

The future of
**SURGICAL
SIMULATION**
and
**SURGICAL
ROBOTICS**

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Over the past decade and a half, information technologies have revolutionized how skills-based training can be accomplished. The potential for simulation of clinical and robotic procedures lies in two basic premises that have been mainstays of other industries for a half-century. The first requirement is a computer representation of the product (in the case of surgery, the “product” is the patient). With the use of sophisticated three-dimensional (3-D) graphics and high-resolution computed tomography (CT) scans, it is possible to create an accurate, computerized, 3-D representation of patient organs. The second requirement is the understanding of robotics as an “information system with arms,” and a CT scanner as an “information system with eyes,” such that it is now possible to create a system that uses both 3-D graphics and robotics together as a single, integrated “information system.”

ROBOTIC SURGERY:

Current status and research trends

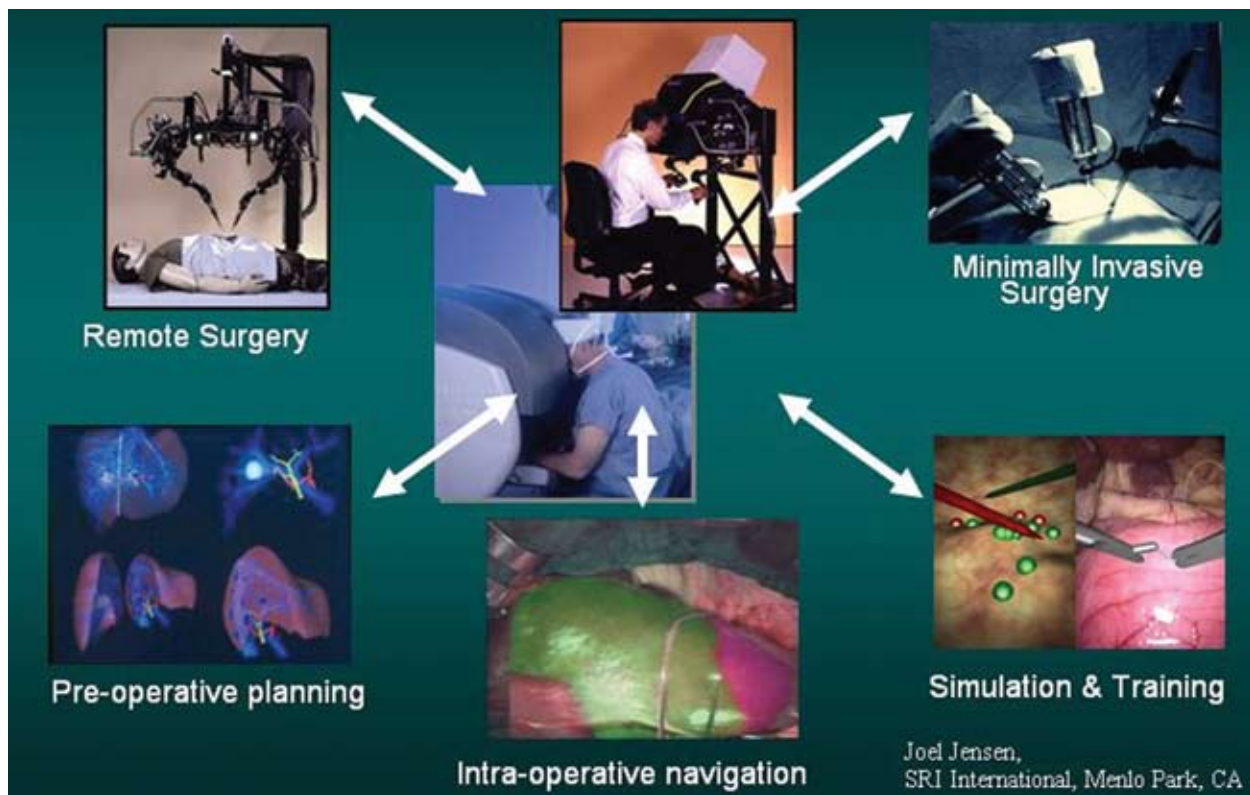
Based on these fundamental premises, the surgical console of the robotic system becomes the place where integration of surgery occurs. Only with a robotic surgical system is it possible to do open surgery, minimally invasive surgery, remote telesurgery, preoperative planning, surgical rehearsal, intraoperative navigation (image-guided surgery), and surgical simulation all from one place: the console (see photo, page 15). This is the overall architecture that will provide even greater capabilities in the future—and this is just the beginning.

A next-generation robotic system is being researched by the military. In this program, Trauma Pod, the first phase is to build an operating room that doesn't need to be staffed by people. This concept is based on the current industry standard of integrating cooperating robotic systems into a single robotic “cell.” There are no people changing instruments on industrial robots; instead, there are “tool changers.” Furthermore, there are no people handing parts

to robots; rather, there are supply dispensers. Now that surgeons are using robots, the next logical step is to integrate tool changers (scrub nurses) and supply dispensers (circulating nurse) into the surgical robotic system. Such a prototype, referred to as the “operating room without people,” has been successfully demonstrated as a military-sponsored research project involving the currently available DaVinci robot (see photo, page 16).

Although this is simply an early prototype system, it has proven that certain repetitive tasks (such as handling instruments or fetching supplies) can be done more efficiently with integrated robotic systems. This would relieve scrub nurses and circulating nurses from the drudgery of repetitive tasks so they are able to perform more intellectually challenging tasks, or it could decrease the number of nurses needed in the OR (a single nurse can perform both circulating and scrub nurse functions). In addition, every time an instrument is changed or a supply is dispensed, three things occur automatically: The patient is billed, an order to restock the OR is sent, and a request is sent to the supply center to reorder a replacement—all within 50 milliseconds and with 99.99 percent accuracy. This automatically incorporates operating room function with the hospital logistics and information systems, such as supply chain management, just-in-time inventory, asset tracking, and so on, further increasing efficiency and quality. In essence, the OR communicates directly to the logistics and supply center automatically, without human intervention.

With such a system, the following scenario would be possible. A patient is taken to the preoperative holding area, placed in the correct position for surgery, and anesthetized. A CT scan of the area for surgery is taken and the patient is taken to prepping. While the patient is being prepped and is moved into the OR, the surgeon sits at the console and rehearses the critical part of the surgical procedure on the patient's CT scan, thereby making any errors on the patient's image and not the patient (the military calls this “mission rehearsal”). Thus, when the patient is brought into the OR and docked with the robotic system, the surgeon is already familiar with the anatomy and knows



The integration of the spectrum of surgical components by the robotic surgical console. (Courtesy Joel Jensen, SRI International, Menlo Park, CA, 1999.)

what to expect. Throughout the procedure, the logistic and information systems are continuously updated, and a record of the operation is automatically generated. It should be noted that this is an early developmental state of the project, and the final outcome would likely have slightly different implementation; however, the important factors of improved efficiency, quality, and total integration can be achieved, just as they have been the standard in all other industries for the past three decades.

Such a scenario logically leads to the concept of the solo surgeon controlling a robotic surgical system, with no other person in the OR. At this time, this system is not quite achievable; however, in the not-too-distant future, it will be possible.

SIMULATORS:

The basis for skills training and assessment

Surgeons have often been compared with fighter pilots, so it is worthwhile to consider the recent accomplishments of these pilots. Until 2002, the fighter pilot was “king of the air,” flying dangerous missions into combat. In 2003, the Predator unmanned aircraft was introduced for surveillance, then hunter-seeker, and then attack. Now the military is specifically training pilots on computer consoles to fly the unmanned aircraft—these pilots will never climb into a cockpit. Will the surgeons of the future follow a same pathway and operate on their patients remotely, never to enter the OR?

Similarly, surgery can learn from aviation in

regard to surgical education and training. Flight simulators have been in use for more than 50 years, but surgical simulators are just now entering into surgical education and training. Current flight simulators are highly sophisticated, with accurate representation of the aircraft performance and ultra-realistic, specific graphic representations of every airport in the world. In addition, training engages the entire cockpit crew into an integrated team using crew resource management training. The lessons for surgery are to develop simulators with even more sophisticated graphic representation of anatomy, to develop libraries of many different procedures and anatomic variations, to import patient-specific anatomy for surgical rehearsal, and to institute OR team training.

SURGICAL CURRICULA:

The keystone to surgical training

As important as these first steps are in the development of surgical simulators, the real fundamental issue is not the simulator; rather, it is the curriculum. The simulator is just another tool, and it is the curriculum that will determine the training of the surgeon. Thus, it is necessary to incorporate the basic principles of adult education, curriculum design, setting of quantitative performance metrics for outcomes, and validation of the curriculum. Then, and only then, should the appropriate simulator be incorporated into the curriculum. Recent experience with curricula revealed that simulation provides the unique opportunity to radically change the method of surgical skills training, changing from time-based training to criterion-based training.

Currently, students are trained for a certain length of time, number of days, or number of trials (*infra vide*). In addition, today residents become experienced surgeons depending on whatever



The “operating room without people” project from the military’s Trauma Pod program. To the left are DaVinci robot arms, in the center the “scrub nurse,” in the rear is the tool changer, and to the right is the supply-dispensing “circulating nurse.” (Courtesy of Pablo Garcia, SRI International, Menlo Park, CA, 2006.)

random surgical procedure “walks in the door”; by building virtual libraries of all the essential surgical procedures, structured training programs with standardized curricula can be developed to ensure that every resident is trained (to criterion) in every essential surgical procedure.

The Accreditation Council on Graduate Medical Education, in collaboration with the American Board of Medical Specialties, has defined the six competencies that every physician must demonstrate (see Figure 1, page 17). This has provided a huge challenge to the surgical education community, because with the exception of knowledge and patient care, there are neither available curricula nor methods of testing these competencies. What is the appropriate training for professionalism or communication skills, and what objective measures are available to assess these skills? Can they be simulated?

We are at a unique moment in history, when so much new technology is being introduced and new requirements for training have been established that the surgical education process is in complete

revolution. History shows that revolutions in surgical education have occurred only once every 50 to 100 years, so whatever is developed during this coming decade will likely endure for at least the next three generations of surgeons, perhaps as long as a century. There is a short window of opportunity, while program directors are engaged in establishing new training programs to meet the newly established requirements, to develop a national standardized curriculum, and to validate assessment tools that will provide a uniform level of training and certification. There are numerous efforts at curriculum development; however, most incorporate a series of fundamental steps (see Figure 2, this page). This approach includes a definition of the goals of the training and description of the anatomy and the steps of a procedure. However, most curricula do not include a thorough explanation of the errors that can occur.

In training residents, it was discovered that the same error was frequently repeated; when questioned, the residents usually responded that they were not aware that they had committed an error. Educators spend so much time teaching students the correct thing to do that they forget to teach what an error is, so the student can learn to avoid errors or to recognize when one has occurred. Once this didactic portion of the curriculum is completed, the student should be tested *before* starting the simulator. Theoretically, any errors that occur on the simulator would be because of psychomotor skills, as the students had already proven that they understand the initial cognitive part of the training. Finally, the outcomes (quantitative measures from the computer) need to be provided to the student for improvement. Although this is a generic approach to curriculum design, it can provide a template for standardizing curriculum development.

OBJECTIVE ASSESSMENT:

Quantifying performance

Just as important as the curriculum development is the objective assessment methodology. Reznick¹ has introduced the objective structured assessment of technical skills (OSATS) and Fried² has provided the McGill Inanimate System for Training and Evaluation for Laparoscopic Skills as excellent examples of methods of objective assessment. For each task, specific, quantifiable measures have been

FIGURE 1:

The six physician competencies

established by 2001 consensus by the Accreditation Council on Graduate Medical Education and the American Board of Medical Specialties

- Knowledge
- Patient care
- Interpersonal and communication skills
- Professionalism
- Practice-based learning and improvement
- Systems-based practice

FIGURE 2:

Standardized curriculum suggested template

- Goals of the simulation
- Anatomy
- Steps of the procedures
- Errors
 - Test
- Skills training
- Outcomes

determined and a mentor observes the student and grades the student performance based on these metrics. Although this is extremely accurate, it is also very demanding on faculty time.

Emerging new simulation tools, such as the Red Dragon from the University of Washington, are capable of precisely measuring hand position, motion, force, and so on. The record of the performance can be displayed as a graphic “signature” (see photos, page 18) in addition to the specific measurements, which can be used to guide the student to improved performance. Automatic recording of performance with direct feedback has the potential to decrease (but not eliminate) the amount of faculty time.

CRITERION-BASED TRAINING:

Successor to time-based training

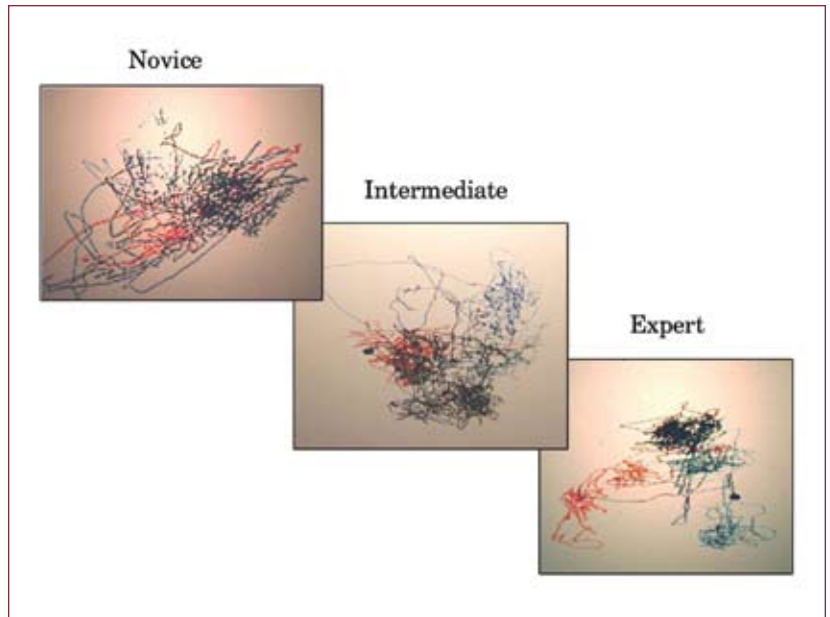
One of the most significant benefits of simulators has been the ability to assess the performance of an expert or experienced surgeon and

then use those performance measures as the benchmark or criteria to which the student must perform. This radically changes the training from time based (that is, training on the simulator for a given length of time or number of trials) to criterion based (training as long as necessary until the student achieves the criterion measures on two successive trials). Theoretically, no resident will perform a procedure on a patient until it is proven that he or she can achieve the same level of proficiency as an experienced surgeon. Unequivocal evidence has been demonstrated by Seymour et al that training to a criterion (or proficiency) on a simulator reduces operating time by 29 percent and errors by 85 percent.³

Likewise, there is a growing public demand for demonstration of maintenance of competency by practicing surgeons; thus, simulation with specific benchmarks can provide a cost-effective way for practicing surgeons to demonstrate maintenance of their skills and certification.

NEXT-GENERATION SURGICAL EDUCATION: Emerging technologies

We have come through three generations of simulation: From aviation to surgical simulation (1939-1987), from simulation to curriculum development with validation (1988-2002), and from time-based training to criterion-based training (2003-2006). The next generations of simulators are in the laboratory exploring issues of haptics (sense of touch), incorporation of simulation into the DaVinci robotic console, intelligent tutoring, and judgment assessment. It is unclear at this time how critical haptics are to training, and although every experienced surgeon is aware of the importance of the sense of touch in open



A typical set of motion signatures while tying a laparoscopic intracorporeal knot using the Imperial College Skills Assessment Device (ICSAD). (Courtesy of Ara Darzi, Imperial College, London, England, 2003.)

surgery, the major degradation of haptics in laparoscopic surgery seriously questions the need for haptics in laparoscopic simulators. In robotic surgery, there are efforts to develop virtual reality simulators; the two approaches are to modify current laparoscopic simulators in a cost-effective manner, or to incorporate a simulator into the console of the DaVinci robot. Both approaches are in their infancy but will be important to growing use of surgical robots. The added advantage of having the simulation embedded into the surgical console is that the simulation mode can then import patient-specific images to be used in preoperative planning and surgical rehearsal.

The remaining two areas—embedded intelligent tutoring and judgment assessment—involve a significant combination of curriculum and simulator development. For intelligent tutoring, expert surgeons initially identify (for the curriculum and simulator) the critical errors for a procedure as well as the instructions to prevent

or correct an error. Once these have been defined (via consensus conference of experts), they must be incorporated into the simulator by the commercial company. The result will be a “virtual mentor”: Whenever the student makes an error, there will be immediate (proximate or formative) feedback that includes the information about the error, specifically its identification and its correction. For judgment assessment, the new technology of eye tracking projects a dot on the computer monitor that designates the position where the student is looking. By simultaneously recording the hand motions from the instrument handles, it may be possible to compare hand positions and eye motions to infer what the student was thinking. Although eye tracking is a standard and well-developed technology for advertising and marketing, it has not yet been translated to surgical training and assessment.

CERTIFIED TRAINING CENTERS:

Toward national standards

The American College of Surgeons has recognized the importance of simulation, curriculum development, objective assessment, and maintenance of skills (certification). With so many new training centers being established, the College has taken the bold initiative to ensure the highest-quality training by promoting ACS-certified educational institutes. There are two levels to educational institutes: Level II: Basic Training Laboratory, which provides the fundamental skills, curricula, personnel, and space to train surgical residents and surgeons; and level I: Comprehensive Center, which trains multiple surgical and medical specialties, medical students, and nurses, and which conducts research and validation studies in surgical education and simulation. It is expected that comprehensive centers would become assets for an entire region. In addition, there will be a consortium of the comprehensive centers, which would play an important role in helping develop, organize, and establish national-level guidelines, standards, and so on. The College has recognized its responsibility for stewardship of surgical education and intends to seize this unique opportunity to revolutionize surgical education on a global level.

CONCLUSION:

A unique moment in surgical education is here

The paradigm has shifted: The robots are coming and simulation and objective assessment are here to stay. Information systems, robots, and simulators are being incorporated into the daily practice of surgery and perhaps the inevitable direction will be that every surgical procedure will automatically and continuously include rehearsal, training, recording, and assessment. The expected features of next-generation simulation could include intelligent tutors, judgment assessment, virtual mentors, complex procedures, digital libraries with varying anatomy, and patient-specific data for surgical planning and rehearsal. Although these advances are speculative, it is critical that each new technology and each new curriculum and simulation undergo the same stringent validation to ensure that there is value added to the training. □

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