improvement was attributed to the use of high-fidelity endovascular simulations in the vascular surgery course. In addition, engagement of the SBME increased students' interest in the specialized area. 70% of students considered listing vascular surgery as a potential career option at the end of the course, compared to only 10% of students who expressed their interest. Almost all of the students' vascular surgery knowledge had been expanded after the training [31, 59, 63].

Lastly, simulator-based courses may also provide the opportunity to pre-screen and recruit talented medical students into future surgical training programs. Yedavalli et al. reported that the simulation system might potentially be employed as a screening test for surgical talent[64, 65]. Trainees were divided into two groups [20, 26]. One group was trained on the simulator; the other group was trained on a video box trainer correlated with real operational performance. After completing the training program, the trainees in each group were tested on the training modality. Although students in both groups demonstrated improvements in terms of performance and final score in the screening tasks, the group trained on the simulator received a significantly higher score than the video-trained group [41]. Such scores could be translated to better operational performance. The impact of SBME has been studied by several different groups. These studies indicated that simulation training with force feedback produced significantly better performance than training programs without a feedback strategy[36, 62]. It is also true in clinical CPR practice, that SBME could have a positive influence on trainees' clinical behavior.

Conclusion

Nowadays, most of the clinical technique is accumulated by learning from the actual patients after graduation. It is a continuously evolving issue to find the best way to deliver a useful, long-lasting method of education. Currently, a comprehensive reform of teaching and learning is happening worldwide. The reform of medical training represents the need to improve the traditional medical education methods and to look for more active and efficient ways of training. High-quality SBME will be an excellent tool that could improve medical education quality and trainees' confidence, reduce the medical error risk in care provider practice, and increase patient safety. The needs for each particular simulation will be identified by accurately and thoroughly analyzing the simulation performance. Risks for patients in a clinical setting are often complex and volatile, especially during anesthesia, surgery, emergency treatment, etc. It depends on the correct judgment and quick completion of technical operations to reduce the risk of diseases, therefore protecting the safety of patients. The fidelity of SBME _ENREF_1rests on the thoroughness of medical knowledge and the environmental factors in clinical settings, which take time to develop.

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