

Simulation and its role in medical education

Col Rashmi Datta*, Brig KK Upadhyay, VSM[†], Surg Cdr CN Jaideep[#]

ABSTRACT

Medical education is increasingly laying emphasis on a curriculum based on cognitive, psychomotor, and affective domains of learning which were originally proposed nearly 50 years ago. These reforms are framed around best standards of care, error management and patient safety, patient autonomy, and resource allocation. There is a worldwide shift in the method of medical education towards experiential ('hands-on') medical learning; however, applying this concept to real patients is less acceptable to society and is subject to legal and ethical issues.

Simulation is the artificial representation of a complex real-world process with sufficient fidelity with the aim to facilitate learning through immersion, reflection, feedback, and practice minus the risks inherent in a similar real-life experience. Medical simulation offers numerous potential strategies for comprehensive and practical training, and safer patient care. It is a technique, rather than just a technology that promotes experiential and reflective learning. It is also a key strategy to teach crisis resource management skills. Simulation can benefit the individual learner, the multidisciplinary team, and the hospital as a whole. In this review, the authors discuss the role of simulation in five situations namely undergraduate teaching, postgraduate training, continuing medical education, disaster management, and military trauma management and dwell upon the experience of medical simulation in the Armed Forces.

MJAFI 2012;68:167–172

Key Words: medical education; simulation

INTRODUCTION

It is now universally recognised that appropriate and timely management of critical events or situations is the core of clinical competence. This depends upon an integrated and cohesive team of healthcare providers (HCPs) with a commonality of appropriate orientation towards the event. Towards this end,

a paradigm shift in the methodology of all levels of medical training has occurred. Stress is now laid on repeated protocol-based training practice of the appropriate management of a clinical situation. This aims at reducing the margin of error for unexpected emergencies especially those at unfamiliar locations (e.g. battlefield, high-way, or hospital emergency room).^{1,2}

For this type of training, patients on whom accepted educational principles can be demonstrated and medical concepts effectively illustrated are required. However, such patients may not always be available. Also, certain clinical situations do not warrant delay in management while teaching is going on. Additionally, health is now regarded as an industry with greater stress being laid on accountability, transparency, and quality assurance. This mandates an increasing degree of professional regulation and more stringent monitoring of the type of healthcare imparted by all levels of HCPs from the paramedical to the super-specialist level.¹ Therefore, newer methods have been tried to bridge the gap between traditional 'didactic' medical teaching (lectures, tutorials, laboratory work, bed-side consultations) and problem based learning (PBL). Simulation-based medical education (SBME) aims to provide correct attitude and skills among HCPs to cope competently with real-life critical situations in a planned and prescribed manner without compromising ethical and legal rights of patients. Employing medical simulation techniques can help move medicine from the old method of 'See One, Do One, Teach One' to a 'See One, Practice Many, Do One' model for success.³

SIMULATION

Simulation refers to the artificial (and almost always simplified) representation of a complex real-world process with sufficient fidelity to achieve a particular goal, such as in training or performance testing. The aim is to facilitate learning through immersion ('immersed into the clinical scenario'), reflection, feedback, and practice minus the risks inherent in a similar real-life experience.⁴

Fidelity is the common industry term used in simulation to describe the degree of realism and technical complexity of models. This is dictated by the needs of the application; more complex is the task, more is the fidelity of the model. Low-fidelity models can be developed and updated rapidly while high-fidelity models cost more to engineer and maintain but are more flexible when applied to different uses. Not everything needs to be taught in a high-fidelity simulation.

*Senior Advisor (Anaesthesiology & Critical Care), Army Hospital (R&R), Delhi Cantt. – 10, [†]Brig Med (CC), Lucknow, [#]Associate Professor, Department of Anaesthesiology, AFMC, Pune – 40.

Correspondence: Col Rashmi Datta, Senior Advisor (Anaesthesiology & Critical Care), Army Hospital (R&R), Delhi Cantt. – 10.
E-mail: rashmidatta@rediffmail.com

Received: 20.03.2010; Accepted: 19.11.2011
doi: 10.1016/S0377-1237(12)60040-9

Some objectives are better suited to part-task trainers while the others benefit from a higher fidelity simulation.

Classification of present-day medical simulators as per type is given in Table 1^{3,5-7} and as per fidelity in Table 2.^{5,7-9} Each has its own advantages and disadvantages. Screen-based

text simulators are relatively simple to construct and require little memory, thus reducing the cost too. Although these simulators permit learners to practice in isolation, they focus on single skills and as they lack graphical elements, there is poor immersion.

Table 1 Classification of simulators as per type.

Type	Specifications	Remarks
<i>Compiler driven</i>	Specific part-task trainers replicating a particular part of the anatomy Varying levels of sophistication is used to practice specific procedures or interventions	E.g., Intravenous-insertion arms, laparoscopic aides, urinary catheter trainers, airway management heads, central line placement torsos, spinal columns (for spinal taps and epidural placement) Also includes store-bought items such as pigs' feet (suturing), oranges (skin biopsies), and watermelon (epidural anaesthesia)
<i>Event driven</i>		
• Standardised patients/ care actors	These are actors trained to reliably role-play history taking, physicals, and test communication skills in a clinical encounter	E.g., Simulated clinical situations, including mock disaster drills
• Hybrid simulation	Combination of standardised patients and part-task trainers	
• Computer-based simulators	Uses mouse-and-keyboard navigation for multiple pharmaco-physiological models	Categorised as per fidelity (see Table 2)

Table 2 Classification of simulators as per fidelity.

Low-fidelity simulators

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|------------------------------|---|
| Screen-based text simulators | <ul style="list-style-type: none"> • Create scenarios with user selecting one of several responses • Based on the user's choice, a new text narrative is generated and more management choices are offered e.g. in a scenario involving a patient with severe headache, the user may be offered options such as prescribing an analgesic or getting a CT scan of the head |
| Static mannequins | <ul style="list-style-type: none"> • Used for hands-on practice e.g. intubation, laparoscopic training or cardio pulmonary resuscitation ('Ressuci' dolls) |

Medium-fidelity simulators

- | | |
|-------------------------------------|--|
| Screen-based graphical simulators | <ul style="list-style-type: none"> • Particularly well-suited to demonstrate physiological modelling and pharmaco-kinetic and dynamic processes associated with drug administration • Usually, only a mouse interface is involved e.g. Gainesville anaesthesia simulator ('Gasman') and 'Body' |
| Mannequins with mechanical movement | <ul style="list-style-type: none"> • Includes a mannequin and software which can simulate the interaction between a student and teacher • Computer-based pictures help confer practical skills • Includes 'range of normal variation' e.g. cardio-pulmonary resuscitation (AMBU Man) and ultrasound (UltraSim®) |

High-fidelity simulators

- | | |
|--------------------------------------|---|
| Non-physiologic (static) programming | <ul style="list-style-type: none"> • Manually set parameters dependent on operator • Parameters need to be reset after intervention |
| Physiologic programming | <ul style="list-style-type: none"> • Parameters change from baseline dependent on intervention and independent of operator • Automatic generation of appropriate physiological responses to treatment-interventions in the mannequin allowed e.g. human patient simulator |

AMBU: air mask bag unit, CT: computed tomography.

Screen-based graphical simulators provide a more realistic representation, are portable, and relative less costly. These help one to understand the conceptual theory underlying drugs but usually do not confer actual practical skills. They also prevent the learner from being fully immersed in the situation and require active 'stage management' of scenario in response to interventions.

High-fidelity simulators make use of full-body mannequins which behave like 'real' patients with the ability to speak to the learners until they lose consciousness, breathe with measurable realistic gases, have demonstrable peripheral pulses and blood pressure, produce urine, have blink, and demonstrate pupillary reaction to light. Cardiac rhythm is visible on attached monitors. Administered medications produce physiologically appropriate responses based on their programmed age and sex. The level of training and immersion can be increased by creating a realistic working environment such as a simulated intensive care unit (ICU) or operating theatre (OT) coupled with feedback from observers and video cameras to assist improvement in skills.⁷⁻¹⁰ Advantages are outlined in Table 3.

Virtual reality trainers offer a transition from the two-dimensional (2D) world of the textbook to the three-dimensional (3D) world of simulated patients.⁵ They are of two types:

- Virtual workbenches in which a 3D environment is seen on a graphic monitor.
- Total immersion virtual reality which allows interaction and navigation in 3D space.

REASONS FOR INCORPORATING SIMULATION AT ALL LEVELS OF MEDICAL TEACHING

Changing profiles of hospital patients and societal expectations have led to increasing medical accountability with minimal margin for medical errors. Medical accidents also follow the Heinrich's Model of Accidents. Heinrich original statistics of accidents was one major injury being preceded by 29 minor injuries and 300 no-injury accidents (300:29:1). To reduce accidents, safety measures should be instituted well in advance to prevent the occurrence of both minor injuries and no-injury

accidents. For medical errors, the generally quoted Heinrich's ratio (Figure 1) is 600:30:10:1, i.e. for every 600 non-reportable incidents there are 30 reportable incidents, 10 accidents, and one fatal accident. The first two are clubbed together as medical incidents, the reduction of which would translate into a reduction in accidents.⁷ Flaws in an organisation cause accidents and incidents, represented best by the Swiss-cheese model of accident causation. Incomplete holes in the slices of the Swiss cheese manifest as incidents. Accidents occur when all the holes come in a straight line. Larger the holes, more the critical incidents (Figure 2).¹⁰ In the medical analogue, the role of junior doctors and/or those senior doctors not exposed to periodic updates is equivalent to large 'holes' with resultant increase in critical incidents.

Doctors have been found deficient in performance of clinical skills, problem-solving, and application of information to patient care especially in unexpected situations despite possessing reasonably sound basic knowledge. To mitigate this, medical teaching was converted to a system-based core curriculum with learning objectives based on cognitive, psychomotor and affective domains. Aim was to produce a persistent, predetermined alteration in behaviour, acquired skills, and attitudes in the learner with a tilt towards PBL.^{2,6} But, these domains in most critical and/or uncommon events cannot be taught on 'real patients'. Also, this high-lighted certain ethical and legal rights of patients used for teaching. A patient's consent for participation in teaching programmes becomes invalid if prompted by fear of a compromise in care following refusal. Any payment to the patient towards the expenses and inconvenience of participation may constitute an inducement especially if it exceeds what can be considered 'reasonable recompense'. This can invalidate the consent. Furthermore, in most medical schools, patients' data information is stored and if the clinical and non-clinical staff has access to this, the issues about confidentiality and data protection need to be addressed.^{3,4}

An alternate solution to 'real' patients is the need of the hour, which will effectively illustrate the various depths of medical concepts and reinforce the HCPs' knowledge.

Table 3 Advantages of mannequin-based computer simulators.

- Students can refine and apply their skills in realistic healthcare situations
- Learning tailored to the educational needs of students
- Allows unlimited creation of situations that might be too dangerous or expensive to perform live
- Allows students repeated practice of procedures to reach proficiency
- Allows adherence to standard guidelines by reinforcement
- Allows evaluation of individual or group performance
- Scenarios can be halted at any time to allow for discussion of management strategies
- No issues of patient safety or confidentiality

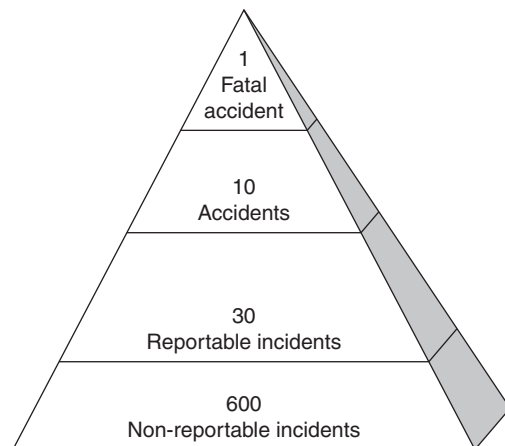


Figure 1 Modified Heinrich ratio for medical errors.

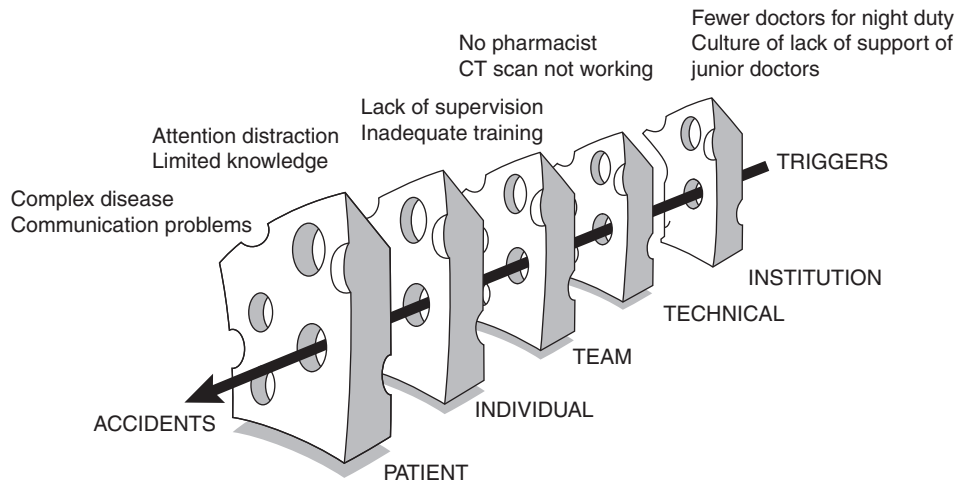


Figure 2 'Swiss cheese model' of medical errors.
CT: computed tomography.

Table 4 Reasons for more adverse effects in junior doctors.

- Lack of prior exposure to rare events like emergencies and unusual clinical syndromes
- Exhaustion and hunger due to long duty hours
- Distraction due to multiple clinical scenarios occurring simultaneously
- Management of critical events not supervised/taken over by senior staff with/without inadequate debriefing
- Lack of application of theoretical knowledge to an individual patient
- Lack of ability to confirm and clarify directions when in doubt or who to seek advice from

SIMULATION IN UNDERGRADUATE TEACHING

Undergraduate medical students are of prime concern because they have only one year to transit from a theoretical environment of the four and a half year course to dealing with patients independently, have a long professional life-span, do not have to unlearn habits, and are the future taskforce for teaching the next generation of HCPs.^{1,3} In addition, most adverse events are seen to occur in the first few years after graduation (Table 4).

Scheduled simulation can complement traditional clinically based training. Undergraduates can be exposed to uncommon emergencies such as pericardial tamponade, tension pneumothorax or malignant hyperthermia. However, at present, a general consensus regarding standards for cognitive domains in undergraduate curricula has not been reached for procedural skills. Clearly, such standards have to be context-specific for different procedures (e.g. familiarity with the 'steps' may be sufficient in central line insertion but automaticity might be expected for intravenous cannulation at the undergraduate level). The curricular time devoted to each procedure should be as per the targeted attainment level.^{1,8,9}

Taking the role of simulation further, it has been suggested that the evaluation of candidates for medical schools should be simulation-based to assess non-cognitive merits.³

SIMULATION IN POSTGRADUATE TRAINING

Simulation-based medical education allows implementation of protocol-based practise into the curriculum of postgraduate training.¹⁰ Second year medicine residents who had gone through simulator training were found to adhere to the American Heart Association guidelines 68% of the time, as compared with 44% of the time for traditionally trained third year residents.¹¹ Communication skills can be improved by demonstrating the value of speaking honestly and individualising the language and approach of each resident.⁴

Simulation can also create a model for patient safety when innovations are translated into clinical environments. When used as a pilot study in an OT, it identified 20 defects in safe delivery of a new procedure of intra-operative radiation therapy (including radiation safety, teamwork and communication, and equipment/supply problems) prior to trying it on patients. This allowed for changes to be made before performing that procedure on patients.¹²

SIMULATION IN CONTINUING MEDICAL EDUCATION

Based on what has been made mandatory in countries like Australia, UK and UAE, the Medical Council of India (MCI) has recommended that a quality assurance framework should be in place for identification, development, and promotion of standards for quality for practicing doctors, extending the utility to improve the competence and incorporate new knowledge periodically to this group.^{1,6} Here, advanced simulators like Harvey Cardiology Simulator, the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills will have a

larger role to play. Regarding simulation-based competency assessment for procedure performance, the United States Food and Drug Administration (US FDA) will now only certify competency of a clinician to perform carotid stenting procedure of a patient if competency is demonstrated in a simulator first.⁴

SIMULATION IN CIVIL AND MILITARY DISASTER MANAGEMENT

In disaster, unusual life-threatening conditions are seen under unusual circumstances. Since disaster is not an everyday event, there is limited practical experience. Cost to conduct mass casualty exercises is prohibitive. Standardised patients/care actors have been generally used for disaster simulation to assess individual readiness with respect to equipment, medications and procedures, team readiness in rapid response teams, and organisational readiness in case of a natural disaster or bioterrorism. The large scale use of computer-based or even hybrid simulators has not been explored for training in civilian disaster management unlike military trauma management where high-fidelity computer-based simulation can replicate combat-specific wounds and battlefield environmental stressors.^{3,6} The newer version of the human patient simulator has come with biological warfare simulations which have been upgraded to be in one with the Armed Forces.

EXPERIENCE IN THE ARMED FORCES

The Armed Forces has extensive experience. Two high-fidelity simulators with physiologic (non-static) programming (HPS, Medical Technology Inc.) are with the Department of Anaesthesiology and Critical Care while most departments have a number of low- and medium-fidelity simulators. Simulation-based medical education is incorporated into both the under- and post-graduate medical curriculum with a weekly two hours time slot and 4–6 two hours time slot in continuing medical education courses. However, the time allotted was felt to be dismally short by the participants, even though efforts are made to ensure repetitive practice.

Over a six months period, 230 7th and 9th term medical undergraduates were scheduled to attend a two-hour HPS-based training-program following an initial period of familiarization with the simulator and equipment. In the programme, students were first given a didactic lecture about one of the three scenarios, namely myocardial infarction, shock, and trauma with pneumothorax where cognitive or knowledge-based aspects including review of current evidence-based management, review of anatomy, indications, contraindications, complications of any procedure required were taught by a variety of non-simulation-based teaching modalities (black-board or computer presentations).

Students worked in teams of five each with each team completing the same scenario twice (baseline and repeat). The baseline scenario (15–20 minutes duration) tested entry-level skills. The first 10-minute period of each scenario was

standardised and scripted to allow consistent scoring and comparison between baseline and repeat performances. After the initial test-period, if required, the coordinator offered suggestions to students to direct them towards appropriate management. This was to ensure that correct treatment was eventually given, the ‘patient’ survived and the simulation experience was positive for the students.

Peer-assessment of each team was accompanied by a facilitated discussion during which the coordinator guided the students to develop a systematic approach to the medical situation. Students were subjected to a questionnaire at the end seeking their views on learning processes in simulation and use of simulation in their assessment.

Students rated the programme highly and found it a valuable learning experience. In all, 193 (83.9%) students identified improved communication skills and teamwork skills as key learning points; 190 (82.6%) felt they had learnt how to approach a problem better, particularly in terms of using a systematic approach, and 175 (76%) felt they had learnt how to apply their theoretical knowledge in a clinical setting better. Around 212 students were positive about the use of simulation in their training, 204 students wrote that simulation should be used more or should be mandatory in training 205 students commented positively on the realism of the learning experience, and 197 students said they valued the opportunity to learn new skills in a safe environment.

The drawback felt was that only a few medical procedures could be taught on the HPS, (e.g. thoracentesis, intubation, paracentesis) but this is offset with the range in task difficulty available. Twenty-one postgraduate students in Anaesthesiology and Critical Care, six months into training, were subjected to practice sessions in anaesthesia in difficult intubation ranging from ‘external manipulation’ situation to a ‘can’t-intubate–can’t-ventilate’ situation. The teaching room was made akin to an OT but complete mimicking in the form of dress change, donning of sterile apparel was not possible. Eighteen scenarios lead to critical incidents. Levels of immersion and stress of the student as the scenario progressed were observed by peers in the form of facial expression, change in voice tenor while giving directions, hyperactivity, sweating, and hyperventilation. Most (90.4%) students started out without the same level of stress faced in real-life situations. Immersion was maximum within three minutes into the scenario. Signs of stress appeared in all students which increased to that felt in real-life situations in 20 scenarios (95.2%). In a post-scenario questionnaire, most students opined that a feeling of vulnerability due to peer-review led to greater anxiety before the procedure but it enhanced the performance. All students later admitted that their initial worries had been groundless.

Part-task simulators are available for procedures like cardiopulmonary resuscitation (CPR), peripheral and central catheterisation, tracheostomy, laparoscopy, and lumbar puncture. Simulation covers the primary technical aspects of the procedure: use of equipment, review of anatomy, sterile techniques, troubleshooting techniques, and demonstration of technique by instructors. About 132 doctors ranging from Medical

Officers to super specialists in three batches, all with 10–12 years working experience, in different specialties were taught the new CPR guidelines in two groups, one through didactic lectures and the other on different part-task simulators. Both groups were subjected to a questionnaire and demonstration after two days. It was seen that a careful approach was followed by slightly more participants whilst appreciably more remembered to shout for help (44% vs 71%) after working on part-task simulators. A clear advantage was also seen with simulators training in terms of those who opened the airway as taught (35% vs 56%), for checking breathing (66% vs 88%), and for mentioning the need to phone for an ambulance (21% vs 32%). Little difference was observed in correct or acceptable hand position between the didactic group and the simulator group. The biggest differences related to the number of compressions given. The mean delay to first compression was 63 and 34 seconds, and the mean duration of pauses between compressions was 16 seconds and nine seconds, respectively. Average performed rates were similar in the two groups, but more in the didactic group compressed too slowly whereas more in the simulator group compressed too rapidly.

The commonly cited barriers to the implementation of SBME include realism of simulators, cost, time allotted and availability of resources. The initial and recurring cost of maintenance and procurement of disposable parts in the all the simulators including HPS is high as is the high-cost of creating and maintaining a simulator environment. Also, incorporating a two hours time slot of SBME in an already burdened under- and postgraduate medical curriculum as well as in continuing medical education courses is difficult. Another limitation is the resource personals. A dedicated and exclusive team is not always available. An instructor to learner ratio of 1:3–4 is ideal which is not feasible in the current medical curriculum where each session consists of a batch of 10–15 medical students. Even with low ratios, early implementation of simulation-based procedural curriculum on real patients is necessary which is not always possible.

CONCLUSION

Learning while making errors serves as a nidus for critical thinking and questioning regarding the multiple aspects and components of SBME. These questions, in turn, will lead to empirical research that will provide feedback concerning changes that may be necessary to attain the goal of improving professional performance. Based on such research, SBME can be held accountable for its outcomes, i.e. whether its educational techniques indeed result in decreased occurrence of errors or not, and whether the ability to cope with the errors that do occur is significantly improved. Whether improved performance would result from didactic lectures given before simulation exercises and whether simulation education and assessment could help practitioners mitigate legal risks are debatable topics.

To be an effective education tool, simulation integration can be achieved through an interdisciplinary approach, appointment

of a program director, allocation of capital equipment, a dedicated budget and office space. Factors easing integration of simulation use include using peer-reviewed cases with tailored learning objectives and the relocation of tutorial sessions and lectures to simulation labs. There is also a need to define a newly emerging profession—SBME educator.

CONFLICTS OF INTEREST

None identified.

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