Simulators in surgery

FREDRIK H. HALVORSEN, OLE JAKOB ELLE & ERIK FOSSE

The Interventional Centre, Rikshospitalet, Oslo, Norway

Abstract
The introduction of minimally invasive surgery has demonstrated the need for training surgical skills outside the operating room using animal models or simulators. As laparoscopic surgery involves displaying images on a screen, virtual reality simulation of the surgical tasks is feasible. Different types of simulators have become available. The existing trainers can be divided into three groups: mechanical, hybrid, and virtual reality. This article aims at giving an overview of the different simulators available and the potential of simulators in the education of surgeons with focus on virtual reality simulators. All simulators aim at training psychomotoric skills and some simulators also allow training in decision-making and anatomical orientation. In the future virtual reality simulators may become a tool for training and validation of surgical skills and monitoring the training progress.

Key words: Laparoscopy, simulators, virtual reality

Introduction
The traditional method of learning technical skills in surgery has been based on the Halstedian principle of “see one, do one, teach one” (1, 2). This method may work in open surgery where the apprentice can directly observe the surgeon’s hands, the instruments, and the results of manipulation. In endoscopic surgery this method may not work as well, as the results of manipulation are transferred to a screen and can not be observed simultaneously with the surgeon’s hand movements (3). Endoscopic surgery requires other skills than open surgery, like spatial orientation, work with long instruments with reduced tactile feedback, manipulation in a 3D environment visualized on a 2D screen, and the obstacle of the fulcrum effect and degradation of image quality (4, 5). In addition to this the “degrees of freedom” (DOF) are reduced from six to four.

On the other hand, as laparoscopic surgery involves working with images on a screen with instruments that are manipulated outside the line of vision, the introduction of simulators in training is facilitated. This is also the case for radiology guided interventions.

Within the last decade a number of simulators with varying complexity for different medical professions have become commercially available within almost all medical fields. Thus simulators can be used for training in interventional radiology, surgery, internal medicine, life support, ear-nose-throat or eye surgery. The simulators can be divided into three groups depending on the type of technology used: Mechanical, hybrid, or virtual reality.

Mechanical simulators are boxes in which objects or organs are placed and manipulated using surgical instruments. Visualization is achieved by using a digital camera or a laparoscope and a screen. The quality of the tactile response using these simulators is the same as in the operating room. If the performance is to be evaluated, an experienced surgeon must observe the trainee and give feedback as there is no inherent registration of performance. The simulator must be reassembled between training sessions.

A hybrid simulator is similar to a mechanical simulator in that it uses a box with objects or organs. In addition the performance is monitored by a computer which is able to give guidance on how to perform the tasks and objective feedback to the trainee based on preprogrammed metrics. Thus, an experienced surgeon is not mandatory.
in order to give the trainee feedback. These systems also give the same tactile feedback as actual surgery. They require reassembly between training sessions.

Virtual reality is defined as a collection of technologies which allow people to interact efficiently with 3D computerized databases in real time using their natural senses and skills (6). Virtual reality simulators use computer-generated images of organs or objects linked to a human computer interface allowing the trainee to manipulate the images and to get objective feedback on the performance from the computer. Reassembly between training sessions and storage of organs is not necessary. Tactile response can be simulated, but not fully recreated, using force feedback interfaces, and the quality of the graphic design is still not able to recreate every aspect of real life (7).

This article focuses on mechanical, hybrid and virtual reality simulators aiming at educating surgeons in laparoscopic surgery with focus on virtual reality simulators.

Simulators

Mechanical laparoscopic simulators

The LapTrainer with SimuVision (Simulab Inc., Seattle, Washington, USA, www.simulab.com) is a box trainer with a simulated laparoscope (SimuVision) using a boom mounted digital camera in an open box trainer (Figure 1). The camera head can be adjusted to create 0°, 30° or 45° scope angles and can be plugged into a laptop using a USB 2.0 port. The camera allows the user to reposition the field of view within the operative cavity and zoom in on the operative site. Simulab has bundled four standardized exercises ranging from basic to more advanced laparoscopic skills aimed to develop coordination, technique, and precision. These tasks were developed for use within Simulab’s LapTrainer with SimuVision providing students and instructors with a practice/teaching environment outside the operating room. Skills set includes one pegboard pattern, one key trainer, two suture pads and one large intestine which can be placed in the box trainer.

URobotics Lab (Johns Hopkins University, Baltimore, Maryland, USA, urology.jhu.edu/urobotics) has developed mechanical simulators and a set of experiments for laparoscopy training and evaluation providing quantifiable scales of dexterity. Three different training devices put increasing demand on the surgeons’ skills by a step-by-step strategy that addresses the different components of difficulty in performing instrument maneuvers. The first stage is an inverted manipulation training device for laparoscopy under direct (3D) vision (Figure 2). Training objects or organs can be visualized directly as well as the instrument movements. Stage two is a closed “pelvic trainer box” for training of inverted movements under regular 2D-vision on a screen. To make a more natural bridge from the box-trainer to a real surgical case, a third step mechanical simulator (Lapman) has been developed as a high-fidelity synthetic torso with realistic anatomical properties. Animal or synthetic organs can be put into the thoracic or abdominal cavity, and a pump is connected to the torso to make respiratory movements. The group has also used the experiments and early step trainers to evaluate the performance of robot-assisted versus manual laparoscopy. A set of experiments has been performed with the Zeus (Computer Motion Inc., Goleta, CA, USA) tele-manipulator system to compare its performance with the manual approach.
The experiments showed no improvement in surgeon performance using the system (8).

**Hybrid laparoscopic simulators**

The ProMIS (Haptica Inc., Boston, Massachusetts, USA, www.haptica.com) is a hybrid simulator combining a box simulator and a computer; it aims at training basic skills including suturing and knot-tying (Figure 3) (9). Real instruments passed through ports enable manipulation of physical objects in a box simulator and provide real haptic feedback. ProMIS analyses performance by tracking instruments in 3D space. The key measures are time, path length, and smoothness - the degree to which movements are fluid or erratic. The simulator assesses the student’s performance and compares it to a defined proficiency level.

**Interface devices and virtual reality laparoscopic simulators**

The Laparoscopic Surgical Workstation (with force feedback) and Virtual Laparoscopic Interface (without force feedback) (Immersion Inc., Gaithersburg, MD, USA, www.immersion.com) are hardware interfaces with software enabling tracking of the instruments for use in conjunction with virtual reality surgical simulator software (10) (Figure 4). The Phantom devices (SensAble Technologies Inc., Woburn, Massachusetts, USA, www.sensable.com) are hardware interfaces and have both three and six degrees of freedom force feedback capabilities (Figure 5). The Phantom Premium 1.5 is used in conjunction with virtual simulators to provide the trainee with realistic physical feedback (11, 12). SensAble Technologies offers software toolkits and haptic application development such as the Open Haptics™ toolkit, which enables software developers to add haptics and 3D navigation to the actual application, and the GHOST® SDK, designed for developers who have haptics knowledge and who need a software development kit (SDK) with a built-in scene graph.

The Xitact LS500 Laparoscopy Simulator (Xitact S.A., Lausanne, Switzerland, www.xitact.com) is a
modular virtual reality simulation platform with software for training and assessing the performance of laparoscopic procedures, particularly cholecystectomies. It incorporates training of basic suturing skills, a clip-and-cut task and a peritoneal dissection module for opening Calot’s triangle (13). According to Schijven and Jakimowicz this simulator is a hybrid, combining laparoscopic instruments and a mechanical abdomen with a computer providing the virtual reality scenery and haptic feedback (14). Xitact provides a haptic interface table-top model available as a tracking-only device (ITP) and a force-feedback enabled system (IHP) (Figures 6 and 7). The Xitact LS500 system is an open platform, and is compatible with software from laparoscopic surgery simulation vendors, some of which resell the LS500 with their own software. Some validation studies of the Xitact Laparoscopy Simulator have been performed (13, 15).

Lapmentor (Simbionix Inc., Cleveland, Ohio, USA, www.simbionix.com) is a virtual reality simulator and hardware with optional force feedback (using hardware from Xitact LS500) and aims at training both basic and advanced laparoscopic skills including knot-tying and laparoscopic procedures (laparoscopic cholecystectomy) with varying anatomy (Figure 8). It also aims at training medical and operative decision making, physiological and medical knowledge, as well as team work.

Surgical Education platform (SEP) (SimSurgery, Oslo, Norway, www.simpsurgery.no and Medical Education Technologies Inc., Sarasota, Florida, USA, www.meti.com) is a virtual reality simulator with both hardware and software aiming at training port placement, camera navigation, basic skills including suturing, knot-tying and tissue dissection,
procedures, knowledge and judgment by seamless integration with multimedia (Figures 9 and 10). It can assess the students based on specific metrics and compare the performance to preformed proficiency criteria levels. The software technology platform for 3D simulation provided by SimSurgery is suitable for interaction with deformable objects and is licensed by several other companies (16).

_LapSim_ (Surgical Science Lmt., Gothenburg, Sweden, www.surgical-science.com) is a virtual reality simulator with hardware from third parties (Immersion (17) or Xitact (15) (Figure 11). It includes basic skills including suturing exercises and procedure-oriented tasks for laparoscopic cholecystectomy and gynecology (17). LapSim utilizes 3D technology, including interactive live video, aiming at providing the trainee with a realistic virtual working environment. The simulator can provide force feedback with the proper hardware.

_Procedicus MIST™_ (Mentice AB, Gothenburg, Sweden, www.mentice.com) is a virtual reality simulator with hardware from Immersion aiming at training basic skills including suturing and knot-tying technique. The system comprises a frame holding two standard laparoscopic instruments electronically linked to a low-cost personal computer (Figure 12). The screen displays the movement of the surgical instruments in real time 3D graphics. Trainees are guided through a series of tasks of progressive complexity, aiming at developing the skills essential for good clinical practice. Each task is based on a key surgical technique employed in laparoscopic cholecystectomy, using simple geometrical shapes rather than tissue to allow the trainee to concentrate on the development of key psychomotoric skills (Figure 13). Left and right hand repetitions are also employed to encourage ambidextrous working. The simulator is able to assess the students using specific metrics. MIST™ was one of the first simulators on the market (18) and it is the quantitatively most validated simulator.

_EndoTower_ (Verefi Technologies Inc., Elizabeth-town, Pennsylvania, USA, www.verefi.com) is a virtual reality simulator software with hardware from Immersion aiming at training laparoscope navigation for 30°, 45° or 70° scopes. The EndoTower surgical simulator uses a digital virtual environment to provide instruction in surgical navigation using an angled laparoscopic lens/camera combination. The
task for the EndoTower trainer entails identifying randomly placed arrows in the virtual EndoTower (Figure 14). EndoTower records metrics such as the time it takes to find all the arrows, number of redouts (i.e. when the lens touches the tower and gets smudged with virtual blood), percentage of time the camera is off of level orientation, and total length of the path the user followed while searching for the arrows. Validation studies have been performed (19).

Reachin Laparoscopic Trainer (Reachin Technologies AB, Stockholm, Sweden, www.reachintech.com) is a virtual reality simulator using either the Laparoscopic Surgical Workstation from Immersion or Phantom devices from Sensible Technologies as hardware interface. It aims at training basic dexterous and advanced skills and laparoscopic procedures (laparoscopic cholecystectomy). The system aims at assessing the trainees through different training courses with varying difficulty levels. The simulator movements are recorded to make it possible to measure the progress. The system has web access for administration and pre-training. Reachin Core Technology aims at providing a software and
hardware platform for building general haptic applications. This is mainly achieved through a software interface (Reachin API) that lets the user model 3D graphics and force feedback models on the same software platform and a dedicated hardware setup (Reachin Display). This is a display system that integrates force feedback devices with stereo monitor and supporting components. A mirror is used to create an interface where graphics and haptics are co-located so that the user can see and feel the object in the same location (Figure 15).

**Vest System (Virtual Endoscopic Surgical Trainer)**
(Select-IT VEST Systems AG, Bremen, Germany, www.select-it.de) is a virtual reality simulator consisting of software and hardware (Figure 16). The KISMET simulation software is used for the real-time interaction between deformable objects and instruments and the manipulation of the virtual tissues as well as the interaction between rigid objects and instruments. As a surgeon-computer interface, a “Trainer Input Box” (TIB) is used as an artificial cavity together with the correct instrument set, maintaining the environment of a laparoscopic operation. Inside the box, mechanical guidance systems are used for each instrument and a camera with specially modified Laparoscopic Impulse Engines (LapIE) providing force feedback. Two foot switches are implemented providing surgical (coagulation) functions. The system aims at training both basic laparoscopic skills (20) and laparoscopic procedures such as gall-bladder removal (laparoscopic cholecystectomy) and laparoscopic surgery in gynecology. The performed task or procedure is recorded and special events can be viewed after the session.

**Simendo (Simulator for endoscopy)**
(DeltaTech, Delft, Netherlands, www.simendo.nl) is a virtual reality simulator consisting of hardware and software aiming at training basic eye-hand coordination and 30° laparoscope navigation. The software can be installed on a regular PC to which the hardware, two joysticks resembling laparoscopic instruments, can be connected. New exercises for the simulator can be downloaded from the internet.

**Discussion**
Box trainers for laparoscopic surgery were introduced as an alternative to training on animals. The vendors of disposable tools for laparoscopic surgery built training facilities where surgeons could train both on animals and in box trainers. Training facilities outside industry have become more common both as independent institutions and in hospitals.

The use of animals, box trainers and hybrid trainers invariably requires some organizational logistics due to legal and ethical factors as well as for technical reasons. Even a box trainer requires acquirement of organs and setting up of the system by an experienced technician. The advantage of box and hybrid trainers is that the tactile response is the same as in real laparoscopic surgery and the real organs allow training not only of dexterity, but also of decision-making and orientation in the anatomy. The advantage of hybrid trainers compared to box-trainers is that they can provide the trainee with feedback on both scores and guidance on how to perform the task.

Pure virtual reality trainers do not require the logistics necessary for mechanical trainers.
One of the simulators, the Xitact LS500 Laparoscopy Simulator, has been categorized in this paper as a virtual reality simulator. Schijven and Jakimowicz describe this simulator as a hybrid because it combines laparoscopic instruments and a mechanical abdomen with a computer providing the virtual reality scenery and haptic feedback (15). Compared to the ProMISTM simulator (9), which uses physical objects in a trainer box, Xitact has virtual objects and organs to manipulate.

A number of well-designed studies comparing the performance results of experienced laparoscopic surgeons and novice laparoscopic surgeons on virtual reality simulators show that the experienced surgeons score better than the novice surgeons (4, 26–28), indicating that virtual reality simulators are valid tools for the assessment of surgical skills.

Although studies have been performed to demonstrate increased operating skills by simulator training, there is no real proof of such an effect. Arnold et al. concluded in a review article in 2002 that the reason for this could be a lack of studies based on learning theories (29). So far most published studies are small and there are differing conclusions.

A study presented by Seymour et al. (30) claims to show that virtual reality training improved operating room performance. Although this study demonstrated increased skills in the virtual reality group the conclusion is uncertain as the difference between the groups may have been present but not detected prior to the training period, and the group received training in the operating room in addition to simulator training.

Hyltander et al. (31) also concluded that virtual reality simulator training improved operating room performance, but they did not include a practical test prior to training.

Grantcharov et al. (32) found similar results in a randomised study which included a similar test prior to and after training, but the study was uncontrolled and the study population consisted of only 16 subjects.

Ahlberg et al. (33) found that virtual reality simulator training did not improve operating room performance. However, the training period in this study was limited to two training sessions. None of the studies were based on learning theories.

In a study on training robot assisted suturing skills with the Zeus robot comparing one group of medical students going through a training program with actual robotic suturing with another group training on the SimSurgery virtual reality simulator with a Zeus interface demonstrated any preparation by a technician the surgeon can train on the simulator. This opens for a flexible approach to training, where the logistics of a large training centre is no longer required. As price comes down every surgeon in training could have a simulator in his office and train skills whenever it fits his time schedule.

Since the idea of using virtual reality simulators in the education of surgeons was proposed in the early 1990’s (21), a number of simulators have been produced and an increasing number of studies performed focusing on validating the use of virtual reality simulators in education.Virtual reality simulators hold a great potential in the education of healthcare professionals. They offer an available learner-centered environment where skills, knowledge, and judgment can be assessed, taught and trained repeatedly, feedback given without the presence of a teacher and mistakes done without any risk to patient safety (22, 23), thus improving operating room performance and patient outcome.

The main obstacle to virtual reality trainers has been the lack of computer graphics power. To simulate e.g. the random movements of a thread or a realistic bleeding requires advanced mathematical simulations and graphics. Thus, the most successful trainers during the first years were trainers that focused on abstract figures. The skills were trained by moving cubicles or cutting off edges of squares etc. (18). There is little doubt that dexterity and spatial orientation can be trained by manipulating instruments in an abstract setting. To train specific basic surgical skills (i.e. knot-tying, suturing, dissection etc.) or complex surgical procedures in a realistic setting more advanced graphics and simulation models are needed. Today the graphical obstacles are being overcome and some of the new systems give a realistic graphical image. Thus the modern virtual reality trainers not only train psychomotoric skills, but also give the possibility to train decision making. This is important as only 25% of a skillfully performed operation is related to psychomotoric skills, the rest is attributed to making the right decisions (24). On the other hand, a surgeon without the necessary technical skills per se is considered incompetent. Therefore most of the surgical simulators still focus on psychomotoric skills and/or specific technical skills.

A virtual reality simulator should be able to both train and assess technical skills since the two are interrelated. Both assessment and feedback require specific metrics, and a number of such have been suggested by Satava et al. (25).

All the hybrid and virtual reality systems described above have some sort of monitoring performance.
identical increase in skills between the two groups. Both groups had a similar test before and after the training program. Thus we concluded that the learning effect of the virtual reality simulator equaled actual robotic suturing (34). The study did not, however, evaluate operating room performance.

At the moment there is no standardized way to validate simulators before using them in the education of surgeons. Comparison of the different simulators by using the literature is therefore difficult (25).

The virtual reality simulators all have some possibility to register technical skills, for example by registering the number of hand movements required to perform one stitch or the time that is used. Virtual reality simulators thus have the potential to be used in regular assessment of surgical skills and to be used in recertification of surgeons analogous to the certification practice of commercial pilots. When validating these simulators as assessment tools it is important to assess the reliability of the different systems (6). With time it may also be possible to assess the predictive validity, but this should be done carefully since the form of learning curves varies for each individual (35).

Surgical outcome depends on the condition of the patient, the condition of the disease and, most important, the condition of the surgeon (36). There are a number of skills needed to become a competent surgeon. They can be defined by dividing them into three groups: cognitive skills (factual knowledge, clinical judgment, decision making and the ability to think and work under stress), affective skills (motivated, compassionate, professional attitude and effective communication skills) and psychomotoric skills (perceptual motor skills and physical proficiency skills) (24, 36–38). Bloom defined the triad of competence as factual knowledge, psychomotoric skills and attitude (how knowledge and skills are combined) (39).

Since most simulators focus on training and assessing only technical skills, it is important that they become part of a total educational curriculum (40) which focuses on training all the necessary skills needed to become a competent surgeon (41), not only technical skills.

Conclusion

Virtual reality simulators have the potential to play a part in the education of surgeons (2, 22, 37, 39), and simulator training may become an integrated part of the surgical education. Simulators may also become a useful tool for evaluating skills and in recertification of surgeons. This requires systematic validation of simulators and standardization of simulator performance. Virtual reality simulators make it possible to train outside organized centres, but the actual value of simulators for training surgical skills is not fully documented although some studies exist.

References