Video Trainers, Simulation and Virtual Reality: A New Paradigm for Surgical Training

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"*We need a system, and we shall surely have it, which will produce not only surgeons but surgeons of the highest type, men who will stimulate the first youths of our country to study surgery and to devote their energies and their lives to raising the standard of surgical science.*"

William S. Halsted (1852–1922)

William S. Halsted established an educational system of graded learning in which surgical postgraduate trainees would, over time, do more and more of an operation as their training progressed. The apprentice model has been in place ever since, but economic pressures and work hour limitations have competed to hurry training along. A popular surgical adage is "see one, do one, teach one", and under this model, trainees after very limited experience would be empowered to perform procedures on patients.

The apprentice model may no longer be working. The National Academy of Science in 1999 and its publication *To Err is Human* noted that approximately 98,000 deaths occur each year due to medical error.[1] In fact, they identified error in the performance of an operation as one of the many causes of mortality. The Institution of Medicine further challenged that alternative methods of surgical training needed to be developed.

The cost of training is not cheap. Bridges et al broke down the financial impact of teaching surgical residents in the operating room.[2] In 9,733 cases with residents versus 4,719 cases without residents, they found that cases with residents took an additional 12 minutes per case. In their analysis, they charged US$4.29/minute and assumed 1,014 US residents. The cost to society was US$53 million per year to train surgical residents in the operating room. No wonder as we scrutinize costs in the operating room, the most expensive "instrument" seems to be operative time.

Halsted's apprentice model of graded learning seems to work with general surgery in that trainees begin by making the incision, tying a knot, tying a series of knots and then performing simple procedures and eventually complex operations. However, these "open" hand skills are not transferable to laparoscopic procedures. The master "open" general surgeon may not be able to perform the most basic of laparoscopic procedures safely. Laparoscopy uses fixed ports with elongated instruments. Laparoscopy lacks the same tactile feedback and often uses a two-dimensional visual system. Tying a traditional two-handed knot does not mean that the surgeon can tie an intracorporeal laparoscopic knot. So simply waiting for a junior resident to become a senior resident does not mean that they would then have the ability to perform laparoscopic surgery. Learning these techniques in the operating room may also prove too costly to the hospital; therefore, new techniques and ideas about how to train surgeons had to evolve.

The laparoscopic revolution began in 1987 with laparoscopic cholecystectomy. In the early 1990s, thousands of surgeons began to embark on this new field. Most surgeons would take a weekend course which included operating on a pig before bringing the new instruments into the operating theatre for their next case. Unfortunately, the rate of common bile duct injuries increased five-fold as surgeons not expert in these techniques took on new

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approaches and technologies.[3] As surgeons mastered basic laparoscopic operations such as cholecystectomy, they began to challenge their skills unchecked with more and more difficult operative procedures such as laparoscopic gastric bypass, laparoscopic colectomy, and laparoscopic oesophagectomy. Minimally invasive surgery was here to stay, but we still needed better ways of teaching our surgical trainees.

In 1997, we asked whether one could teach and practice skills outside the operating room; thereby, making our operative time more efficient and our operations safer. Working with industry, we developed the team video trainers. Groups of surgical trainees could come to the skills lab and hone their laparoscopic skills using inanimate models.[4,5] While the literature had many examples that training on inanimate models improved performance on inanimate models,[6] never before had the outcome of classroom training been studied in the operating room. We hypothesized that intense training on inanimate models could actually improve operative performance. At the University of Texas Southwestern Medical Center, we tested 2nd (PGY2) and 3rd (PGY3) year surgical residents in the skills lab and in the operating room.[7] All trainees ($n = 22$) were pre-tested performing a set of tasks on the video trainers and were evaluated while assisting on a laparoscopic cholecystectomy. Half the trainees were formally trained in the skills lab by practising 30 minutes daily for 10 days. The other group had no formal additional skills lab training. At the end of 1 month, all PGY2 and PGY3 residents were again tested in the video trainer as well as during their performance of a laparoscopic cholecystectomy. The five tasks included the checker board, bean drop, triangle move, run rope, and endostitch (Figure 1). Performance of a laparoscopic cholecystectomy was assessed by surgeons blinded to whether or not the residents had trained in the skills lab using a Likert

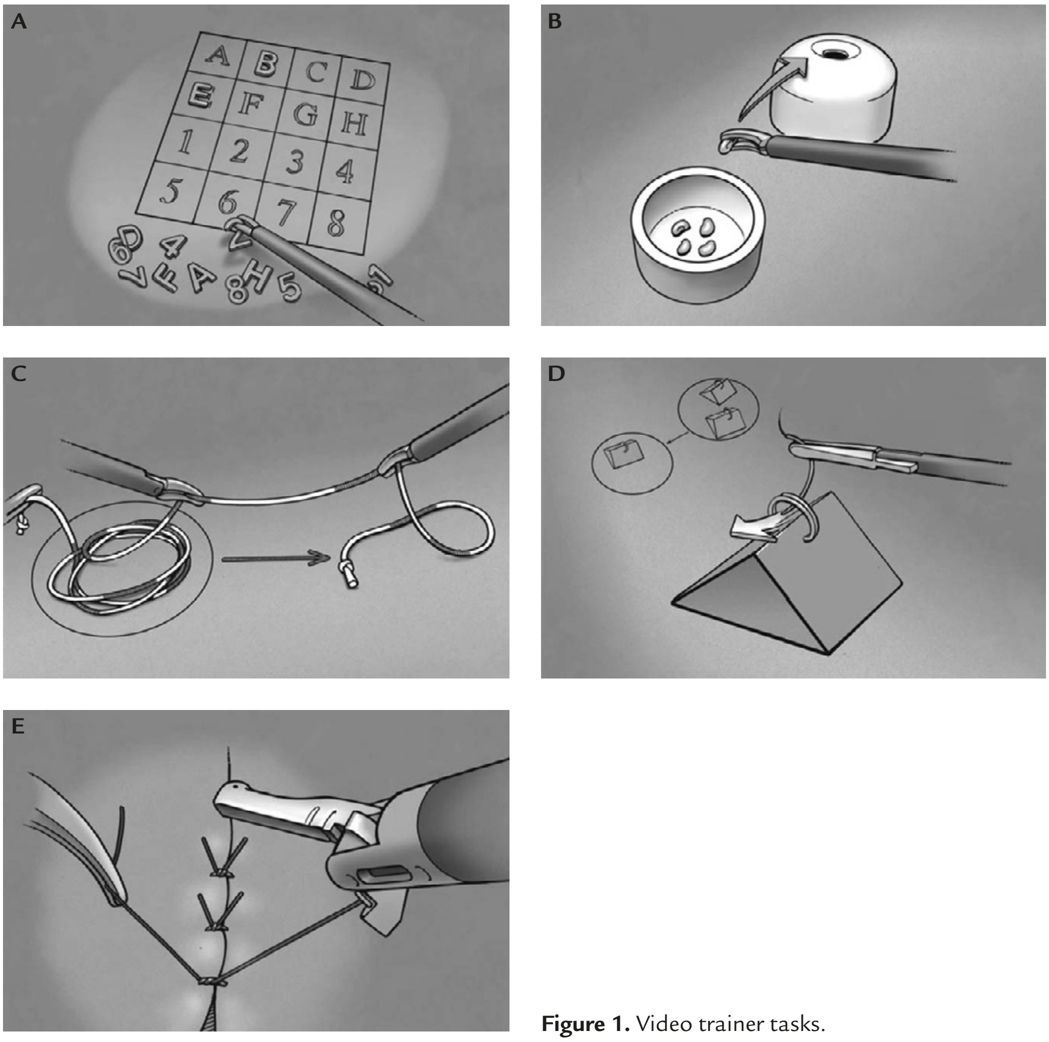

Figure 1. Video trainer tasks.

scale: (1) respect tissue, (2) time and motion, (3) instrument handling, (4) knowledge of instruments, (5) flow of the operation, (6) use of assistants, (7) knowledge of specific procedure, (8) overall performance. As expected, trainees who had practised on the video trainer improved their task performance on the video trainer compared to those who had not formally trained in the skills lab. This was no surprise as we all know that practise on a game improves performance. More importantly, this study demonstrated that operative performance also improved after training. Specifically, there was significant improvement compared to controls with regard to respect for tissue, time and motion, instrument handling, use of assistants, and overall performance. There was no difference in knowledge of instruments, flow of operation or knowledge of specific procedure; this result further strengthens the study as none of these performance criteria were being taught on the video skills. For the first time, we had demonstrated that practising skills outside the operating room improved operative performance in the operation room. Multicentre studies demonstrated construct validity of these same video trainer tasks.[8]

How early in one's training should we use simulators? To help answer this question, the study was repeated with 2nd year medical students as well as 2nd and 3rd year surgical residents.[9] All participants were pre-tested on video trainers, trained for 30 minutes each day for 10 days, and then again assessed using the video trainers. What we found for all five tasks is that, on average, medical students showed the greatest improvement in task performance. We also found that after 30–35 repetitions on these tasks, most residents had achieved a plateau in their task performance (Figure 2). This study suggested that beginning training as early as medical school may have benefit and that many of these tasks should be performed over and over. What we did not know is whether our medical students performed better because they were more rested than the residents or whether they had some innate ability acquired, say, from video-gaming that gave them an advantage. It was also possible that our residents had more distractions and concerns with floor management during the time of their testing and therefore did not perform as well. Or maybe the medical students just rushed through the task without any concern to the precision given to the skills.

To get a handle on the importance of precision, we introduced the Minimally Invasive Surgical Trainer Virtual Reality (MIST-VR). These are essentially computers that assess motions of both the left and right hands. Task completion time, error, economy of motion and economy of diathermy are measured. To asses whether this precise feedback to the learner was advantageous, we compared the video trainer to the MIST-VR trainer.[10] Interns and PGY2 residents ($n = 50$) were randomized to training and no training. All participants were pre-tested in both video trainer skills and virtual reality skills. All PGY2 residents were assessed in their performance on a laparoscopic cholecystectomy. Residents randomized to the video trainer practised 30 minutes daily for 10 days. Residents randomized to the MIST-VR trained in the MIST-VR for

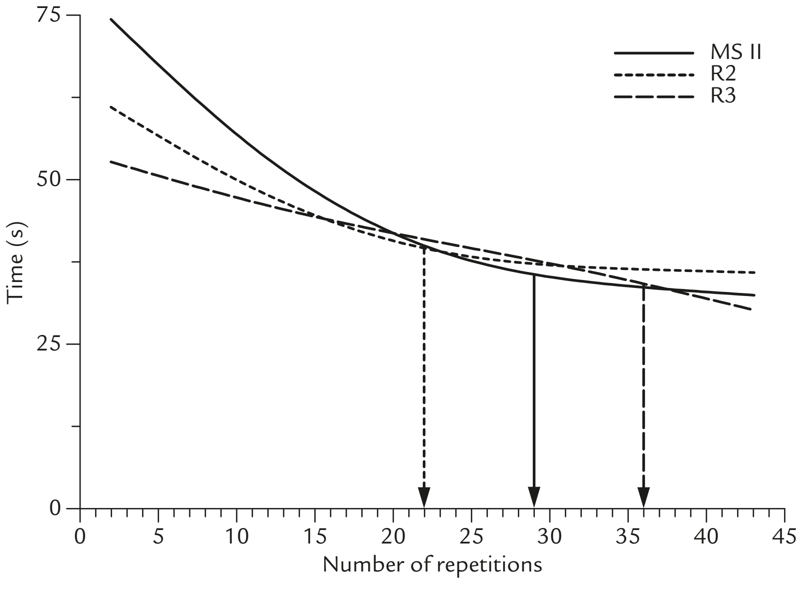

Figure 2. Medical student (MS II) and 2nd (R2) and 3rd year (R3) surgery resident average task performance times for bean drop. Plateaus occur after approximately 20 repetitions for this video trainer task.

30 minutes daily for 10 days. Afterwards, all participants were assessed in their performance of both video trainer and the MIST-VR. Furthermore, PGY2 residents were compared during their performance of a laparoscopic cholecystectomy. We found that residents who had practised in the video trainer improved in the video trainer but they also improved to a lesser degree in the MIST-VR. Likewise, residents who trained on the MIST-VR performed much better on the MIST-VR post-test but also to a lesser degree improved their video trainer skills. This suggested that no matter which training modality you were trained on, these new abilities transferred to the other training modalities. But when it came to which modality improved operative performance, the MIST-VR proved more beneficial. Immediate feedback with the emphasis on precision of the left and right hand had a greater impact on operative performance then did end points of "time" alone. Other studies have furthered our understanding of a skills-based curriculum and confirmed that training on models, video trainers, and simulators can improve operative performance and decrease error.[11–23]

The ability to measure error in the MIST-VR has been used to assess the effects of sleep deprivation on task performance.[24] In this study, we tested residents on trauma service pre-call and post-call using the MIST-VR. Residents were asked how much sleep they had achieved the night before and subsequently, their level of fatigue. Pre-call residents averaged about 6–7 hours of sleep, and post-call, they had less than 2 hours of sleep. Those residents pre-call recorded fatigue at a level of 2; however, post-call they recorded subjective fatigue score of 7 (maximum score is 8). The study found that the time to complete the task in the MIST-VR was not significantly different between pre-call and post-call. However, the number of errors reported post-call when residents were fatigued were more than pre-call when residents were rested. This was the first time in the surgical literature that sleep deprivation was correlated with errors in performance.

Practising specific skills improved task performance in the operating room, but we had not demonstrated that we had taught content of an operation. We next developed the laparoscopic TEP hernia simulator and curriculum.[12] The model was a replica of a pelvis that allowed the performance of a laparoscopic hernia repair (Figure 3). The model itself was first casted from a cadaver and refined by an artist in the operating room at Parkland Hospital. The multimodality curriculum included: (1) the TEP simulator, (2) TEP operative video, (3) interactive CD-ROM. The model's insert clearly visualizes the pubis, the Cooper's ligament, iliopubic tract, the epigastric vessels, the femoral, direct and indirect hernias as well as relevant anatomy of the iliac vessels and vas. Trainees insert the dissecting balloon via the port, expand the preperitoneal space, fold and pass the mesh, and tack the mesh to the pelvic floor. When the model's insert is removed, the tacks can be inspected for location and proximity to critical anatomy. In this study, PGY3 and PGY4 surgical residents ($n = 21$) were evaluated while assisting on a laparoscopic hernia repair. Half the group underwent formal training 30 minutes daily for 10 days, which included use of the model, watching an edited video of a laparoscopic hernia, and use of an interactive CD-ROM. The other half of the residents received no additional formal training during their general surgery rotation. Afterwards, all residents were post-tested in the operating room performing a laparoscopic hernia repair. Not only did residents who were trained show significant improvement in time and motion, flow of the operation, use of assistants, and overall performance, but for the first time, we demonstrated in the operating room increased knowledge of the specific procedure. Training in a simulated environment not only improved task performance, but also knowledge.

Figure 3. Laparoscopic hernia simulator.

Currently, at the Carl J. Shapiro Simulation and Skills Center (SASC) at the Beth Israel Deaconess Medical Center (BIDMC), we use models, video trainers, simulators and simulation to train Harvard medical students, Boston surgical residents, and community doctors. Video-eye-hand skills are taught with the bean drop, triangle move and intracorporeal suturing. Laparoscopic hernia anatomy is best taught with a model, and the internet-based tutorials guide our students through basic surgical suturing

Figure 4. Simulation of laparoscopic cholecystectomy allows trainees to practise the entire procedure.

techniques. Other models include laparoscopic common bile duct, laparoscopic ultrasound simulator, upper and lower endoscopy simulator, and virtual reality cholecystectomy simulator (Figure 4).

The skills lab boasts a video education library that maintains edited videos from the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and from the American College of Surgeons (ACS). These videos serve as an easy reference prior to an operation. We also use the video library for a monthly video conference, which focuses on operative technique and management. Harvard medical students will use models and videos during their gross anatomy course to correlate with their anatomy sessions. Real-time video broadcast of operations further emphasize the clinical relevance of the anatomy of the neck, abdomen and pelvis.

Junior trainees master basic laparoscopic skills in video trainers and simulators. Trainees have protected time each week free of clinical responsibilities to practise in the skills lab with one-on-one instruction. Furthermore, residents have key access 24-7 to the skills lab to practise. As skills develop, trainees are challenged with more complex tasks such as laparoscopic cholecystectomy in a virtual environment. In this environment, the learner may have to deal with bleeding or ductal injury, interpret simulated cholangiography images, and manage disease.

Central to the skills lab is the teleconferencing room from which we can link to the other skills centres throughout the United States, and we do so on a monthly basis. During educational programmes for community doctors, the teleconference centre is also a place for broadcasting operations from our MIS endosuites to our learners in the skills lab. As we look to the future and to our skills lab, we believe that there will be a stronger role for teleproctoring and teleconsulting using teleconferencing[25] and web-based technology. In fact, teleproctoring cameras and monitors already link offices and the skills lab to the operating room at BIDMC so that junior surgeons can consult with expert surgeons. While it is difficult to anticipate what the operating room of the future will become, clearly robotics will play a role and arguably should be part of any regional skills centre. The SASC has recently undergone expansion with a mock ICU and mock operating room so that the entire operative team can build communication skills and practise crisis scenarios.

The Residency Review Committee has stated that all general surgery residencies should have access to a basic skills lab by 2008. Moreover, the ACS has established specific criteria for learners, curriculum, personnel and resources for centres seeking ACS accreditation as a Comprehensive Education Institute (Level 1) or a Basic Education Institute (Level 2). For example, the Comprehensive Institute must provide education to at least three different learner groups (physicians, residents, medical students, nurses, allied health professionals) in addition to surgeons. Activities would include: collaboration with other centres, curriculum development, expansion of practice, interdisciplinary training, introduction of new skills, long-term follow-up of learner, maintenance of skills, team training, and remediation of practice. The curriculum should incorporate psychomotor and cognitive skills, and the facility should accommodate at least 20 trainees in no less than 1,200 contiguous square feet. An additional 4,000 square feet would accommodate conference rooms, storage, vivarium, teleconferencing and offices. The Basic Education Institutes would require less space, personnel and resource commitment, but would have explicit educational goals, appropriate models and simulators to meet learning objectives, and a formal assessment of educational programmes. A variety of different models and simulators exist, and the ACS will inventory resources to facilitate collaboration between institutes (Table). In 2006, the ACS and Association of Program Directors have initiated a working committee to establish a skills-based 5-year curriculum for all surgery trainees.

As an ACS Level 1 accredited Comprehensive Education Institute, we envision our centre not just as a regional resource for learning but also for testing proficiency. For example, in the field of minimally invasive surgery, the

Table. Types of educational models and simulators that the American College of Surgeons will inventory in Education Institutes

Airway model	Operating microscope
Anaesthesia simulator	Promist
Bench models	Prostate model
Breast model	Pelvic model
Devices used to do open procedures	Trauma Man
Inguinal hernia model	Simulators
Laparoscopic cholecystectomy simulator	Ultrasound simulator
Lower endoscopy simulator	Upper endoscopy simulator
Mirrors	Urology simulator
Mirror trainers	Ventral hernia model
MIST-VR	Video trainers

MIST-VR = minimally invasive surgical trainer virtual reality.

SAGES/ACS Fundamentals of Laparoscopic Surgery (FLS) examination uses video trainers to assess laparoscopic dexterity as well as a written examination to test understanding of the principles of port access, physiology of the pneumoperitoneum, procedures and safe use of energy devices. Beta test sites for FLS has demonstrated that the FLS examination does in fact assess competency in laparoscopic surgery.[26] To date, the FLS has been required of the SAGES Board of Governors, and FLS is soon to be required of surgeons of the United States military. At BIDMC, all PGY4 residents must pass the FLS examination become entering their chief year of surgical residency, and all faculty of the Section for Minimally Invasive Surgery have completed the FLS examination. Next, we plan to establish FLS as a new minimum standard for credentialling of laparoscopic privileges at BIDMC for all surgical specialties. Undoubtedly, the Comprehensive Education Institute will play an even greater role in assuring competency across all learner groups and surgical specialties in the years ahead.

In summary, minimally invasive surgery has become the new standard of performing abdominal procedures. Inanimate models, simulators, virtual reality, and ultimately robotic technology will likely better prepare our medical students and surgical house officers. The ACS has taken the lead in establishing an accreditation of both the basic skills lab and Comprehensive Education Institute for the introduction, maintenance, and remediation of new skills. Surgeons currently in practice will need to demonstrate skills in validated simulators to maintain their credentials in hospitals.

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