REVIEW ARTICLES

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Simulation in Echocardiography: An Ever-Expanding Frontier

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INNOVATIONS IN TECHNOLOGY have made it possible to create "virtual reality circumstances" of specific scenarios to refine training and education. Because of its virtual nature, ie, no consequences of failure and no risk to a patient, simulation-based education has become an integral component of medical training. Simulation technology traditionally has been used as a "situational" teaching tool to facilitate multidisciplinary team building, communication, and complex decision making. The development of "phantom models" has broadened the scope of simulation as a teaching adjunct to improve skills in performing procedures (regional anesthesia, central venous access, and laparoscopic surgery). The art of image acquisition during echocardiography is another such discipline that requires a complex interaction between an operator, the equipment, and a subject. The cognitive component of proficiency in echocardiography consists of a theoretical understanding of cardiac anatomy, physiology, and the echocardiographic image display through specific "echo windows." The manual dexterity component requires repetitive, mentored, hands-on experience to acquire interpretable standardized images reliably. The multifaceted skill sets required to gain expertise in echocardiography further require a clinical context for their application. Such dedicated clinical training is available to anesthesia residents as an elective during their "core" residency or as a part of an accredited cardiac anesthesia fellowship.

The recognition of perioperative echocardiography as a vital monitoring modality is obvious from the introduction of echocardiographic educational initiatives from the American Society of Anesthesiologists (ASA), the Society of Cardiovascular Anesthesiologists (SCA) and the Society of Critical Care Medicine (SCCM) to their memberships. The availability of echocardiographic simulators in this context is particularly interesting. These simulators provide an opportunity for hands-on experience as a teaching aid to acquire proficiency in this complex clinical technique. The echocardiographic simulators available for training range from online software programs to mannequin-based transesophageal echocardiographic (TEE) and transthoracic echocardiographic (TTE) simulators. The available options include normal and abnormal cardiac anatomies and functions and recording feedback. There also is a wide variation in the available features, price, and quality/robustness of the software programs. Therefore, the authors thought it prudent to provide the readership with an overview of the status of simulation in echocardiography. In this article, the authors review the significance of simulation in anesthesia in general and echocardiography in particular. Starting with a brief historical perspective, the challenges associated with the current paradigm of echocardiographic training and the opportunities offered by the echocardiographic simulators as teaching tools are discussed. Taking stock of the major advancements in technology for simulation in echocardiography, the available options are reviewed. The authors also make suggestions on what needs to be done to advance the potential of this unique teaching tool.

For the purposes of this review, the authors conducted a thesaurus-based search (medical subject headings) of key terms, such as *simulation in echocardiography* (TTE and TEE), *simulation-based medical education*, *simulation*, and *metrics* on PubMed and on the Internet. After identifying the manufacturers/academic programs involved in the development of a simulation-based education, the authors communicated directly with the manufacturers and developers and requested information on the design, features, and capabilities of their products. Communication methods included mail, electronic mail, direct conversations, and information reported on Web sites. The authors report the capabilities and features of the simulators, which are commercially available or close to being available (ie, tested at beta sites identified by the manufacturers).

ORIGINS OF SIMULATION IN ECHOCARDIOGRAPHY

Anesthesiologists have been involved in the inception and development of simulation training in medicine. What appeared to be a technique of resuscitation gave birth to the idea of medical simulation. In the 1950s, Dr Peter Safar, an anesthesiologist, discovered that he could provide adequate artificial ventilation to sedated volunteers simply through mouth-to-

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mouth ventilation.[1] When he presented his findings at a research congress, it caught the attention of Dr Bjorn Lind, a fellow anesthesiologist, who collaborated with Asmund Laerdal, an entrepreneur, to translate the concept into a life-sized mannequin for mouth-to-mouth ventilation training. The mannequin was reviewed by Dr Safar who recommended that a spring be added to the chest wall to add recoil to allow for practice of chest compressions. Thus, the world's first medical mannequin, "Resusci-Anne," was born.[2]

The journey from the earliest resuscitation simulators and standardized patient encounters to the current generation of complex systems consisted of a combination of necessity, intellectual curiosity, and technologic innovations. The advent of minimally invasive procedures in the 1990s necessitated the development of simulation systems to "rehearse" the surgical procedures to decrease the initial learning curve in performing complex manual tasks.[3] The earliest of such simulators consisted of intra-abdominal anatomy models to practice laparoscopic surgical skills. Simulators with similar designs, which allowed a "warm-up" practicing of procedures, were adopted quickly as "task trainers" and "haptic systems" for other specialties requiring fine motor skills, eg, interventional cardiology.[3] In this context, Ultrasim (MedSim Inc, Ft. Lauderdale, FL) was the first ultrasound-based teaching simulator, which consisted of actual patient ultrasound datasets of normal gynecologic intra-abdominal anatomies and pathologic states.[3]

Because they lack haptic information of the transducer motion and because of their "pre-determined" nature, cardiac anatomy illustrations/echocardiographic clips are of limited value in teaching echocardiographic image acquisition skills. The earliest report of a "virtual" solid model of the heart was reported as a means of teleconsultation for echocardiographic consults.[4] Teleconsultation with a "solid" 3-dimensional (3D) model enabled virtual digital "slicing" of the volumetric ultrasound data to mimic transducer manipulations during an actual examination. The simultaneous display of the 3D model and the "sliced" 2-dimensional (2D) standardized image improved spatial orientation and facilitated communication during teleconsults.[4] A similar solid "static" heart model and a virtual TEE probe also were developed as educational tools.[5] The virtual TEE probe's motions and controls in this simulator could be operated with the computer mouse. This particular TEE simulator was not developed into a commercial product.

The major technologic impediments consisted of difficulties in the development of a dynamic and anatomically correct model of the heart and a spatially aligned TEE probe and a scan plane. The availability of the National Library of Medicine's Visible Human Project, however, was a major step in facilitating the conceptualization of such a project. The next generation of echocardiographic simulators, used currently, consist of online software programs or mannequin-based products with normal and abnormal cardiac anatomies and functions with actual TTE/TEE transducers to learn probe manipulations.

MEDICAL EDUCATION: ONE PATIENT—ONE PROCEDURE

Conventional medical education is based on an "apprenticeship" model constituting the acquisition of cognitive knowledge, manual dexterity, and exposure to a wide variety of clinical scenarios. The clinical exposure is graduated, with progressive autonomy during the course of the apprenticeship. Medical training, particularly procedure-oriented specialties, involves a wide variability in clinical opportunities. One patient representing one procedure makes the medical training volume-centric. Hence, the challenge in procedure-related training is to overcome this "one patient, one procedure" paradigm to maximize training opportunities with no compromise in patient safety and comfort. Trainees can benefit particularly from simulation training for procedures that are invasive in nature. Although the Accreditation Council for Graduate Medical Education (ACGME) has specified minimum individual training requirements, which include a specific numbers of procedures, for accredited institutions, clinical exposure can vary (private *v* public and university *v* community hospital). For example, trainees at an urban center are likely to have a greater exposure to trauma compared with trainees at a rural center. In this context, simulation has the potential to play a pivotal role in leveling the field for all trainees. Simulator training can benefit not only individuals but also groups of individuals in the facilitation of team-building exercises and complex decision making.

SIMULATION-BASED MEDICAL EDUCATION

Simulator-based medical education (SBME) has been shown to be superior to the traditional didactic system of education.[6,7] Many clinical specialties have used simulation to augment the learning of their trainees, and anesthesia in particular (situational and procedural) has benefitted greatly from SBME.[8-15] The ACGME has defined competency in terms of six components: patient care, medical knowledge, practice-based learning, interpersonal skills, professionalism, and systems-based practice.[16] SBME has shown the potential to facilitate proficiency in all six.[16] Simulators allow the re-creation of clinical scenarios, common (intubation) and uncommon (arrhythmias), as and when needed so that medical education and training can be standardized.[15,16]

During routine patient care, the exigencies of patient care take precedence over medical training. A simulator enables a trainee to practice high-risk procedures and refine skills without patient involvement.[15] Therefore, SBME decreases the initial learning curve for procedures requiring repetitive performance without adding to patient risk or discomfort.[17] By focusing on trainee needs instead of patient needs, a simulated learning environment can be tailored to meet the learning requirements of the trainee and can provide an objective appraisal of the trainee's performance.[18] Performance can be recorded and progression can be tracked.[15]

Medical students remember much more of what they perform than of what they only read.[19] Simulators allow the repeated practice of clinical skills that require manual dexterity, such as advanced cardiac life support, laparoscopic surgery, cardiac auscultation, hemodialysis, thoracentesis, and central venous catheter insertion.[6,7] This improved proficiency has led to better patient care and management and improved patient outcomes, eg, fewer catheter-related bloodstream infections and improved perinatal outcomes.[20-22]