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When Simulation in Surgical Training Meets Virtual reality

Editorial

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Abstract

For hundreds of years, apprenticeship with experts and the method of "Learning by doing" represented the gold standard for surgical education and acquisition of surgical dexterity. At the best of times, animals, cadavers and patients constituted the «surface» on which surgeons would train, but whichever the model of simulation, it was not without its disadvantages. The evolution of laparoscopic and endoscopic surgery, mainly based on monitor-image, lacked 3-dimensional image information and haptic feedback; this shortcoming, along with the difficulties in eye-hand coordination, dictated the need to seek a new simulating model.

The development of surgical virtual reality-simulators (VR - simulators) can offer a much-needed new dimension to the training of novice surgeons, students and residents by providing a safe and viable alternative. Models of a virtual patient can provide an evolved and realistic human anatomy that can simulate normal and pathological conditions in a virtual reality environment. In addition, VR-simulators can provide a structured learning environment with controlled levels of difficulty.

Training in a virtual reality environment could help surgeons to overcome the two most common difficulties in image-guided surgery: the lack of tactile and three-dimensional image information. Equally important is the training in a VR - environment, which could help surgeons avoid errors during real surgical performance. The level of transferrable learning to the operating room is acceptable.

Key words:
Simulation in Surgery, Virtual Reality, Surgical Simulator, Surgical Training, Surgical Education

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Introduction

Traditionally, novice surgeons were trained by didactic and apprenticeship experience. Animals, cadavers and patients constituted the «surface» on which surgeons would train . It would not be unreasonable for one to maintain that the performance of live-animal surgery requires highly skilled personnel. However, one should bear in mind certain important considerations: the anatomy of animals sometimes varies greatly from that of humans; use of an animal incurs increased cost; the surgical procedure in animals offers just a one-time experience and finally, the use of animals raises ethical issues. As concerns surgical training on a cadaver, this model does not offer the requisite functional response due to dead tissue; the surgeon acts with less caution and again, as with training on animals, it can only provide a one-time, costly experience of the surgical procedure in question. Finally, surgical training on patients carries the obvious risk to patient safety and is not always feasible.

In Table 1, we tabulate the factors motivating the use of alternative methods of surgical training, according to R. Barnes [1]. Establishing alternatives of surgical training, coincides and confirms the need to develop more objective methods of assessing operative skill [2]. The dictum "To Err is Human", is the best motivating criterion for building a safer health system, beginning with education, technical skill and training [3]. The inadequacies of our current system of training are scrutinized.

The methodology approach "learning by doing" demands a new strategy in training, especially in surgery.

The dawn of the era of laparoscopic surgery and the evolution of modern image-guided surgical techniques, led to the development of new models of teaching surgical technical skills and training in a safe and educationally acceptable environment. To come to grips with laparoscopic surgery techniques, ideally demands higher-level abilities, such as visual-spatial and perceptual abilities. We can consider visual-spatial and perceptual abilities as human factors that may need less or more improvement, depending on the individual. In terms of refining human input, the main goal is to improve performance, reduce errors and increase user satisfaction. Human strength and its limitations in relation to the system used should be assessed and measured. If we acquire this knowledge (of assessment and measurement), we could achieve a better design with better training results. This editorial will try to bring into the Hellenic Surgical domain, the concept of virtual reality-simulation (VR-simulation) as a practical educational tool in surgical art and science.

Table 1 Factors motivating the use of alternative methods of training

• Increasing complexity of operations
• Constraints on the use of animal models
• Limitations of available patient material
• Medicolegal pressures; must have optimal skills
• Fiscal mandates for cost-effective performance

Laparoscopic surgery and endoscopy dictated contemporary modes of surgical training

Laparoscopic surgery, the so-called image-guided surgery or minimally invasive surgery and endoscopy, has long been established among surgeons of miscellaneous specialties as an elective surgical approach in a number of surgical procedures and endoscopic interventions. Cholecystectomy, appendicectomy, hernia repair, Nissen fundaplication or anterior and posterior partial fundaplication, common bile duct exploration, adrenalectomy, nephrectomy, colectomies, gastrectomy, oesophagectomy, diagnostic laparoscopy and many other procedures, have now become common surgical procedures performed laparoscopically. Over four decades ago, several endoscopic procedures, such as colonoscopy, gastroscopy, enteroscopy and so on, were making their debut. Surgical laparoendoscopic interventions present a difficulty in their performance and a delay in learning; in some instances, the learning curve is quite high. The two main difficulties in image-guided surgery lie in the relative or absolute lack of tactile or haptic feedback, and the major difficulty to extract three-dimensional image information from the two-dimensional images seen on the monitor screen. During laparoscopy, the two-dimensional images shown on the monitor screen highlight the lack of stereo-visual information, mainly that of depth. This lack of perception of image depth can hamper eye-hand coordination [4]. All these technique-related difficulties require intensive training of surgeons and practice of skills with emphasis on 3D-orientation, eye-hand coordination and instrument handling. An example of instrument handling in laparoscopy is the well-known «fulcrum effect» [5], which entails the surgeon moving their hand to the patient's right, left or upper side, while the operating tip of the instrument is moved to the opposite side on the monitor, respectively. This means that the abdominal wall, at the point of each port, acts as a «fulcrum».

The development of surgical virtual reality-simulators (VR simulators) can offer a much-needed new dimension to the training of the novice surgeons, students and residents by providing a safe and viable alternative. Models of a virtual patient can provide an evolved realistic human anatomy, simulating normal and pathological conditions in a virtual reality environment. In addition, simulators can provide a structured learning environment with controlled levels of difficulty.

Training in a virtual reality environment could help the surgeons to overcome the two most common difficulties in image-guided surgery; the lack of tactile and three-dimensional image information. Equally important is the training in a virtual reality environment, which could help surgeons avoid errors during real surgical performance [6]. Lawrence Way and his colleagues [7], in an analysis of 252 cases, stated that almost "97% of errors leading to laparoscopic bile duct injuries stem principally from misperception, not errors of skill, knowledge, or judgment. The misperception was so compelling that in most cases the surgeon did not recognize a problem. Even when irregularities were identified, corrective feedback did not occur, which is characteristic of human thinking under firmly held assumptions. These findings illustrate the complexity of human error in surgery while simultaneously providing insights". The claim that bile duct injuries stem principally from misperception, while feasible, could also be argued as being arbitrary, since the criteria used to support it were based on a rather subjective evaluation. Nonetheless, were this claim to be considered, we could arbitrarily hypothesize that this misperception would be minimized if a strong training in a VR environment preceded the operating room performance.

The concept of simulation. Surgical simulation models.

The use of simulation in the field of surgical education was first recorded some centuries ago. Existing evidence suggests that in 2000 BC, Egyptian surgeon priests may have simulated rhinoplasty on cadavers that were being prepared for mummification [8]. In the USA, the concept of simulation derived from the primordial flight simulators. It had taken over 20 years, from late 1930 until 1955, before flight simulators were validated by the Federal Aviation Administration of USA and incorporated as a mandatory requirement for annual flight certification. Nowadays, all pilots must train and be certified in their technical skills on a flight simulator specific to the aircraft they will fly [9].

Over the last decades, surgical simulation has relied on several models of simulation. The most common of these and their properties are illustrated in table 2.

Table 2 Simulation models and their properties for surgical training

Simulation models	Major Properties
• Animal and Cadaver models	High fidelity and cost, medicolegal and ethical issues, lack of repetitiveness
• Video and web-based simulations	Low cost, repetitiveness, portability but low fidelity
• Mechanical models -Box -Mannequins	Low cost (not always), valuable for students and novice surgeons for basics in laparoscopic surgery Box-trainer and Mannequins (portability)
• Virtual reality simulations	Medium or high cost, medium fidelity, without medicolegal and ethical issues, repetitiveness, portability
• Hybrid simulation	Combination of box and VR-simulation in the same unit

By far, animal and cadaver models of simulation were the first to provide simulations of highest fidelity. However, as we have said, we cannot discount certain limitations in daily practice. A major limitation is that the animal or cadaver can only be used for simulation once for each organ. That is to say, there is an inability to repeat or reproduce simulation. Another limitation is the high cost, and of course the medicolegal and ethical questions that arise from the use of animals and cadavers. Nevertheless, I stand by my conviction that cadaver model simulation, especially Thiel's human cadaver model (preserved cadaver using a technique that conserves human tissue in a non-rigid form, similar to that found in a living human), resembles in vivo conditions and as such, is superior to any other model of simulation [10, 11].

Video and web-based simulation, unlike previous high fidelity models, offer low cost, portability of simulators and the capability to train a large number of trainees at the same time [12].

Mechanical simulators are the most widely used and are well-known for their implementation in surgical training. These simulators are not expensive. The most common type is the box trainer model that consists of a camera, a light source, a monitor and laparoscopic instruments. The instruments enter the box through a rigid or pliable interface (usually the upper-front wall of the box) representing the human body (patient). There are variations to this system, mainly with a view to reducing cost and complexity. The MISTELS (McGill Inanimate System for Training and Evaluation of Laparoscopic Skills) and the University of Kentucky (UK) programmes are both sophisticated teaching models that have been developed and validated for box-trainer skills [13, 14].The MISTELS programme comprises five skills (tasks), illustrated in Table 3:

Table 3 The five tasks of MISTELS programme

• Peg transfer
• Pattern cutting
• Endoloop placement
• Extracorporeal knot tying
• Intracorporeal knot tying

The above five tasks in Table 3 have been incorporated in the elementary education of the Fundamentals of Laparoscopic Surgery (FLS) training programme. The university of Kentucky (UK) models also comprise five-part task modules that represent the key elements to five common surgical procedures (Table 4). The FLS programme was inspired by the Society of American Gastrointestinal Endoscopic Surgeons (SAGES) in an attempt to succeed uniformity of laparoscopic training, and developed mainly by Soper and Swanstrom [15,16].

Table 4 University of Kentucky FLS training programme

• Laparoscopic cholecystectomy with intraoperative cholangiography
• Laparoscopic appendicectomy
• Laparoscopic inguinal hernia repair
• Laparoscopic bowel mobilization and enterotomy closure
• Laparoscopic splenectomy

Both MISTELS and Kentucky training programmes offer inexpensive intermediate-fidelity simulations that enable surgical trainees to practice laparoscopic skills safely transferable to the operating room. The mannequin-based simulation has been very popular in recent years [17]. These simulators are already acceptable as an effective simulation task in surgical training, especially in trauma or a difficult airway.

History of virtual reality and surgical simulation

It was Myron Krueger18 who first coined the term "artificial reality", in the 1970s, but the origin of the term "virtual reality" can be traced back to the French playwright, poet, actor and director, Antonin Artaud [19] . In his seminal book, «The Theatre and Its Double» (1938), Artaud described theatre as "la réalite virtuelle". The earliest use cited by the Oxford English Dictionary was in a 1987 article, but the article did not concern VR technology. Jaron Lanier claims that he coined the term in the early 1980s [20]; however, this was almost fifty years after it appeared in Artaud's book. Nowadays, the technology of virtual reality is utilized, among others, for training in medical specialities.

It has been nearly two decades since simulation was first attempted for surgical training in an environment of virtual reality. Three dimensional (3D) visualization on a screen, is known as virtual reality [21]. As computer power advanced, so the quality of the VR surgical simulation developed, achieving continuous progress in visual fidelity. At the same time, tactile feedback was being incorporated, step by step. These incredible early accomplishments did not escape the notice of professional organizations who realized the potential in establishing a new educational system of the surgical training. This new revolution in surgical education would change the certification process. Along with such success, came the awareness of the limitations and enormous shortcomings yet to be solved. The four most important and essential points that concern the quality of VR-simulation are: a) reliability, b) cost-effective surgical training, c) repetitiveness, and d) realistic training incorporating tactile (haptic) feedback. Until 2004, relatively little work had been carried out on haptic perception. [22].

In Europe, since 1986, the so-called software package KISMET (Kinematic Simulation, Monitoring and Off-Line Programming Environment for Telerobotics) has been under development at Kernforschungszentrum Karlsruhe (KfK) in Germany, for the support of numerous robotics and teleoperation applications during equipment design, task planning, training and execution [23].

The software provided a real time 3D virtual "synthetic" view of the teleoperation workcell, using interfaces to the tool control systems or other means of position sensor acquisition. Apart from these application areas typical within nuclear research, KISMET was found convenient and appropriate for modelling and training in laparoendoscopic surgery. In Berlin, October 1994, U Kühnapfel et al presented the preliminary results of 3D graphical simulations with KISMET for laparoscopic surgery, with the cooperation of Prof. G. Buess and his team from minimally invasive surgery of the University of Tübingen [24].

Some years later for the purpose of education and training in the field of minimally invasive surgery, Maab and Kühnapfel presented for the first time a system that had been developed at the research centre of Karlsruhe, simulating the interactions between surgical instruments and biological tissue graphically [25]. The physicians used "real" instruments, which were located in an input box, while the virtual operation scenario was shown on a screen. According to the motion of the instruments, the deformation and movement of the organs was simulated in the same way that they would have behaved in a real life operation. They concluded that it was possible to develop a virtual reality programme for training in minimally invasive surgery with realistic user-interface [26]. Table 5 illustrates the incorporated capabilities of such a proposed training programme.

Table 5 Training programme for real-time simulation of surgical interactions. Incorporated capabilities.

• Grasp, Clip, Cut, Coagulation, Irrigation, Slings, Suturing
• Active deformable objects: Organ motility
• Particle Systems for fluid simulation
• Virtual reality-based surgical simulation systems must become more and more realistic in the future
• They must be integrated into multimedia teaching and training environments
• All surgical disciplines will be covered

Meanwhile, in the United States of America, scientists yielded their initial work on VR. The science of virtual reality originated from the laboratory of Michael McGreevy and Steve Ellis at the National Aeronautics and Space Administrative (NASA) Ames Research Center [27].

In 1989, Joseph Rosen, MD, and Scott Delp, PhD, members of this NASA team, used the new technology to construct the first VR surgical simulation which concerned orthopaedic surgery [28]. They built a virtual model of a lower limb, with thin red lines that referred to muscles and their tendons, with a view to simulating tendon transplants for reconstructive surgery in gait disorders. Once the desired tendon had moved to its new position, they observed the leg's walk in order to predict the gait of the patient. This initial attempt at simulation incorporated both operative planning and predictive outcome.

The next simulator was created by Dr. Richard Satava and Jaron Lanier (who claimed to have coined the term "virtual reality") and was presented in 1993 [29] (Fig. 1,2). The models allowed lap cholecystectomy to be practised in an environment of virtual reality. Richard Satava also outlined the 5 requirements of a realistic VR-simulation (Table 6).

Table 6 The 5 requirements of a realistic VR-simulation outlined by Dr. R. Satava [29].

• Fidelity - the image must have high resolution for real appearance
• Object properties - the organs must deform when grasped and must fall with gravity
• Interactivity - realistic interaction between the surgeon's hand and instruments with the organs
• Sensory input - force feedback, tactility, and pressure must be felt by the surgeons
• Reactivity - the organs must have appropriate reactions to manipulation or cutting, such as bleeding or leaking fluids

Fig. 1 Dr Richard Satava a pioneer of virtual reality in surgery

Fig. 2 Jaron Lanier : The man who coined the term virtual reality

In 1994, the Visible Human Project emanated from the National Library of Medicine [30]. This was a complex dataset of 3D-human anatomy, (though very simple in conception), comprising computed tomography [CT] scanning, magnetic resonance imaging [MRI], and phototomography derived from an actual human being. This project proved that the CT scan of any patient could be reconstructed into a full 3D-image and imported into a VR surgical simulator. The Visible Human data became available over the Internet, pointing out its significance as a fundamental building block for all future medical education. The Visible Human dataset was taken by Delp and Zajac, who built the first CT scan-based surgical simulator for the military: the Limb Trauma Simulator [31]. This simulator incorporated high-end graphics with excellent and accurate anatomic representation, involving tissue properties, such as muscle contraction and bleeding. Precise ballistic wound definition, a haptic interface and interaction of surgical instruments with tissue and their fragments, were also incorporated. This complex modelling of the leg and instruments required considerably more computer power, which left only a limited amount for visual fidelity. As a result, the simulation did not look as realistic as the aforementioned visible human leg, which coerced the computer to spend almost its entire power to accurately represent the anatomy of the skin, muscles, tendons, and blood vessels. As computer power increased, so did the capacity for visual fidelity to approach photo-realism.

In 1996, Jeff Levy, in collaboration with Engineering Animation Inc, developed a hysteroscopy simulator that imported actual patient data from CT scans. This enabled him to practise multiple different surgical approaches and optimize each patient's operative procedure [32].

In France, Pr. Jacques Marescaux created a simulation for liver surgery using patient-specific data sets of liver lesions. The emphasis here was as much on preoperative planning as on the execution of surgical technique. Simulation allows the student to generate a number of different views of the liver concerning any single segment or combination of the arterial, hepatic venous, portal venous, or biliary tree, as well as colourization of the segments [33]. Using the computer mouse, the student can select various segmental resections to determine the optimum procedure.

Meanwhile, Fraunhofer MEVIS, the Institute for Medical Image Computing in Bremen developed a programme of 3D CT imaging that would prove to be very useful, not only in daily practice and training, but also in surgical planning. In 2002, in a study conducted by Herfath [34] ,data of seven virtual patients were presented to a total of 81 surgeons at different levels of training. Surgeons were stratified according to 2D and different types of 3D presentations. It was found that the impact of individual 3D reconstruction on surgical planning was significant, and precision had increased quantitatively.

Another innovation of the technology was the implementation of real-time analysis of hand motions to give continuous assessment of skill performance. Drs. Robert Playter and Marc Raibert of Boston Dynamics Inc. developed the Anastomosis Simulator, which tracks hand motions as the student performs an anastomosis [35]. During training, there is a graph in the upper left hand corner that displays in real time the amount of pressure or accuracy which is produced by the hand motion of the student, thereby providing the student with instant feedback on their performance. At the end of the procedure, the programme is able to tabulate a score. By this means, the student has an objective analysis of the skills performed [36-38].

Hybrid simulators were developed at about the same time as virtual reality simulators. In 1988, David Gaba, MD, in collaboration with CAE Link, Inc., created a lifelike human head and torso mannequin, with thorough technical mechanisms, allowing reproduction of patient reactions (dilation of the pupil, twitching of the arm, etc) [39]. The surgical simulator ProMis is a good example of a hybrid simulator that enables users to use instruments in both virtual and actual reality in the same unit. It provides the so-called “mixed reality“ tasks or hybrid reality or hybrid approach [40, 41].

Shortly thereafter, Dr. Sinclair and Peifer of Georgia Tech produced an ophthalmology simulator to teach corneal and other surgical procedures[42].

Of all the simulators, the most realistic was the UltraSim. A mannequin-based ultrasound simulator, the UltraSim was initially introduced for obstetricians and gynaecologists, but is currently expanding into other abdominal simulations [43].This simulator uses a mock-up of a standard ultrasound system and a hand-held ultrasound probe with a tracker. The trainee moves the transducer over the mannequin abdomen exactly as in an ultrasound examination on a patient. Numerous full 3D ultrasound data sets are stored within the computer. As the probe is moved, the image is reproduced on the monitor. The application is broad enough to train ultrasound technicians, radiologist and surgeons.

Contemporary experience and implementations

The British Journal of Surgery in 2004 published a randomized clinical trial of virtual reality simulation for laparoscopic skills training from the Department of Surgical Gastroenterology of Aarhus University in Denmark [44]. This study examined the impact of virtual reality surgical simulation on improvement of psychomotor skills, relevant to the performance of laparoscopic cholecystectomy, in two groups of trainees. During the laparoscopic procedure, taking into account the “before” and “after” training on the VR-simulator, or no training at all, the following were assessed: a)Time to complete the procedure b) error score and c) economy of movement score. Surgeons who received VR-simulator training showed significantly greater improvement in performance in the operating room than those in the control group. They concluded that VR-surgical simulation is therefore a valid tool for training of laparoscopic psychomotor skills and could be incorporated into surgical training programmes.

In another study performed in North Carolina, USA, Stefanidis et al [45] assessed skill retention in the operating room following completion of a proficiency-based laparoscopic skills curriculum where novices ($n = 15$) were randomized to a control and a training group that practised to proficiency on the fundamentals of a laparoscopic surgery suturing model. The performance of both groups was assessed both on the simulator and on a live porcine laparoscopic Nissen fundoplication model at training completion (posttest), and 5 months later (retention test). They concluded that proficiency-based simulator training results in durable improvement in operative skill of trainees even in the absence of practice for up to 5 months.

In the American Journal of Surgery in 2008, a pilot study was published which looked at the relationship between learning style, as measured with the Multiple Intelligences Developmental Assessment Scales (MIDAS), laparoscopic surgery experience and psychomotor skill performance using the micro-invasive surgery VR-surgical simulator. Five groups of volunteer subjects were selected from undergraduate tertiary students, medical students, novice surgical trainees, advanced surgical trainees and experienced laparoscopic surgeons. Authors found that there was a striking homogeneity of learning styles amongst experienced laparoscopic surgeons. Significant differences in the distribution of primary learning styles were found ($P < 0.01$) between subjects with minimal surgical training and those with considerable experience [46]. A bodily-kinesthetic learning style, irrespective of experience, was associated with the best performance of the laparoscopic tasks. In a more recent study from

Saint Mary's Hospital, in Waterbury of Connecticut [47], the authors compared the training results between two simulators, with haptic feedback and without, on the same groups. They found that in the more advanced tasks, haptics allowed superior precision, resulting in faster completion of tasks and a trend toward fewer technical errors. In the more basic tasks, haptic-enhanced simulation did not demonstrate an appreciable performance improvement among our trainees. On the other hand, two authors from India support the advantages that the perception of haptics has to offer when added to the enviroment of a simulator[48]. These data suggest that the additional expense of haptic-enhanced laparoscopic simulators may be justified for advanced skill development in surgical trainees as simulator technology continues to improve. The findings seem consistent with a preliminary estimation of Batteau et al (computer scientists) in 2004 that the haptic latency in a simulation (the latent time between haptic and visual feedback) cannot be detected by 99% of humans if it is less than 54ms and by 95% of humans if less than 67ms [22]. This was a significant conclusion for the relevant implication in the design and improvement of surgical simulators.

However, the haptic feedback properties of a simulator add significantly to the cost of the devices, and data assessing the value of haptics in skill acquisition and development is limited.

A group of authors from the University of Marburg in Germany presented their four-year experience in surgical simulation and showed that spatial perception, as well as stress management, correlates positively with virtual laparoscopic skills [49]. A high degree of spatial perception led to faster adaption to a non-stereo environment and correlated with a high level of laparoscopic skills.

Generally, it seems that "coping with stress" represents the greatest benefit for those laparoendoscopic surgeons who had received extensive and continuous training on surgical simulators. This training familiarizes surgeons with how to cope with stress.

Doctors from three affiliated hospitals in London [50] tried to determine whether virtual reality training can supplement or replace conventional laparoscopic surgical training (apprenticeship) in surgical trainees with limited or no prior laparoscopic experience. In a systematic review of randomized controlled trials, they studied 23 trials with 612 participants. Four trials compared virtual reality versus video trainer training. Twelve trials compared virtual reality versus no training or standard laparoscopic training. Four trials compared virtual reality, video trainer training and no training, or standard laparoscopic training. Three trials compared different methods of virtual reality training. Most of the trials presented a high risk of bias. In trainees without prior surgical experience, virtual reality training reduced the time taken to complete a task, increased accuracy, and decreased errors compared with those who had received no training; the virtual reality group was more accurate than the video-trainer training group. Among the participants with limited laparoscopic experience, virtual reality training reduced operating time and error more than the standard in the laparoscopic training group; the composite operative performance score was better in the virtual reality group than in the video trainer group. These findings confirm the validity and the superiority of surgical simulation training.

In 2005, a group of scientists of the Virtual Reality in Medicine Group of Computer Vision Lab at ETH Zurich (is a science and technology University in Switzerland), created a web-based repository of surgical simulator projects and recorded the surgical simulators until 2005. They published the record of 45 surgical simulators available on the market [51]. From the reviewed simulators, 75% modelled minimally invasive surgery scenarios, 60% of reviewed simulators used physically based deformation models and 82% provided haptic feedback [29]. I am quite confident that after six years, a much larger number of simulators would be recorded today.

The Telehealth Research Institute, John A. Burns School of Medicine, in conjunction with the National Biocomputation Center at Stanford University, evaluated a prototype low-cost virtual-reality motor-skills simulator (VRMSS [52]. The VRMSS is specifically designed to teach baseline fine-motor skills used in surgery that are based on a matrix of elementary technical skills that comprise the tenets of surgical technique. Fifty-seven participants were randomly assigned to one of three groups (VRMSS, box trainer or no training). After training, each group was evaluated using the LapSim from Surgical Sciences (a type of simulator). The VRMSS and box trainer were similar in performance, but significantly better than the no-training control group. The VRMSS has significant advantages over the box trainer, in that the VRMSS can provide scoring on several parameters of the task without the need of an instructor and the VRMSS is approximately 1/16th the cost of the LapSimTM .

Over the last twenty years, we have witnessed a boom in the evolution of virtual reality and digital technology, giving rise to the development of many programmes for surgical training, and reduction in the cost of computers. This confirms Gordon Moore's prediction (Fig 3), co-founder of Intel, who in 1965, forecast with incredible perspicacity a doubling in computer power and a halving in price every 18 months, widely known as "Moore's Law". The development of new programmes for surgical training was dictated by the need to acquire new training methods. Everybody in the surgical community was seeking a new educational and training method, using novel techniques, for minimally invasive surgery. Indisputably, the era of improvement in accuracy and fidelity of virtual reality imaging and representation coincided with that of minimally invasive surgery. The convergence of these two developments resulted in the birth of a new surgical educational method: surgical training in a virtual reality environment.

Fig. 3 Gordon Moore: Intel co-founder

Assessment of Tasks Performed in a Virtual Reality Environment

Traditionally, non-validated and unreliable tools, such as subjective reports from senior colleagues, have been used in the assessment of a task performed by trainees. In a virtual reality environment, assessment of trainees is a very essential component of the learning process [53]. VR-simulators, however, have the ability to provide an automatic, instantaneous, non-biased measurement of performance [54], and must demonstrate acceptable validity and reliability before they are integrated into high-stakes assessment.

In general, a contemporary surgical educational method must ensure three basic principles. The first is that it should not raise any ethical issue. This basic principle is absolutely assured with the education and training on VR-simulators. The second principle is that the method must ensure repetitiveness at low cost, (VR-simulators can provide this, but the low cost is not always viable) and the third principle is that whatever the task performed on a simulator, it should always be assessed.

The assessment should be able to demonstrate:

i. *Validity*, in its several forms (see table 7),
ii. *Reliability*
iii. *Feasibility*

In common usage, validation is the process of checking whether something satisfies a certain criterion. Validity signifies that a system is working correctly and satisfies the required criteria, hence, "the system is valid". Examples would include checking whether a statement is true, if an appliance is working as intended, if a computer system is secure, or if computer data are compliant with an open standard.

Validation may be defined as having subjective approaches and as having objective approaches [55,56,57,58]. Subjective validation (e.g. on VR-simulators) is usually the process of examining the opinion of trainees and experts after a performance of a task or set of tasks on a simulator. Subsequently, they are questioned about their experience with the simulation, and asked to complete a questionnaire. These are examples of subjective validity such as face and content which can derive from the experts' opinion (expert face validity), and referents' opinion (referent face validity) respectively.

Consequently, face validity is the degree to which a questionnaire or other measurement appears to reflect the variable it has been designed to measure. Content Validity, (a type of face validity), is verification that the method of measurement actually measures what it is expected to measure.

One example of face validity measurement (subjective) is demonstrated in a report by M Bajka et al [57] in Surgical Endoscopy in 2008, who determined the realism and training capacity of HystSim, a new virtual-reality simulator for the training of hysteroscopic interventions. All participants after a 20-min hands-on training on the simulator filled out a four-page questionnaire. In response to the statements, 95.2% confirm that HystSim allows procedural training of diagnostic and therapeutic hysteroscopy, and 85.5% suggest that HystSim training should be offered to all novices before performing surgery on real patients. In this way, the authors established a face validity for this simulator.

Another report for face validity comes from the Netherlands, by DI Ayodeji et al [59]. The goal of their study was to determine expert and referent face validity of the LAP Mentor, the first procedural VR-simulator Content validity verifies that the method of measurement actually measures what it is expected to measure. The face validity is a type of content validity.

Table 7 Types of Validity

Subjective Validity	Objective Validity
• Face Validity	• Construct Validity
Expert Referent	Convergent Validity Discriminant Validity
• Content Validity	• Criterion Validity
	Concurrent Validity Predictive Validity

On the other hand, objective validities are: construct, discriminative, concurrent, criterion, and predictive validity; objective validities are uninfluenced by emotions or personal prejudices. Generally, they involve experiments to ascertain whether or not a simulator can discriminate between different levels of expertise or evaluate the effects of simulator training by measuring real-time performance. Construct Validity indicates whether or not the simulator is able to discriminate the various levels of experience (experienced vs. inexperienced surgeons). Convergent and Discriminant validity are both considered subcategories or subtypes of construct validity [40, 41].

Construct validity purports the degree to which an instrument (in this case, the simulator) measures the characteristic being investigated; the extent to which the conceptual definitions match the operational definitions. In lay terms, construct validity answers the question: Are we actually measuring what (the construct) we think we are measuring?" In their review, JR Korndorffer et al support that most types of validity are woefully outmoded [60]. They contend that only construct validity could remain of contemporary relevance. They also claim that validity and validation only concern and establish the simulators' abilities and are not applicable to determinations regarding training use.

Criterion Validity compares the evaluation results from the new simulator with those of the old technique. It is the extent to which the measures are demonstrably related to concrete criteria in the "real" world and can be of concurrent validity or predictive validity. Concurrent validity is the extent to which the simulator correlates with the "gold standard". In concurrent validity, a task in a simulator is performed at the same time or some days later (some approximation is acceptable). Predictive Validity is the effectiveness of one set of test or research results as a predictor of the outcome of future implementations. One such example of predictive validity is given below: the grades that students received in high-school math can be used to predict their success in college.

Reliability measures the ability of a test to produce the same results if repeated several times.

Feasibility, the third factor of assessment contends that an assessment tool deriving from VR-simulator must be easy for use and implementation.

But have VR-simulators been substantially assessed in order to fulfil the aim for which they are built?

Undeniably, the answer is yes!

Since 2004, European consensus guidelines for validation of VR-surgical simulators have been established and were published in 2005 [58]. Regarding surgical simulators, group members of consensus collected the available evidence on validation, while performing a literature search and communicating with experts in the domain of surgical simulation. The evidence was rated and decoded in order to establish a level of recommendation. Evaluated simulators became commercially available in July 2004; these simulators are illustrated in table 8.

Table 8 The evaluated surgical simulators in consensus guidelines

Laparoscopic non-procedural simulators	Laparoscopic procedural simulators
• Lapsim Basic Skills (Surgical Science,Gothenburg,Sweden)	• Lapsim Dissection Module (Surgical Science,Gothenburg,Sweden)
• ProMIS (Haptica Ltd., Dublin,Ireland)	• ProMIS (Haptica Ltd., Dublin,Ireland)
• LapMentor (Simbionix, USA)	• LapMentor LapChole Module (Simbionix, USA) Predictive Validity
• Procedicus MIST (Mentice, Gothenburg,Sweden)	

Apart from simulators of table 8, another group of simulators for flexible endoscopy were also validated [58]. We note some findings regarding the level of recommendation of the abovementioned consensus. Among laparoscopic non-procedural simulators, the highest level of recommendation was given for Procedicus Mist: level 2 for all tasks, while LapSim Basic Skills gave only a level 4 recommendation for all tasks probably because the studies had not yet been published. The assessment for all tasks was based on construct and criterion validity (both concurrent and predictive) for Procedicus MIST$^{\text{TM}}$. For LapSim$^{\text{TM}}$ Basic Skills the assessment for all tasks was based on face, content, construct and criterion validity (both concurrent and predictive).The studies undertaken on ProMis$^{\text{TM}}$ and LapMentor$^{\text{TM}}$ simulators, both laparoscopic non-procedural and laparoscopic procedural, were erratic. The consensus group had some reserves concerning the results, yet there was some hope that this situation would change in the future time owing to the upgrading of some systems.

As regards the competency of the training programme for basic endoscopic surgical psychomotor skills based on a VR-simulator, a more recent consensus meeting successfully convened [61], with the participation of eight European hospital centres. These centres, with their extensive experience of LapSim™ validated VR-simulator, constructed a training programme and defined the parameters that can be utilized for the benchmark criteria of a training programme. For example, as acquisition of psychomotor skills improved in laparoscopic cholecystectomy, the time-frame of the learning curve decreased [62,63]. It therefore emerges that the abovementioned simulator for a training programme can help to develop basic psychomotor skills in endoscopic surgery.

Nowadays, all the above mentioned simulators have evolved and various modules for several procedures and for many specialties are available in the market.

Are learned technical skills in a virtual reality environment transferable to the operating room?

The ultimate goal of learning a technical skill or task in a virtual-reality environment is to increase the possibility and capability of putting this learning into practical use in an analogous but real situation. This raises the question of whether or not the learned skills on a VR-simulator are transferable to the real operating room – a question which requires a very clear answer. Although there are not many well-designed, randomized, controlled trials that examine the abovementioned transfer to the operating roo8, the few existing studies strongly support that learned skills on a VR-simulator are transferable to the real operating room. A classical report is that of colonoscopy. Three blinded, randomized controlled trials [64,65,66] offer strong evidence that skills in colonoscopy learned in a VR enviroment, result in a better performance, especially during the initial phase of the learning curve on live patients. On the other hand, as concerns gastroscopy, there are conflicting data about the transfer of learned skills on VR simulator to real patients [67,68]. The transfer of skills from a VR-enviroment to real laparoscopic surgery has already been demonstrated in many studies [69-71] and in several randomized trials [63]. In figures 4, 5 and 6 (By NA Seymour et al) [63] are illustrated the results of transferring the learned skills on VR-simulator to live patients that were submitted to laparoscopic cholecystectomy. The authors randomized residents to two groups: the first group was trained on a VR-simulator (MIST-VR) and the other was the control group (standard training). The authors found: "No differences in baseline assessments between groups. Gallbladder dissection was 29% faster for VR-trained residents. Non-VR-trained residents were nine times more likely to transiently fail to make progress (P <.007, Mann-Whitney test) and five times more likely to injure the gallbladder or burn nontarget tissue (chi-square = 4.27, P <.04). Mean errors were six times less likely to occur in the VR-trained group (1.19 vs. 7.38 errors per case; P <.008, Mann-Whitney test)".

Two years later, Grantcharov et al confirmed the previous findings and results were replicated in a very well designed, blinded, randomized, controlled study with validated assessment measures [44].

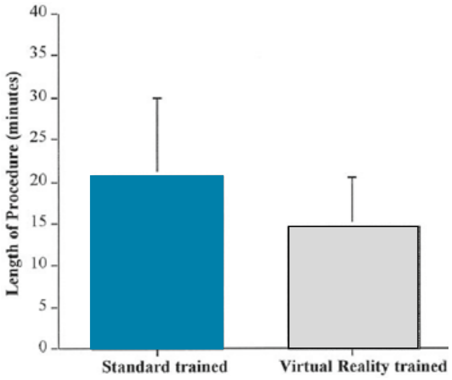

Fig.4 Mean duration of operative procedure on live patients in minutes for the Virtual Reality and Standard Training groups. (from NA Seymour et al Ann Surg 2002;236:4)

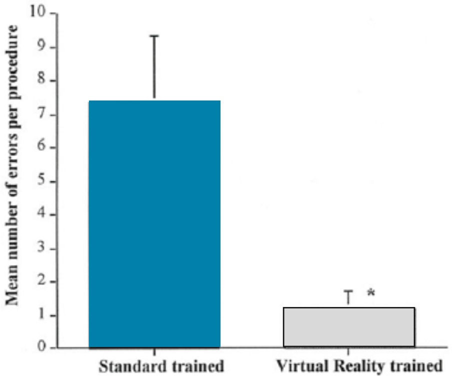

Fig.5 Mean number of errors scored per procedure on live patients for Virtual Reality and Standard Training groupswas significantly greater in the Standard Training group ,(P < .006). (from NA Seymour et al Ann Surg 2002; 236:4)

These studies reinforce and confirm the conception that the learned skills on VR simulators for endoscopy and laparoscopic surgical training are transferable to the real operating room. Moreover,they

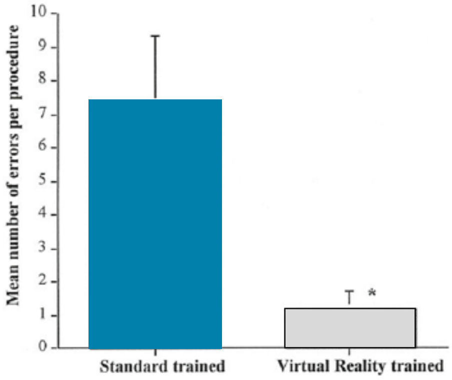

Fig.6 Total error number for each error type. LOP, lack of progress; GBI, gallbladder injury; LI, liver injury; intraperitoneal, incorrect plane of dissection; BNT, burn nontarget tissue; TT, tearing tissue; IOV, instrument out of view; AT, attending takeover. In all error categories except LI and TT, a greater number of errors were observed in the Standard Training group than in the Virtual Reality group. (from NA Seymour et al Ann Surg 2002; 236:4)

would benefit the patient‘s safety and resident surgeon's self-confidence. The data of these studies, and many others, were summarized in a consensus document established by the European Association of Endoscopic Surgeons in 2005 [58] and in a more recent consensus from eight European Centres in 2011 [61]. In addition, a meta-analysis from LM Sutherland et al [72] confirms the superiority of VR simulation versus non-training or versus standard or video training.

Conclusions

The environment of a hundred million pixels of virtual reality and the concept of simulation represent the most flexible and contemporary evolution and tool for training in surgery. Simulation techniques have been identified as potential methods to reduce risks to both students and patients by allowing training, practice and testing in a protected environment prior to real-world exposure. In the last decade, surgical training on virtual reality simulators has comprised the most demanding and modern method for residents' surgical education. The degree of transferable learning to the operating room is high when the education is performed on validated simulators. Hence, the provision of a proper validated simulator must be the main parameter to be taken into consideration.

Proposal

At the close of this editorial, I would like to address a message to the president and my other friends of the Executive Committee of the Hellenic Surgical Society. In these difficult times for our country, I believe that the Hellenic Surgical Society has the ability and the financial capacity to offer much more to the significant issue of surgical education, with the development of a complete repeated training programme on VR-simulators for novice surgeons and residents. The human and building substructures are already there; the will is self-evident; all that remains is the decision.

Conflict of interest

The author declares that he has no conflict of interest

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΄Οταν η Προσομοίωση στη Χειρουργική Συναντά την Εικονική Πραγματικότητα

Editorial

Κωνσταντίνος Χ. Καραλιώτας

Περίληψη

Παραδοσιακά η πρακτική εκπαίδευση στη χειρουργική τέχνη γίνεται κυρίως κατά τη διάρκεια λήψης της ειδικότητας δίπλα σε έμπειρους χειρουργούς και η εκμάθηση αποκτάται δια της εφαρμογής των όσων ο εκπαιδευόμενος προσλαμβάνει κυρίως στην αίθουσα του χειρουργείου. Βεβαίως υπήρχαν και υπάρχουν εκπαιδευτικά κέντρα, όπου μέρος της πρακτικής εκπαίδευσης γίνεται με προσομοίωση χειρουργικών επεμβάσεων, σε πτώματα και πειραματόζωα. Προκύπτουν όμως σημαντικά ζητήματα ηθικής και δεοντολογίας αλλά και υψηλού κόστους και στις δύο περιπτώσεις, ενώ απουσιάζει η παράμετρος της επαναληπτικότητας. Η απευθείας εκπαίδευση στον ασθενή, φυσικά πάντοτε υπό την επίβλεψη εμπείρου χειρουργού, εμπεριέχει τον κίνδυνο επιπλοκών, ενώ θα πρέπει να υπάρχει η συναίνεση εκ μέρους των οικείων ή του ίδιου του ασθενούς.

Η ανάγκη ανάπτυξης κάποιου νέου εκπαιδευτικού μοντέλου στη χειρουργική ειδικότητα, όσον αφορά στο πρακτικό μέρος της εκπαίδευσης και σε ευρεία κλίμακα, κατέστη περαιτέρω αναγκαία με την εμφάνιση της λαπαροσκοπικής χειρουργικής και της ενδοσκοπικής επεμβατικής παρέμβασης. Οι δυσκολίες που ανέκυψαν λόγω απώλειας της τρίτης διάστασης στην εικόνα του μόνιτορ αλλά και της αφής, δημιούργησαν πολλαπλά προβλήματα όχι μόνο στους νέους χειρουργούς αλλά και σε όσους έμπειρους επιθυμούσαν να ασχοληθούν με την λαπαροσκοπική χειρουργική. Η εικόνα υψηλής ανάλυσης καταρχήν με την προβολή Video σε προσωπικό η συλλογικό εκπαιδευτικό επίπεδο ήταν το έναυσμα να αξιοποιηθεί η προβολή έτι περαιτέρω. Όμως αυτό βοηθούσε μάλλον τη θεωρητική κατάρτιση παρά την πρακτική. Έτσι επικράτησε να εισαχθεί στην εκπαίδευση η προσομοίωση διά της εικονικής πραγματικότητας (virtual reality) μέσω συστημάτων υψηλής πιστότητας και απόδοσης των υπολογιστών. Η συνεχής εξέλιξη των ταχυτήτων των computers στην επεξεργασία μεγάλου όγκου πληροφορίας ιδίως τα τελευταία είκοσι χρόνια, οδήγησε στην κατασκευή και συνεχή βελτίωση διαφόρων μοντέλων προσομοιωτών, με τη βοήθεια των οποίων επιτυγχάνεται ένα πολύ καλό επίπεδο πρακτικής εξάσκησης και βελτίωσης της καμπύλης εκμάθησης. Σήμερα σε πολλά εκπαιδευτικά κέντρα εκμεταλλεύονται τις δυνατότητες διαφόρων προσομοιωτών στην απόκτηση συγκεκριμένων εγχειρητικών δεξιοτήτων εκ μέρους του νέου χειρουργού. Το φάσμα των εγχειρήσεων ή των συγκεκριμένων δεξιοτήτων σήμερα είναι τεράστιο και αφορά σε όλες τις ειδικότητες. Η αξιολόγηση κάθε προσομοιωτού και κάθε εργασίας που εκτελείται δι'αυτού καθώς και η εγκυρότητα είναι απαραίτητα στοιχεία, προκειμένου τα προκύπτοντα αποτελέσματα από την εκπαίδευση να είναι αξιόλογα. Υπάρχουν «softwares» που επιτρέπουν την ανάπτυξη σημαντικών εκπαιδευτικών προγραμμάτων ειδικά στην γενική χειρουργική για τις συχνότερες και σημαντικότερες χειρουργικές επεμβάσεις που εκτελούνται λαπαροσκοπικά. Το μεγάλο πλεονέκτημα όμως που διασφαλίζεται με την προσομοίωση της εικονικής πραγματικότητας, είναι η επαναληπτικότητα της εκπαιδευτικής διαδικασίας και η αυτόματη αξιολόγηση διαφόρων παραμέτρων του ασκούμενου στον προσομοιωτή (ταχύτης, λάθος κινήσεις, ακρίβεια κινήσεων κλπ). Σήμερα πια είναι δεδομένο ότι μεταφέρεται σε σημαντικό βαθμό η κτηθείσα εμπειρία στον προσομοιωτή, οπότε η εγχείρηση πραγματοποιείται με ασφαλέστερο τρόπο. Πιστεύουμε ότι είναι ανάγκη η Ελληνική Χειρουργική Εταιρεία, να αναλάβει συγκεκριμένη δραστηριότητα στην εφαρμογή προγραμμάτων προσομοίωσης με την απόκτηση ενός ή δύο προσομοιωτών. Άλλωστε αυτή είναι η αποστολή της: η εκπαίδευση.

Λέξεις κλειδιά

Προσομοίωση, Προσομοιωτής, Εκπαίδευση χειρουργών, Λαπαροσκόπηση, Εικονική πραγματικότης

- 'Β Χειρουργική Κλινική και Μονάδα Χειρουργικής Ογκολογίας, Νοσοκομείο "Κοργιαλένειο Μπενάκειο" ΕΕΣ Αθήνα