Simulators for Laparoscopic Surgical Skills Training

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Prevention Management of Laparoendoscopic Surgical Complications. Chapter 14. ed. Paul Alan Wetter, MD., 2005

Sources of Support:

This work was supported in part by Contract NLM/NIH 185N034

Précis

Surgical simulators with force feedback are available commercially to assist surgeons in acquiring and practicing the technical skills necessary for videoendoscopic surgery. These simulators are currently being validated to establish their efficacy in surgical training programs. Early results demonstrate that both surgical proficiency and safety are improved.

ABSTRACT

The learning of the fundamentals of laparoscopic procedures by surgical trainees has improved with today's surgical simulators. These simulation devices range from simple, homemade boxes to sophisticated systems mimicking operating tables with plastic manikins or virtual patients. First-generation systems utilized physical objects (such as cotton string, pegs, latex tubes, and rings) to teach the basic psychomotor coordination actions necessary for laparoscopic surgery. Some of these systems offer electronic metrics. Other members of this group are computer-based and afford virtual images and instruments projected onto monitors/displays. Second-generation devices take advantage of the huge computational advances in graphical representation of tissues and organs. These devices, which can be haptically enabled, allow practice of the basic skills, gestures, and instrument-tissue manipulations typically choreographed into surgical procedures. The most advanced of the second-generation systems incorporates virtual 3D models of human anatomy and can support distributed, web-based learning at remote sites. This chapter provides a description and classification of many of the surgical simulator systems currently available and offers a set of evaluation criteria against which to judge their usefulness.

Videoendoscopy has changed everything!

Surgeons don't operate on patients any more; they operate on (their) images.

INTRODUCTION

Among the dramatic changes in surgical education during the last half-century in the United States has been the introduction of a national system of the Accreditation Council on Graduate Medical Education (ACGME)-approved residency training programs at large medical centers, featuring multiple clinical rotations and specialized instructors. This organization of residency programs has helped to standardize training objectives and the duration of training and has expanded the variety of clinical experiences available for each surgical trainee. However, along with other major changes in health-care delivery, it has contributed to a variable, often reduced, competence of trainees in performing specific procedures during their training years and has contributed to poorer assessments of competence by instructors. The ACGME Outlook Project seeks to broadly improve medical training of all physicians. The 6 competencies of physicians recently identified by ACGME[1,2] are patient care, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, professionalism, and systems-based practice; the acquisition and maintenance of surgical technical skills are included in patient care and practice-based learning and improvement requirements.

Teaching, developing, and practicing basic surgical skills via the apprenticeship model of training and their assessment are no longer considered appropriate in the operating room (OR).[3] A variety of newer methods to prepare trainees for the OR have been implemented in recent years, due in large part to the fact that that surgical procedures are changing from open surgery to minimal access surgery (MAS) [or minimally invasive surgery (MIS)], a practice requiring new suites of technical skills. Further, issues of patient safety[3,4] and cost-effectiveness involved in MAS training require alternative methods of instruction.

Over the past several decades, other modes of training (eg, the use of synthetic objects, animal models, and video training) have supplanted early phases of apprentice-style learning in the OR. Accordingly, "clinical skills-labs," "part-task trainers" (defined below), and "animal surgery" have been introduced into training programs with increasing frequency for providing hands-on instruction of technical skills. On a parallel track following successful experience with objective, structured, clinical examinations (OSCE's) for assessing mastery of cognitive knowledge and decision-making, Martin et al[5] and Wanzel et al[6] developed a new assessment method that provides objective, structured assessments of technical skills (OSATS). First evaluated among general surgical trainees, this formative assessment method has also been used to guide learning and for assessing performance of trainees in obstetrics and gynecology.[7]

At the beginning of the 21st century, progress in computer technology offers another remedy for surgical training. Basic MAS/MIS maneuvers can be learned and practiced by residents and instructors using computer-based virtual environments, and performances can be assessed objectively before proceeding to patients in the OR. Studies[6,8-12] reported during the past 2 years with simulation-based instruction using first generation, part-task trainers have demonstrated enhanced performance of trainees in either animal or human OR settings. In one study[12] in which safety was considered, the number of surgical errors was also reduced. Evaluations of second-generation systems that may be considered *procedure-simulators* are now underway.

DEFINITIONS OF TRAINERS AND SIMULATORS

The term "part-task" trainer has been adopted from its original use in the psychology field, where psychomotor procedures were deconstructed into their component parts and identified as tasks.[13] Part-task trainers include two types of simulators; those that afford practicing basic skills, the psychomotor actions*,* and those that focus on more complex tasks of surgical procedures, such as suturing. An example of a "basic-skills" trainer is one that teaches the eye-hand coordination required for using surgical instruments. Navigating cameras, grasping tissue, picking and placing, and handing of objects between instruments can be learned and must be practiced for proficient surgical performance. These skills are also called the "surgical gestures"[14] of surgery, much as a mime "goes through prescribed motions". In practice, basic skills represent the enabling skills necessary to be learned before conducting more comprehensive tasks. Not all basic-skills trainers afford examples of more complex tasks, such as dissection or suturing, that involve more than one basic skill necessary for performing a surgical task or manipulation. Several basic-skills trainers have added modules that support practicing manipulations of increasing complexity. For them, the exercise of deconstructing tasks into their individual components is beneficial because practicing these technically demanding components is critical in the performance of instrument-tissue manipulations. As part-task trainers continue to evolve, this separation is likely to diminish and be less important.

An example of a part-task trainer supporting complex manipulations is one that focuses on a component of a laparoscopic cholecystectomy, such as dissection of the triangle of Calot, the anatomical region where the cystic duct and cystic artery emerge adjacent to each other in unpredictable configurations, and are at risk for inadvertent injury during dissection. The manipulations necessary for exposure of these structures are grasping and retracting, incising sharply with a scissors or with a selected energy modality (electrosurgery, ultrasound or laser), pushing and/or pulling to extend an initial incision and to separate the fibrous tissues that encase them, elevation of the identified tubular structures to assure their separation/isolation, clipping or suturing to interrupt the lumena, and cutting to divide the structures. Inspection for hemostasis and irrigation of blood and possibly bile from the dissection site are additional necessary manipulations. The actions required to accomplish them exceeds those offered by basic-skills trainers.

Two systems, the LapSim trainer of Surgical-Science AB and Simbionix, Ltd have labeled this above exercise as *Dissection.* The requisite set of surgical manipulations requires using target skills (see below), but this dissection component of the surgical procedure is but one part of a laparoscopic cholecystectomy. Exploration of the common bile duct may be needed as another component, and dissection of the gallbladder from the liver and removal of the excised structure from the abdomen are additional manipulations. Many simulators designed to support dissection of Calot's triangle have been offered as LapChole simulators, but most are part-task trainers that are not comprehensive for all of the necessary actions/manipulations of a LapChole. Remarkably, efforts to simulate the introduction of trocars into surgical spaces, the chest and abdomen, have not been commercialized. This complex, coordinated action is another example of a laparoscopy part-task **(Table 1)**.

Beyond part-task trainers, procedure simulators enable the user/learner to practice the more comprehensive and higher level target skills that enable tissue-instrument interactions, such as multiple dissections, development of vascular pedicles, or electrosurgical, ultrasonic, or laser coagulation of pathological surfaces. The eight fundamental manipulations of tissues by surgical instruments that we emphasize are those that have been taught since 500 BC, first described by Sushruta, the Father of Surgery.[15,16] These are exploration [both visual and haptic (touch)], aspiration/injection, incision, excision, extraction, evacuation, scarification (purposeful injury),

and closure (including suturing, clips, etc). Implantation/transplantation, a new manipulation developed during the 20th century, has been added as the ninth. Vascular cannulation, another modern procedure, is considered an extension of the aspiration/injection manipulation.
These familiar manipulations, known as the *Hidden Technical Curriculum of Surgery,*[17,18] must be mastered by junior trainees, yet they are rarely taught explicitly– rather trainees learn by observation but have had few methods for practicing them. These manipulations when choreographed into a series of appropriate surgical actions required to accomplish the objective of a surgical prescription are integrated into a surgical procedure, or operation. The vocabulary that is used to describe these common manipulations is very familiar to surgeons, but not to computer scientists and cognitive scientists who prize their elaboration as a guide during simulator development.[18] Often, more than one method using different steps or approaches may be used to accomplish a similar surgical objective. Heinrichs[18] has pointed out the similarity of surgery to figure skating. The professional skater studies, learns, and practices to perform the required steps and jumps, inserts them into a program, choreographs them to appropriate music, and practices again and again preparing for the actual, live performance, then dons appropriate garments, and steps onto the ice for the performance–the equivalent of a surgical operation. Practicing this routine repetitively is the essential ingredient for success in figure skating and offers a model for surgical professionals. Another similar, commonly rehearsed skill is playing musical instruments by professional musicians. Each discipline has its own vocabulary. The *macro* to *micro* progression of graphical components begins with surgical procedures done by different methods and moves deeper to the tissue/instrument manipulations, and finally collisions of instruments with polygons of the virtual organs/tissues[18] **(Table 2)**.

For the haptic component of simulators, Rosen et al[19] and Kowalewski et al[20] have recently characterized the *macro* to *micro* progression from total procedures, to steps of procedures, to tool/tissue interactions, and finally to mechanical forces and torques, as analogous to books, the chapters, the words, and their pronunciation.

CLASSIFICATION AND DESCRIPTION OF SIMULATORS

A feature that distinguishes some trainers and simulators from others is the type of construction with physical components such as manikins into which hardware is installed and surgical instruments are inserted. These are labeled *physical reality* systems in contrast to *virtual reality* (VR) systems that are software-based. Physical reality trainers (sometimes called *mixed reality* trainers) may be designed with video cameras or camcorders that provide a graphical image on a display, utilize electronic sensors that are activated upon touching with an instrument or a physical object, and are able to provide data and reports about performance. The earliest group of "box trainers" were simple Lucite or plastic shells into which laparoscopic instruments were inserted for manipulating physical objects, animal tissues, or even placenta. Commercial physical reality trainers incorporate a computer that compiles performance data, and it may serve as a display, too. Alternatively, a CRT display may present the graphics. In virtual reality systems, the graphical images are software-generated, and they utilize a physical interface of surgical handles that direct attached virtual instrument tips, instead of real surgical instruments. Virtual reality-based systems are always computer-based, serving the computational needs of the simulation as well as compiling and reporting the performance data.

The majority of computer-based surgical simulators that have been developed are designed to enhance the technical skills of videoendoscopic surgery. I have elected to classify them on the basis of their ability to provide instruction or practice with the increasing complexity of tasks, manipulations, and procedures conducted with image guidance methods, relating them to clinical tasks, manipulations, and procedures, also of increasing complexity. The term *image-guided interventions* includes most invasive procedures that have been simulated by various systems. A previous effort to classify surgical simulators[21] stratified them using criteria of increasing complexity for skills, part-tasks, and procedures, but included several systems not (yet) commercialized, and others have been added in the field since July 2001. Another classification focusing on most of the commercially available simulation systems was released on-line from Penn State University (J. Henry) in 2004.[22] This classification focuses on the fidelity of systems compared to the human body. A list of categories of image-guided procedures appears in **Table 3**. Invasive, image-guided actions, extending from basic skills trainers, to needle-based interventions, vascular and catheter-based interventions, to diagnostic and operative laparoscopy, provide a common and familiar thread. The visual/video source for the images generated may be either an optical system and a camera, or a fluoroscopic visualization, all produce images visible to users on CRT or LCD monitors/ displays.

Simulator systems are not static; many continue to be developed as commercial products with new features and additional modules. Also, many systems have been developed as research projects in academic institutions and have not emerged as products. The process of design to commercialization is difficult to track, particularly for those systems being developed outside the U.S. **Table 3** lists most of the trainer or simulator systems commercially available for each category of procedures, but is not exhaustive. The list is restricted to vascular access and catheterization and endoscopic and laparoscopic surgery excluding other simulators for thoracic surgery, ophthalmology, otolaryngology, orthopaedics, and neurosurgery.

Simulators for computer-assisted learning of basic surgical skills are now available from several commercial providers. These devices range widely from physical reality simulators*,* such as the LTS 2000-IBD60,[23] to haptic interfaces that interact with animal tissues or other objects, such as the ADEPT (Advanced Dundee Endoscope Psychomotor Trainer[21]). Other systems utilize video-based graphics with small-to-large segments of physics-based simulation, such as the AccuTouch endoscopy simulator.[24] These have a common platform with real endoscopes introduced into an elongated box in which the travel of the end-piece activates progressive views of anatomy to be navigated. A plastic face, genitals, or buttocks with an aperture for introducing the endoscope, provides the context for the procedure. Haptics in this system is mechanical, based on sliding the endoscope into the system. The physics-based capability affords performing biopsies, resections of lesions, and other things.[25] Several, but not all VR simulators afford bimanual haptic interfaces that manipulate synthetic models of organs, but nonhaptic interfaces are also available. Of those with synthetic models, several offer part-tasks of dissection of the cystic duct (triangle of Calot) for laparoscopic cholecystectomy,[26,27] and pelvic procedures, such as tubal sterilization, excision of ectopic tubal pregnancy, suturing of myoma-excision sites,[27] and hysterectomy.[26] Three have demonstrated broadband Internet transmission capability **(Table 2)**. Some VR simulators offer enclosures (cages) to hide computer hardware and haptics interfaces inside them, simulating an operating table with drapes. These may be considered “containers” for the simulators that also offer convenient “fold-down” displays; however, these physical attributes are irrelevant to the above classification based upon applications. Others may consider making a separate category for simulators with the container feature.

VALIDATION OF SIMULATOR SYSTEMS

“Validation of surgical simulators” refers to the process of evaluating these systems to determine their quality and value as training and/or assessment tools.[28] Initial evaluation begins when the system is under development and includes beta-testing to check that the system performs according to the design specifications and usability testing to ensure the trainees find it easy to use. In addition, content experts, in this case experienced surgeons, must review the system to check the accuracy and realism of the simulated tasks and procedures, as well as the usefulness of the internal metrics or scoring mechanisms, if these features are included.

Residency training program directors and others who are interested in adopting these technologies will be interested in knowing how the simulator has performed in formal validation studies with trainees, such as studies of construct validity, teaching effectiveness, skills transfer, and curriculum integration, or field studies. In **Table 4**, these types of evaluation studies are defined by the evaluation question they seek to answer. The last column in the table identifies the person(s) whose simulator performance and/or opinion is sought.

The first 2 types of evaluation presented in **Table 4** are usually conducted when systems are under development; content validity and curriculum integration are based on the judgment of experienced professionals, and those remaining are based on educational research using a true experimental design. Meaningful studies of this type usually incorporate a control group that receives no training, or an interrupted time series design in which the subjects serve as their own control. It is also important to control for the amount of training received by each group and to ensure that observers/raters are trained for consistent scoring and blinded for which group received the training.[29] Recent reports[30-32] emphasize that variability in performance may stem from different visual perception capabilities.

It is imperative that we conduct validation studies of these new technologies, particularly in medicine and surgery where established methods developed over decades effectively protect the interest of patients. Introduction of simulation technologies must enhance, not jeopardize, this commitment to patient care.

HOW MUCH TRAINING MAKES A DIFFERENCE?

Several studies using physical-reality systems or simple tasks, such as grasping and placing a ball into a cylinder, using 3 or fewer repetitive practice experiences one day or a few days apart, were ineffective in demonstrating an effect of training.[33,34] Therefore, 3 or fewer experiences can be thought of as *familiarization* with the system, rather than producing a change in skill level, but this hypothesis needs to be studied. Our data in a trial comparing no training with twice-weekly practice sessions for 2 weeks with either a box trainer or a VR trainer demonstrated significant differences produced in VR trainees **(Table 5)**. Data obtained with a latex physical simulator indicate that an average of at least 9 practice sessions over a 2-week period are necessary before performing laparoscopic cholecystectomies (latex models) when a nadir in proficiency is reached.[33]

Transfer of skills to real-life situations has been analyzed in several studies in which training was assessed by performances in the operating room, either with patients or with animals.[8-12,35] The obvious difficulty with scheduling patients with comparable pathologies, accessibility, and other things, for conducting *VR-to-OR* transferability and having resident physicians with equivalent, prior surgical experiences has prolonged such studies with patients. Animal surgery has the limitations of species-specific anatomy, usually no pathology, and lack of the urgency and responsibility of human ORs. However, with forethought, relevant performance objectives can be constructed in animals, such as “pick-and-placing” beans as gallstones, “grasping-and transferring” colored stitches placed on the anti-mesenteric portion of bowel to mimic “running-the bowel,” and exposing mesenteric vessels for “grasping-clipping-cutting” exercises. In vivo simulations of exercises are often instantiated into box trainers with inanimate objects, such as string, beans, cloth, and latex tubing, but real equivalency is very difficult to achieve between these static environments. For example, a string target placed on the floor of a box trainer remains stationary until it is moved by a user, but the bowel’s peristaltic action presents a moving target. Mobility of targets may be a major advantage of VR systems. Validation studies, like clinical trials of any type, benefit from conducting them in several centers simultaneously. Caution is warranted for qualifying novice trainees who are recruited by their prior experience with video games,[34,36] visual perception ability,[30-32] and prior surgical “exposure.” In summary, one can say that 4 practice sessions of 45 to 60 minutes’ duration at 3- to 4-day intervals make a significant difference in performance of simple part-tasks, and that after 8 to 10 sessions of the same duration and interval, the learning curve becomes nearly flat, indicating that the simple task has been mastered.[34-36] We look forward to data about learning curves established with *procedure simulators.*

SIMULATION SYSTEMS OF THE FUTURE

First-generation simulators (physical and computer-based) are clearly helpful in the process of acquiring surgical competence.[12] However, practicing enabling skills by using first-generation simulators falls short of the subsequent steps necessary for surgical proficiency. For example, skills identified and defined during “task analysis” of surgical procedures must be integrated back into a total performance, a process relying on a cognitive “executive subroutine,” as the enabling, psychomotor skills are practiced. Integrating them into manipulations and procedures becomes semi-automatic.[28] Answers that remain to be determined experimentally are whether acquiring the higher-level target surgical skills will further hasten the learning curve of trainees, improving their surgical proficiency and safe performances. An important question is whether second-generation simulators can be incorporated into surgical curricula independently of first-generation methodologies, or whether they will add value. Yet another question is whether advanced trainees will be attracted to utilize these emerging learning technologies, or whether they will dismiss them as a waste of time because of perceived simplicity. The fundamental issue is the level of authenticity necessary to achieve the “suspension of disbelief.” This level is likely to vary with the prior experience of individual trainees.

We readily acknowledge that the necessary or optimal level of authenticity and simulation of real structures, instruments, and force feedback remains to be achieved, or even defined. The optimal requirements for the suspension of disbelief that is the essence of simulation must be determined in the training arena, via field studies, over time. This process will certainly necessitate availability of introductory, first-generation services, with the inclusion of more complex systems as needed to satisfy the demands of users at different levels of proficiency. Further technical development is essential to obtain reasonably realistic visual cues associated with manipulations of tissues. Virtual synthetic models have heretofore been modified by introducing layers of tetrahedrons beneath the surface textures, to afford the appearance of fluid motion and distortion. Also, the size and number of tetrahedral layers required for authentic models has been based upon *haptic memory*, which depends upon surgical experience. However, this intuitive and possibly arbitrary approach must be replaced in future simulator development with rigorous, quantitative tissue density and nonlinear, visico-elastic data determined objectively with tissue-organ force probes.[37] Another approach, MR elastography with slow sonographic perturbations of anatomic structures offers promise for providing such tissue characterization for both healthy and disease states.[38]

To meet these many challenges, the next generation of surgical trainers and simulators should provide the following features and consequences:

- The graphics and haptics components must look and feel realistic; otherwise, barriers to engagement are established.
- Reducing trainee frustration, and embarrassment, and instructor fatigue will enhance the quality of time in training and increase efficiency. A consequence anticipated is a shortened duration of training.
- Further adoption of quantitative metrics will improve global qualitative scoring that is often time-inefficient.

- Supporting self-assessment, providing a learning curve, and producing competence and confidence in trainees as they practice for enhancing their skills.
- Providing transfer of training with enhanced performance and improved patient safety in the OR are desired outcomes of training that can be quantified.
- Reducing surgical time and patient care costs must be established in field studies.

These laudable objectives and milestones can only be established over time as adoption of simulation technologies is expanded and becomes commonplace. They will be realized as experience and data are collected from many users and training sites.

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Acknowledgments: Patricia Youngblood, PhD, kindly assisted with the section on evaluation and assessment. Other colleagues at SUMMIT, Kevin Montgomery, PhD; Sakti Srivastava, MBBS, MS; Kenneth Waldron, PhD; Camillan Huang, PhD; and Parvati Dev, PhD, have taught me about computer-based systems. I thank Steve Glotzbach, PhD, for assisting with editing, and Anders Hyltander MD, PhD, and Anders Larsson, ME, for discussion of an early draft of the manuscript.

Table 1.

Comparison of part-task trainers and procedure simulators. Most part-task trainers are first-generation trainers for basic skills. Procedure simulators usually are trainers that have evolved from basic skills systems into those with greater complexity.

Learning Feature	***Part-task* Trainers**	***Procedure* Simulators**
Objective:	*Enabling* skills	*Target* skills
Content:	Eye-hand coordination	Instrument–tissue manipulations
Focus:	Individual actions	Manipulations and Choreography
Role:	Elementary level	Intermediate level

Table 2.

Progression (*Macro to Micro*) of vocabulary used in simulator design.

GRAPHICS (Visual) Heinrichs[17]	Surgical Procedure(s)/ Operation(s)	Alternative Surgical Methods	Surgical Steps (choreography)	Surgical Instrument/ Tissue Manipulations	Collisions of Virtual Surgical Instruments with Images
HAPTICS (Touch) Rosen[19]	Surgical Procedure(s) / Operation(s)		Surgical Steps	Tool/Tissue Interactions	Force/Torques Generated

Table 3.

Categories of image-guided part-task and procedure simulators: Complexity and function increases from the beginning to the end of the list. Only computer-based systems are included.

Category	*Topic*	*Provider*
Image-guided needle procedures	Phlebotomy Central venous catheter Epidural space catheter* Chest catheter Peritoneocentesis	AccuTouch™ systems, Immersion Medical, Inc., Gaithersburg, MD * academic institutions: Ohio State University, Bristol University
Image-guided endoscopy a) **diagnostic**, including minor surgery (eg, biopsy, electro-surgery/laser for hemostasis, extraction of foreign body, etc.)	Bronchoscopy Esophago-gastric-duodenal (Upper GI with ERCP)* Flexible sigmoidoscopy Urethro-cysto-uretero-pyeloscopy	AccuTouch™ systems, Immersion Medical, Inc., Gaithersburg, MD *5DT Simulation Co. GI–Mentor, Uro-Mentor Simbionix, Inc., Cincinatti, OH
b) **operative** endoscopy (eg, excision of polyps, neo-plastic lesions, etc.)	Transurethral resection of the prostate (TURP) Hysteroscopy	Simulab, Inc. Seattle, WA Immersion Medical, Inc.,
Image-guided laparoscopy a) All videoendoscopic surgeons	Basic laparoscopic skills	ADEPT LTS2000 IBD60 MIST (Mentice AB) LapSim (Surgical-Science AB) Reachin Technologies AB Symbionix, Inc., Xitact, Inc.
b) General surgery	Dissection of cystic duct/artery Nissan fundoplasty	Reachin Technologies AB Symbionix, Inc., Xitact, Inc. LapSim (Surgical-Science AB), Select-IT Vest AG

c) Gynecology	Tubal sterilization Excision of tubal ectopic pregnancy Salpingectomy (Excision of salpinx) Suture of myoma-excision site in the uterus Ovariectomy (Excision of ovary) Hysterectomy (Excision of uterus)	LapSim (Surgical-Science AB) VestOne, Karlsruhe, DE
d) Urology	Transurethral prostatic resection (TURP), Ureteroscopy	Uro-Mentor (Simbionix, Inc.) (Simulab) (Immersion Medical, Inc.)

Table 4.
Types of Evaluation Studies.

Type of Evaluation	**Evaluation Question**	**Source of Data**
ß-Test	Does system performance match the system specifications? Do the metrics reliably measure the user's performance?	Software developers; Surgical trainees
Usability	Is the system easy to use?	Surgical trainees
Content Validity	How closely does the simulator replicate the surgical task?	Expert surgeons
Construct Validity	Can the systems differentiate the performance of novices from experts?	Novices, surgical trainees and expert surgeons
Teaching Effectiveness	Do trainees learn from it? (What are the intended and unintended learning outcomes?)	Studies with surgical trainees
Skills Transfer	Do skills learned on the system transfer to real practice?	Studies with surgical trainees
Curriculum Integration (Field Studies)	What are the costs and benefits of using the system in a training program? E.g., does use of the simulator reduce overall training time/duration?	Training Program Directors Certification Board Directors

Table 5.

Acquisition of Eye-hand Coordination Skills. Performances and learning curves of novices using a physical (box) simulator with camcorder-generated, image-guided tasks. The subjects were instructed with demonstrations before their first bi-weekly sessions and were isolated from interruptions. Results (Performance Time, seconds ± SD) were obtained from videotaped sessions. Self-described video game players had shorter performances during the first two sessions than non-players; both were equally proficient during the third session and thereafter. Unpublished data from reference 34.

Task One: Grasping and transferring pins (8) – modified Purdue pegboard					
	First session	Third session	Eighth session	Percent change	Probability
Controls (n=15)	116±47	0	84±31	28	n.a.
Experimental (n=14)	116±54 –	63±30 –	– 44±8	46 62	0.004 0.001
Task Two: Stretching, positioning rubber bands (12 pegs) into prescribed shapes					
Controls (n=15)	76±34	0	46±12	41	n.a.
Experimental (n=14)	56±19 –	39±1 –	– 31±14	30 45	0.01 0.001
Task Three: Placing a pre-tied 2-cm loop-suture onto a foam tube and cutting a 1-cm distal segment of tube					
Controls (n=15)	127±45	0	114±44	10	n.a.
Experimental (n=14)	141±35 –	108±39 6th session	– 86±23	23 40	0.006 0.001