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Role of laparoscopic simulators in the development and assessment of laparoscopic surgical skills in laparoscopic surgery and gynecology (Review)

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Abstract. The aim of the present review article was to provide an overview of the evaluation and capability of the different types of laparoscopic simulators in the application of training in laparoscopic gynecological surgery. The literature suggests that the acquisition of surgical psychomotor skills is best achieved in a simulated laboratory outside of the live operating environment. The present review article includes scientific publications on current laparoscopic gynecological simulators, including laparoscopic box trainers, laparoscopic virtual reality simulators, animal models, human cadavers and lightly embalmed human cadavers. At present, controversy exists as to the superiority of virtual reality simulators over laparoscopic box trainers on the transferability and development of minimally invasive surgical skills for the justification of their increased cost. The present review article covers the role of simulation-based surgical education in the development and assessment of the appropriated surgical skills for laparoscopic gynecological procedures. Within the surgical curriculum, the tertiary laparoscopic training hospitals should include surgical simulation-based programs for laparoscopic training to gynecologists outside the live operation rooms under appropriate supervision.

Contents

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1. Introduction

The traditional method of obtaining technical skills in surgical specialties is based in the principle of 'see one, do one, teach one' when the apprentice, after observing a particular procedure for the first time, is then expected to be able to perform that procedure without complications and is also expected to be capable of training another apprentice on how to perform effectively the same procedure. However, this method may not be applicable to minimally invasive surgery, which involves working with images on a screen and instruments that are manipulated outside the line of vision and therefore, the trainee is not able to observe the surgeon's hands, the instruments and the operative results of manipulation simultaneously as it happens in open surgery (1,2). In addition, there is a general agreement if the safety of the patient is at risk when a resident performs a surgical procedure after observing it only once (3). The surgical outcome depends not only on the condition of the patient and the condition of the disease, but most importantly, on the skills of the surgeon (2,4). The surgeon must be extremely familiar with the anatomy, the patient selection, preparation and positioning, the equipment used during surgery and the post-operative care. The surgeon benefits from i) observation and imitation; ii) deliberate practice with skill repetitions, which are combined with structured training and informative feedback; and iii) adaptation for the final development of the necessary cognitive, affective and psychomotor surgical skills. The cognitive skills of a surgeon are the factual knowledge, clinical judgment, decision making and the ability of thinking and working under conditions of stress; the affective skills are compassionate and professional attitude and effective communication skills; the psychomotor skills are the perceptual motor skills and the physical movements of surgeon. With observation and imitation, the trainee enters the cognitive phase, then following deliberate practice enters the associative phase and with the combination of time and practice, then enters the autonomous phase. Furthermore, non-technical factors, such as communication, teamwork and leadership play a substantial role in surgical success (2,4-21). It has been suggested that acquisition of adequate knowledge and experience reduce medical errors during surgery (22-24). The number of cases required to master a particular procedure depend on the learner, the trainer and the environment (25). As regards the supervision of the residents during an operation, Itani *et al* (2005) found that the level of resident supervision in the operating room did not adversely affect clinical outcomes for surgical patients, even when qualified surgeons were not present in the operating room, but were available if needed (26). In a prospective randomized trial, Mahmoud *et al* (2012) demonstrated that senior surgical residents were able to act without compromising patient safety as teaching assistants for junior residents under faculty supervision (27). Skill repetitions are important for the development of a comprehensive surgical curriculum. Moulton *et al* (2006) suggested that a surgical residents' practice on micro-vascular anastomoses over a period of 4 weeks was superior to practice for 1 day (28). With the current implementation of restricted work hours for clinical training and the spending of less amounts of time in the operating room, residents must practice in simulation laboratories to obtain equivalent experience (29,30). McGaghie *et al* (2011), in a meta-analysis of 14 articles, revealed that the simulation-based medical education with deliberate practice was more effective than traditional clinical education (31).

Minimally invasive surgery compared to open surgery has a longer learning curve as it is more difficult to learn and master (30). Over the past few years, the use of surgical simulation in minimally invasive surgery outside the operating room has increased significantly for the acquisition of cognitive knowledge and surgical skills and for shortening the learning curves of the residents (21,30). It has been demonstrated that delicate training on simulators by surgical residents results in i) an improved technical performance in the operating room with fewer errors and injuries; ii) an enhanced ability to attend to cognitive components of surgical expertise; iii) the efficiency of movements during the operation; and iv) a significant decrease in operative time (30,32-36). In addition, the operating room is a suboptimal place for novice training in minimally invasive surgery, as in variable cases with high complexity and high stress conditions, the trainer often subconsciously guides the trainee or more usually takes control away from the trainee in order to maintain control of the case and avoid complications due to surgical errors. This assistance is perceived by the trainee as a false sense of control and mastery, as these are the parts of the procedure in which the trainee needs the most guidance. Therefore, in such crucial times of an operation, simulation allows trainers to improve performance in a controlled setting outside the operation theater (28,30,37). For all these reasons, any expense of training for the purchase of minimally invasive simulators for the residents in surgical specialties further justifies the prolonged time for training in the operating theater, which subsequently results in an increased cost afforded to the patient and the healthcare system (21). In addition, increasing awareness for medico-legal implications and the greater premise that it is ethically unacceptable for one to be surgically trained on real patients, further favors the development for a simulation-based surgical curriculum (38). Furthermore, before surgical residency, simulation may be helpful for the identification of appropriate individuals who will become technically competent surgeons. Simulators may be useful for credentialing the processes of surgeons for the reduction of adverse events, analogous to the certification practice of commercial pilots (2,20).

2. Surgical simulators for training in laparoscopic surgery

Effective surgical simulators can be either task-specific or unique to a particular situation or surgery (21). The simulators should play a dual role, functioning both as training and testing platforms for the evaluation of surgeons (20). The criteria for simulation-based learning were previously addressed by Kneebone (2005) (39). The concept of validity dictates the process of evaluation of a simulator and addresses the question of whether the measurements obtained from the simulator vary with the educational construct the simulator is intended to measure. There are 5 types of validities that are applicable to medical simulators: Face, content, construct, concurrent and predictive validity (20,21,30,40). Face validity determines the overall property of a task of the simulator. Face validity is usually assessed by experts in the field response to questionnaires and shows whether trainees accept or not the simulation as a valid educational tool (20,30). Content validity reflects the extent to which the task of the simulator under study includes all relevant steps of the techniques or procedure. Content validity is often assessed by interviewing expert surgeons. Face and content validity are subjective assessments of a simulator's validity (20,21,30). Construct validity defines the extent to which the simulator measures what it is supposed to measure and demonstrates whether there is a statistically significant difference in performance measured between different groups with different experiences and skills. Demonstrating a significant difference in the scores between novices, senior residents and expert surgeons demonstrates that the simulator correctly identifies quantifiable aspects of surgical skill. A simulator has construct validity, as a training system, if it results in an improved task performance of inexperienced surgeons to the level of expert surgeons in minimally invasive surgery (20,21,30). Concurrent validity measures the degree to which the simulator correlates with existing performance measures of the same surgical task or procedure, e.g., by another simulator of the same type that has previously undergone validation (20,21,30,31). Predictive validity measures and predicts the degree to which the test can associate with other measures of the same type test at a later time in an operating room environment for standardized outcomes of surgical procedures (20,21,30).

One way to classify surgical simulators is based on the technology they use and are described as low- and high-tech simulators, while another way is based on the degree of their fidelity or evaluates characteristics, such as tactile and interaction feedbacks and visual clues. Low-tech simulators are not computer-driven and are either the synthetic models or the organic simulators comprised of human cadavers, animal models and harvested animal tissues, which are animal tissues attached to synthetic frames. Synthetic models are i) bench top models designed to teach open surgical procedures and include the tasks for knot-tying, fascia closure and suturing; and ii) video-box trainers or the tower trainers designed to teach minimally invasive procedures, which are typically portable, low cost, low maintenance and can be used repeatedly by multiple users (19,41).

Video-box trainers. Video-box trainers include a box with a lid and holes cut on the lid for the trocar's insertion. A laparoscope inside the box is connected with a digital camera and provides video output to a monitor on which the trainees are watching their own movements, while performing the teaching task. Laparoscopic instruments, such as laparoscopic graspers and laparoscopic scissors are inserted through the trocars into the box, where the tasks are taught (Fig. 1). These inexpensive models are designed to develop hand-eye coordination and bimanual dexterity and can simulate a variety of techniques, such as laparoscopic peg transfer, circle cutting, intra-corporeal and extra-corporeal-suturing, knot-tying using a prettied loop and clip-applying (19,41). In addition, relatively inexpensive and easy to construct laparoscopic trainers have been designed for residents who wish to develop their skills at home, such as box models with optical systems based on two parallel mirrors or box models using HD webcam as the camera (42).

The system McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS) consists of 5 exercises performed in an endo-trainer box (laparoscopic ring transferring, laparoscopic cutting, laparoscopic legating loop, laparoscopic intra-corporeal and extra-corporeal suturing) and is the core of the Fundamentals of Laparoscopic Surgery (FLS) program and mandatory for board certification by the American Board of Surgery (43). The limitations of the synthetic models are on the one hand the fact that they do not teach an entire operation, but only one surgical technique, and on the other hand, the lack of objective assessment of performance as they need the presence of an expert to demonstrate the procedure and provide feedback on performance for the acquisition of the technical skills.

Organic simulators. Organic simulators are termed as ‘high fidelity’ as they approach real-life situations. Human cadavers provide perfect anatomy and normal tissue consistency; however, human cadavers are not portable and other disadvantages are their limited availability, their loss of tissue fidelity compared with live models, their inability to simulate complications such as bleeding, their single use and some medical concerns for disease transmission and ethical issues. The animal models provide realism during operative training and provide good practice in the maintenance of hemostasis and mimic complications, but they are expensive as they require specific places for the animals with a veterinarian to take care of the animals and in addition, they have anatomical differences from the human body. In addition, there are serious ethical concerns. The pig, goat, or other mammalian uteruses, fallopian tubes and ovaries have no practical resemblance to those of women, making organic animal-based simulation of minimally invasive procedures, such as oophorectomy, myomectomy and hysterectomy essentially unfeasible. Harvested tissue models are perfect for training of skills that require many repetitions and provide haptic feedback. However, harvested tissue models provide the operation without perfusion, require special facilities for storage and are used only for limited procedures (19,20,36,41,44-53).

Figure 1. The laparoscopic video (box) trainer: The laparoscopic ‘ovarian cystectomy’ task.

Hybrid trainers. Hybrid trainers combine virtual-reality with video-box simulation, guide on how to perform the entire operation, promote team based training, provide realistic haptic feedback as in actual surgery and give metrics without the need of the presence of an experienced surgeon in order to give the trainee feedback. However, hybrid trainers are not portable and require facility, time and effort for preparation and maintenance (2). An example of a hybrid trainer is the ProMIS (Haptica Inc., www.haptica.com) which aims at the training of basic minimally invasive surgical skills including suturing and knot tying. Real instruments are inserted through specific holes and enable manipulation of physical objects in a box simulator. Performance analysis of the ProMIS hybrid trainer includes parameters of time for completion of the task, economy of movements and smoothness for tissue manipulation and compares it to a defined proficiency level. The ProMIS trainer provides realistic haptic feedback reactions (2).

Another example of a hybrid trainer is the LapTrainer with SimuVision (Simulab Inc.). This trainer is an open box-trainer with a simulated laparoscope (SimuVision) using a digital camera plugged into a laptop. This hybrid simulator has bundled four standardized exercises ranging from basic to more advanced laparoscopic skills (2). Virtual reality simulation training in minimally invasive surgery has come to the foreground as a method of teaching surgical skills into the trainer repeatedly with mistakes to be able to be made without any risk to patient safety (Figs. 2-4).

Figure 2. The laparoscopic 'cutting' task on the LapVR simulator.

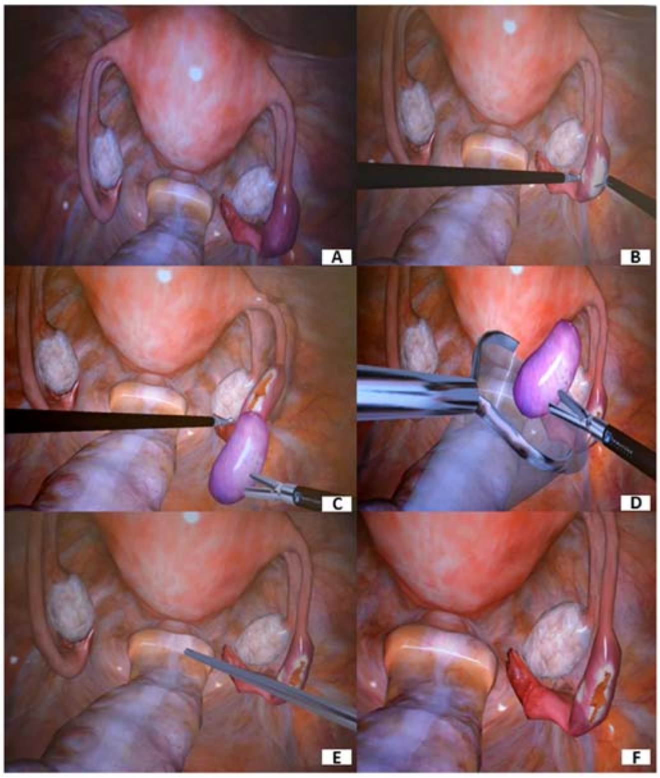

Figure 3. (A-F) The laparoscopic 'salpingotomy' task for ectopic pregnancy on the LapVR simulator.

Virtual reality (VR) trainers. Virtual reality (VR) trainers allow the learner to interact realistically with a computer-generated environment that comprised of handles, foot pedals for diathermy, and other devices similar to those encountered in an actual operating room environment and can include additional sensory information, such as sound and haptics for the provision of a sense of force feedback to simulate touch. Significant advantages of VR systems are their ability to recreate individual basic surgical skills, e.g., knot-tying,

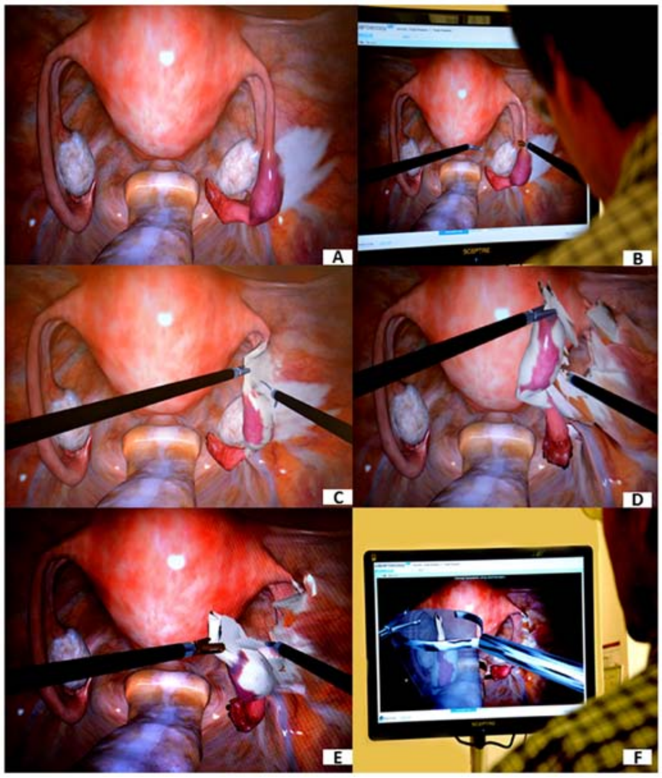

Figure 4. (A-F) The laparoscopic 'salpingectomy' task for ectopic pregnancy on the LapVR simulator.

suturing, dissection, moving cubicles or cutting off edges of squares or to recreate surgical skills of entire procedures along with possible procedural complications in a realistic setting with advanced graphics. They provide objective metrics on a vast majority of parameters by registering, for example, the total time taken to tie an intra-corporeal knot or even providing information regarding the security of the knot without the presence of a teacher, thus improving operating room performance and patient outcome. Furthermore, the modern virtual reality trainers have the possibility to train surgeons to make the right decision (2,20,47,54-56). Over the past few years, a number of VR trainers with varying complexity for different medical fields have become commercially available including the Simendo (Simulator for endoscopy) (DeltaTech), the Lapmentor simulator (Simbionix Inc.), the LapSim (Surgical Science Ltd.), the Surgical Education Platform (SEP) (SimSurgery and Medical Education Technologies Inc.), the Procedicus MIST TM (Mentice AB), the EndoTower (Verefi Technologies Inc.), the Reachin Laparoscopic Trainer and the Vest System (Virtual Endoscopic Surgical Trainer) (Select-IT VEST Systems AG). Thus, VR simulators can be incorporated into the curricula of anesthesiology, interventional radiology and ultrasonography, obstetrics and gynecology, general surgery, cardiovascular surgery, orthopedics, urology, internal medicine, emergency medicine, ear, nose, and throat or eye surgery (2,57-60).

Augmented reality (AR) laparoscopic simulator. Another laparoscopic simulator system is the augmented reality (AR) laparoscopic simulator, which refers to systems that overlay computer graphics images and real video images into a single perception of an enhanced world around the user. Augmented reality connects both worlds: The virtual and the real world. Augmented reality simulation is combination in one system of physical and virtual reality. Some of the augmented reality laparoscopic simulation approaches are i) anatomical overlays; ii) visual pathway of the instruments; iii) realistic haptic feedbacks; iv) realistic training environment, which is based on real instruments, which interact with real objects; and v) objective assessment at the end of the performance of the trainee. The laparoscopic task is demonstrated by a video on the screen, and after the trainee's performance there is an objective assessment without the need for an expert laparoscopic surgeon to observe and guide the trainee during the training. In the recent years, several augmented reality simulators have been developed for example the ProMIS AR laparoscopic simulator (61-63).

3. Scoring systems to objectively assess acquired skills from laparoscopic surgical training

Different tools for the specific laparoscopic skills needed for the minimally invasive operations have developed. Global Assessment of Laparoscopic Skills (GOALS) tool was developed by Vassiliou *et al* (2005) to assess laparoscopic depth perception, bimanual dexterity, efficiency, tissue handling and autonomy (64). The GOALS tool has been validated for the assessment of basic laparoscopic skills (64), laparoscopic cholecystectomy (64), appendectomy (65) and inguinal hernia repair (66). The observational clinical human reliability analysis (OCHRA) tool is an analysis method that is specialized in counting errors and near misses enacted during surgery by analyzing operative videos. It has been validated in assessment of laparoscopic colorectal skills (67). Similarly, the Objective Structured Assessment of Technical Skills (OSATS) for laparoscopic skills has good construct validity (68).

4. Effectiveness of Surgical Stimulation in Laparoscopic Training

The evidence for effective laparoscopic learning using simulators has been provided by many studies. As regards the synthetic training tools, Traxer *et al* (2001) in a blinded, randomized controlled trial of urological surgeons inexperienced with laparoscopy found that practice on a video trainer resulted in significant reduction in time measured on the simulator and in an improvement of their technical ability measured by a validated global assessment tool in a porcine laparoscopic nephrectomy model in comparison with a no-training control group (69). Similarly, transfer validity to animal models has been demonstrated by Fried *et al* (2004) (43) and Sidhu *et al* (2007) (70), on human cadavers by Anastakis *et al* (1999) (44), and in the operating room by Scott *et al* (2000) (71) and Hamilton *et al* (2001) (72).

A number of trials have examined the role of virtual reality (VR) simulators in teaching technical laparoscopic skills. Seymour *et al* (2002) demonstrated, in a prospective, randomized, blinded study, the validation of transfer of training laparoscopic skills from virtual reality to the operating room of residents during laparoscopic cholecystectomy (33). Similarly, Sroka *et al* (2010) demonstrated that proficiency training with the Fundamentals of Laparoscopic Surgery (FLS) simulator resulted in an improvement of performance of junior residents during laparoscopic cholecystectomy (73). McCluney *et al* (2007), using the FLS system, demonstrated that laparoscopic simulator performance independently predicts intra-operative laparoscopic skills as measured by the Global Operative Assessment of Laparoscopic Skill (GOALS) (74). In addition, Stefanidis *et al* (2008) demonstrated that the group randomized to an FLS suturing model demonstrated significant improvement in performance on a live porcine laparoscopic Nissen fundoplication model (75).

There is evidence that training on simulators results in the durable improvement of minimally invasive surgical skills of trainees, even in the absence of ongoing practice on simulators in the operation theater (75-79). Haptic systems are an advancement that provides tactile feedback to the trainees practicing on virtual-reality simulators and they feel the force on their instruments. Therefore, the haptic systems provide higher degree of realism to the simulators. However, the haptics enhanced simulators have an increased cost and Thompson *et al* (2011), in a study on novices, demonstrated no improvement in efficiency or effectiveness of simulation training in minimally invasive surgery (80). In addition, Panait *et al* (2009) investigated the role of haptic feedback in laparoscopic simulation training among medical students with similar baseline skill levels and found that haptic enhanced simulation did not exhibit an appreciable performance improvement for the laparoscopic peg transfer task (81).

5. Laparoscopic virtual reality simulators versus laparoscopic box trainers

In the literature, it is not clear whether the virtual reality simulation-based training have some demonstrable advantages over the box trainers in the development of minimally invasive surgical skills considering of their increased cost (82). Munz *et al* (2004) compared the performance of medical students who were tested in baseline tasks (laparoscopic circle cutting and laparoscopic clipping) with LapSim VR simulator vs the classical laparoscopic box trainer and found no significant differences between the groups (83). In addition, Newmark *et al* (2007) found equivalent outcomes for the measurement of time to task completion and number of errors after the training of medical students on a LapSim VR simulator versus that on a video box trainer (84). Moreover, Debes *et al* (2010) examined the transferability of basic laparoscopic skills between a VR simulator (MIST-VR) and a video trainer box (D-Box) in medical students. They found that skills learned on the MIST-VR are transferable to the D-Box better than the D-Box to VR (85). Similarly, Diesen *et al* (2011) found that both laparoscopic box trainers and laparoscopic VR simulators were equally effective in teaching laparoscopic skills to novice learners (86). Tanoue *et al* (2008) compared the effectiveness of students training on the MIST-virtual reality (VR) simulator and laparoscopic box trainer for teaching the fundamental skills of endoscopic surgery and found that both laparoscopic VR and box trainers had i) better performance than controls and ii) different outcomes for training different skills (87). Madan and Frantzides (2007) found the combination of laparoscopic VR and laparoscopic box trainers to be superior to either system used alone in their study on preclinical medical students without prior operative experience (88). By contrast, Hennessey and Hewett (2014) concluded that testing with the low-fidelity FLS box trainer appears to demonstrate greater validity than the high-fidelity Lapsim virtual reality laparoscopic simulator (89). Hamilton *et al* (2002) compared the impact of video trainer (VT) vs VR on surgical technical skills in the operating room during a laparoscopic cholecystectomy procedure with 19 second-year residents assessed before and after training sessions and found the operative performance to be improved only in the laparoscopic VR training group (90). However, a limitation of that study was that the training sessions were not supervised and feedback was provided only to trainees using VR simulators by the metrics, while trainees on VT had no feedback on VT apart from the time taken. In addition, all trainees were not assessed by the same surgeon as a training group, and individually before and after the training (82). Beyer *et al* (2011) compared two groups of training on simulators; the first group was trained on the VR-LAP Mentor and the second group was tested on a simple VT with the Mac Gill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS). Both groups compared to a control group during a laparoscopic cholecystectomy in the operation room. Both intervention groups demonstrated improvement compared to the control group, but there were no significant differences in the trainees between the VT- LAP Mentor and the MISTELS groups (91).

Youngblood *et al* (2005) compared the impact of the VT (Tower Trainer®), Simulab Corporation Seattle) and the LapSim® on surgical technical skills in live pigs between surgically naive medical students. They found superiority on live surgical tasks for the LapSim group compared with those trained with a traditional box trainer (92). However, no baseline tests were performed between both groups in order to ensure that both groups were comparable. In additoin, another limitation of that study was the fact that the assessment tool was not a validated score (82).

6. Evidence for training with laparoscopic simulation in laparoscopic gynecological surgery

Although the operative laparoscopy in gynecology was popularized in the 1970s with tubal sterilization; in the 1990s, laparoscopic procedures have increased in clinical practice and synthetic simulators were then used to assess validity of gynecological tasks in simulation laboratories (93). Loukas *et al* (2011) tested 25 inexperienced surgeons on for basic tasks and the effects of training were assessed on laparoscopic adhesiolysis, laparoscopic bowel suturing and laparoscopic cholecystectomy in a virtual reality (VR) simulator. They found that the improvement in basic training was transferred to laparoscopic procedures (94). Furthermore, Molinas *et al* (2008) developed a trainer box on the laparoscopic skills testing and training (LASTT) of 3 basic tasks: i) Camera navigation; ii) camera navigation and forceps handling; and iii) forceps handling and bimanual coordination. The authors found construct validity between 10 experts and 14 novices; this finding was also confirmed in a larger study during skill evaluation workshops (organized by the European Academy of Gynecological Surgery) comprised of 42 experts and 241 novices (95). In addition, Arden *et al* (2008) validated the innovative Pelv-Sim trainer for laparoscopic gynecological suturing with 4 laparoscopic tasks: i) Closing an open vaginal cuff; ii) transposing an ovary to the pelvic sidewall; iii) legating an infundibulopelvic ligament; and iv) closing a port-site fascia incision between obstetrics and gynecology residents and third-year medical students. The parameter of time to complete each task was taken into consideration and their performances were compared. Subjects were randomized into 2 groups as follows: In group A subjects were asked to train with the Pelv-Sim for 1 h per week for 10 weeks, while group B was the control group. To evaluate the effectiveness of training with the Pelv-Sim model, both groups of residents were retested at the end of the 10-week training. Pre-training and post-training performances were compared within each group. The authors found that before the intervention, the residents completed all four tasks in significantly less time than the medical students. When retested after the 10-week study period, group B showed no significant performance changes. Group A showed significant progress in the performance for the vaginal cuff closure task and the ovary transposition task but not for the infundibulopelvic ligament ligation or the fascia closure tasks (96).

Gynecologists from the Gynecologic Oncology Division of the University of Washington (Seattle, WA, USA) have conducted several studies to validate surgical skills in residents using a 6-station objective structured assessment process of technical skills (OSATS) including laparoscopic (salpingostomy, intracorporeal knot and ligation of vessels with clips) and open abdominal operations (subcuticular closure, bladder neck suspension, enterotomy repair, and abdominal wall closure). They concluded that OSATS is a reliable and valid method to assess surgical skills administered in either a blinded or unblinded fashion and could be included in the residency curricula (97-99).

Tunitsky-Bitton *et al* (2014) created a cost-efficient surgical model for training in laparoscopic sacrocolpopexy using as materials a vaginal manipulator stent, a stent cover, a sacrocolopexy tip, a RUMI advanced uterine manipulation system and the Fundamentals of Laparoscopic Surgery (FLS) box trainer. The construct validity was measured by comparing the performances on the model between experts and trainees. It was concluded that this model has construct validity. In addition, previous surgical experience had a strong association with performance on the model (100).

The validity of VR simulators as regards laparoscopic surgery in gynecology have investigated by a number of researchers. Lentz *et al* (2001) assessed on 36 residents on 6 laparoscopic tasks, including running the bowel, bead transfer, manipulating intracorporeal sutures, peg transfer, running a pipe cleaner and tissue handling using a simulator (Tap Pharmaceutical Products, Inc.). Residents were timed at each given station and were given a rating score by two examiners. Assessment of construct validity demonstrated significant differences on the rating of overall performance and individual tasks by residency levels (101).

Gor *et al* (2003) suggested that the Minimally Invasive Surgery Trainer-Virtual Reality (MIST-VR) simulator provides objective assessment of laparoscopic skills in gynecologists (102).

Hart *et al* studied 5th-year medical students and medical doctors during their first and last years of training in obstetrics and gynecology. Standard gynecologic procedures before and after MIST-VR training were undertaken on sheep. The procedures of salpingotomy, salpingectomy and clip sterilization were video-recorded and were scored by an independent observer blinded to the name and seniority of the participant using specific parameters and penalties. The higher the score, the better the surgical procedure was performed. The participants had practical training on the VR equipment over a 2-month period. The VR scores were recorded and scored by software using the default scoring algorithm. The authors found that the baseline VR scores were significantly related to the overall pre-training scores and also, a better initial VR score was predictive of better surgical performance (103).

Moore *et al* (2008) evaluated whether performance on the MIST-VR simulator reflects laparoscopic experience among gynecologic surgeons, trainees or medical students and found that increased operating room experience and age were associated with worsening simulator performance. The authors speculated that the laparoscopic operating room experiences might explain these observations (104).

Larsen *et al* (2006) demonstrated construct validity for the LapSim VR simulator in basic tasks of lifting and grasping, cutting, and clipping (105). Schreuder *et al* (2009) demonstrated for LapSim VR simulator construct and face validity (106). Furthermore, Schreuder *et al* (2011) found face and construct validity for the Simendo-VR simulator (107).

There are some publications in which the salpingectomy module on the LapSim VR simulator has been assessed in terms of its validity as a training and assessment tool for gynecologists. Aggarwal *et al* (2006), in a prospective cohort study, divided the participants into 3 groups as novices with <10 laparoscopic procedures, intermediate level participants with 20 to 50 laparoscopic procedures and experienced participants with >100 laparoscopic procedures. All of them had to perform 10 repetitions of the virtual ectopic pregnancy module and their operative performance was assessed by time taken to perform surgery, blood loss and total instrument path length. The authors found statistically significant differences between groups at the second repetition of ectopic module for time taken, total blood loss and total instrument path length. However, the learning curves of the experienced operators showed a plateau at the second repetition, while seven repetitions were necessary for intermediate and nine for novice surgeons to achieve similar levels of skills (108).

Similarly, Larsen *et al* (2006) showed that expert gynecologists during the second session performed significantly better than intermediate and novice gynecologists in terms of time, path length and total score (105). These are also confirmed by Schreuder *et al* (2009). The opinion of subjects resulting from the questionnaire about the realism and training capacities of the tasks was favorable among all groups (106).

Therefore, gynecologists with minimal laparoscopic experience can improve their skills during short-phase training on a VR procedural module. It seems that VR simulation is useful for the early part of the learning curve for gynecologists who wish to learn to perform laparoscopic salpingectomy for ectopic pregnancy.

Tang *et al* (2011) described the design of a training phantom that enables trainees to practice key skills and steps used for the procedures of laparoscopic salpingotomy and laparoscopic salpingectomy. In this module, the porcine small bowel is used to simulate the fallopian tube, while porcine liver and red food dye blended in a hand blender are used to simulate ectopic pregnancies inside the fallopian tube; mesentery imitates mesosalpinx. They concluded that this animal tissue model of laparoscopic salpingostomy and laparoscopic salpingectomy in ectopic pregnancy is realistic, cost-effective and simple enough to be produced for use in laboratory-based surgical training courses (109).

Levine *et al* (2006) suggested a lightly embalmed human cadaver model for practicing laparoscopic surgical techniques for adnexal surgery, pelvic dissection, laparoscopic hysterectomy and dissection within the space of Retzius. The training efficacy of this model was demonstrated using an physical-reality simulator for three outcomes (bead transfer time, number of beads transferred, and suturing time on a stuffed vinyl glove), and an embalmed cadaver pelvis for suture placement in two specific areas, with one slightly more difficult than the other. The residents demonstrated a significant improvement after the course in relation to baseline testing in a relatively short time (110).

A live porcine model for teaching advanced laparoscopic skills in gynaecologic oncology fellows has been determined by Hoffman *et al* (2009) to be a good model for laparoscopic lymphadenectomy, uretero-neo-cystostomy, repair of vascular injury, bowel anastomosis, distal pancreatectomy, nephrectomy, partial hepatectomy, diaphragm stripping and diaphragmatic resection. However, this model seems to be inadequate for other surgical procedures such as liver mobilization and splenectomy (111).

Mathews *et al* (2017) examined the role of training in laparoscopic simulator for the credentialization of gynaecologists for laparoscopic surgery and for the maintenance of their laparoscopic technical skill levels, particularly for those with low-volume laparoscopic gynecologic operations. The LapSim simulator (Surgical Science Ltd.) was used based on its face validity and haptic feedback. The physicians were gynecologists with laparoscopic privileges and performed 3 basic skills tasks, which require the use of both hands and are proven correlated with the performance in the operating room: Enforced grasp peg transfer, lifting/grasping and cutting with 2 repetitions of them. The performance measures assessed in each simulation task (total time, efficiency/tissue damage and error scores) were correlated with the average number of laparoscopies per month of each gynecologist. The majority of the physicians who participated in the study were low-volume surgeons and the most common performed procedures had low complexity (diagnostic laparoscopies and adnexal laparoscopic procedures). It has been found that the total time for each of the 3 tasks in the laparoscopic simulator was significantly correlated with the average monthly laparoscopic surgical volume. The authors concluded that higher-volume gynecologists and fellowship-trained specialists were more confident in their laparoscopic skills (112).

Paquette *et al* (2017) in their prospective, comparative study, examined the efficacy of a laparoscopic simulator to assess training levels and improve basic laparoscopic skills in residents (juniors and seniors) in obstetrics and gynecology training programs. The LAP Mentor II virtual reality surgical simulator (Simbionix USA) was used. The participants performed 9 laparoscopic simulator tasks with 2 repetitions of them (snap photos of balls with camera at 0°, snap photos of balls with camera at 30˚, touch flashing balls with blue and red tools, clip leaking ducts within specific segments, grasp and clip leaking ducts with both hands, grasp with one hand and handle with the other, cut a circular form with both hands, cut highlighted with hook electrode and overlap objects with their shadows). It has been found that junior trainees significantly improved their speed of execution, accuracy and maintenance horizontal view, whereas senior trainees performed better than junior trainees and shortened their speed in completing different tasks. The authors concluded that virtual simulators are useful pedagogic tools and should be integrated into residency curricula before performing laparoscopic procedures in the operating room (113).

Crochet *et al* (2017) evaluated the validity of a virtual reality simulator producing key specific components of a laparoscopic hysterectomy procedure until the step of colpotomy. The LAP Mentor virtual reality surgical simulator (Simbionix USA) was used. The participants (experienced and intermediates) performed laparoscopic hysterectomy without guidance (2 repetitions) followed by laparoscopic hysterectomy with guidance (1 session). The inexperienced participants were subdivided in 2 subgroups as follows: The first subgroup performed laparoscopic hysterectomy without guidance (10 repetitions) and the second subgroup performed laparoscopic hysterectomy with guidance (8 repetitions) followed by laparoscopic hysterectomy without guidance (2 repetitions). It has been found that there were significant inter-group differences between experienced, intermediate and inexperienced group for time, number of movements, path length, tissue respect and number of bladder injuries. In addition, score differences between the first and second repetition were found, while the learning curves plateaued between the 2nd and 6th repetition. In that study, it was concluded that the virtual reality program for laparoscopic hysterectomy provides validity evidence. Furthermore, the authors suggest that with the use of a structured methodology in a laparoscopic training curriculum, specific quantitative and qualitative goals are possible to be achieved (114).

Hackethal *et al* (2019) developed an online questionnaire in order to assess the practical laparoscopic training in the gynecological endoscopy working group (AGE) certified training centers in Germany and evaluated the possible implementation for a manual dexterity skills-training within the minimal invasive surgery certification process. The majority of the responders were qualified with the highest minimal invasive certification; the majority of them were subspecialized in gynecological oncology. It has been found that the grasping for the basic curricula and the needle movements and suture exercises for the advanced curricula were of the highest value. In addition, the supervised laparoscopic box training was thought to have the most positive influence on surgical performance. Moreover, the responders thought that the pressure/tension was valuable for evaluation of tissue handling of the participants during training in laparoscopic box trainers. The gynecological endoscopy working group (AGE) Certified Training Centers in Germany favors box trainers with sensors for objective measurement of time, errors, instrument movements and tissue handling (115).

Mannella *et al* (2019) examined the role of simulation in laparoscopy on improving technical skills of the residents in obstetrics and gynecology. In addition, they examined the role of the laparoscopic simulator as evaluation tool to self-assessment of the laparoscopic capacities of the trainees with the use of a modified OSATS (Objective Structured Assessment of Technical Skills) scale. The Simsei training system (2018 Applied Medical) was used. The participants received a simulation program consisting of 5 tasks of basic laparoscopic surgical steps as creating pneumoperitoneum, positioning trocars under vision, demonstrating the appropriate use of dominant and non-dominant hand (moving pegs on a platform, changing the shape of a rubber band and cutting precisely a circle printed on dual layer gauze) and making single stitch and knot. It has been found that senior trainees had better score than junior trainees. In addition, the junior group showed significant improvement after more task-repetitions. Moreover, the self-assessment of all of the trainees was in agreement with the evaluation of the external experts. In that study, it was concluded that the training in laparoscopic simulators improves laparoscopic surgical skills in residents in obstetrics and gynecology and also it is a powerful tool for the evaluation and self-assessment of the trainees before their practice on patients (116).

Soriero *et al* (2019), in their study, described directions on how to build a simple, low cost and realistic homemade laparoscopic box trainer (LABOT) and its validation as a training instrument. Expert surgeons completed a questionnaire after performing basic and advanced laparoscopic procedures about realism, ergonomics and usefulness for surgical training. The participants (group with residents with at maximum 5 years of laparoscopic surgical experiences and group with students without previous laparoscopic surgical experiences) performed 3 different tasks. The participants demonstrated the appropriate use of dominant and non-dominant hand with the use of two atraumatic forceps by passing a thread through a ring path, putting five bolts on top of each other and passing a bolt from one hand to the other and putting it in a box. It was concluded that this simple and low-cost laparoscopic box trainer permits improvement of the basic technical laparoscopic skills, particularly at the beginning of the surgical training (117).

Torricelli *et al* (2016), in their review article, suggested that a short period of training with laparoscopic stimulators improves laparoscopic surgical skills. Also, the authors suggest that the best way for the dissemination of laparoscopic surgery is the induction of laparoscopic simulators in the training of residents in surgery (118). Moreover, Papanikolaou *et al* (2019) suggested that teaching hospitals should introduce training programs using laparoscopic simulators with standardized and reproducible tasks in order to achieve better patient care with safety, efficiency and lower cost (119).

7. Conclusion

Laparoscopic surgical training using simulation has many advantages, such as i) it is a risk-free environment for the patient; ii) it provides novice training in variable cases with high complexity; iii) it provides immediate feedback of the training tasks; iv) it is ethically acceptable as the training is not performed on real patients; v) it is helpful in the identification of the appropriate individuals who will become technically competent surgeons; vi) it is useful for the credentialing processes of surgeons for reduction of adverse events; and vii) it ensures the residents of less practical time in the operating room for improvement of their psychomotor and cognitive skills. Different simulators are used for these purposes including laparoscopic box trainers, laparoscopic VR simulators, animal models, human cadavers and lightly embalmed human cadavers with their effectiveness shown by many researchers although some controversies still exist. The clinical training curriculum of obstetricians-gynecologists should include laparoscopic VR simulators through an integrated evidence-based, simulation-based education program due to the growing request for advanced laparoscopic gynecologic surgery with adjustment of innovative techniques in order to ensure high-quality laparoscopic training.

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Authors' contributions

MV, NN, VKV, FNV, EG and CL all equally contributed to the writing, drafting, revising, editing, reviewing and the conception and design of the study. All authors have read and approved the final manuscript.

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Competing interests

The authors declare that they have no potential competing interests.

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