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Simulation in Medical Education: Brief history and methodology

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Abstract:

Background and Aim: Preventable medical errors result in more than 400,000 American citizens each year and are the third cause of death in the United States, followed by cardiovascular diseases and cancer. The roots of such alarming statistics may be found in medical education, and innovative educational approaches are necessary. Simulation based medical education can be a valuable tool for the safe delivery of health care. The purpose of this article is to perform a brief review the history and methodology of simulation, and highlight its unique importance in the medical teaching and learning scenario.

Conclusion: Simulation has unique features, since it provides a safe and controlled environment to teach a wide variety of not only technical abilities but also non-technical skills as well, and it is also a reliable educational assessment method. Therefore, providing appropriate simulation for medical training is a major path compliant with best educational standards and ethical principles in the process of medical education.

Keywords: simulation; medical education; simulation-based medical education

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INTRODUCTION

Preventable medical errors result in more than 400,000 deaths each year in the United States and are the third cause of death in this country, followed by cardiovascular diseases and cancer (1). Nonfatal iatrogenesis results in disability in 3.5 million American patients per year (1). One of the main reasons of such alarming statistics may be related to the medical education culture. Since the Flexner report (2) many advances have been made in technology and teaching strategies, however, it is still not unusual for medical students to be taught almost as the same way they were decades ago.

Evidence based methodology, patient safety, andragogy, accessible high-quality media production, computers, smartphones, the Internet, 3D printers, high and low fidelity mannequins – most of this is basically not taken into consideration when defining the curriculum and the pedagogical methods to shape and enhance the background of future health care professionals. Meanwhile, other high hazardous industries such as aviation and spatial engineering were able to embrace

several of these advances, specially simulation-based learning models, leading to a 50% reduction on aircraft accidents and spatial conquests (3).

Simulation based medical education can be a valuable tool for better clinical practice. It provides a safe, controlled environment in which problem-based learning is developed and competences are practiced in high-standards. Although the use of simulation in medical education has increased during the last two decades, it has happened in an unsystematic manner. The purpose of this article is to review the history and methodology of simulation-based technique in the medical education.

HISTORY

The origins of medical simulation

Simulation is a technique that replaces and amplifies real experiences. It can evoke and replicate substantial aspects of the real world in a fully interactive manner (4). In the medical field, one can find its origins in Antiquity, when models of human patients were built in clay and

stone to demonstrate clinical features of diseases and their effects on humans. Such simulators were present across different cultures, and even enabled male physicians to diagnosis women in societies where social laws of modesty used to forbid exposure of body parts (5). In the 18th century Paris, Grégoire father and son developed an obstetrical mannequin made of human pelvis and a dead baby. The phantom, as the mannequin was named, enabled obstetricians to teach delivery techniques which resulted in a reduction of maternal and infant mortality rates (6). On the other hand, historical data document the use of animals in the training of surgical skills since the Middle Ages throughout modern times (7). While the unsystematic use of inanimate and live simulators is reported along the history of medicine, the origins of medical simulation as we know nowadays comes from other science: aviation (6,7).

Brief history of nonmedical simulation

In 1929, Edwin Albert Link had invented the first flight simulator, a prototype named "Blue Box". The simulator was a fuselage-like device equipped with a cockpit and controls (8). The capacity to reproduce flying motions and sensations allowed Link to teach his brother to fly during the same year. After succeeding this innovating idea, Link named the prototype as a "Pilot maker" and started to commercialize it, but the Blue Box only interested amusement park operators. In 1934, several American postal carriers' crashes were documented as consequence of poor meteorological conditions. At that moment, the President of the United States of America (Theodore Roosevelt) hired the US Army Air Corps believing that they would address the US postal mail needs. The result was the same: bad weather conditions leading to fatal accidents. Shortly after, the Link Simulator started to gain national attention. The Army Corps purchased six trainers, and soon the simulator became a mandatory part of pilot training in many countries (6,9).

The rationale behind the Blue Box provides support to state why simulation became successfully applied in many human endeavors. The flight simulation creates a controlled and safe environment where trainees are exposed to high-risk conditions that could be rarely experienced otherwise. In addition, the process is standardized and can reproduce settings of various levels of complexity, which allows pilots with different levels of skills to achieve flight expertise.

Modern era of medical simulation

In the early 1960s, Peter Safar described the efficacy of mouth-to-mouth cardiopulmonary resuscitation (7). Encouraged by his work, Ausmund Laerdal, a plastic toy

manufacturer, designed a realistic simulator to teach mouth-to-mouth ventilation (7). He named the mannequin Resusci-Anne, inspired by a popular European history of a young girl that was found dead floating on the River Seine, back in the late 1890s. Resusci-Anne enabled physicians to practice hyperextension of the neck and chin lift, two techniques of airway obstruction management that every healthcare professional must know nowadays. Later, Laerdal was advised by Safar to include an internal spring attached to the mannequin's chest wall, which permitted the cardiac compression simulation. This was the birth of the most widely used CPR mannequin of the 20th century (7,6).

In 1968, during the American Heart Association Scientific Sessions, Doctor Michael Gordon from the University of Miami Medical School presented Harvey, the Cardiology Patient Simulator (7). Harvey was named after Doctor W Proctor Harvey, professor of cardiology at Georgetown University during Gordon's cardiology fellowship, and who is credited for first applying modern technology to the practice of 20th-century medicine through the use of phonocardiographic records to illustrate the nature of auscultatory findings (10). The mannequin can reproduce almost any cardiac disease by varying blood pressure, heart sounds, heart murmurs, pulses and breathing. Its efficacy as an educational tool has been proved throughout time, henceforth it has been applied for training and assessment of trainees in various medical schools, residency programs and emergency departments (6,7).

Resusci-Anne and Harvey represent cornerstones of the beginning of modern era medical simulation. After their development, many other types of simulators were developed for education and training (6,7). All of them share a common characteristic: the use of technology to achieve a more effective learning experience.

However, modern simulation is not only based on lifelike mannequins. The use of actors to portray patient encounters was first reported by Howard Barrows in 1964 (11). In the early 1960s, during his last year as a neurology resident at the New York Neurological Institute, Barrows ran into David Seegal, a professor of neurology that used to sit down and do a detailed assessment of his resident's performance during a patient encounter. He was impressed with Seegal's capability to evaluate interview skills, physical examination techniques, and clinical thinking. In that same year, Barrows observed that patients can get extremely annoyed when they participate in repeated clinical assessments by trainees, and that they could even modify neurological findings. Soon after he got his first academic position and inspired by these observations, Barrows

started to systematically use healthy actors to simulate patient’s signs and symptoms, in order to teach and assess his students (12). The standardized patient was born, an umbrella term for situations where a person is trained to simulate a clinical case or an actual patient is trained to present his or her illness in a standardized way (12).

As technology improved during the 1980s and 1990s, software and computerized systems that can mimic physiologic responses and provide real feedback were produced. At Stanford University, a group led by David Gaba developed the comprehensive anesthesia simulation environment (CASE) (13). The initial prototypes combined commercially available technology, such as a Machintosh computer, a mannequin and waveform generators to simulate a patient during the process of anesthesia (Figure 4). The rationale of the CASE simulator was to incorporate the aviation model of crew resource management for the sake of teamwork training in a realistic environment. After the success with CASE, Gaba’s group advocated for the implementation of SBME into the anesthesia crisis resource management curriculum, which led to significant advances on team-based training (4,14).

Recently, even more realistic environments were introduced through the development of virtual reality simulation. In 2007, medical schools created forums in an internet-based world called “Second Life”. This virtual life tool provided an environment where students could practice history taking and clinical examination skills (9,15,16). Therefore, the use of simulation has been shown to have many advantages: SBME allows repeated practice of clinical skills and exposure to rare but high-risk scenarios; and it reduces the inconvenience of using real patients for teaching purposes and is also a valuable tool for assessments of medical competences and performance (17–19).

WHY TO STIMULATE

Adult Learning Theory

Andragogy, the science related to adult education, is not a new field of study. Several authors have proposed different approaches and principles, most of them based on the key aspects of improving motivation and providing adequate guidance (20–22). To accomplish this task, it is important to recognize the differences between andragogy and pedagogy. Malcom Knowles put forth the main assumptions that should be considered when developing educational plans for adults (Figure 1). The spectrum from pedagogy to andragogy is a continuum that manifests itself differently in different situations.

There are indeed aspects of extrinsic motivation and reflection that play a central role in medical education that are not classically addressed by andragogy (23) – other theories, such as Transformative Learning, are alternatives that address some of such aspects. The main point, however, seems to be the adoption of a student-directed model, which is being consistently shown to yield good results both in improving knowledge and increasing engagement (22,24–27). Facing a student with a list of classes and chapters goes against the direction of recent effective approaches that take in account adult learning theory.

Simulation may play a central role in a student-directed learning model (28,29). It helps to create a clear “need to know”, since it mimics real life situations and gives students the chance to practice procedures – both within the safety of a controlled environment and the possibility to determine in advance the nature of the cases to be addressed. Thus, it becomes possible to cover in an ordered manner the most important diseases (namely, the most prevalent and acute conditions that may require immediate interventions), overcoming the expected variability of real scenarios in a hospital setting. Various objectives can be accomplished by adopting simulation, as described more thoroughly later in this review, but in all cases it can be tailored to meet the adult learning assumptions.

A critical aspect of simulation is constant feedback (23). This task is mainly done through debriefing, which

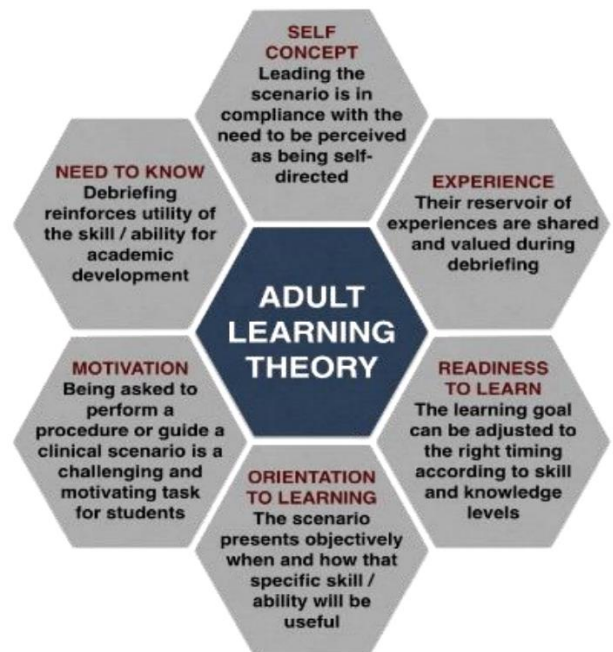


Fig.1. The characteristic of adults learning process

must be seen as a unique opportunity to reinforce the core assumptions of adult learning, as well as provide external motivation and stimulate guided reflection. Understanding how the experience affects future practice is a crucial step to improve performance (30). Simulation by itself does not guarantee learning, but within the proper environment, it is a tool of paramount importance for modern curricula oriented by the adult learning theory (31).

Ethical Issue

In 2000, the National Institute of Medicine report *To Err is Human* brought up to light that the number of deaths due to medical errors exceeded those from breast cancer and AIDS combined (38). More recent epidemiological studies suggested that 400,000 American patients die each year due to medical errors and that it is the third cause of death in the US (1). A recent international Patient Safety Movement calls for raising safety and quality of healthcare (17,32).

The increased demand for patient safety has pushed educational institutes to rethink the medical education system. The current model of medical training has remained unchanged during the past hundred years. Based on apprenticeship model, trainees are exposed early to patients in medical school, and pass through increasing levels of difficulty in patient care. In such hierarchical system, clinical decisions are shared among attending physician, senior residents, and students. Although the final decision relies on the physician, trainees are taught "hands on". This can be problematic considering the practice of risky procedures, and training of complex and critical problems (17).

One of the main bioethical principles taught to all healthcare professionals worldwide is the "primum non nocere" or, in English, "first do not harm" (33). However, it is inevitable that trainees will occasionally cause preventable injuries to patients. From the ethical viewpoint, such injuries are only justified when all effort is made to minimize patient harm (22). Simulation provides an innovative approach to medical education, in which trainees can practice medical skills to be better prepared for clinical encounters, potentially reducing such risks.

Other major ethical concern in modern medicine approached by simulation is the respect of patient autonomy. Current standards of informed consent establish the patient's right to make their own decisions about their healthcare, which includes accepting or rejecting their treatment by a trainee (34). However, training of medical procedures by students in recently dead or sedated patients is a common practice (34-36). A

survey on 449 coordinators of emergency medicine and critical care programs showed that 39% of these reported the use of recently deceased patients to practice invasive procedures, such as intubation, thoracotomy, cricothyroidotomy, central venous line placement, pericardiocentesis, among others (34,35). The classic medical pretext for using patients as commodities is the societal need to have well trained professionals in life-saving techniques (36). On the other hand, simulation offers options for practicing invasive procedures rarely seen otherwise, helping to mitigate these ethical dilemmas.

Error Management and Error Prevention

Medical practice is characterized by a constant pursuit of perfection. During medical school and residency, trainees strive for an error-free practice in an environment where mistakes are not well accepted (37). As a result, physicians have difficulties in dealing with error and admitting them as well (37). Besides its advantages as a teaching and learning tool for conventional medical skills, simulation is also a useful approach to provide competence in new areas. Among the proposed changes to achieve a safer healthcare system, the report *To Err is Human* recommended simulation as an educational technique on error management and error prevention (17,38,39).

Error management involves understanding the nature and cause of errors in order to avoid further mistakes (40). The concept comes from the Crew Resource Management training of the aviation field. Pilots are trained on how to change conditions that induce errors and also on nontechnical skills that can prevent them, such as optimal communication and teamwork behavior (41). Although medicine has lagged behind on the development of error control practices, simulation is an innovative approach of learning based on mistakes. It has the potential to improve performance in core competences such as: knowledge, communication skills, team work, patient care, clinical skills and professionalism (42). Therefore, simulation-based medical education has the potential to provide professionals with the correct attitude and skills to prevent and cope with errors in medical practice (43).

Skills evaluation

Changing the concept of standard evaluation to an analytical learning process is not an easy task. When Professor Harden published his objective structured clinical examination (OSCE) (44), he was not only turning public a remarkable method for evaluating different skills domains. But OSCE is the perfect complement for

simulation as it provides an objective way to analyze performance and substantiate feedback – a fundamental step for continuous improvement (45,46).

Since its first release, OSCE has grown worldwide to become an indispensable part of health care students and professionals’ evaluations (47–50). In fact, several countries require some clinical skills test, most of them on the OSCE format, to provide medical license or specialty degree.

A particularly important aspect of OSCE is the possibility to analyze separately different skill domains. From history-taking to communicating skills, imaging interpretation to technical procedures, throughout different scenarios, OSCE allows each domain to be explored and individually evaluated.

As any evaluation method, OSCE has limitations. Validity, reliability, objectivity and feasibility are major criteria that must be considered when analyzing a method of assessment. Despite some controversial findings, OSCE generally demonstrates good capability of actually evaluating a representative sample of achieved subjective matter and other educational objectives (51–53). Consistency drops when stations are in reduced number or little time is used. Other aspects that affect reliability are training of patients, staff organization, and fatigue after long periods of examination (for the student, patient, and/or examiner) (54,55). Structured checklist configures an acceptable way to standardize evaluation, providing examiners are trained in adequate manner. A possibly important drawback relies on the resources required to properly apply OSCE. It is fundamental to consider the number of students, available staff and patients, space, time, and financial investment. There are, however, less costly alternatives that may be applied (51,56–59).

Simulation appears as a fundamental part of evaluation in medical schools through OSCE. To obtain better results, it should be carefully planned and combined with other assessment methods.

METHODOLOGY OF SIMULATION-BASED MEDICAL EDUCATION

Defining goals and modality

Several conditions are associated with creating an easier and more effective strategy of learning in a simulation environment (Table 1) (60). The effectiveness of medical simulation depends on the appropriate application of its methodology and on the knowledge of its different modalities.

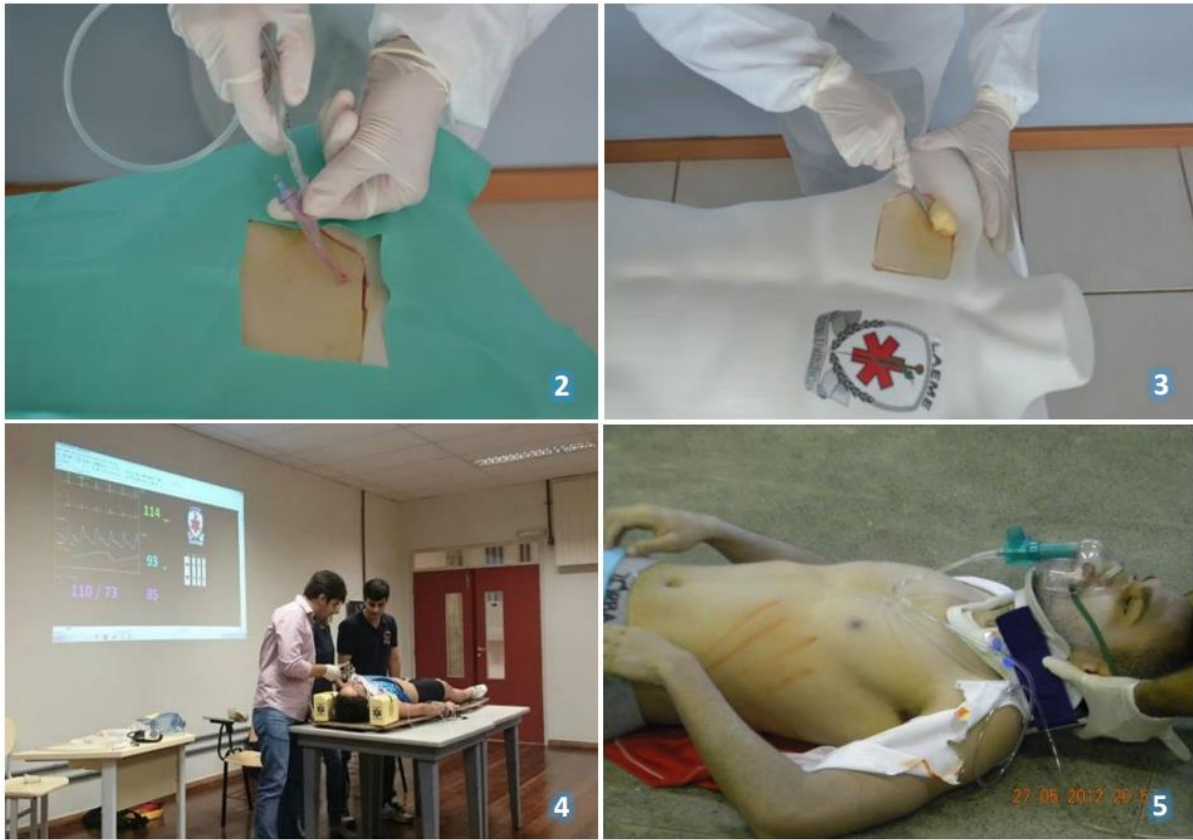
The simulation modalities can be classified into five major groups (17,34):

1. Low-technology: relatively low-cost models or mannequins used to teach basic knowledge or particular psychomotor skills (Figure 2 and 3).
2. Screen-based computer simulators: software for training and assessment of clinical knowledge and decision making.
3. Standardized patients: actors trained to play patients, which enables training and assessment of history taking, physical examination, communication skills, and professionalism (Figures 4 and 5).
4. Complex task trainers: computer-based simulators used for high-fidelity training of procedures.
5. Realistic patient simulators: computer-based mannequins used for high-fidelity replication of complex and high-risk clinical conditions in lifelike settings.

Despite there are different simulation methodologies with wide applicability (Table 2), there is no right or wrong template for a simulation exercise. Several combinations of techniques are possible depending on who the target population, previous background and the specific educational goals of the activity. On the other hand, financial resources may be an important restriction when defining modalities, but not an unsurpassable one. One of the arts of simulation is tailoring educational objectives according to available resources, a process in which innovation and student participation may play a central role. As an example, the Academic League of Trauma and Emergency Medicine of Bahia (LAEME, in Portuguese) is an institution with 10 years of existence composed by medical students of the Federal University of Bahia (UFBA), Brazil. The group promotes simulation sessions that uses a mix of relative low-cost mannequins with students that simulate patients to create a relative complex environment in which students are trained on decision making, history-taking, clinical examination, procedure techniques, and teamwork and communication skills (Figures 4 and 5).

Defined outcomes and educational goals
Utilization of multiple learning strategies
Controlled environment
Wide range of complexity level
Student-directed learning
Repetitive practice
Provision of feedback
Integration with traditional curriculum
Simulation validity

Table 1. Conditions associated with learning facilitation in simulation



Figures 2-3: Low-cost mannequin for central venous line placement. Figures 4-5: LAEME members performing trauma

How the medical simulation session work

According to Pazin et al (2007), a simulation session is characterized by the presence of four core components (Figure 6). The first component is termed “exposure”, which consists of the trainees’ introduction to the problem ahead, and it is also referred as “briefing”. The second element is “sequence”, defined by a progressively escalating complexity during the session, which helps the trainees to build upon consolidated knowledge, and allows them to have a better performance throughout the exercise (61). The third core component is named “feedback”, and it refers to the continuous exchange of information between trainer and trainee. This process takes place during and/or after the simulation session, and the instructor must be observant of the trainees’ abilities and performance in order to guide the learning process. Finally, the last component is “repetition”, which provides improved retaining of knowledge learned during a session (61).

Preparation

The preparation of a simulation session involves the creation of a welcoming and positive learning environment.

Trainees should be presented to all materials and resources that may be used during simulation, as well as become familiarized with terms and singular aspects of simulation – such as which decisions should be explicitly mentioned, what aspects of physical examination will be measured or told by the trainer and others. Such systematic approach avoid unexpected breaks in the virtual reality pact, an agreement with all involved personnel that commits them to immersing into the scenario and provides the concentration and emotional binding that are essential to educational success (61).

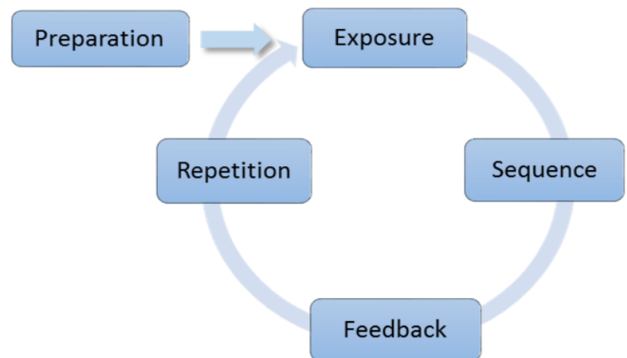


Figure 6: The five major components of a stimulation exercise.

Simulation method	Educational applications
Low-technology simulation	Central venous line placement mannequin, endotracheal intubation mannequin, cryothyroidotomy animal model, basic life support mannequin
Screen-based computer simulation	Software for physiology learning, software for problem-based learning
Standardized patients	Basic semiology training, low fidelity trauma simulation, objective structured clinical examination assessment (OSCE)
Complex task trainers	Virtual reality devices, videolaparoscopic simulators, endoscopy simulators
Realistic patient simulators	High fidelity full team anesthesia simulators, Advanced cardiac life support simulators

Table 2. Examples of applications of simulation-based medical education

Conduction

Dealing with the trainee during simulation is a dynamic and complex task. There are different ways to approach this task and there is no single best method. The decision on if or how to perform an intervention, whether or not to help with clues, how flexible to be with various types of conduct deviations, when to stop, allowing, forbidding or forcing a “patient” to die, are all key aspects that should be addressed when defining how the trainer will guide the scenario. These decisions should be taken according to learning objectives and trainee preparation (61).

When using sophisticated manikins, it is usually necessary to sketch a flowchart with all possible pre-set scenarios. This may be useful also for training standardized patients and for less experienced trainers.

Debriefing

Debriefing is the most important component of a simulation session. It refers to a moment in which the trainee is guided through a process of reflective thinking, by discussing his or her performance in the exercise (62). The goals of a debriefing session is to give the opportunity to the trainees to conceptualize the learning goals set by the trainers, and gain insight toward a better understanding of the event and its application on future experiences (63).

There is no gold standard approach to the debriefing session. However, it is recognized that the trainer must act as a facilitator, and his or her ability to assess the trainees’ skill is fundamental for the learning process (63). In addition, facilitators must create a nonthreatening environment that promotes active participation of trainees through the use of open-ended questions and positive reinforcement (63). The use of

audiovisual tools helps trainees to analyze, synthesize, and evaluate the experience in order to be able to apply the lessons in future events. Debriefing provides learners an opportunity to learn from their mistakes, and therefore is the one of the ways in which many of the advantages of simulation occur, as previously discussed. It is also applied following real clinical settings, and it has been successfully implemented in obstetrics (62), resuscitation (64), and critical care (65).

CONCLUSION

The To Err is Human report highlighted the need to improve patient safety on medical practice. The first step to provide a better quality of care begins on how healthcare professionals are trained. Simulation has the characteristic of providing a safe and controlled environment that suits learner centered approaches. In addition, it can mitigate traditional ethical dilemmas of medical training by reducing patient exposure to inexperienced trainees. Simulation also has unique features, such as the ability of being tailored to train technical skills or other abilities and attitudes such as teamwork, communication skills and leadership, as well as being a reliable assessment method through OSCE. More than that, as it enables learning from mistakes, simulation has the potential to change a traditional medical difficulty of dealing with error. Therefore, providing simulation-based training is a path compliant with best educational standards and ethical principia that should be adapted according to each institution’s singularities.

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Conflict of interest and financial disclosure

The authors followed the International Committee or Journal of Medical Journals Editors (ICMJE) form for disclosure of potential conflicts of interest. All listed authors concur with the submission of the manuscript, the final version has been approved by all authors. The authors have no financial or personal conflicts of interest.

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