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REVIEW

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Virtual Reality in Laparoscopic Colorectal Surgery Training

Nikoleta SINOU[a, b], Natalia SINOU[a, b], Maria PAPPA[a, b], Theodoros MARIOLIS-SAMPSAKOS[c], Dimitrios SCHIZAS[d], Dimitrios FILIPPOU[a, b]

[a]Department of Anatomy, Medical School, National and Kapodestrian University of Athens, Greece

[b]Research and Education Institute in Biomedical Sciences, Athens, Greece

[c]Department of Anatomy, School of Nursing, National and Kapodestrian University of Athens, Greece

[d]1st Department of Surgery, Laiko Hospital, Medical School, National and Kapodestrian University of Athens, Greece

ABSTRACT

Introduction: *The advantages of laparoscopic colorectal surgery have been proven in several studies, but its use is limited in some countries and not widely practiced. One of the primary benefits of laparoscopic surgery is that it reduces patient discomfort and hospital stays compared to traditional open surgery. This study presents an overview of the virtual reality training method for laparoscopic colorectal surgery and offers evidence for the effectiveness of this training curriculum and the associated learning curve.*

Material and methods: *To conduct this research, we conducted a thorough review of the relevant literature in the PubMed database, focusing on studies related to "Virtual reality and colorectal laparoscopic surgery training".*

Results: *The vast majority of the publications included in the current review suggest that that laparoscopic surgery in colon has many advantages in contrast to open surgery. Also, virtual reality is essential to all surgeons in order to be familiarized with laparoscopy, while cadaveric and animal models may be useful for the curricula.*

Conclusions: *Appropriate skills are required from surgeons to perform laparoscopic colorectal surgery, which offers various benefits such as quick recovery, decreased postoperative pain, and enhanced safety. Training programs using virtual reality simulators can significantly enhance laparoscopic surgery skills of qualified and resident surgeons.*

Keywords: colon, laparoscopy, surgery, training, virtual reality.

Address for correspondence:
Nikoleta Sinou
18 Vakhou, Agia Paraskevi, Athens, GR-15342, Athens, Greece
Tel: +30.6944043122; email: nikoletta.sinou@gmail.com

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ABBREVIATIONS

LCS: laparoscopic colorectal surgery
VR: virtual reality
PRISMA-ScR: Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews

INTRODUCTION

Since its first successful implementation in 1991, multiple well-documented studies have demonstrated the significant advantages of laparoscopic colorectal surgery (LCS) over traditional open approaches. These benefits include faster patient recovery, reduced hospitalization, and decreased postoperative pain. As a result, demand for LCS training has significantly increased (1, 2). Training for laparoscopic surgery has traditionally involved learning through a pig model or a cadaver. However, simulation-based instruction has now become prevalent, imparting practical skills, technical approaches, and theoretical knowledge to prepare surgeons and medical students for the laparoscopic operating room (3, 4). Thanks to the latest advancements in computer graphics and haptic feedback technology, virtual reality (VR) now offers an unparalleled degree of realism through highly accurate representations of anatomy and related pathologies. This maximizes the learning experience (5, 6).

The aim of this review is to familiarize readers with the benefits and drawbacks of laparoscopic colorectal surgery. Additionally, it aims to outline the useful tools and techniques for training in LCS, as well as examining the cognitive frameworks that LCS training is based on, including both animal and human models. ❑

MATERIALS AND METHODS

The PubMed database was extensively searched using specific keywords such as colon, laparoscopy, surgery, training, virtual reality for relevant published sources. To ensure accuracy and adequacy, information was gathered through a common data extraction form designed for the aforementioned keywords. The research study adhered to the guidelines of PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews), a comprehensive approach for conducting scoping reviews. By following PRISMA guidelines, a total of 29 records were initially identified through the PubMed search, and an additional 14 records were obtained through a thorough review of references. After removing duplicates, the final number of screened records was 43. A total of 22 full-text articles were assessed for eligibility, resulting in the exclusion of 21 articles, titles, and abstracts that were not relevant. Hence, the specific article is based on the information retrieved from 22 reliable references (Figure 1, Table 1). ❑

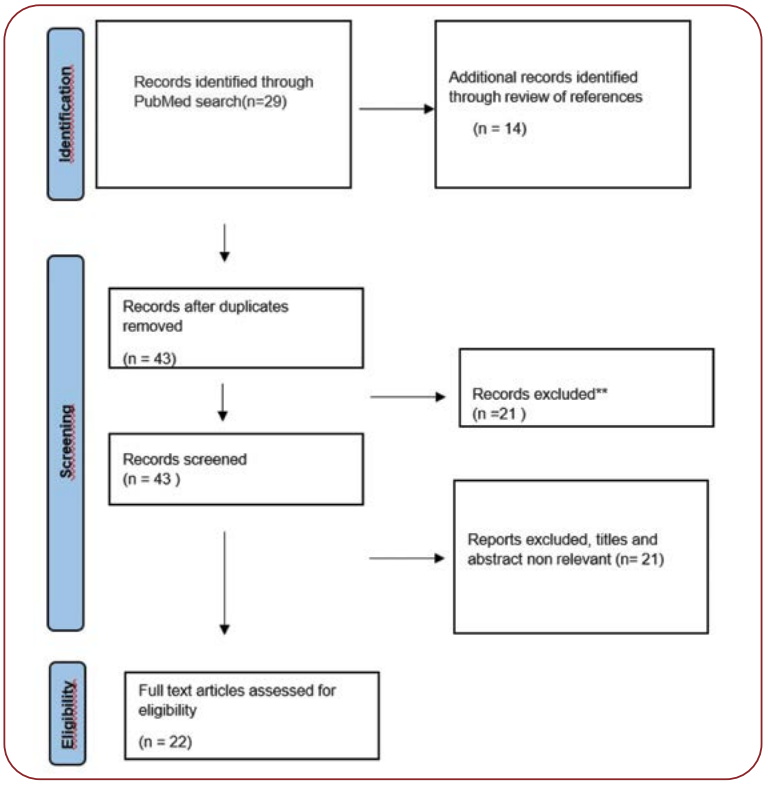

FIGURE 1. Virtual reality in laparoscopic colorectal surgery training PRISMA

RESULTS

A total number of 43 records finally matched the criteria for our study. Twenty two of them were assessed for accuracy and therefore used in the present review work. Of all study participants, surgically unexperienced novice surgeons were the ones with the most significant enhancement from the VR laparoscopic training model. The detailed analysis and discussion of the 22 reviews suggested that VR simulation, despite its highly expensive cost of acquisition, reduced the learning curve for colorectal laparoscopy,

TABLE 1. Virtual reality in laparoscopic colorectal surgery training. Characteristics of studies

Study	Who participated	Where was the study conducted	Number of participants	Advantages of VR in laparoscopic training surgery	Use of the learning curve
Nugent E, *et al* (2012)	Royal College of Surgeons	Ireland	NM*	Yes	NM
Shanker BA, *et al* (2016)	Accreditation Council for Graduate Medical Education and American Board of Colorectal Surgeons operative statistics	Orlando, USA	NM	Yes	Decreased
Palter VN, *et al* (2012)	International experts	Toronto	19	Yes, the Delphi method	NM
Yang C, *et al* (2018)	Laparoscopically naive medical students in clinical semesters	The University Hospital Dresden	48	Yes	NM
Foster JD, *et al* (2015)	NM	Italy	NM	Yes	Reduced
Sankaranarayanan G, *et al* (2021)	NM	Texas	NM	Yes	Reduced
Alaker M, *et al* (2016)	No experienced, Novice laparoscopic surgeons, Expert laparoscopic surgeons	NM	1288	Yes	NM
Neary PC, *et al* (2008)	Surgeons, experienced but novice in LC, experienced laparoscopic colorectal surgeons	NM	14	Yes	No change
Sinitsky DM, *et al* (2020)	Novices and experts	London	60	Yes	Decreased
Wynn G, *et al* (2018)	Expert surgeons	Cleveland, Ohio, USA	6	Yes	Decreased
Shanmugan S, *et al* (2014)	Surgeons, general surgeons, and colorectal surgeons	Cleveland	106	Yes	NM
Gaitanidis A, *et al* (2018)	NM	Alexandroupoli, Greece	NM	Yes	Decreased
Araujo SE, *et al* (2016)	First-year residents in digestive tract surgery	University of Sao Paulo Medical Center	14	Yes	Steep
Pan JJ, *et al* (2015)	NM	NM	NM	Yes	Shorter
Beyer-Berjot L, *et al* (2016)	Novice, intermediate and experienced surgeons	London and Marseille	<70	Yes	Reduced
Jin C, *et al* (2021)	Medical students, interns, resident doctors and specialists	China	NM	Yes	Steep
Leblanc F (2010)	Trainees	Cleveland, OH, USA	38	Yes	Steep
Seymour NE, *et al* (2002)	Surgical residents in postgraduate year	Yale University School of Medicine Department of Surgery	16	Yes	Trained out
Lehmann KS, *et al* (2013)	Attendees	Germany	105	Yes	NM
Araujo SE, *et al* (2012)	Residents of a university-affiliated hospital with the same level of clinical experience in laparoscopic colorectal surgery	Cleveland, OH, USA	14	Yes	NM
El-Beheiry M, *et al* (2017)	All first-year surgery residents in general surgery, urology, obstetrics and gynaecology, orthopaedic surgery, vascular surgery, cardiac surgery, neurosurgery, otolaryngology, plastic surgery and oral maxillofacial surgery	New York	NM	Yes	NM
Slieker JC, *et al* (2012)	Surgical residents in their first and second year of training	The Netherlands	11	Yes	Decreased

*NM= Not mentioned

with the experienced surgeons having more intense learning and the novice doctors having faster progress.

The training program VR surgical skills course in colon aims to teach the trainee how to accurately handle laparoscopic tools, place a needle in a specific designed area and not damage the surrounding tissues. Numerous studies support the superiority of VR training compared to box and video trainers in terms of greater efficacy and accuracy, although no significant statistical difference between training methods has been furthermore established. Multiple investigations demonstrated that cadaveric and animal models were appropriate foundations for VR training, providing realistic haptics, increased skills in dissection and controlling bleeding, despite the disadvantages that they sometimes have. ❑

DISCUSSION

Participants in the study were categorized into four groups: (a) individuals with no previous experience; (b) medical students who lacked laparoscopic surgery experience; (c) beginner surgeons with limited laparoscopic surgery experience; and (d) expert surgeons with complete knowledge of laparoscopic surgery who underwent virtual reality (VR) training.

A recent study found that novice surgeons' surgical skills were significantly enhanced through VR training, whereas the improvement of those with no previous laparoscopic experience was not statistically significant. However, the difference in incremental improvement between the two groups was not statistically significant (7-10).

Numerous studies worldwide have suggested the importance of the learning curve, despite debate over the efficacy of its calculation. Various factors, such as clinical outcomes, conversion rates, and case complexity, contribute to measuring efficiency (11). While multiple studies estimate learning curves, proficiency is estimated at 11-70 cases using a single-parameter approach and 200-250 cases using a multiple-parameter approach. The complexity of this issue highlights the necessity of measuring and examining knowledge for optimal clinical outcomes (12). Furthermore, self-taught surgeons' learning curves reflect the structured curriculum, and VR simulation has been shown to decrease the learning curve for colorectal laparoscopy according to numerous papers (13-15). Despite a systematic review and meta-analysis questioning the adequacy of VR training for novice residents and students, it was found that VR training was superior in reducing the learning curve. In addition, a comparison of the learning curve was conducted among doctors at varying experience levels – those with no experience, novice, intermediate, and expert doctors. Different opinions emerged, with one study suggesting that experienced doctors had more intense learning, while the other two studies showed that novice doctors had faster progress with greater motion economy (16). The last two studies revealed the importance of age difference between groups when it comes to learning new things and emphasized the need for early introduction of VR training. Overall, these findings indicate the significance of VR training in enhancing learning outcomes.

VR model. Several studies have shown that the lack of simulation training outside the operating room had many disadvantages in contrast to a curriculum for surgeons before enter the operating room. Specifically, the trainer cannot direct the trainee's hand and correct possible problems that may occur during the operation and secondly the surgeon has to work in a third environment *via* a second screen. Systematic reviews have agreed the superiority of VR training compared to no training at all, in terms of lower operative times, fewer errors, higher scores in validated performance scores and higher overall accuracy (12, 17, 18).

VR surgical skills course in colon. Laparoscopic surgery necessitates the use of specialized tools such as laparoscopic scissors, electric hooks, stapling devices, and graspers. In order to train for the virtual reality curriculum, the same tools used in real-time operations are required, in addition to a laptop computer. This training program has two stages. Firstly, trainees must handle a needle with two laparoscopic instruments. It takes place in an iconic environment presented in 3D. Specifically, the trainee must use one instrument to grip the needle and the other to lift a block without losing control. The needle must be accurately placed in a designated area, with the trainee minimizing contact with adjacent organs to prevent damage to the surrounding tissue. Each trainee performs the task and the simulator evaluates their performance and damage to the tissue, assigning a specific score. During the simulation, a needle is used

instead of a pathological or alien structure of the colon to provide a realistic experience for the trainee. Additionally, the VR course aims to teach trainees how to accurately handle laparoscopic tools and use an electric hook to dissect small vessels. Trainees are commonly asked to dissect the cystic duct and cystic artery during a laparoscopic cholecystectomy. The simulator calculates a score for each trainee based on factors such as the amount of vessel damage, time taken, and successful outcome (14, 19).

Due to the above-described benefits, the use of VR models in laparoscopic surgery is necessary to train surgeons and undergraduate doctors. VR technology has been shown to enhance surgical skills and provide objective performance assessments (19). This tool allows for realistic graphics, repeated tasks to improve skills, and candidate performance recording. Additionally, VR simulators offer flexibility in terms of timing and difficulty levels. With realistic haptic feedback, instant feedback is provided to correct mistakes (6, 20). Furthermore, VR simulators establish proficiency-based curricula that prepare surgeons for challenging tasks and increase their familiarity with the high risks of real operations. There are two important examples of this statement, a prototype VR training in laparoscopic rectum surgery and a randomized controlled trial (with novice, intermediate and experienced surgeons based on the number of laparoscopic colorectal resections they have performed as a primary operation) with a curriculum for LCS (performing a sigmoid colectomy). They both showed a significant reduction in the learning curve and in both curricula there was not a problem with the haptic feedback provided by the VR model. All those concluded that there would be an improvement in patient's safety (14, 15).

VR models have a steep price tag, hindering their widespread adoption. In the USA, a study performed in 1999 showed that annual training costs per resident were $11,995, highlighting a major obstacle to VR simulators for trainees (12). Conversely, some argue that traditional training is similarly costly and that VR models have comparatively low operational expenses (15). However, VR training is often criticized for being an incomplete curriculum and failing to equip surgeons with knowledge of anatomy and necessary decision-making skills (9).

Virtual reality *vs* video trainer. Several studies compared virtual reality to video training. Five relevant studies totalized 152 participants, who were all unexperienced in laparoscopic surgery, except one study which included 50 novice surgeons. The outcome demonstrated that time was the judged factor (7, 8). In another systematic review, there was no big difference in the learning curve between virtual reality and video trainer and also no difference in terms of time and scores (16).

Virtual reality *vs* box trainer. The earlier mentioned systematic review and meta-analysis also investigated the disparities between virtual reality training and box trainers. While both methods demonstrated a similar learning curve, there were divergent findings concerning other factors. One study implied that individuals trained *via* box trainers displayed superior performance during real-life procedures, while other studies took into account that VR training resulted in greater accuracy and efficiency. Furthermore, another systematic review and meta-analysis, which considered crossover studies, found no significant statistical difference between the two training methods (21).

Training models in laparoscopic surgery. Multiple investigations have demonstrated that cadaveric and animal models were appropriate foundations for VR training. One comprehensive analysis discovered that cadaveric instruction was more effective than VR training, leading to an enhancement of skills such as dissection, retraction, suturing, bleeding control, hand-eye coordination, and reduced time to task completion. Thus, incorporating cadaveric and animal training into VR instruction is advisable. A separate examination focused on laparoscopic colorectal surgery showed that the cadaveric model, especially when utilizing a novel embalming technique for maintaining tissue flexibility and plasticity as close to normal as possible, was superior to both animal and VR models. This conclusion was derived from a survey of surgery residents who had prior VR experience (22). Both models are highly realistic and effective for training, offering increased skills in dissection, controlling bleeding, and faster completion times. However, each model has its own unique advantages and disadvantages. Although cadaveric models provide more accurate dissection and hands-on experience with real conditions and instruments, they lack acute perfu-

sion. Conversely, animal training models offer better availability, working conditions, and live complications that allow for direct reactions, while also being less expensive. Nevertheless, both models face drawbacks such as low availability, ethical concerns, and limitations. Cadavers have a limited duration for use and anatomical variations, while animal models can spread zoonotic infections and have differences between humans, which restricts their use (6, 12). ❑

CONCLUSIONS

The training for laparoscopic colorectal procedures has been shown to enhance the technical proficiency of surgeons and ultimately result in superior outcomes and maximum safety for patients. Surgeons can benefit from multifaceted technical abilities and haptic feedback during simulations, which can be valuable for many laparoscopic surgeries. Although VR models are often presumed to be expensive, one study suggests the opposite. Many studies highlight the importance of the learning curve and how it can be reduced through VR simulation. While cadaveric training is considered more effective than VR and animal models when it comes to enhancing trainers' skills, animal models are more accessible to trainers. Therefore, it is recommended to incorporate curricula based on VR knowledge acquisition, followed by cadaveric and animal models, to optimize laparoscopic training. Further research is necessary to prove the direct advantages to patients, but the VR colectomy module can serve as a reliable indicator of performance in actual surgical situations. Additionally, simulation training can enhance several crucial skills that are vital for surgical success. ❑

Availability of data and materials: The data were collected via PubMed database. The information of this systematic review is available and accessible in the database mentioned using the keywords that have been mentioned above.

Conflicts of interest: none declared.

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