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EVOLUTION OF TRAINING IN MINIMALLY INVASIVE SURGICAL TECHNIQUES

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Abstract
The advent of minimally invasive techniques has resulted in the need for specific training tools. Important differences between open surgery and endoscopic approaches have made it clear that new training models are required to train a proficient surgeon. Over the last four decades several training approaches have been proposed and analyzed in this setting. The main training tools are box trainers, animal models and cadaveric models. In this article the authors summarize tools that are currently available, describe the development of minimally invasive techniques and possible future directions.

Key words: surgical simulation, cadaveric model, animal model, box trainers, surgical education

Introduction

Medical simulation is a branch of simulation related to education and training in the field of medicine. A simulation can be performed in a classroom or in spaces designed specifically for its practice [1]. It can involve simulated human patients – be it artificial (dummies), live people (actors) or a combination of both – educational documents with detailed simulated animations, casualty assessment in homeland security and military situations, emergency response and support virtual health functions with holographic simulation. In the past its main purpose was to train medical professionals to reduce error during surgery, prescription, crisis interventions and general practice. Combined with debriefing methods it is now also used to train students in anatomy, physiology, and communication skills during their training.

In many aspects medical training is similar to aviation training. In both scenarios, simulation is a powerful tool in training.

Pilot training on an aviation simulator is one of the most crucial elements to ensure safety when operating an aircraft. It minimizes the negative impact of the so-called 'human factor', i.e. minimizes the possibility of erroneous actions taken by the crew.

The first successful use of simulation in aviation began in the late 1920s with the development of the Link Trainer. This early flight simulator was developed by Edwin Link and consisted of a small wooden airplane with a fuselage and wings mounted on a universal joint [2]. During the following decades flight simulators became much more sophisticated. It is widely accepted nowadays that simulation is an inherent part of the training of each member of flight personnel.

Simulation in minimally invasive surgery has a notably shorter history than that of aviation. The reason for this is obvious when we realize that minimally invasive surgery did not gain popularity until the early 90ies.

The aim of this study is to present the training tools that are currently available for minimally invasive surgical techniques as well as a short historical background of them.

Historical evolution

In the very early days of minimally invasive surgery it quickly became obvious that changing the surgical tools should lead to changes in training tools and training modalities.

When the first cases of laparoscopy were performed, all diagnostic and therapeutic endoscopic procedures were carried out under direct visualization through the optical system with a connected light cable. The only person in the operating room who observed the operation field was the operating surgeon. After Camran Nezhat performed the first endoscopic surgery seen on a monitor in the early 1980s, using very heavy and awkward video camera equipment that had been produced for other purposes, all the participants in the operating room started to see the same endoscopic picture as the lead surgeon [3]. Thus, more complex procedures can be performed with the help of the assisting surgeons. The moment when the endoscopic view became available equally to all members of the operating team was a milestone not only for ergonomics, but also for generations of surgeons, since the operating surgeon ceased to be the only person who observes the operation field. This breakthrough was probably one of the reasons why the development of newly designed training programs in minimally invasive surgery became vital.

By the mid 1970s training in laparoscopy had been added to "all major gynecological residency programs" in Europe. And by 1981, the American Board of Obstetricians and Gynecologists followed suit and made laparoscopic training a required component of U.S. residency programs [4].

One of the crusaders in the implementation of surgical technique in minimally invasive surgery, or so called "pelviscopy", was the first gynecologist to perform a laparoscopic appendectomy for acute appendicitis. Kurt Semm recognized that the traditional Halstedian training model "see one, do one, teach one" cannot be fully applied to minimally invasive training. He developed a new tool for training in minimally invasive surgery called the "Pelvi-Trainer". "The art of pelviscopic operating may not be acquired by assisting as in laparotomy, as assisting means only holding instruments and occasional observation. Therefore, the training method has to be modified" stated Semm in his iconic publication on *Operative pelviscopy* published in 1986 [5: 293].

With this model, all endoscopic operations may be learned step by step. The instruments are used first without endoscope, then the endoscope is used with occasional "cheating" by looking through the transparent "abdominal wall" of the model and finally, the Pelvi-Trainer is covered by a non-transparent cover and the operating field of vision is entirely reduced to that of the pelviscope. In this manner, all operative steps may be learned and practiced with models of extirpated uterus-adnexial organs or placentae [5].

The invention of the Pelvi-Trainer can be described as a starting point in the development of simulation box trainers for minimally invasive surgery.

Through the ages surgeons were trained according to the apprenticeship model, in which the trainee was the observer and assistant to a leading surgeon and when "enough time" had passed he was allowed to perform surgical procedures by himself. An American surgeon at the beginning of the 20th century William Stewart Halsted modified this practice to the "see one, do one, teach one" model.

Contrary to that model, the teaching of endoscopic and technological skills is best conducted in the setting of a skills laboratory and its absence should in the near future disqualify a hospital from recognition for postgraduate training in surgery. Training should be carried out both in the operating room, in a debriefing meeting and in a skills lab. However, suturing techniques learned in open surgery are not automatically transferred into laparoscopic suturing skills due to the visual constraints and differences of motion, they require different techniques, skills, and practice to master [6]. Thus, the classic surgical apprenticeship system is still valid, although it has to be expanded to accommodate some important new elements prerequisite for minimally invasive surgery training [7].

According to a *Systematic review of skills transfer after surgical simulation-based training* three Randomized Controlled Trial (RCTs) concluded that simulator-trained participants made significantly fewer intraoperative errors than those not trained on the simulator. One study found that simulator training was associated with lower intraoperative and postoperative complication rates for the first total extraperitoneal hernia repair performed after training [8].

Although postoperative surgical outcomes are extremely important, it should not be forgotten that training can improve other parameters as well. So, for example, if we take into account economic indicators such as the cost of one minute of operating time, we can find out that deductive training in intracorporeal knot formation can reduce the cost of surgery. So, if we consider the average value of the cost of operating time of €40–50 per minute of surgery, it would mean a cost saving of at least €120–150 for a partial node [9].

In addition, we can observe a trend in the reduction of operating room time per week in the European Union. The residents spend less time in the hospital learning, thus an operation previously seen 10 times by the resident may now be observed only a few times before graduation [10].

The SARS-CoV-2 pandemic can potentially reduce the number of procedures performed even further, due to a reduction in the number of elective cases and the much more precise decision making prior to every case [11].

Types of training tools

Training boxes

Training boxes have proved to be an effective method of acquiring laparoscopic skills outside the operating room [12].

One of the most recognized surgical education programs, which includes training boxes, is Fundamentals of Laparoscopic Surgery (FLS). The FLS Manual Tasks include 5 tasks: PEG Transfer, Pattern Cutting, Endoloop Placement, Extracorporeal Suturing, and Intracorporeal Suturing. The system that was incorporated in the FLS program was a derivative of the MISTELS (McGill Inanimate System for Training and Evaluation of Laparoscopic Skills) program originally developed at McGill University for this purpose. Since 2008, FLS has been a requirement for General Surgery Board eligibility [13].

Another important element should be the motivation for training. In several studies it was found that residents did not perform exercises on their own without the assistance of their mentor, even if there was free access to the training boxes [14].

And last but not least a training box allows one to train at home. For this reason, plenty of training boxes can be found at online stores. It is also quite possible to build a self-made training box at home from simple and easy-to-buy elements in order to practice in one’s spare time (Figure 1). In a study by Li and George the cost ranged from £3 to £216 for do-it-yourself simulators and £60 to £1007 for commercial ones [15].

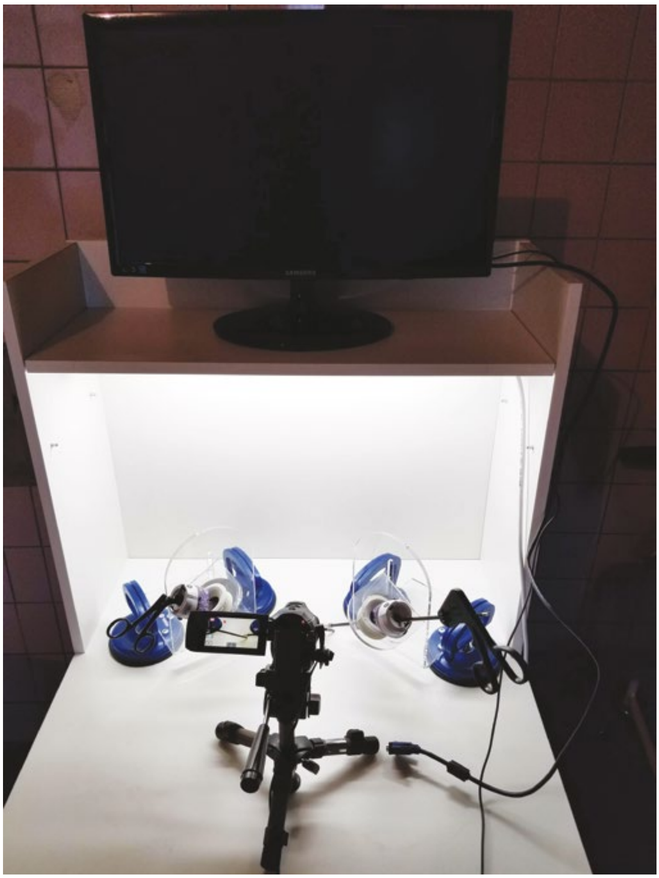

Figure 1. Homemade training box. Source: author’s photo.

The cost of laparoscopic equipment (instruments and laparoscope) was not included in cost estimates for non-commercial simulators. However, a number of articles have suggested the use of expired disposable instruments obtained from the operating department at no cost to the trainee. The authors of some early papers on home hands-on training suggest the use of previously used ultrasonic shears as a free analog of graspers [16].

A working space can be created most simply with a plastic container with several port openings for the different angles of working instruments.

A study performed by Chandrasekera *et al.* showed that, compared to the manufacturer pelvic trainer, training with a low-cost cardboard training box shows no significant difference in scores or times for the two placement tasks between the two groups when assessed on the cardboard box trainer. However, although both groups had similar scores for cutting out a disc, the conventional pelvic trainer group perforated the balloon in 56% (10 of 18) of cases compared to 22% (4 of 18) for the group trained on the cardboard box. Interestingly when assessed on the conventional pelvic trainer, the group trained with the cardboard box had significantly faster completion times for three of the four transfer tasks than the group that trained on the pelvic trainer [17].

In the article by Jaber we can find a simple solution using a customized shelving and drawer system, which can be found at a furniture store. Laparoscopic instruments are placed in the holes of a pull-out shelf, and using this different position angles of the instrumentation can be mastered. In this scenario web camera is used with a notebook [18].

The source of the video signal also can differ, from a simple mobile phone or tablet pc to web cameras and action cameras. Phone and tablet solutions can provide an "app-based" skills planner and even assessment tools in the future [19,20].

These results demonstrate that this inexpensive system is at least as effective as a standard trainer in acquiring basic laparoscopic skills.

Animal training

Among the many animals, including rat and canine models proposed for the mastering of the laparoscopic skills, the pig and sheep models remain the best solutions.

There is a variety of surgical techniques and approaches that can be explored during animal model training. The advantage of the animal model is the possibility of real bleeding, the feeling of the biological tissues, and precision of the movements which is required of a surgeon. In the animal model very complex procedures can be practiced, included Hepato-Pancreato-Biliary (HPB) surgery, with a focus on the methods of liver parenchima transection, Pringle manoeuver, division of liver ligaments, dissecting the structures inside the hepatoduodenal ligament, dissection of the hepatic veins and left lateral liver sectionectomy [21]. With experienced surgeons the animal model can provide even more, especially those exposed to open procedures can advocate conversion to open for bleeding control and damage reparation that occurs, while the younger generation can study MIS damage control without any doubts.

As a matter of fact every year the medical industry provides us with new equipment, expanding radically our arsenal of surgical tools and solutions.

Stephenson and Freiherr have pointed out that according to the Food and Drug Administration (FDA) of the United States of America, 9% of all medical device failures are directly related to user error. They mention that the actual rate of user-related errors is probably even higher. User errors in anaesthesiology, for example, can account for as many as 90% of deaths and injuries to patients [22].

Appropriate training in the accurate environment with the risk of bleeding or visceral injury can potentially reduce errors in the operating room. As for the accessibility of this type of training, in most European countries and the USA, training using live animals is permitted, unlike the UK, for example.

Despite having a lot of the advantages, animal training has some important drawbacks, i.e.: high cost, the necessity of veterinarian equipment and veterinarian-anesthesiology team, special high-cost lab, and expensive equipment, which is the same as in the regular operating room. Another important point to mention is that animal anatomy differs significantly from humans, which can put limits on the procedure list. On the other hand, obtaining proficiency in the control of bleeding in the animal model can reduce mental fatigue in human procedures. It also offers properties of biological tissues which are extremely comparable to humans, and the possibility to feel tissue approximation with intracorporeal stiches and knotting. These advantages can neutralize the above-mentioned disadvantages.

Manual skills in particular should be performed in a stress-free atmosphere with the opportunity to practice and perfect the surgical procedures. Additionally, learning to use high-energy devices such as diathermy, dissection or tissue handling, with the current simulators available, is still more efficient in an animal model compared with inanimate simulators [23].

An interesting way of combining the advantages of the animal model with virtual reality while eliminating some problems inherent in live animal training is the use of advanced combined training simulators. A good example is a tool designed at the University of North Carolina where an ex vivo model consisting of a porcine tissue block that is artificially perfused and mounted in a human mannequin with a silicone based abdominal wall was prepared. The final result was evaluated as a very realistic platform that can help even experienced surgeons to practice [24].

Cadaveric training

Cadavers offer a realistic model for many, but not all, surgical procedures. While offering one of the best simulated surgical experience its use is severely limited by availability and high costs. The storage, maintenance and access to a proper training space are also an important issue. In summary, cadaveric training in minimally invasive techniques, while offering a high quality of training, is and most probably will stay in the near future inaccessible to a wider surgical audience [25].

Health risks

Like real minimally invasive surgical operations a simulation environment can also pose health risks for trainees. In one study for Virtual Reality (VR) training in anatomy some medical students experienced eye strain, eye pain, and headaches while using the 3D-VR application, which affected their concentration. These issues could be related to direct eye exposure to high-intensity screen light [26].

Taking into account the authors' own experience, ergonomics should be a very important aspect of training because bad habits can be transferred from the training laboratory to the operating room, which in turn can lead to the development of progressive health problems. We can observe health issues for medical practitioners in the field of minimally invasive surgery, including abdominal surgery and gynecology [27].

Conclusion

Over the 40 years of the development of minimally invasive techniques it has become clear that they require a specific set of technical and skills and knowledge that only specially designed training programs can provide. While there is still a universally accepted training curriculum, it seems that a combination of the available methods, which include box trainers, live animal models, animal tissue models and cadaveric simulation, can result in an appropriately trained endoscopic surgeon.

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Rozwój szkolenia w zakresie minimalnie inwazyjnych technik chirurgicznych

Streszczenie
Wprowadzenie do użytku technik chirurgii minimalnie inwazyjnej stworzyło potrzebę opracowania nowych narzędzi. Istotne różnice między chirurgią klasyczną a zabiegami endoskopowymi jasno pokazały, że istnieje również konieczność wypracowania nowych schematów szkolenia w celu wykształcenia dobrze przeszkolonego chirurga. W ciągu ostatnich czterech dekad opracowano i przeanalizowano szereg takich schematów. Głównymi technikami są: trenażery laparoskopowe typu *box trainer*, modele zwierzęce oraz model ludzkich zwłok. W artykule zebrano dostępne obecnie metody szkolenia, opisując historię ich rozwoju i możliwe kierunki przyszłych badań.

Słowa kluczowe: symulacja chirurgiczna, model ludzkich zwłok, model zwierzęcy, trenażer laparoskopowy, edukacja chirurgiczna