A critical approach to medical simulation

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***Editor's note**: The following article is based on a keynote address that was originally presented at a workshop on surgical simulation co-sponsored by the American College of Surgeons, Boston, MA, April 20-21, 2002.*

Physicians are justifiably proud of our residency experience, with long days and nights on call treating whoever "comes in the front door." We accept that the vagaries of illness and accidents will provide us with enough experience to prepare us for a lifetime of practice. We learn from older faculty members in large academic medical canters, training on rich and poor alike, but more frequently on the poor or uninsured. This traditional system dates back to Halsted, but has its origins in the ancient Egyptians, who would apprentice young boys to a master "mechanical healer" whom we would today call a surgeon. We accept these customs as necessary rituals of learning. Medicine's traditional methods of learning have been just that—traditional.

Yet surgeons must also remain current in the present state of the art and new methods that develop after the end of residency. When continuing medical education (CME) was introduced, we maintained our edge by attending didactic lectures or reading journals and answering CME quizzes. Hands-on animal courses provided us with certificates of attendance that demonstrated competence performing new procedures in surgery, cardiology, radiology, and other procedural specialties. These one- or two-day animal courses were accepted as valid learning methods for complex new surgical procedures because there was little alternative. As a result, organized learning of surgical techniques became a cottage industry of weekend pig courses with the experts. The educational role of organized specialty societies diminished.

At a two-day conference in Boston, MA, sponsored by the American College of Surgeons and the National Board on Educational Testing and Public Policy on April 20-21 of this year, leaders from the College met with experts from academic medical centers, educational testing designers, engineers, and computer scientists to discuss alternatives to the traditional methods of surgical learning, especially the use of medical simulation. As the opening lecturer for that meeting, I was able to demonstrate the current state of the art, and present the issues surrounding the development of medical simulation, the challenges that remain, and the potential roles that simulation could fulfill in lifelong medical learning. My comments were based upon my background as an interventional radiologist, an educator, and a researcher in the field of medical simulation. This article presents a summary of the points I made for the leaders of the College during that keynote lecture.

Note: During the meeting, the phrase "simulation technology" was used to encompass the entire domain of computer-assisted learning techniques, from CD tutorials to interactive learning. The term "simulators" was used to describe skills trainers or procedural training systems that to a greater or lesser degree incorporate computers for presentation, control, and metrics. Most of the remainder of this article will discuss simulators as learning systems under the more global rubric of simulation technology.

Why simulation?

Organized medicine had the gauntlet thrown at its feet in 2000, when the Institute of Medicine released its report, *To Err Is Human: Building a Safer Health System*.[1] This report, which awakened the general public to the prevalence of medical errors, also challenged medicine to do better. According to this report, at least 44,000 Americans die from medical errors every year. In other words, *the seventh leading cause of death in this country is being cared for by a physician.* As part of the plan for improvement, the authors stated in their recommendations that health care organizations should incorporate proven methods of training such as simulation.

The key phrase in that statement is that we should adopt "proven methods of training." In medical disciplines such as anesthesia, established curricula for team training and crisis management have demonstrated outcomes improvement after simulator training. In fact, in Massachusetts, anesthesiologists who have had simulator training receive a discount on their annual malpractice premiums. For anesthesia, simulation is a "proven method of training." Surgical simulation, by comparison, is just beginning to define a course that will result in proven effectiveness. But there is much work to be done before College members can exchange today's two-day for-profit pig courses for independent, sanctioned, validated training in new laparoscopic, endoscopic, or catheter-based techniques.

However, when we do create these new learning tools, a powerful educational revolution will occur. For example, in a simulation system, new techniques can be practiced over and over, alone or with a mentor, without the need for animals. Errors can be tracked while the operation continues until the surgeon recognizes the error. At that point, an effective simulator will have an UNDO button, and the operation can be "rewound" to a point before the error.[2] The surgeon can then practice the technique again, either on his or her own or under the eye of a tutor who could guide the trainee through the point of error safely. With a RESTART button, the correct technique can be practiced over and over until it becomes a natural response.

The VIRGIL™ Chest Trauma Training System.

Mistakes would lose their consequences and become ways to learn. And one master surgeon's new trick of the trade, one critical maneuver during an operation, could be learned in situ by every simulation user. The opportunity to learn something new in this way has never before been available to medicine.

Simulation also offers benefits outside of the realm of error reduction, for both novices and experts. It could:

- Permit learning in a completely safe and risk-free environment for patients.
- Refresh techniques for surgeons returning to practice after an extended absence.
- Correct for case-mix inequalities in a training program, so that what you learn in your residency doesn't depend on what comes through the front door while you're on call.

• Allow examining boards to certify competence through a technical examination of skill rather than an oral discussion.

• Permit prototyping new procedures *in silico*, giving a whole new meaning to the phrase “the practice of medicine.”

• Allow biomedical engineers and designers to test new devices in a simulated environment.

• Eventually, with the proper design, permit patient-specific rehearsal of operations involving anomalous anatomy or other variants that would have bearing on intraoperative decisions.

For the purpose of this brief discussion, one more aspect of continuous professional learning deserves comment. While we are all familiar with the concept of a learning curve at the beginning of our careers, there is also a curve at the end of our careers. This decline in skills and judgment has traditionally been assessed by individual surgeons or chiefs of service. A mature, validated system of simulation-based education could offer for the first time a lifelong log of performance on standardized techniques, allowing measurement of skills independent of age or other arbitrary milestones.

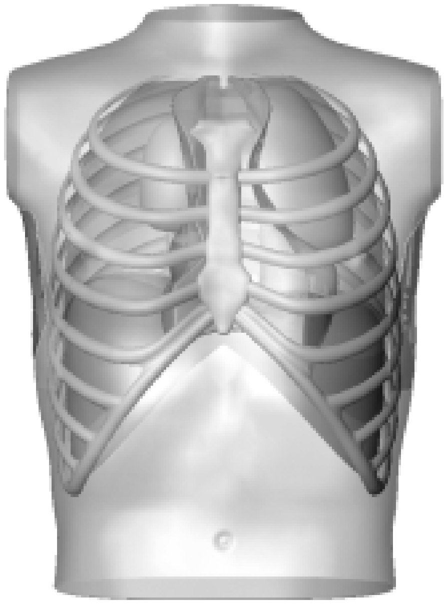
What is required?

Most simulators today are designed as technical boxes that allows one to practice a series of hand-eye maneuvers without the benefit of performance measures. A few systems have been designed with metrics as an integral component of learning assessment,[3] and studies showing transfer of knowledge from simulation to the operating room are just beginning to appear.[4] To become a learning system, and not just an elaborate game, requires that designers carefully consider content, purpose, end-users, and eventual metrics that will be used to prove transfer of learning. The challenges that face the designers may be generalized into three broad areas:

• *Realism:* Realistic organ responses, realistic tissue-tool interactions, realistic visual display, and real-time interaction.

• *Authenticity:* Integrated educational content, clinically useful training, and validated transfer of learning.

• *Acceptability:* Testing in medical centers, acceptance by teaching physicians, and approval by specialty organizations, such as the American College of Surgeons.



A computer-aided design (CAD) drawing of a torso.

The exploded CAD model used to make the chest torso of the VIRGIL Chest Trauma Training System.

In general terms, these three areas are, respectively, best addressed by research scientists, physicians, and organized medicine. But physicians must be involved at each level of content choice, system design, educational content, and validation measures. Without continuous involvement by informed medical advisors, system designers may create simulators that superficially resemble training systems, but that are neither clinically relevant nor educationally effective.

What is a simulator?

Simulators may be considered a broad taxonomy consisting of two classes—mannequin-based and computer-based. A third class, hybrid simulators, incorporating elements of both computer- and mannequin-based systems, is just being designed and will likely become the standard simulation architecture in future systems.

Mannequin-based systems, sometimes called realistic patient simulation, use a patient form as the trainee interface. These systems are most familiar in Advanced Cardiac Life Support and Advanced Trauma Life Support® (ATLS®) courses, and in anesthesia simulations. The system frequently incorporates extensive physiologic responses to drug administration, cardiac compression, intubation, or other predominantly external manipulations. They are excellent systems for team training and crisis management and have an accepted, validated role in anesthesia training. Drawbacks to the systems are their limited adaptability to operative training, relatively high faculty to trainee ratios and relatively high per session training costs. Examples of such systems are the METI patient simulation systems and the Laerdal SimMan7 ATLS systems.

Computer-based simulations use a computer monitor and custom-designed instrument interfaces for interaction with the onscreen display. Because the systems are software-based, there is some degree of adaptability in procedures, and error tracking and correction can be performed easily. These designs easily integrate educational content either as an "upfront" introductory learning phase or as an integral component of the procedure—for example, when an error is committed, a literature review of anatomic variants that could contribute to the error or the likely outcome of similar errors can be called up by the trainee in a hypertext linked document. Drawbacks of these systems are the lack of proven efficacy of advanced systems, and the high development costs for what are currently individual research program efforts. A few commercially available systems have been created, from the MIST-VR basic skills training system (Mentice), which uses abstract graphics, to the CathSim IV access trainer (Immersion Corp.), to the most advanced system, which is called VIST (Vascular Interventional System for Training) (Mentice).[5] The VIST system has been installed in Brussels to train interventional cardiologists in angioplasty, coronary stenting, pacemaker placement, and carotid interventions. During 2002, more than 2,000 physicians will learn these techniques using the VIST simulator.

Since surgical simulation is most likely to arise initially from the computer-based branch of this taxonomy, let's examine in more detail the components that make up a computer-based system. An ideal system consists of the following parts:

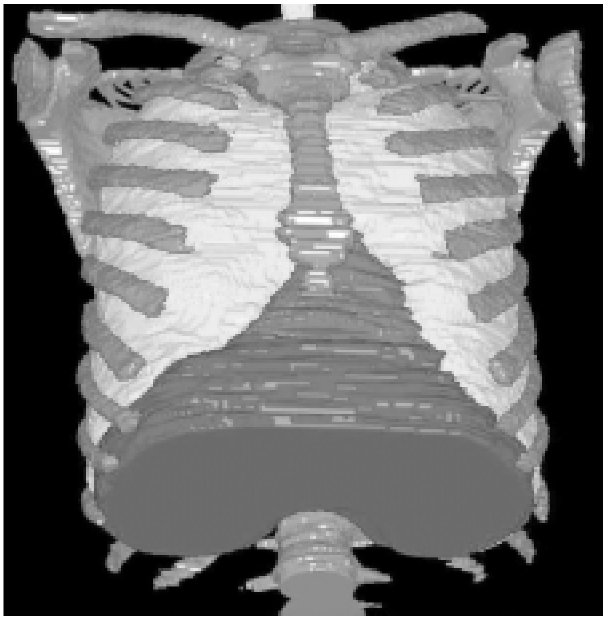
- *Segmentation.* The anatomic area to be represented in the procedure is separated from the surrounding organs, giving an anatomic workspace that incorporates the organs likely to be involved in the procedure. The source data from which the organs are taken can be the visible human data, or cross-sectional imaging studies from a "generic" patient.
- *Tissue modeling.* This idea involves measuring the material properties of individual organs and then creating mathematical models of those properties so that the organ can be represented realistically in a computer program. For surgeons, a critical element of realism will be added when the graphical display of the organ actually feels like the organ. This is a daunting challenge and represents an area of cutting-edge biomedical engineering research at academic centers around the world.
- *Tissue-tool interactions.* Once the organ responses are known, and mathematical rules governing the behavior of the segmented anatomic data set have been formulated, computer programs that represent the collisions and interactions between the surgical instrument and the tissue must be created, in order to allow the surgeon to manipulate the organs.
- *Haptics.* This term refers to the "feel" of the system. Haptics means the feedback that is pro-

vided by the system to the operator, and it is intimately related to both the tissue modeling and the tissue tool interactions mentioned above. The level of fidelity required for effective haptics response is another area of active research, especially as it pertains to the amount of feedback that needs to be apportioned between the visual aspects of the system and the "touch" of the system.

- *Visual feedback*. How does the system show the operator the procedure? Initial simulations used graphics methods available at the time they were developed, and frequently showed false color anatomy or crude abstract graphical representations of geometric shapes rather than actual organs. Some of the most common events in surgery, such as bleeding or the appearance of a suture, represent formidable graphics challenges in simulation research.
- *Physiology*. An ideal system will allow errors to occur and will also include physiologic models that represent the result of those errors. By inference, the physiology model will also accurately portray ongoing homeostatic states such as blood pressure, pulse, and other surgically relevant components.
- *Education*. Unfortunately, most medical simulators developed to date have neglected the most compelling reason for their creation: education. In the near future, any complete medical simulation system must be judged by how well it incorporates medically relevant education. Although medical input is necessary at each level of the system design, it is crucial that physicians be responsible for assuring that the end product incorporates the elements that will make the overall simulation educationally useful. Without educational content, the best simulator is just a very good video game.
- *Real-time system integration*. All the components described previously must come together as one integrated system within which all parts communicate in real time. Any time lag in system performance will immediately destroy the critical state of "suspension of disbelief" that is necessary for immersion into the scenario. If the system doesn't run in real time, it will not be clinically useful, nor will it be accepted by medicine.

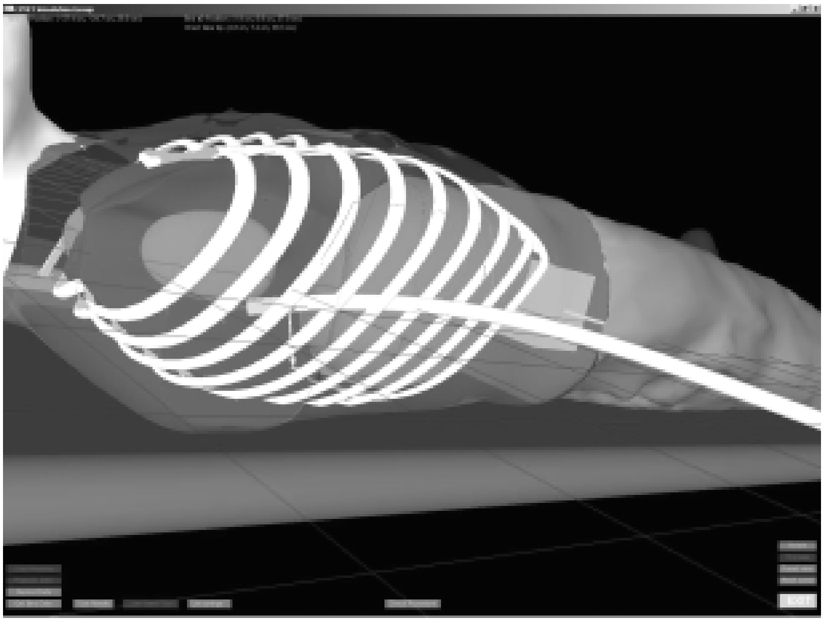
When will simulation be ready?

According to the old story, the three most important words in real estate are "location, location, location." A similar condition can be set for simulation: the three most important words are "validation, validation, validation." Many of us have heard enthusiastic reports about the coming era of silicon-based learning among surgeons of the twenty-first century. Unfortunately, to date, the reality hasn't matched the hype. Too often, existing simulators have been designed by teams of engineers or computer scientists with little or no involvement of the physicians who are actually knowledgeable about what must be learned and how it must be presented. The result for many systems has been either polite but passing attention or rejection by organized medicine's leading practitioners. What's missing is validation of clinical learning: simulation will be ready when proponents can show that clinically useful learning results from simulator use.



A segmented anatomy used to make a CAD model.

Validation is a science familiar to those individuals who write high-stakes tests, such as the SAT, MCAT, and LSAT exams. Within such a test, there are multiple tiers of internal proof so that the exam consistently gives valid results, assuring that performance on any given day reflects the true ability of the examinee. These internal tiers are face



The augmented reality view of the chest after insertion of a chest tube.

validity, content validity, concurrent validity, and predictive validity. A rigorously conceived surgical simulator must incorporate these same internal architectural elements in order to be validated as effective for training. This pedagogical design will underlie and support the educational content necessary to validate the user's clinical knowledge. To date, very few simulation systems have incorporated this thorough educational approach during their design phases; most have concentrated instead on technical elements such as hand-eye interfaces or computer graphics displays. Obviously, experts from both education and medicine must collaborate during the creation of a simulation system that can be rigorously validated.

Physicians will have to make informed a priori decisions about which technical measures are used to determine clinical competence based upon performance on a simulator. The simulator must then be designed to evaluate those metrics. Although this seems like an obvious statement, it has not been a guiding principle for present simulators. To date, the most common metrics are the time to complete a task and instrument path as a task is performed, which are useful initial steps. However, in some situations the time to perform a manipulation may not be a critical clinical measure, as opposed to dexterity or avoiding injury to an adjacent organ, for instance. One current focus is the creation of a generalized, task-independent set of metrics that can be used across various simulator platforms.[3] As simulators become more sophisticated, procedure-specific technical measures will likely become appropriate, but at the current state of development, such specificity is premature.

What is our role?

As practicing physicians, we enthusiastically embrace the challenges that arise from treating patients. In the case of surgeons, or interventional radiologists like me, we want to be personally responsible for fixing what's wrong: "Give me a problem, and let me fix it." Academic surgeons bear a special responsibility for training subsequent generations of surgeons: "Give me a problem, and let me teach someone else how to fix it." Our roles are to cure and to educate, and if we don't accept our responsibility to educate, someone else will step in and do it for us. I have had a corporate officer sit in my office and tell me that his company's business plan is "to become the educational source for the specialty." This particular company had six employees at the time, all but one from the medical device industry.

In the present domain of simulation, venture capitalists are funding entrepreneurial start-ups around single prototypes and a few ideas. If medicine is involved in these start-ups, this might be a good choice. But for most existing companies, physicians are not active creators, and technology's limitations are driving content.

Our role is to ensure that some traditions in medicine continue: medicine must be taught by respected, experienced physicians to eager young physicians. Mistakes must be made under a watchful eye and corrected without impairment to the patient. Training must encompass the broadest range of cases so that when we are alone at night, not much will surprise us. The decision about *how* we learn is at a crossroads: we can continue to use the same methods we've used for centuries, or we can keep the best of the traditional methods and simultaneously leverage new techniques that we derive from the revolutions in computing and information technologies that are occurring in parallel with our own revolutions. We can invest in the science that will create revolutionary ways to learn, making our mistakes in realistic, but not real, situations where patients are not put at risk. We can work together to create learning situations where it's okay to make a mistake, and learning how to correct that mistake can be shared among every surgeon, not just the one at your side in the operating room. And our investment can be used by every one of us in practice, when our colleague 3,000 miles away comes up with a new way to do a fundal plication, or someone in a related field discovers a new way to treat an aortic aneurysm. Ω

Research members

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