
History of Anesthesia Simulation

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Simulation seems to be coming up everywhere in anesthesia today. It is part of training programs. Simulation-based objective structured clinical examination is part of American Board of Anesthesiology (ABA) board examinations. It is one possible component for completion of ABA Maintenance of Certification in Anesthesiology (MOCA). Where did this all come from and why is it being pushed as hard as it is?

■ Definitions

Simulation

The initial response of many people is to think of anesthesia simulation as a simulated clinical environment with a robotic mannequin, surrounded by clinical equipment (or simulated clinical equipment), a team of other learners, and an instructor who is running the show. I would like the reader to think more broadly and to say that simulation is “experiential learning,” that is, it is letting the participant not only think about an action but to actually put that action into practice. Using this approach, I would argue that any hands-on learning experience could be interpreted as simulation. Hence, doing an Advanced Cardiac Life Support (ACLS) class with the hands-on skills stations, an airway lab with mechanical heads as a new airway tool is introduced, a role-playing exercise in a course about managing the difficult patient, or performing ultrasound on volunteers or even peers as one hones ultrasound skills, all are simulation exercises.

Task Trainer

A task trainer is a simulator that is designed to help the learner learn a specific task. An example would be an airway trainer that is a head that

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he/she can ventilate with a bag and mask or perform laryngoscopy on. The learning objective is mastering a specific task rather than integrating it into a clinical situation. The task trainer is not meant to make an expert of someone; rather it is to let them master the fundamental skills necessary to carry out a clinical task. Again using the airway management example, the task trainer enables learners to familiarize themselves with holding and using airway management tools, visualizing normal anatomy, and work through the sequence of events associated with airway management. It does not let them work with variations of anatomy and airway management observed in clinical practice. A task trainer does not replace clinical exposure in training; rather, it lets the clinical exposure be more fruitful because the fundamental skills have been learned on the task trainer. The clinical exposure enables the learner to move from novice to master.

Immersive Trainer

The usual perception of a simulated clinical experience in a mock operating room (OR) or other clinical space, with a sophisticated mannequin and an entire team, is referred to as immersive simulation, mannequin-based training, or high-fidelity simulation. The goal is to reproduce the clinical space and have the learner manage a clinical problem, which would typically encompass recognition of a problem, formulation of hypothesis and generation of diagnosis, management of the clinical problem, and management of the team in the room. The learner needs to take in multiple clinical cues, and use the resources around him/her in a timely manner. In contrast to the task trainer, where he/she focuses simply on one task, in this case, the learner uses problem solving, clinical knowledge, and team management in addition to manual tasks. High-fidelity or immersive training tends to be resource heavy, with the need for a space, mannequin, clinical (or simulated) equipment, and personnel.

Role Playing

Role playing with simulated patient actors has been a part of medical school training for many years, particularly for communication and introduction to clinical examination courses. As the importance of communication between the physician and patient and between the physician and the rest of the team is being recognized as increasingly important, role-playing simulation is becoming more important.

In Situ Simulation

An immersive simulation experience is most commonly carried out in a dedicated simulation center in which all the aspects of the simulation

can be controlled. In contrast, simulation in situ refers to a simulation exercise in which the simulation exercise is carried out in the clinical space where the actual clinical tasks usually occur. The advantages of simulation in situ include convenience for the learners as they do not have to come to the simulation center, and having the participants perform their simulation experience in the setting in which they usually work, with familiar personnel and equipment. This allows the opportunity to analyze system issues in the clinical setting, for example, suboptimal physical layout, equipment that is challenging to use, or protocols that are difficult to put into actual practice. The challenge with in situ simulation is that it requires coordination between the simulation team and the area where the in situ exercise will occur so as not to interfere with patient care. Also, simulation technology may fail as it is moved from setting to setting.

■ Role of Simulation

First, we should ask what the role of simulation is. What is it that we are attempting to accomplish by using this tool?

Education

Education is the most obvious role. Simulation has been embraced in most medical schools and simulation experiences are a requirement for anesthesia training in the United States today.¹

One could argue that it would be a valuable tool for presenting new material to learners. However, given that simulation experiences are typically very resource intensive, requiring equipment, trainers, spaces, and dedicated time, simulation, although making for a rich experience, may not be the most efficient way to present new material.

The more efficient way to use simulation is to think of it more like a rehearsal, with the assumption (which may be proven wrong as the simulation plays out) that the learner(s) know the cognitive material, but need to have an opportunity to put it together in a clinical setting. This is also a role of simulation for the more experienced clinician, where they get an opportunity to practice management of uncommon situations that they may encounter once or twice in their entire career, but that as an anesthesiologist they should be the expert on managing, for example, an intraoperative cardiac event or malignant hyperthermia crisis.

Simulation has also been proposed as a tool for quality improvement and systems engineering. It provides investigators an opportunity to recreate clinical situations to search for solutions. It also provides planners an opportunity to “try out” their new setting. As an example, a new pediatric intensive care unit was opening in a hospital, and before

opening, they ran simulated cases where they found a number of potential problems that they were able to address before opening.²

Task Trainer

Task trainer development has been a function both of need and of affordable technology. Early task trainers were primarily mechanical, but the low cost of microprocessors and 3D printing has enabled the development of increasingly sophisticated task trainers that utilize both simulated anatomy and, increasingly, virtual anatomy and pathology.

An example of this is the airway trainer. The simplest airway trainers were a head complete with mouth, teeth, oropharynx, larynx, and upper trachea. These were primarily based on anatomic studies and drawings. These evolved to include an esophagus, cricothyroid membrane that one could puncture, lungs, and more degrees of movement at the temporomandibular joint and cervical region to not only allow training for laryngoscopy but also bag and mask ventilation. Many of these models were criticized for not being true to the actual anatomy of living patients as characterized by computed tomography and magnetic resonance imaging scans.³ Hence, many newer airway trainers have evolved to have anatomy based on actual computed tomography and magnetic resonance imaging examinations. They have also evolved to include pulse oximetry tones to simulate falling saturations and allow the anatomy to be made more difficult by changing the mobility of the jaw and the cervical spine. Recognizing that the role of the task trainer is to move a learner from novice to someone possessing basic skills, for example in airway management, preparation for the procedure, anticipation of challenging airway, bag and mask skills, and adaptability in the face of changing circumstances, excessive resources going into making an anatomically perfect trainer may be a case of diminishing returns. There is a maxim in aviation simulation that you only use as much simulation as is necessary to achieve your learning objective. Any time there is increasing sophistication, there is usually increasing opportunity for malfunction and breakage. A damaged task trainer is of no use to anyone.

Virtual anesthesia task trainers are trainers in which all imaging is created by a computer; there may be a mechanical component that lets you control the image. This is like a console-based video game. Virtual trainers have recently come on the market for training of transesophageal echocardiography, point-of-care ultrasound, and ultrasound-guided regional anesthesia.

Task trainers allow repetition in learning a skill. Learning a skill also requires meaningful feedback so that poor habits are not reinforced. Feedback was traditionally presented by a tutor critiquing the task trainer performance. Task trainers are now being developed that will score a performance and by monitoring the learner's performance

compared with an “expert” be able to provide automated feedback to the learner.

Screen Based

Screen-based simulation refers to utilizing a virtual environment on a computer to manage a clinical case. As gaming on the personal computer was evolving in the mid 1980s, particularly flight and driving simulators, one of the first screen-based graphical anesthesia simulators⁴ was developed. It evolved into “Anesoft Anesthesia Simulator.”⁵

A screen-based simulator is limited by the interface between the learner and the computer, usually a keyboard and mouse. However, its benefit is that it can provide hints, feedback, and objective scoring on a performance. In contrast to a virtual task trainer in which the emphasis is on learning a particular skill or task, screen-based simulators are generally more about solving a clinical problem.

In July 2017, the American Society of Anesthesiologists, in partnership with CAE, developed SimSTAT, a screen-based simulator that, in addition to focusing on the management of the patient, emphasizes nontechnical skills, including anticipating problems, utilizing the personnel in the room, and communication between the surgical and anesthesia teams.⁶ It is aimed primarily at practicing clinicians rather than novices.

Task trainers like computer simulators that focus on a specific topic in anesthesia have been developed in parallel with the comprehensive simulators. Gasman, which models the uptake and distribution of inhaled anesthetics, in real time or an accelerated mode, was initially released in 1984, and with updates in the content and format, continues to be an outstanding screen-based resource for learners today.⁷ It allows the user to observe the consequences of fresh gas flow changes, body habitus changes, drug costs, shunts, and duration of anesthesia, among other adjustable variables. The Virtual Anesthesia Machine, developed at the University of Florida in 1999,⁸ is a screen-based simulation of an anesthesia machine in which the user can follow gas flow through all the circuits and simulate anesthesia machine faults, and note the consequences of those faults.

Immersive High Fidelity

The most common image in people’s minds when they think of simulation in anesthesia is a mannequin in a clinical space, for example, an OR or intensive care unit bed, with monitors, a medical team, and a clinical “story” or scenario that the learner experiences. Requirements for successful simulation of this type include the technology of the mannequin, well-designed scenarios, and thoughtful debriefing after the scenario is completed. Many would suggest that performing a scenario

without a debriefing, that is, an analysis of performance, is simply playing games.

Resusci-Anne was first introduced in 1960 by Laerdal. The company was originally a doll and toy-making firm, but they have evolved into one of the largest manufacturers of medical training equipment. Resusci-Anne was developed jointly by Drs Peter Safer, James Elam, and the toymaker, Asmund Laerdal. Interestingly, Anne's face was based on the death mask of an unidentified young woman who drowned in the river Seine in the 19th century (www.laerdal.com/us/docid/1117082/The-Girl-from-the-River-Seine). This was a passive mannequin that was initially developed to teach mouth-to-mouth ventilation; later, a compressible chest to facilitate chest compressions was added.

SimOne was the first mannequin that was able to respond to interventions. It was developed by Dr Stephen Abrahamson (a PhD medical educator, who, among other innovations, brought the concepts of educational theory and utilization of standardized patients into medical education) and Dr J Samuel Denson, Chief of Anesthesiology of the University of Southern California. They first conceived of a computerized patient simulator in 1964. On March 17, 1967 SimOne was unveiled.^{9,10} They were awarded Patent #3520071 entitled Anesthesiological Training Simulator on July 14, 1970.¹¹ The head, torso, and arms of a mannequin were bolted to an OR table with electric and pneumatic equipment below the table and both analog and digital control equipment in 2 separate consoles. An operator controlled the mannequin at a separate console (Fig. 1).

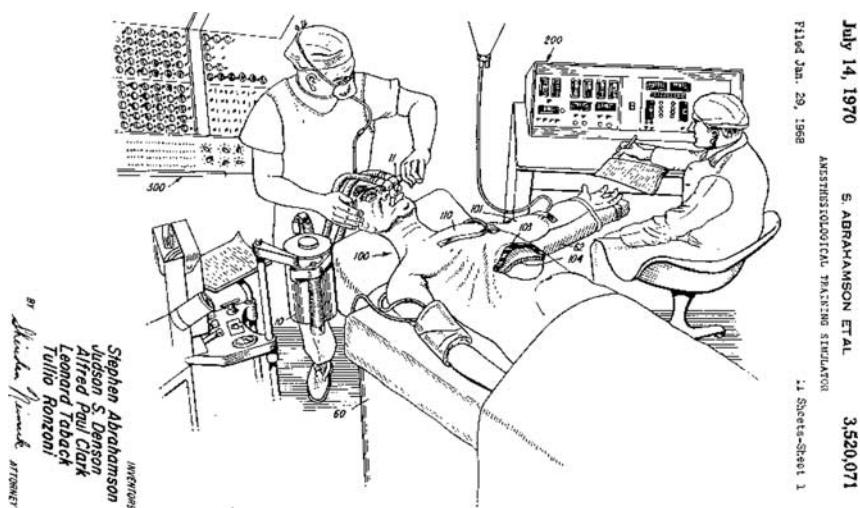


Figure 1. A drawing of SimOne with the learner managing the patient and the mannequin operator at a separate console controlling the mannequin. From US Patent #3520071.

Similar to modern high-fidelity mannequins, it could breathe, the left and right lungs were separate and could be collapsed, temporal and carotid pulses were present, heart sounds were audible, eyelids responded, and pupils were responsive to light. There was an anatomic airway with the potential for laryngospasm. It could detect drugs that were being injected and would respond to 10 different drugs in a preprogrammed manner. It had a number of features that even today are not present on mannequins or are just in different stages of development: the patient could “buck,” fasciculate, and vomit. The eyebrows could wrinkle. Sensors could detect improper or overly rough mask placement and jaw movement. The mannequin’s skin could change diffusely from pink to blue to gray, representing cyanosis. The capabilities were remarkable, especially considering the limited computing power of the day. Abrahamson et al¹² describe one of the first instances of using simulation to train anesthesia residents using a simulator. Unfortunately, Sim One “died” in 1975 because of the unavailability of replacement parts. A second SimOne was never built.

Mannequin-based simulation suffered a hiatus until the mid 1980s. The advent of affordable computing power at the microcomputer level was likely one of the driving factors for this rebirth. The Comprehensive Anesthesia Simulation Environment (CASE) was developed at Stanford by Gaba et al,^{13–15} by tying together off-the-shelf components and controlling them with microcomputers. CASE was originally designed as a research tool rather than for educating. At the same time as Gaba was developing the technology for simulation, he and his team began to bring concepts from commercial aviation’s cockpit resource management into the OR. Anesthesia Crisis Resource Management (ACRM) arose from this focus on how to make a team work effectively together.¹⁶ In 1992, CAE-Link, makers of aviation simulation technology, bought the technology for CASE. The technology was purchased from CAE-Link by Medsim Eagle in 1997, who, by 1999, abandoned the product. There are still a number of Medsim Eagle products in use.

At the same time as Gaba was developing CASE, Drs Michael Good, S Lampotang, and JS Gravenstein at the University of Florida in Gainesville partnered with LORAL, another aviation equipment company, to develop their own simulator. Gainesville had a team with skill developing software simulators of tasks within anesthesia, for example, the Virtual Anesthesia Machine and models of different breathing circuits. These simulations continue to this day. Rather than develop a research tool for team performance, their goal from the beginning was to develop a high-fidelity system to facilitate training of anesthesia residents. Their simulator was based on computerized simulations of physiology and pharmacology, so that rather than telling the mannequin to display hypotension, the operator would need to decide to either render the mannequin hypovolemic, or decrease the contractility, or

change the peripheral vascular resistance. The mannequin modelled human response to situations. It was also designed so that the mannequin gave “outputs” to the world that could be sensed by any clinical equipment, for example, it output CO₂ and agents in the concentrations that the models predicted that could then be sensed by whatever clinical equipment the training facility had; the signals of electrocardiogram outputs were signals of the same magnitude that would come off of a human chest wall so that unaltered electrocardiogram monitors could be used. The Gainesville Anesthesia Simulator was first developed in 1987. As the mannequin became more generalized so that it could be used in milieus other than anesthesia, it evolved into the Human Patient Simulator. Its first commercial sale was in 1993 to the Icahn School of Medicine at Mount Sinai Department of Anesthesiology in Manhattan. LORAL licensed the technology in 1994. By 1996, the technology was taken over by Medical Education Technologies Inc. (METI). In 2011, CAE Healthcare took over the technology from METI. METI and CAE Healthcare have also developed pediatric and neonatal mannequin simulators and portable simulation mannequins.

In 2000, Laerdal released SimMan, a high-fidelity mannequin that had many of the features of the previous mannequins at a significantly lower price point. It was also able to take advantage of much of the maturation of computer technology. It was completely instructor driven, meaning that the instructor would specify what vitals are displayed and what the mannequin was doing and how it responded to medications and interventions rather than depending on sophisticated physiological modelling such as the METI Human Patient Simulator. Laerdal has gone on to develop and market wireless versions with increasingly sophisticated features and infant models. They have also developed a lower fidelity obstetrics mannequin that is aimed at underdeveloped regions.

The SOPHUS anesthesia simulator was released in Denmark in 1993. It was used in a number of European studies, but in 2003 merged with Laerdal. Gaumard was originally developing task trainers, but in 2000, released Noelle. They later released a pediatric and neonatal mannequin. All 3 were designed to have modest fidelity, but at significantly lower price point to make simulation accessible to a larger audience. Similarly, their HAL models, released in 2004, were designed to be somewhat less sophisticated, but at a lower price point.

■ Practice Changes Arising from Simulation

A number of practice changes have evolved that can trace their endorsement to simulation and some of the pioneers of simulation.

- Active team training. Team training, in which emphasis is placed not on training any 1 person to be a master, but rather recognizing the

dynamics of a team and that how the team functions can contribute to the success or failure in management of a situation. Some of this arose from Gaba and Holzman's development of ACRM.¹⁷ Aspects of team training have been embraced throughout health care and are now incorporated into ACLS training.

- Management of local anesthetic cardiac toxicity. Utilization of lipid emulsion and modification of ACLS has been recognized as effective treatment for local anesthetic cardiac toxicity for many years. The American Society of Regional Anesthesia (ASRA) developed a flowchart-based algorithm for the management of this emergency.¹⁸ Use of this flowchart was subsequently shown to improve performance in managing simulated local anesthetic cardiac toxicity cases.¹⁹
- Checklists are becoming increasingly more common in day-to-day procedural settings and in the management of crisis situations. Development of anesthesia crisis management checklists, alternatively known as cognitive aids, arose initially from Harrison and Gaba.²⁰ Subsequent dissemination throughout numerous centers around the world has been facilitated by another simulation expert, Goldhaber-Fiebert, and the Stanford team.^{21,22}

■ What Factors have led to the Embracing of Simulation in Anesthesia?

It is interesting to speculate on why SimOne was a single prototype and "died" after only a few years, and yet, now ~40 years later, simulation has become part of almost every hospital and training program.

The easy answer is that technology has evolved. Simply looking at the cumbersome equipment shown in Figure 1 with SimOne and Figure 2 with CASE 1.3 shows what a daunting task it was to build, maintain, and run the equipment. The equipment and personnel requirements were sophisticated and expensive. The advent of cheap, ubiquitous, and reliable microprocessors and microelectronics has made things possible today at a modest price that was unfathomable 30 and 40 years ago.

The more subtle answer might be that the environment has changed. Payers and recipients of health care are demanding that caregivers be better trained (along with documentation of the same). The entire patient safety movement has led to institutions and organizations struggling to improve outcomes and safety. At the same time, we are working in an environment in which work hours of physician trainees are limited and educational institutions are constantly asked to do more with less. This has led to seeking out innovative techniques that can give trainees exposure to uncommon cases in a consistent manner. As the "science of education" has been embraced more avidly within



Figure 2. CASE 1.3 showing the copious quantities of equipment required to keep it functioning. Dr Steve Howard is shown managing the patient. Photo provided by Dr David Gaba, personal collection.

medical training, medical educators are recognizing the need to have trainees practice managing challenging situations and move beyond simply mastering the science of medicine, but without putting patients at risk as we move from content-based education (what do you know) to competency-based education (what can you do).

At the same time, medical specialty boards are constantly working to improve the examination process for new trainees and developing continuing professional development processes for those already in practice. Within anesthesia, the ABA has traditionally utilized a written exam to assess primarily cognitive knowledge and an oral examination to again probe cognitive knowledge, and assess the candidate's ability to demonstrate decision making, organization, and communication skills in handling clinical situations. They are now adding an objective structured clinical examination in which simulation will play a role. Since 2002, simulation-based assessment has been a component of the Israeli Anesthesia board certification²³ in addition to written and oral components. Berkenstadt emphasized that they were able to measure different strengths and weaknesses in candidates with each of the assessment modalities, i.e. the simulation exercises measured performance components that could not be assessed in the written or oral examinations.

■ The Future

Any exploration of the past should be seen as a springboard for exploring what the future may hold. Simulation training is still viewed with skepticism by some members of the medical community. I suspect that this will fade as a new generation of practitioners, for whom simulation was 1 modality of their training, move into the “decision-maker” roles in their careers. It will have been such a part of their training that they simply will not see what the fuss is all about.

Another barrier to greater embrace of simulation has been the expense of offering simulation exercises: not simply the cost of the equipment, but the cost of tutors/technicians, and cost of being away from clinical practice. Perhaps we will see more reliable equipment, and more importantly, equipment that can provide feedback to the trainee directly without the need for a tutor. This would also offer the possibility of providing simulation in smaller “chunks” during light clinical duty periods.

Just-in-time training, training for a procedure just before doing it, would be possible with more portable equipment that is available in the clinical area rather than being stowed away in a physically distinct simulation center. Simulation has been used as preparation for novel cases, for example, separation of conjoined twins, both in planning the procedural aspects and the logistical aspects – there is the potential for this to be used even more frequently.

Finally, simulation may become part of systems engineering. Consider if any time a new clinical area is constructed, simulated practice were to occur there before opening to identify both architectural issues (do the beds fit through these doors) and systems issues (how do we get an echocardiogram machine here). Alternatively, consider if a simulation of a sentinel event were a part of the sentinel event investigation. Centers are working on both of these but, standardized approaches are yet to be developed.

I would suggest that simulation has been the victim of enthusiasm and hype. Simulation is a valuable tool to facilitate education and assessment. However, it is important to recognize that it does not replace 150 years of medical education practices. It is a useful adjunct—an important new tool to make education better.

■ Summary

Simulation, really hands-on practice in a nonpatient setting, is not a new concept; however, the technology and subsequently its use have evolved dramatically. The first sophisticated mannequin-based anesthesia trainer, SimOne, developed in the late 1960s, was never really embraced. It was a good idea at the wrong time—both the technology and the medical environment were not ready for it.

That is no longer the case today as simulation is embraced for training, continuous professional development, and assessment. In addition, it is seeing roles in addressing practice challenges within the health care system.

The author declares that there is nothing to disclose.

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