Patient simulation for training basic and advanced clinical skills

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Introduction Patient simulators are increasingly used in the education and training of healthcare professionals. This paper describes the history of human patient simulator development, the features of contemporary simulators, the acquisition of basic and advanced clinical skills using patient simulators, and the benefits, cost, limitations and effectiveness of this innovative learning modality.

Simulator development The development of human patient simulators began in the late 1960s, and accelerated in the late 1980s and early 1990s. Several simulator systems are now professionally manufactured, commercially available, and used at hundreds of medical centres, universities and colleges in the USA and throughout the world. Contemporary patient simulators have many clinical features, and look and respond to interventions with ever-increasing degrees of realism because sophisticated physiological and pharmacological models automatically control many features.

Simulator use in medical education Simulators are used to teach basic skills, such as respiratory physiology and cardiovascular haemodynamics, and advanced clinical skills, e.g. management of difficult airways, tension pneumothorax, pulmonary embolism and shock.

Benefits, costs and limitations The simulation laboratory offers distinct educational advantages, especially for learning how to recognise and to treat rare, complex, clinical problems. Costs of simulator-based educational programmes include facility, equipment and personnel. Current limitations include clinical realism of the patient manikin and faculty development.

Keywords education, medical, undergraduate/ *methods; *patient simulation; curriculum; clinical competence/*standards/economics; costs and cost analysis.

Medical Education 2003;37(Suppl. 1):14–21

Introduction

Patient simulators are increasingly used in the education and training of physicians, nurses, emergency care personnel and many other healthcare professionals. Learners can effectively acquire both basic and advanced clinical skills using patient simulation. This review first briefly describes the recent development of patient simulators and their initial educational applications. Next, the typical clinical features to be found in modern-day patient simulators are described. The review then provides several examples of both basic and advanced clinical skills that are being learned using patient simulators, and concludes by discussing the benefits, costs, limitations and effectiveness of this innovative learning modality.

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Sim One[1,2]

In the late 1960s, Abrahamson, Denson and colleagues at the University of Southern California developed a patient stimulator referred to as Sim One. Their original patient simulator had a heartbeat synchronised with temporal and carotid artery pulsations, a measurable blood pressure and spontaneous breathing. The eyes and mouth opened and closed, and through computer program control, the simulator responded to several intravenous anaesthetic medications and to inhaled oxygen and nitrous oxide. Sim One was used educationally to help first-year anaesthesia residents learn the basic skill of intravenously inducing general anaesthesia and performing endotracheal intubation. Although the number of study subjects was small, Abrahamson found that residents trained using the simulator achieved proficiency with fewer trials and in less time than residents who learned exclusively in the operating room.[2]

Key learning points

Learners can acquire both basic and advanced clinical skills using patient simulation.

Today, human patient simulators are used by one-third of all medical schools in the USA, and at hundreds of medical centres, universities and colleges throughout the world.

Patient simulators have a unique role to play in helping students, postgraduates and practising clinicians learn to recognise and treat infrequently occurring and often highly complex clinical problems.

Abrahamson proposed several noteworthy advantages of learning clinical skills with a patient simulator, advantages that persist today. These included: (1) planned and gradual increase in the difficulty of problems to be solved (instead of performing new tasks as the necessity for them arises in the clinical care setting), (2) unlimited repetition, (3) immediate feedback, and (4) learners proceed at their own pace.[2]

GAS and CASE

In the mid-1980s, teams of anaesthesiologists and engineers at the University of Florida and at Stanford University began simulator development efforts at their respective institutions. The team at Florida created the Gainesville Anaesthesia Simulator (GAS), and sought to help first-year anaesthesia residents acquire basic anaesthesia skills more rapidly, as well as to allow more senior anaesthesia residents to practise detecting and correcting rare and complex failures within the anaesthesia gas delivery equipment.[3] The team at Stanford created the Comprehensive Anesthesia Simulation Environment (CASE)[4] and used their system to develop and implement an educational curriculum entitled Anesthesia Crisis Resource Management (ACRM).[5,6] Throughout the late 1980s and early 1990s, both groups significantly enhanced their patient simulators with successive refinements, including simulating additional clinical features and developing additional educational applications. Several patient simulators were also developed in Europe.[7,8] The Florida and Stanford groups eventually transferred their technology to corporations that manufactured the patient simulator systems professionally, and made them available for purchase to other educational institutions.[9,10] Today, human patient simulators are used by one-third of all medical schools in the USA, and at hundreds of medical centres, universities and colleges throughout the world.[11]

Features of contemporary acute care patient simulators

Modern-day patient simulators look and respond to interventions with ever-increasing degrees of realism. Medical manikins are used to physically represent the patient. Most simulators use a complete manikin that includes head, neck, trunk, pelvis and limbs, though a few use only an airway intubation manikin comprising head, neck and upper thorax. Many clinical features are embedded. Pulses are palpable over the carotid and radial arteries. Speakers broadcast heart and lung sounds over appropriate areas of the chest that can be heard with a correctly placed stethoscope. Normal and abnormal sounds can be selected manually by instructors, or automatically in pre-programmed clinical scenarios. Pulses and heart tones are synchronised with the electrocardiogram, and breath sounds are synchronised with the rise and fall of the chest during each respiratory cycle.

The airway of the manikin connects to a lung model, some of which are quite sophisticated, enabling the simulated patient to breath spontaneously, receive assisted and controlled mechanical ventilation through a face mask or endotracheal tube, and to consume oxygen, exhale carbon dioxide and take up or exhale anaesthetic gases. The incorporation of such a high fidelity lung model allows the simulated patient to be connected to sophisticated respiratory equipment such as mechanical ventilation systems, spirometers, manometers and gas analysers in a realistic manner and with realistic measurements obtained. Similarly, electromechanical and electro-optical actuators allow standard electrocardiographs, non-invasive blood pressure monitors, and pulse oximeters to be connected to the patient simulator with realistic measurements reported on the corresponding data displays.

Human patient simulators have many critical care, airway rescue, cardiac and trauma resuscitation features. Invasive arterial, central venous and pulmonary artery (PA) pressure waveforms can be transmitted to and displayed on a standard physiological monitor. Under instructor control, the PA catheter can be advanced successively through the superior vena cava, right atrium, right ventricle, pulmonary artery, and into the pulmonary artery occlusion or 'wedge' position, with appropriate waveforms demonstrated at each position, including the real-time influences and changes associated with each cardiac and respiratory cycle.

A measurement of cardiac output can also be obtained by simulating the thermodilution technique. The neck of the simulator manikin permits transtracheal needle, catheter or tube placement, enabling transtracheal jet ventilation and emergency cricothyrotomy to be practised. Electrical posts mounted on the chest of the manikin enable electrical cardioversion and defibrillation to be performed using standard hospital equipment. If tension pneumothorax is suspected, needles can be introduced into the second intercostal space at the mid-clavicular line; if the diagnosis is correct, gas under pressure rushes from the needle as the pneumothorax decompresses. Related technology enables a needle appropriately advanced at the left xiphochondral junction to aspirate pericardial fluid and blood. Standard chest tubes can be placed through small slits in the lateral chest wall along the mid-axillary line. When the simulator's actuator system is charged with air, fluid or blood, these substances empty through the chest tube into the collection system.

The patient simulator is 'brought to life' to achieve tremendous realism because of sophisticated physiological and pharmacological models that automatically control the majority of its features.[12,13] High-fidelity patient simulators integrate multiple models, which may include both mathematical and mechanical models, to determine automatically and in real-time the parameters and variables that define circulation, ventilation, gas uptake and the distribution, pharmacodynamics and physiological controls of a human being. The models interact with one another and with the electrical, mechanical and physiochemical sensors in the patient manikin to create realistic patient conditions and realistic responses to therapy and other interventions. For example, when intravenous morphine is injected into the patient simulator, the respiratory rate slows, and if the dose is sufficient, the blood pressure may also decrease. If the resulting hypoventilation is severe, and depending on the concurrent concentration of inspired oxygen, arterial hypoxemia may register on the pulse oximeter. In addition to these clinical changes, computer display screens can simultaneously and graphically show the dynamically changing blood and effector site compartment concentrations of the injected drug,[14] a capability not possible with real patients.

Patient simulator technology is evolving rapidly. Issenberg and co-authors[15] reviewed selected simulator technology for health care professionals, specifically laparoscopic, cardiovascular, multimedia and anaesthesia simulation systems, and, after drawing comparison with music and sports, which share the requirement for 'deliberate practice', commented that these simulation systems should help to address poor skills training and proficiency among health care professionals. Kneebone[16] described a number of simulators for use in surgical training. These included: (1) precision placement simulators such as those used to learn intravenous needle insertion or lumbar puncture, (2) simple manipulation simulators, which allowed practice in manipulating an instrument in response to a visual display, for example, endoscope and bronchoscope, (3) complex manipulation simulators such as those used to learn laparoscopic surgical techniques, and (4) integrated procedure simulators with extensive features as described above.

Both clinical features and the engineering aspects of human patient simulators are continually improving. Paediatric patient simulators are already available commercially.[17] Simulator control hardware has become increasingly robust and compact, allowing the development of portable simulators that can be used to train and assess in the out-of-hospital setting. A notable example is the Mobile Human Patient Simulator Program of the Shock Trauma Air Rescue Society (STARS) in Alberta, Canada.[18] This organisation was the first to make the patient simulator technology and expert instruction mobile, travelling to rural communities to provide critical care skills training in a simulated emergency room environment. Senior Medical Director Michael J. Betzner, MD, explains:[19] 'Our current focus includes physicians, nurses, paramedics, and emergency technicians. In the rural setting, it is very difficult for these providers to get away as a team for medical training. Hence, we take the training on the road to them.'

Learning basic skills

Medical students at my institution learn using the human patient simulator at several points during their curriculum. For example, first-year medical students learn respiratory physiology in the simulation laboratory.[20,21] Groups of 20 students attend a 2-hour hands-on workshop that consists of 5 clinical scenarios lasting 20 minutes each. The clinical scenarios include a medication error causing accidental neuromuscular blockade, opioid-induced hypoventilation, congestive heart failure with pulmonary oedema, spontaneous pneumothorax and hypercarbia caused by increased equipment dead-space. The learning objectives for these sessions include gaining an understanding of the basic concepts of respiration (such as tidal volume, minute ventilation, dead space ventilation, shunt fraction, alveolar gas concentrations, alveolar ventilation, hyperventilation and respiratory quotient); exposure to clinical decision making; introduction to the use of physiological monitoring instruments in clinical decision making, and familiarity with clinical equipment and procedures used in clinical practice. Students rate the workshop 4·7 on a 1 = low to 5 = high scale, scores that are consistently among the highest of all course evaluations throughout this medical school. Comments included 'learned a lot', 'liked hands-on approach better than traditional lecture', 'more workshops should be done with the HPS.' The students' self assessment of their ability to understand and to apply important respiratory physiology concepts in the clinical setting increased significantly when compared with a pre-workshop assessment.[21]

Similarly, third- and fourth-year medical students learn cardiovascular haemodynamics in the simulator laboratory, which replaces teaching exercises previously demonstrated using live animal experimentation.[22,23] Learning objectives for the simulator-based haemodynamic monitoring laboratory include the application of non-invasive monitors, evaluation of vital signs, insertion of peripheral and pulmonary arterial catheters, measurement of cardiac output and pulmonary artery occlusion pressure (PAOP, or 'wedge'), and the calculation of a complete haemodynamic profile. The patient simulator is programmed with a simulated patient exhibiting hypotension and tachycardia. The students are unaware of the underlying cause, which is prospectively selected by the instructor. Possible diagnoses include hypovolaemia, congestive heart failure and septic shock. The students must assess the patient using non-invasive and invasive monitors, generate a differential diagnosis and initiate treatment. Specific actions required include the insertion of a pulmonary artery catheter and an identification of its various waveforms, performance of thermodilution cardiac output measurements, calculation of the haemodynamic profile and the administration of intravenous fluids and vasoactive medications. With appropriate therapy for the selected diagnosis, the condition of the simulated patient improves; with inappropriate therapy, the condition deteriorates further.

The response of medical students and medical educators to simulator-based learning has been assessed.[24] Third- and fourth-year medical students completing emergency medicine rotations at the University of Michigan were challenged with critically ill simulated patients. One was a trauma patient with hypovolaemic shock and a tension pneumothorax, and the other was a cardiac patient with marginally stable ventricular tachycardia. Medical educators participating in a physician educator conference at Harvard Medical School also evaluated a patient simulation system programmed with a simulated case of anaphylaxis. Following the simulation sessions, both groups completed a structured questionnaire and provided general written comments about the patient simulator and its educational utility. Eighty-five per cent of both students and educators rated the simulator sessions as excellent or very good. Written comments were very positive (e.g. 'practice without risk', 'promotes critical thinking', 'puts the student in the "hot seat"', 'excellent transition between observation as a student and caring for our own patients') with cost noted as the major current disadvantage.

Residency training programmes are increasingly using patient simulators to introduce first-year residents to clinical care in their specialty and to the procedures and equipment used in their hospital care environment. At the Pennsylvania State Hershey Medical Centre, both anaesthesiology and surgery residents begin their residencies in the simulation laboratory.[25,26] Patient simulators help to accelerate the acquisition of basic skills by novice anaesthesiology residents. In 1 early study, clinical evaluation scores after 3 weeks of training were higher for first-year anaesthesiology residents who had received 10 simulator sessions, compared to those who had participated in didactic sessions covering the same material.[27]

Learning advanced clinical skills

Patient simulators have a unique role to play in helping students, postgraduates and practising clinicians learn to recognise and treat infrequently occurring and often highly complex clinical problems. Examples of complex clinical problems that are typically pre-programmed into modern-day patient simulators include anaphylaxis, cardiopulmonary arrest, difficult airway management, tension pneumothorax, pulmonary embolism and cardiogenic, haemorrhagic and septic shock. Complex scenarios targeting anaesthesiologists and advanced anaesthesiology trainees that can be learned using patient simulation include malignant hyperthermia, contaminated oxygen supply, intravenous air embolism and vaporiser leaks and other malfunctions of the anaesthesia gas delivery system. Patients with significant underlying medical problems and those undergoing difficult surgical procedures can also be simulated in risk-free learning. Consider the patient with moderately severe coronary artery disease who requires the repair of an abdominal aortic aneurysm. During the induction of anaesthesia, if the trainee fails to control the simulated patient's heart rate and blood pressure, myocardial ischaemia will develop. Again, during clamping or unclamping of the aorta, the trainee must appropriately manage haemodynamics or myocardial ischaemia will similarly develop.

The simulation laboratory offers distinct advantages for the learning of how to recognise and to correct rare, complex clinical problems. These situations do not occur with sufficient frequency to allow training during actual patient care, and when they do occur, their severity and acuity demand immediate and full attention to patient care, not trainee education and experience. Consider this situation in anaesthesiology – assume that anaesthesiology residents typically performed approximately 2000 supervised anaesthetics during their training, and that during a career of anaesthesia practice, anaesthesiologists administer approximately 20 000–30 000 anaesthetics. Assume that the frequency of a specific critical incident to be once every 5000 anaesthetics. It is not difficult to conclude that statistically, most critical incidents will not be encountered during supervised training, but that they will be encountered several times during a career of independent anaesthesia practice. Thus, it is obvious that the patient simulator and the simulation laboratory are critically important for first learning and then repeatedly rehearsing the diagnosis and treatment of specific critical incidences.

Indeed, there is growing opinion that simulator-based learning can be life-saving for the real patient who experiences a life-threatening clinical situation while under the care of a simulator-trained clinician. In a newsletter article[28] entitled 'Simulation saves lives', Olympio described 5 cases in which he felt that previous training on a simulator improved patient care and perhaps saved lives. Two of these cases involved the recognition and decompression of a tension pneumothorax, 2 involved failed intubation after rapid sequence induction of general anaesthesia, with rescue accomplished using complex airway management strategies practised on the patient simulator, and the fifth was an oesophageal intubation in which the misplaced oesophageal tube was used for gastric suctioning as practised in the simulation laboratory.

Similar challenging and time-sensitive clinical problems confront clinicians in all areas of acute clinical care. Patient simulators are finding an ever-increasing number of educational applications for those who work in operating rooms, intensive care units, emergency departments, labour and delivery suites, gastroenterology and radiological procedure suites. Recently, human patient simulators have been used to help train anaesthesiologists to treat chemical warfare casualties.[29] In each of these environments, those needing to learn advanced clinical skills include students (medical, nursing, pharmacy, paramedic, therapy), residents and other postgraduates (anaesthesia, surgery, medicine, critical care), practitioners needing continuing medical education (physician, nurse, pharmacist, paramedic), corporate staff (administrators, biomedical engineers, sales representatives), medico-legal professionals (attorney, judge, jury) and community leaders (elected, visitors, dignitaries).

Benefits

Kneebone[16] proposed four key advantages of simulator-based learning. (1) The training agenda can be determined by the needs of the learner, not the patient. Learners can focus on whole procedures or specific components, practising these as often as necessary. (2) Because the environment is safe, learners have 'permission to fail' and to learn from such failure in a way that would be unthinkable in a clinical setting. This gives an opportunity to explore the limits of each technique rather than having to remain within the zone of clinical safety. (3) Simulators can provide objective evidence of performance, using their in-built tracking functions to map a learner's trajectory in detail. An increasing range of metrics are being developed and validated, offering potential for formative and summative assessment. (4) The capacity of simulators to provide immediate feedback in digital form offers a potential for collaborative as well as individual learning.

Related to these advantages is the opportunity for interactive, interdisciplinary health care team learning and team performance assessment. Health care professionals typically acquire individual skills within their own departments or colleges, training with other students and experts in their own profession. Yet caring for acutely ill patients requires many different health care professionals (e.g. physician, nurse, pharmacist, therapist, technician, assistant) to interact together in a coordinated manner with clearly defined roles, responsibilities and activities. Patient simulation provides a unique opportunity for the entire interdisciplinary health care team – both those with members who routinely work together such as trauma teams,[30] and those with members who do not routinely work together such as those responding to in-hospital cardiac arrests[31] – to learn together, and to practise important clinical, communication, leadership and interpersonal skills.

Another benefit of human patient simulation is the reduced use of live animal teaching laboratories and the practising of skills on recently deceased patients. Medical students and residents frequently voice objections when live animals are used for teaching purposes, for example, in learning pharmacology[32] or surgical techniques.[33] Nurses and paramedics raise objections to practising endotracheal intubation on the newly dead.[34] Modern day patient simulators programmed with sophisticated physiological and pharmacological models allow pharmacology lessons to be interactively learned without the use of live animals. A variety of surgical simulators and related task trainers[16] are beginning to offer surgical trainees a similar non-animal learning experience. Airway management skills are readily learned using a human patient simulator, which adds the clinical realism of dynamically changing heart rate, blood pressure, oxyhaemoglobin saturation and other vital signs no longer present in the deceased.

Moreover, patient simulators may offer beneficial ethical implications with respect to 'learning on patients', especially as it relates to new medical technologies. As Iserson & Chiasson[35] noted, 'The only ethical element involved in the use of new technologies over which individual medical practitioners have control, is that of user proficiency with the device, procedure, or drug, and the related information they provide to their patients when obtaining their consent for its use.' High-fidelity human patient simulators offer users of new medical technologies (including pharmaceuticals[14]) a mechanism to gain experience in using the new modality in a correct and safe manner.

Costs

Resources are required to establish and operate simulator-based educational programmes. These costs include facility, equipment and personnel. Kurrek & Devitt tallied and reported the initial start up and first-year operating costs for the Canadian Simulation Centre in the Sunnybrook Health Science Centre at the University of Toronto.[36] The Simulation Centre was created by converting three existing hospital rooms into a simulation room with adjacent control and storage areas, and two seminar rooms for debriefing and computer-based instruction. Construction costs (in 1996 Canadian Dollars) totalled $665 000, and included the simulator purchase ($250 000), operating room equipment ($250 000), room renovation and office equipment ($50 000), audio-visual equipment ($25 000), and oversight personnel ($90 000). First-year operating costs totalled $167 250 and included centre administration staff, simulator upgrades and maintenance, research staff and faculty instructors. Seventy per cent of the operating costs were for personnel. Kurrek & Devitt[36] noted that a large fraction of both the construction and operating costs were absorbed by third parties (e.g. hospital, Department of Anaesthesiology) or obtained through donations (e.g. corporate sponsors).

Limitations

While rating the overall simulator-based educational experience highly, learners frequently cite the 'clinical realism' of the patient manikin as an important limitation. For example, the simulator's skin colour does not change. This is a detractor in simulator-based training programmes for pre-hospital personnel who rely heavily on skin colour changes as a marker of successful interventions.[37] Ongoing simulator development and enhancements will work to ameliorate this and other limitations. One interesting approach to the enhancement of realism is the combined use of patient simulators and standardised patients (actors and actresses trained to portray patients with specific clinical symptoms and conditions). Greenberg and colleagues[38] described an innovative integrated learning experience using both learning modalities together. For example, a medical student on a surgical clerkship first encounters a standardised patient presenting for appendectomy, obtains a history and performs a physical examination. Next, the student proceeds to the patient simulator and participates in anaesthetic procedures. Following this, the student returns to the waiting room to discuss the surgery with a standardised patient representing the patient's spouse, and finally, examines a standardised patient presenting 2 weeks post-operatively with a fever. Developers note that the integration of patient simulators and standardised patients allows the student to 'follow a patient over time' whilst maintaining the maximum clinical realism of patient assessment and therapeutic interventions.

A potential limitation of patient simulator-based learning is the reticence of physicians and other health care professionals to participate in active training models. To date, however, physicians have volunteered readily and subsequently rated educational programmes which use patient simulation highly, including offerings in the academic setting[39] and at continuing medical education conferences.[40] Similar participation and acceptance has been reported from paramedics and emergency medical technicians.[37]

Faculty development must also be considered when implementing an educational curriculum using human patient simulation. For the instructor, helping trainees to learn with a patient simulator differs significantly as compared to preparing a traditional lecture or providing clinical instruction at the bedside. The simulated patients' physiological characteristics and the clinical scenarios to be used must be programmed into the simulator. While user-friendly graphical user interfaces make this task much easier than it once was, faculty that are going to 'teach with the simulator' must learn and hone new instructional skills and techniques. This point was illustrated by Euliano & Mahla who adapted traditional problem-based learning to the patient simulation environment.[41] They developed a learning exercise using a human patient simulator to help anaesthesiology residents learn the emergency management and differential diagnosis of acute intra-operative hypotension. Steps in the development process included a clear definition of learning objectives, preparation of an appropriate patient and case description, the development of clinically realistic scenarios to illustrate the learning objectives and an interactive instructor to stimulate discussion among the learners. Fine tuning the clinical scenario can be a very time-consuming task. Expert clinician reviewers can be used to help enhance the realism of the simulated patient and scenarios when conditions lack explicit treatment guidelines[30] or in which there is significant variation in patient response; however, in some instances, expert clinician reviewers may 'make virtually opposite recommendations'.[41] Recognising this need to develop faculty skills in simulator-based learning, many professional conferences have included special sessions on simulated patient and scenario development, or even entire conferences devoted to these topics. Simulator manufacturers also offer recurring educational programmes and often co-ordinate simulator user group meetings.

Effectiveness

Because of their cost and resource requirements, it is important that the learning effectiveness of human patient simulators be clearly demonstrated. Devitt and colleagues demonstrated the construct validity of a clinical performance evaluation technique using human patient simulation by showing an ability to discriminate the level of training in a large and diverse group of anaesthesiologists.[42] University anaesthesiologists, community anaesthesiologists, final-year anaesthesiology residents and medical students completed a 1·5 h simulation scenario that included a series of clinical problems such as hypotension, atelectasis, coronary ischaemia, pneumothorax, anaphylaxis, hypothermia and anuria. Each participant was scored using a structured rating system based on his or her ability to diagnose and correct the series of problems. University anaesthesiologists and anaesthesiology residents scored significantly higher than community anaesthesiologists and medical students, while community anaesthesiologists scored significantly higher than medical students. The authors concluded that these findings document the construct validity of a simulator-based evaluation process.

Summary

Human patient simulator technology has evolved rapidly over the past two decades. Contemporary patient simulators have numerous clinical features that can be controlled by instructors to create a structured learning environment, a clinically realistic setting in which learning can take precedence over patient care. Using patient simulators, medical students and residents can acquire basic clinical skills while more advanced students and health care professionals in practice can acquire, refine and rehearse advanced clinical skills, both individually and in teams. Ongoing experimentation will be required to optimise patient simulator-based educational curricula, and additional studies are needed to assess the effectiveness of patient simulators in achieving learning and performance assessment objectives.

Acknowledgements

The author thanks Dr Willem van Meurs for his help in reviewing this manuscript. A paper with the title 'Simulação de pacientes para treino de competências básicas e avançadas' and similar content to the present manuscript will be submitted to the Portuguese journal *Educação Médica*.

Conflict of Interest

Dr Good is co-inventor of the Human Patient Simulator. He receives royalties from the University of Florida and owns stock in Medical Education Technologies, Inc.

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Received 27 *March* 2003; *editorial comments to authors* 29 *May* 2003; *accepted for publication* 11 *August* 2003