Simulators and simulation-based medical education

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Introduction

Medical simulators are educational tools that fall into the broad context of simulation-based medical education (SBME). SBME in its widest sense should be defined as any educational activity that utilises simulative aids in order to enable medical educators to enhance the educational message by simulating the clinical scenario.

Simulation devices serve as an alternative to the real patient and permit educators to gain full control of a pre-selected clinical scene without the risk of distressing patients or encountering other harmful aspects of learning on real patients. It must be stressed that SMBE is not an alternative to bedside teaching but rather a valuable, complementary addition.

This chapter will describe the simulation modalities that are presently available for medical education and discuss the driving forces of SBME and the rationale behind the utilisation of simulators in medical education. Furthermore, it will review the different applications of SBME and the various educational environments and delivery models of SBME. The chapter will conclude with a discussion of the challenges the field presents to medical teachers.

SBME modalities

SBME consists of two main families, low-tech and high-tech simulation modalities.

Low-tech simulation modalities

These are characterised by tools which are not computer-driven and serve as models for various educational purposes. This family represents traditional simulation tools that have been in use in medical education for many years.

☛ Use low-tech simulation models for basic clinical skills training

Simple three dimensional organ models

Heart and lung models, for example, serve educators in anatomy classes.

Basic plastic manikin and simple skills trainers

A wide variety of simple skills trainers and manikins are available for learning life-saving manoeuvres such as basic and advanced life support (BLS and ALS). These include dummies (e.g. 'Ressusi Anni') which enable simulation of BLS procedures, and more advanced models for endotracheal intubation, defibrillation and more.

Simple simulators are also available for teaching intimate (and embarrassing) physical examination manoeuvres (such as rectal, vaginal and breast examinations) and for several invasive and noninvasive clinical procedures, such as delivery, wound suturing, insertion of bladder catheters or vascular lines, etc.

Animal models

These may be either live models or isolated animal organ models. For example, live animals are utilised in physiology classes or in advanced trauma life support (ATLS) procedural training in tracheostomy and chest tube insertion. Isolated animal gut may be utilised for surgical training in procedures such as bowel anastomoses.

Human cadavers

These are the most realistic simulation of the human body, although without live response, physiology and pathology. Cadavers mostly serve in anatomy and pathology classes.

Simulated or standardised patients

These individuals represent the ultimate alternative to live patients. They may be volunteers or actors who are trained in standardised role-play of different psychological and physiological aspects of patients, for the purpose of structured training and assessment of clinical skills such as history taking, physical examination and communication (see Ch. 29).

High-tech simulation modalities

Such modalities are characterised by models operated by computers, utilising advanced hardware and software technologies to enhance the realism of the simulation experience and to increase the anatomical and physiological validity of the training tools.

Screen-based simulators

These are computer-based software based on the personal computer (PC); these simulators reflect sophisticated advances in technology and the software includes multimedia and virtual reality components. Screen-based software is readily available today in almost any clinical or basic science domain in medicine and plays a central role in medical education. The screen-based simulators range from simple noninteractive computer programs to advanced fully interactive teaching medical software. These programs enhance cognitive knowledge, clinical reasoning and decision making.

An example of such simulation application is the field of anatomy, where many medical schools have replaced cadaver-based anatomy classes (traditional simulation) with advanced screen-based simulation software. Another example of clinical application of screen-based simulation is the comprehensive multimedia curriculum in cardiology that integrates auditory and visual clues in order to simulate a comprehensive program for medical students.

Realistic, high-fidelity procedural simulators (task trainers)

A new generation of state-of-the art computer-driven realistic simulation devices has expanded the armamentarium of tasks and procedures that can be applied for education, training, assessment and research. These tools, mounted on powerful software, invest static models with advanced audiovisual and tactile interactive cues and create a simulated 'cockpit' for procedural and diagnostic tasks in multiple clinical domains such as radiology (ultrasound simulator), clinical cardiology (auscultation simulator) and invasive cardiology (catheterisation or pacemaker insertion simulators). Also available are endoscopy simulators in the fields of gastroenterology, urology, pulmonology, gynaecology, ENT, orthopaedics, and so on, as well as several minimally invasive surgery simulators for procedures such as cholecystectomy, hernia repair, arthroscopic surgery, etc.

Important common features that characterise this family of simulators include the following.

- Advanced endoscopic and surgical training simulators offer learning experiences in a near-authentic environment, catering for all levels of training from the novice to the expert
- An extensive library covering a broad spectrum of diseases and scenarios is available online
- Post-procedure debriefing and performance assessment are valuable additions to the inherent learning process.

Realistic high-tech interactive patient simulators

Computerised, realistic patient simulators (RPSs) were first introduced in 1966 by Abrahamson for anaesthesia training. Two decades later Gaba and Gravenstein independently led the way in the development of RPSs as we know them today.

> Lifelike, realistic, hi-tech patient simulators simulate multiple clinical conditions and situations that are fully designed and controlled by the medical educator: their applications include individual and team training as well as integration with other simulative methods

RPSs are advanced in the number and detail of their features and in the wide range of programs and trainee types they support. Common features include a realistic, full-size manikin, a computer workstation, and interface devices that actuate manikin signs and drive actual monitors.

RPSs have eyes responsive to light, an anatomically correct, dynamic airway, patient voice, arm movement, heart and breath sounds, and exhalation of carbon dioxide. Additional features include chest-tube insertion capacity, monitoring of neuromuscular transmission and provision of dynamic physical cues mimicking extremity compartment syndrome. Physiological computer models of ventilation, gas exchange, and cardiopulmonary function react, like patients, to drugs and fluids. RPSs may be controlled via direct or wireless means, as well as 'at the bedside'. Patients can be 'designed' on the computer interface using many variables such as weight, blood volume, and indices of heart function.

RPSs have been installed in a variety of flexibly staged, low- to high-fidelity immersive clinical environments (emergency room, intensive care unit, office-based setting, operating room) limited only by imagination, resources and training objectives.

To enable team simulations, RPSs have been integrated with standardised patients, simple simulator tools, and complex task trainers to create actual environmental microsystems.

The aim is to accustom trainees to cope with ambiguity, time pressure, changing workload, interpersonal issues, and to foster adaptability in problem solving. Myriad RPSs have gone into use worldwide since their inception in 1994.

Virtual reality (VR)

The trend in VR is for maturing technologies to be first combined in hybrid approaches with simulation methods, moving to completely digitally represented worlds. The Virtual Human Project (Oak Ridge National Laboratory) is expected to create the human simulation environment of the 21st century – an integrated system of biological and biophysical models, data and computational algorithms, supported by advanced computational platforms.

> Virtual reality (VR) has been defined as 'a system that enables one or more users to move and react in a computer-simulated environment' – Encarta Online Encyclopedia 2000

The progress in VR technology models will eventually enable the creation of 'customised simulation environments' where medical data (derived from MRI or from other imaging modalities) from a particular patient could be downloaded into VR simulation platforms, so that physicians could practise on the virtual patient before actually operating on the real one. Such simulation is expected to have both clinical and educational applications that will radically change the face of medical training.

Driving forces of medical simulation

SBME is now recognised as an increasingly powerful complementary teaching methodology in the medical profession. It is driven by a combination of the following forces:

- *The patient safety movement* – is the most powerful driving force behind the demand to find means that will increase the competence of health professionals and reduce the grave phenomena of medical errors.
- *Objective structured clinical examinations (OSCEs)* are a development that have been strongly endorsed by accreditation bodies and professional boards worldwide. Many of these bodies have already introduced simulated-patient based exams into their formal certification requirements, recognising the unique advantages of simulated environments for evaluation purposes.
- *Patient rights movements and patient ethics issues* have contributed to the growing recognition that medical education should optimise the use of simulation-based education prior to jeopardising patients or even discomfiting them.
- *Animal rights movements* have a stronger voice these days as they demand lesser use of animals for procedural training purposes. The American College of Surgeons (ACS) has recently acquiesced to certain of these demands.
- *Risk management and the medicolegal atmosphere* demand accountability and high safety and quality standards even in a training environment.
- *Economic forces* reduce patient accessibility and decrease the training opportunities in traditional medical education.
- *The simulation industry* is responding to the growing demand for incorporating new technologies and providing educators with more (virtually) realistic, high-fidelity training devices than before.

Benefits and rationale of medical simulation

The rationale for incorporating simulation into medical education lies on solid educational and social grounds:

- Medical simulation is a safe environment where trainees can learn from their errors without the risk of harming a real patient. The very notion that SBME is 'mistake-forgiving' provides educators with a unique opportunity to take advantage of the fact that such mistakes have the potential to be very powerful educational tools in saving human lives.
- Simulation offers a trainee-centred environment that can provide full attention to his or her individual needs, pace, strengths and deficiencies. It enables controlled, proactive clinical exposure of trainees to gradually more complex clinical challenges, including the more uncommon, life-threatening 'nightmare' scenarios.
- Simulation is a 'hands-on' (experiential learning) educational modality, acknowledged by adult learning theories to be more effective.
- Simulation provides unique opportunities for team training; this is seldom addressed in traditional medical education, and lack of such training is increasingly recognised as a major factor in system errors and safety failures in medicine.
- SBME provides a reproducible, standardised, objective setting for both formative assessment, that includes debriefing and feedback, and summative assessment, via testing.
- Simulation provides a unique opportunity to expose trainees to the concept and experience of debriefing – an inherent component in every SBME program; an important value message to convey to all trainees is that debriefing should become a norm in everyday medical practice.

- SBME can assist in increasing public trust in a medical profession that has been increasingly accused in recent years of being weak and deficient in its safety practices and culture.

SBME applications

SBME by its very nature is suited for multiple educational applications with almost unlimited potential as computer knowhow expands.

- Most experiences involve 'hands-on' skill training that can be basic or advanced and serve for clinical training or as a means to enhance cognitive knowledge.
- SBME is destined to serve as a superior continuing medical education (CME) platform, which will provide experienced health professionals with an opportunity to be introduced to new devices and clinical procedures or hone their skills, in today's rapidly changing medical and technological environment.
- Simulation allows for focused exploration of areas of deficiencies in competencies and skills of health professionals, as well as providing a powerful interventional tool to enhance skills of those identified as needing such training.
- SBME can be set up to introduce medical devices and technologies to the health profession in a structured and safe manner.
- Patient safety applications focus on error reduction and may include teamwork and system training, quality assurance and risk management models and issues regarding malpractice insurance.
- SBME provides the medical industry with an opportunity for safe and valid research and development where human factors and the human–machine interface can be explored.
- The ultimate application for SBME may relate to licensing and certification; when this is endorsed as a standard for medical education, it will signal maturity of the health profession and its acknowledgement of a safety culture as appropriate to the high-risk and high-stakes medical field.

Simulation-based teaching environments

Simulative teaching can take place in a broad range of set ups, ranging from traditional classrooms, clinical departments and home PCs to ultra-advanced multimodality/multidisciplinary medical simulation centres. The multimodality and multi-application nature of simulation-based training challenges medical educators to select the appropriate simulation modality and the optimal environment for each educational task.

> Simulation-based training can take place in a wide range of teaching environments. Adjust the appropriate simulation modality to your educational goals

Traditional environments

Classrooms can host SBME as part of a clinical demonstration, utilising a task-oriented simulator or a simulated patient. Similarly, simulators can be placed within clinical departments where they are accessible to residents and students who may practise different clinical tasks in their own free time, or at fixed times.

Clinical skills laboratories

These have evolved as a common site of simulation-based training. They differ from the more comprehensive multimodality, multidisciplinary model in that they usually focus on a single simulation modality and serve a single profession or a narrow professional branch. Although these centres seldom gain an extensive expertise in the full range of simulation modalities, they achieve an in-depth expertise in their specific educational field.

Multimodality/multidisciplinary medical simulation centre

This new paradigm of simulation centres is based on unique multidisciplinary and interdisciplinary principles. The centre serves all branches of the medical profession (horizontal integration) and is capable of providing superior cross-professional training (teamwork). Furthermore a centre of this kind incorporates simulation-based education at all training levels (vertical integration), from undergraduate studies, through residency training and into CME levels.

The centre simulates multiple clinical environments, utilising a variety of simulation modalities, depending on the features of the experiences required. Simulated emergency rooms and operating rooms with sophisticated manikins, and clinics with standardised patients are examples of near-authentic environments. These simulated environments mostly serve in scenario-based training and entail extensive pre-scheduling of logistical and educational support.

This model, the ultimate platform for SBME, if initiated and implemented in a centralised (regional, or national) manner is envisioned to have great potential to induce change in the training and safety culture, while improving cost-effectiveness and utilisation rate. A centre of this kind is functioning with great success in Israel as a National Medical Simulation Center and fulfilling its potential.

Unique challenges and strategies related to SBME

SBME presents challenges for medical educators on many fronts.

Medical and safety culture

Overcoming resistance to change

Medicine is a conservative field that has been based for generations on apprentice methods. When the culture of training is changed by the introduction of proactive SBME, resistance from both conservative educators and trainees is encountered.

Creating a constructive atmosphere

For trainees to appreciate the advantage of learning by means of and from mistakes, it is essential to create an environment that will feel safe, and to carefully plan experiences that will be constructive. A well-designed curriculum should convey and stress the importance of patient safety and error reduction.

Educational

Recognising limitations of SBME

Teachers need to be fully aware of the limits of SBME and that it is complementary to hands-on training on real patients.

Selective use

One of the most challenging demands upon medical educators is to match the appropriate simulation modality to the correct educational goal for a specific target population.

> Select simulation modalities best suited for the educational goal and target population

Simulators should be used selectively, with attention paid to cost-effectiveness. Many important procedures for beginners may be learnt using simple inexpensive manikins, whereas experts often need high-cost cutting-edge equipment.

Combine simulation modalities

Medical educators should strive to develop expertise in multisimulation scenarios and combine simulation modalities to enhance the realism and effectiveness of the training experience.

Incorporating SBME into the formal curriculum

A crucial aspect of the acceptance of SBME as a legitimate and valuable teaching tool is the incorporation of SBME programmes into health professional schools and CME curricula.

Faculty development

Train the trainer

SBME faculty should be trained as SBME trainers and raters, through instructors' courses and raters' workshops, as a prerequisite to their participation in SBME programmes. They should develop expertise in testing and evaluation of clinical competencies, performances and human characteristics.

> Trainers' courses should develop educators' expertise in multiple relevant domains. Developing and applying innovative testing and evaluation tools will raise medical education standards

Debriefing

As debriefing is a key element in SBME, faculty should also gain expertise in audiovisually based transparent debriefing. Teachers should also convey the value message of debriefing as a take-home skill for the trainees to be implemented in real-life practice.

Expertise in testing and evaluation

It is essential that educators using SBME gain basic knowledge and understanding in assessment principles and methods, both formative and summative. Furthermore, it is important for medical educators to join forces with national and international psychometric bodies in order to increase their understanding of the assessment domain, jointly develop new assessment tools and ultimately enhance educators' power to penetrate the certification field (in the spirit of 'assessment drives education').

Research and development

SBME is a rich environment for research in medical education and assessment.

Validation

Teachers of SBME are challenged to provide evidence beyond face value of its effectiveness, in the spirit of the BEME initiative (Best Evidence Medical Education), by pursuing studies that will explore validity aspects, such as the predictive values and transferability and sustainability of skills acquired through SBME.

Performance measures

Educators need to develop and validate measures of performance of health professionals as the key for meaningful formative and summative assessment. New sets of skills must be developed, taught and then tested in parallel with the inevitable expansion of SBME.

Curriculum-driven research and development

Medical educators should take the lead in driving the simulation industry to meet curricular needs, rather than vice versa.

Delivery models of SBME

Cost-effectiveness and educational justifications are major driving forces behind the emerging multidisciplinary/multimodality training centre model. These revolutionary facilities raise a few more considerations.

Multidisciplinary educational and support staff

These are a basic requirement of an effective SBME environment. Dedicated, multidisciplinary staff with educational and clinical expertise across a wide spectrum of health professions, as well as experts in human behaviour, performance measurement and curriculum development, must be thoughtfully recruited. In addition, support staff with expertise in logistics, audiovisual and simulation technology, biomedical engineering, business development, accounting and so on must be mobilised.

Sustainable business model

The high visible short-term costs of simulators and simulation centres, as well as the heavy dependency on educational and support staff, demand that medical educators create a sustainable business model for SBME. Furthermore, evidence must be presented to confirm SBME's significant long-term cost benefits, including safety outcomes in terms of patient mortality and morbidity and medicolegal consequences.

Endorsement by regulators

Medical educators should involve regulators at different levels and in the early stages of SBME programmes, aiming towards eventual acceptance of this modality as a routine and obligatory component of medical education and certification.

Summary

SBME is gaining a central role in medical education, a trend that is expected to expand as social, educational, regulatory and technological changes proceed.

Ongoing technological progress in the simulation and virtual reality industries continuously allows for new cutting-edge simulators to become available, with higher fidelity and at lower cost. Customised simulation models will enable health professionals to practise on simulators tailored to data from individual patients. The delivery models of SBME will refine and emphasise the more cost-effective models such as those serving multidisciplinary/multimodality regional centres.

SBME will become an integral part of the medical curriculum, across all medical professions and throughout medical careers. It will be incorporated as the leading standardised performance assessment method of health professionals' competencies. Regulators at all levels will endorse SBME as an integral part of individual and institutional certification, licensing and malpractice insurance. Finally, safety, ethical and social considerations will continue to force a major culture change in the way medicine is taught and practised. As this process is irreversible and just, medical educators must endorse it proactively rather than react to external forces.

Further reading

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Useful links

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