Chapter

Simulation in Complex Laparoscopic Digestive Surgery

Asanga Gihan Nanayakkara, Phillip Chao, Jonathan B. Koea and Sanket Srinivasa

Abstract

The adoption of laparoscopic techniques for complex digestive surgical procedures, such as hepatectomy and pancreatectomy, has been slow in comparison to other areas of surgery. Laparoscopy presents the surgeon with several challenges including ergonomics, lack of haptic feedback, altered fields of vision, and teamwork meaning that there is a significant learning curve for complex laparoscopic digestive surgery, even for the surgeon experienced in open procedures. Simulation is a useful method to train surgeons in complex procedures and has been suggested as a potential mechanism to decrease the duration of the surgeon learning curve in laparoscopic surgery. This chapter will explore current concepts in simulation for complex laparoscopic digestive surgery. Readers will develop an understanding of the role of simulation in surgical procedural training and evidence-based techniques that may be implemented in their own institution.

Keywords: laparoscopic, simulation, general surgery, virtual reality, augmented reality

1. Introduction

Laparoscopic surgery has been increasingly applied to complex digestive surgery because of the many advantages over open surgery, such as reduced postoperative pain, reestablishment of bowel function, shorter hospital stays, and earlier return to work and full activities [1].

However, the high level of technical complexity of advanced laparoscopic digestive surgical procedures and the steep learning curve pose many challenges for surgeons, surgical trainees, and their teams. There have been studies that suggest a volume-outcome relationship for numerous procedures [2, 3]. For certain gastrointestinal malignancies, particularly those originating in the foregut, surgical resection is only indicated in a minority of cases [4]. Since most minimally invasive surgery for gastrointestinal malignancies occurs in low-volume hospitals [5], this presents a significant impediment to surmounting the learning curve and maintaining competencies. As a result, simulation has become an important tool in training in complex laparoscopic surgery.

This chapter focuses on current concepts of procedural simulation in complex laparoscopic digestive surgery. Examples of the different types of complex procedures can be seen in **Table 1**. Simulation and training in nontechnical skills, such as

Basic laparoscopic digestive procedures	Complex laparoscopic digestive procedures
Diagnostic laparoscopy	Oesophageal procedures
Appendicectomy	Gastric procedures
Cholecystectomy	Biliary procedures
	Pancreatectomy
	Hepatectomy
	Small bowel procedures
	Colorectal procedures

Table 1.
List of basic and complex laparoscopic digestive operations.

communication and team-building, necessitate a separate in-depth analysis. This chapter explores challenges in complex laparoscopic surgery and how simulation may address these. It provides a background to simulation in surgery and evidence-based examples of simulation in upper gastrointestinal (UGI), hepatopancreaticobiliary (HPB), and colorectal (CR) surgery. Finally, the limitations of simulation and possible future directions have been reviewed.

2. Challenges in complex laparoscopic digestive surgery

Surgical training is traditionally an apprenticeship model, based on a trainee learning to perform surgery under an experienced surgeon. Laparoscopic surgery requires a different skill set, which is dissimilar to open surgery; this poses a unique set of challenges for learners. The technical challenges include an unstable video camera platform, loss of depth perception, reduced range of movement of instruments compared to open surgery, decreased tactile feedback, and fulcrum effect, which is the disparity between visual and proprioceptive feedback [6] (**Table 2**). Many of these technical challenges may be mitigated with the increasing experience of the surgeon and operating team. However, patient characteristics, such as pathology and comorbidities, and geography of practice limit the efficiency of achieving the volume required to master those specific skills.

Two-dimensional vision systems, using standard monitors, reduce depth perception.
Decreased ergonomics and dexterity.
Long inflexible laparoscopic tools increase surgeons' natural tremors.
Rigid instruments limit surgeons' range of movement and dexterity.
Fixed abdominal entry points result in a fulcrum effect.
Increased fatigue due to camera unsteadiness.
Limited tactile feedback.

Table 2.
Technical challenges of laparoscopic surgery [12].

2.1 Loss of degrees of freedom

In open operations, surgeons use short instruments which allow a wide range of movements by flexing the upper limbs, back, and hips. However, laparoscopic instruments are long and straight, and the degree of movement is limited within a cone created by the trocar, limiting the degrees of freedom of the instrument.

In complex laparoscopic digestive surgery, the laparoscopic instruments must traverse the length of the abdominal cavity, such as in colectomies. This places the instrument in non-advantageous angles of use. Tasks, such as suturing, which are straightforward for a surgeon in open operations may become cumbersome for a novice in laparoscopic surgery given the constraints of the instruments and their intra-abdominal angulation.

2.2 Adverse ergonomics

The placement of trocars and limitations of the laparoscopic instruments can place surgeons in non-ergonomic positions. The arms and shoulders may be elevated, and in obese patients, the surgeon may need to lean to reach the operative field. In complex laparoscopic operations, this may prolong the operation, reduce the dexterity of the surgeon and lead to fatigue. There have been multiple reports of carpal tunnel syndrome, eye strain, and cervical spondylosis among surgeons performing multiple laparoscopic procedures in high-volume centers [7, 8]

2.3 Unstable camera platform

Advanced laparoscopic surgery requires the surgeon to see anatomy to safely perform an operation. The quality of the image provided partly depends on the camera operator who may be inexperienced. This may lead to rapid camera movements, a view that is rotated away from the horizon, and a narrow view of an operative field without the perspective that comes with visibility of the entire abdomen or thoracic cavity. The unstable view may lead to motion sickness as well as increased fatigue during an operation [9]. These factors can make the laparoscopic image disorientating compared to open surgery.

2.4 Two-dimensional video imaging

Most laparoscopic surgeries are performed with two-dimensional imaging (2D) systems. For operations, such as laparoscopic cholecystectomies, the gallbladder can be well visualized in one 2D frame. In contrast, in complex laparoscopic operations, such as pancreatectomy, a surgeon's perception of the three-dimensional relation of intraabdominal organs and depth is sub-optimal, making complex dissection more difficult. This adds to the learning curve of surgeons training to do advanced laparoscopic surgery. 3D laparoscopic surgery has been found to reduce operative time in UGI and colorectal surgery, however with no overall reduction in complications [10].

2.5 Overcoming the learning curve

The other challenge of complex laparoscopic surgery is an increased rate of adverse clinical outcomes during the learning curve [11]. This raises ethical issues and reinforces the need for ways to decrease complications, particularly in the early part of learning a new operation. Simulation can also play an important role in training for different parts of complex procedures such as forming a jejuno-jejunostomy [12] or medial to lateral colonic mobilization during colectomy [13]. Simulation may also be utilized by experienced surgeons to maintain skill sets and focus on specific procedural aspects that may decay over time and when they often take on the most difficult cases. In the current era, it is no longer acceptable for surgeons to acquire new skills at the expense of patient safety, especially when other methods such as simulation are available to facilitate skill acquisition.

3. Background of simulation in surgical training

Surgical training involving Halstead's apprenticeship model has changed particularly with the uptake of laparoscopic surgery [15]. Patient safety, the ethics of learning and teaching surgical procedures to patients, the development of new technologies, and the need for objective assessment of trainees have meant simulation plays an important role in surgical training.

Given the breadth of technical and nontechnical skills required to perform laparoscopic surgery safely and efficiently, a variety of simulators have been developed. The aims of simulators assist surgeons in ascending the learning curve for specific procedures and provide skills that translate to improved performance and safety.

Simulation has been widely used, particularly in laparoscopic surgery (**Table 3**). Training models include benchtop models, virtual reality (VR), augmented reality (AR), animals, and cadavers. A number of studies have compared different training models with the pertinent finding being that a combination of models is more effective than one model-based training [16].

3.1 Simulation using benchtop models

Benchtop simulators (box trainers) use laparoscopic instruments within a model. They have been mainly used to teach basic surgical skills, such as suturing and knot tying. However, more advanced trainers have been developed for more complex laparoscopic surgery, such as Nissen fundoplication, hepatectomy, and colectomy [17–19]. Benchtop models use either synthetic or animal tissues or organs. They are relatively

Type of simulator	Advantages	Disadvantages
Box trainer	Low initial cost. Can be used repeatedly. Provides sensory feedback.	Require ongoing maintenance and materials. Requires feedback from an observing trainer for maximum efficacy.
Virtual reality	Records multiple procedure metrics. Provides feedback.	High upfront cost. Lacks haptic feedback.
Augmented reality	Haptic feedback. Greater realism.	Expensive start-up cost. Lacks accuracy.
Cadaver and animal models	Best anatomic and clinical-like model.	Limited availability. Expensive. Need operative facilities.

Table 3.
Advantages and disadvantages of different types of simulators.

inexpensive and give tactile feedback, however, require ongoing maintenance and materials as well as an observing trainer to give feedback for maximum effectiveness [20].

3.2 Virtual and augmented reality simulators

VR simulators allow trainees to interact with a computer-generated environment that reproduces individual skills or entire procedures. Modern VR simulators can replicate complex laparoscopic surgery, such as sleeve gastrectomies and colectomies [13, 21]. Some of the advantages of this type of simulation are that they can measure procedure metrics, such as time taken, efficiency of movements, and reliability of knots [22]. The other advantage of VR simulation is that it is convenient for the trainer as performance can be assessed remotely. One of the disadvantages of VR is the capital cost of the systems, although this is decreasing, and lack of haptic feedback.

Augmented reality combines virtual reality settings with physical materials, instruments, and feedback. In AR models, the 3D virtual model is a static preoperative snapshot of a specific part of the body. When applied in real-time, respiratory movements and the surgeon's manipulation of the organ affect the model's utility in navigated surgery [23]. It may be used as a last-minute simulation before performing complex procedures [24].

3.3 Cadaver and animal models

Cadaver and animal models have been used to simulate and teach laparoscopic procedures. This method is excellent for demonstrating tissue dissection, tissue handling, and surgical technique [20]. Animal models have the added realism of blood flow which means trainees must achieve hemostasis and vascular control. The downside of these models is that they require specialized training areas with associated logistical considerations, such as ethics approval, are very expensive, and each trainee will likely only do a part of an operation.

Animal models must be anesthetized during the procedure. Procurement, preparation, maintenance, and disposal all contribute to the expense of the project, making it difficult to apply widely. Anatomic variance and distinction between the animal model and the human equivalent may limit applicability. Porcine models, for example, cannot be utilized for right colectomies due to the anatomy of the right colon, which is not zygosed. For most left-sided colectomies and rectal procedures, porcine and canine models can be used [25].

4. Simulation in upper gastrointestinal (UGI) surgery

There are currently only a limited number of simulators for upper gastrointestinal (UGI) surgery (**Table 4**).

4.1 Esophagectomy

Esophagectomy is a complex multiple-step procedure that is difficult to perform and teach in the operating room. There is currently no simulator for training the entire operation; however, different parts of the operation can be learned on current simulators. *THE* (transhiatal esophagectomy) *GooseMan* simulator allows for training in transhiatal esophagectomies using an intact porcine organ block along with a

Procedure	Simulation devices	Author	Year	Participants	Assessment of simulation	Cost (USD)	Commercially Available
Esophagectomy	Silicone esophagogastric simulator.	Orringer et al. [26]	2020	7 thoracic surgeons, 8 thoracic surgery trainees.	Low realism. Useful in training to do cervical esophagogastric anastomosis.	$500	No
	Ex vivo porcine model: THE (Transhiatal esophagectomy) GooseMan	Trehan et al. [27]	2013	Not validated	Simulates esophageal mobilization, gastric tubularization, aortic, and azygous bleeding.	$200	No
	Ex vivo porcine esophageal anastomosis model.	Fann et al. [28]	2012	13 cardiothoracic surgeons	Highly realistic. Good method of skills training. Stressed important skills.	NA	No
Hiatus hernia repair and Fundoplication	*Ex vivo* porcine Heller myotomy, Nissen fundoplication, and sleeve gastrectomy model.	Schlotmann et al. [17]	2017	5 UGI surgeons	Realistic High face validity.	$400	No
	Ex vivo porcine Nissen fundoplication and Heller myotomy model.	Ujiie et al [29].	2017	25 trainees 5 UGI surgeons	Increased comfort level in performing Nissen fundoplication and Heller myotomy	$280	No
	Various synthetic models in box trainer.	Botden et al [30].	2010	Not validated.	Reusable. Good haptic feedback.	$200	No
Gastrectomy	Box trainer followed by animal, then cadaver model, and preoperative 3D modeling.	Nishi et al [31].	2022	153 patients who underwent laparoscopic gastrectomy.	Validated patient outcomes. Reduces operative time and blood loss.	NA	No

Procedure	Simulation devices	Author	Year	Participants	Assessment of simulation	Cost (USD)	Commercially Available
Bariatric surgery	EndoSuture Trainer Box Simulator (ESTBS)	Gonzaga de Moura Júnior et al [32].	2018	29 consultant surgeons, 8 surgical residents	Better subjective performance than standard laparoscopic simulator.	NA	No
	Cadaveric porcine jejuno-jejunostomy model	Boza et al [12].	2013	8 Surgeons	Similar performances in surgeons completing a jejuno-jejunostomy on the cadaveric model and the patient.	NA	No
	Lap Mentor^{TM} [33] (VR) simulator to recognize the experience in laparoscopic gastric bypass.	Giannotti et al. [21]	2014	10 general surgeons, 10 bariatric surgeons	Significant differences were found in volume of the gastric pouch, percentage of fundus included, and in the complete dissection of angle of His.	NA	Yes
	VirtualiSurg [34] (VR) simulator with HTC Vive headsets - single port sleeve gastrectomy	Barré et al [35].	2019	10 surgery residents	Showed an improvement in mental and physical workload when novice surgeons trained with VR.	NA	Yes

NA: Not Available.

Table 4.
Simulators for upper gastrointestinal (UGI) procedures.

plastic torso, an artificial diaphragm, lungs, heart, aortic, and azygous circulation [27]. This model allows for esophageal mobilization and gastric tubularization while simulating hypotension and aortic and azygous hemorrhage. It is reported to cost less than $200 USD to build. However, this model has not been validated.

A simulation of esophageal anastomosis has been developed with an *ex vivo* porcine model. It allows for the formation of an esophageal anastomosis with staplers and the placement of sutures into the esophageal wall. The model is highly realistic in allowing various types of esophageal anastomosis to be carried out. However, mobilization of esophagus and stomach cannot be carried out. Overall, the participants using this model found it to be realistic and a good method for developing the skills required for esophageal anastomosis [28].

Orringer et al. [26] have described a cervical esophagogastric anastomosis simulator using silicone esophagus and gastric tip allowing for the formation of a stapled anastomosis. In a pilot trial assessing the simulators, seven thoracic surgeons and eight trainees evaluated the model based on fidelity (multi-variable assessment of degree of realism of a simulator) [36]. The participants rated the model low for realism and the trainees rated the closure of the outer anterior layer of the esophagus model as more difficult than the experienced surgeons. However, there were no overall fidelity differences between trainees and experienced surgeons. The participants felt the model would be useful in training to do cervical esophagogastric anastomosis. The overall cost was $500 USD for the model including single-use disposables.

4.2 Hiatus hernia repair and fundoplication

The University of North Carolina has developed a porcine organ block, including heart, lungs, esophagus, diaphragm, stomach, duodenum, liver, and spleen mounted in a human mannequin and perfused with artificial blood [17]. Five expert surgeons performed laparoscopic Heller myotomy, Nissen fundoplication, and sleeve gastrectomies. On completion of a survey after performing the procedures, the model was found to be highly realistic in terms of tissue feel and the use of instruments for all three operations. Some of the limitations of this model were the low number of assessments, the vascularization of the model was not realistic, and it is unclear whether training on the foregut simulator transferred to operative performance in real patients.

An artificial reusable model has been developed of the upper abdominal anatomy, with realistic tissue properties for training in laparoscopic UGI procedures, such as Nissen fundoplication [30]. A range of materials from silicone, latex, and thermoplastic was used to create the model. The advantages included a realistic representation of human anatomy, unlimited preservation, reusable parts, and fixed cost of the model. This model, however, has not been validated.

The Toronto lap-Nissen *ex vivo* porcine laparoscopic simulator increases training surgeons' comfort level when performing or assisting with Nissen fundoplication or Heller myotomy [29]. This model simulates an anatomic model of the human upper abdomen using porcine esophagus, diaphragm, stomach, and spleen in a box trainer. The training model was used as a part of a laparoscopic training course. Twenty-five trainees and five consultant surgeons completed a survey after using the model and subjective measures pre- and post-training showed an increase in knowledge and comfort levels in assisting and being the primary surgeon. The advantages of this model include anatomically appropriate position of diaphragm, and cost-effectiveness given the organs can be obtained from a butcher instead of having an anesthetized animal. It was suggested that the model needs improvement as the stomach is too rigid to wrap around the esophagus.

4.3 Gastrectomy

Simulation for gastric surgery is also limited in the literature. The learning curve for laparoscopic total gastrectomy is between 40–100 procedures [37]. Recently, a stepwise method for training for laparoscopic gastrectomy was described [31]. The initial training involves using a box trainer with supervision from a trainer, followed by animal model and cadaver model training, followed by clinical experience with standardization and preoperative 3D modeling. The results showed an overall reduction in operative time and blood loss for total and distal gastrectomy.

4.4 Bariatric surgery

Simulation has been more widely used in laparoscopic bariatric surgery compared to other laparoscopic UGI surgery. Laparoscopic box trainers help develop basic skills, such as triangulation and spatial perception, and can be used to develop skills in laparoscopic suturing. *EndoSuture Trainer Box Simulator*, (**Figure 1**) a bariatric skills trainer has been shown to be useful in teaching and training bariatric laparoscopic surgical skills as well as being cost-effective [32].

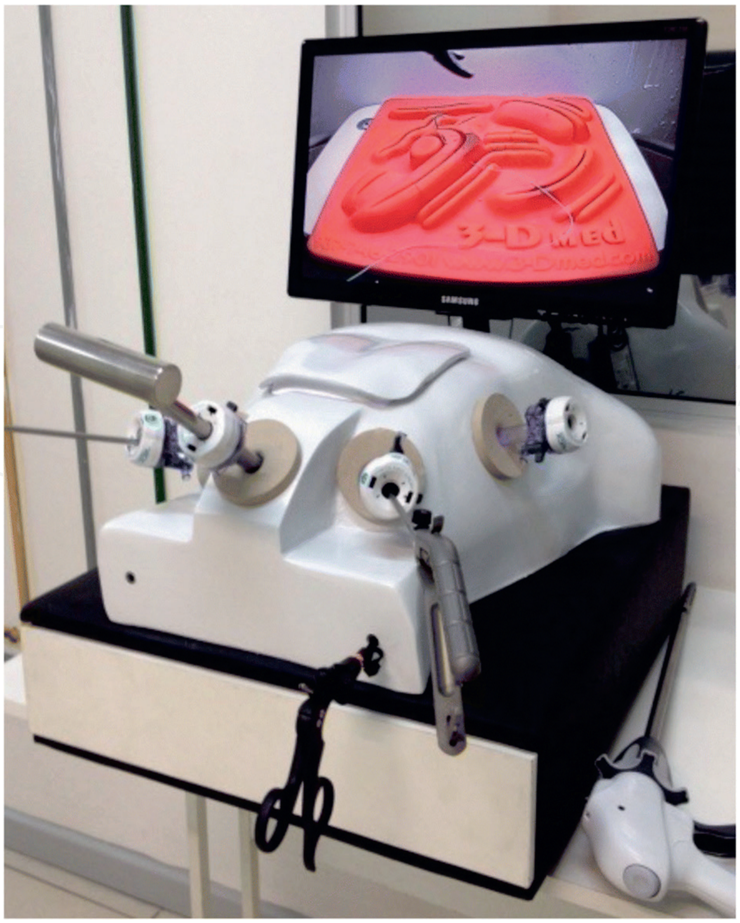

Figure 1.
EndoSuture Trainer Box Simulator ([32], with permission).

Several *ex vivo* models for training in laparoscopic bariatric surgery have been developed. A porcine jejuno-jejunostomy model was created in a box trainer [12]. Eight surgeons performed a side-to-side stapled jejuno-jejunostomy on the model before performing the surgery on a patient scheduled for a laparoscopic Roux-en-Y gastric bypass. The surgeons were assessed using a motion-tracking device. Performances were similar in surgeons forming a jejuno-jejunostomy on the cadaveric model and a real patient.

Human cadaver models are useful for developing skills in laparoscopic bariatric surgery. Thiel human cadavers (THCs) provide better emulation of real human tissue compared to an anesthetized porcine model. A recent observational study analyzing similarities between the procedures on THC and patients also showed that THC presented tissue similar to human patients [38]. Participants found that practicing on cadaver models was the best training for bariatric surgery.

There are limited studies on the use of virtual reality simulators in bariatric surgery. Giannotti et al. [21] used the LAP Mentor^{TM} (Simbionix Corporation, Cleveland, Ohio, USA) [33] simulator to assess specific skills (creation of a gastric pouch and gastrojejunal anastomosis) in bariatric surgery between a group of bariatric surgeons and non-bariatric general surgeons. These investigators found significant differences between the bariatric surgeons and the non-bariatric general surgeons. These included: median difference in volume of the pouch, percentage of fundus included in the pouch, complete dissection of angle of His, and the size and position of the enterotomies. The researchers concluded from their study that the LAP Mentor^{TM} simulator could be used as a certification tool for bariatric surgeons.

VR training on a single-port sleeve gastrectomy was used to assess novice surgeons' physical and mental workload [35]. Participants were divided into a VR group and a control group. Each group of trainees participated in their first real single-port sleeve gastrectomy (SPSG) followed a month later by their second SPSG. The VR training module was designed by VirtualiSurg Company [34] using the HTC Vive headset (HTC Corporation, New Taipei City, Taiwan). The VR environment includes a virtual theatre with use of endo-staplers and real laparoscopic instruments used in bariatric surgery with integrated sensors. The VR group underwent a VR training session in between the first and second SPSG. This study showed a decrease in mental and physical workload between the first and second surgery for the VR group compared to the control group. The limitations of the study include a small sample size (n = 10), no substitution training was proposed for the control group and the real cases were not standardized.

5. Simulation in Hepatopancreaticobiliary (HPB) surgery

5.1 Liver surgery

Laparoscopic liver surgery necessitates a high level of hepatobiliary and minimally invasive surgery training and experience. Laparoscopic liver resection (LLR) is increasingly indicated for minor hepatectomies and major hepatectomies in specialist units [39]. The main methods of simulation used in training in liver surgery are animal and cadaver models (**Table 5**).

White et al. created a 2-day intensive course that included basic skills, laparoscopic left lateral sectionectomy, and laparoscopic right hepatectomy on cadavers [40]. Thirty-two people took part in the study and only their input was considered, with

Procedure	Simulation devices	Author	Year	Participants	Assessment of the simulation	Cost (USD)	Commercially available
Liver surgery	Cadaver model	White et al. [40]	2014	32 surgical trainees	Subjectively the trainees found the course very useful.	NA	No
	Cadaver model	Rashidian et al. [38]	2019	119 participants, 64 responded	Thiel cadavers were superior to other training modalities.	NA	No
	ProMIS augmented reality surgical simulator	Strickland et al. [18]	2011	20 candidates with differing laparoscopic surgical experience.	For time and path length, all four tests indicated construct validity based on experience.	NA	No
	Anesthetized pig	Komorowski et al [41]	2015	2 surgical trainees	Realistic learning environment of exposure of the liver, Pringle maneuver, and dissection	NA	No
	Anesthetized sheep	Teh et al. [42]	2007	Not specified	Surgical anatomy resembled human liver Laparoscopic major hepatic resection can be performed with accuracy.	NA	No
	Ex vivo ovine liver training model	Xiao et al [43] .	2016	33 participants (from novices to experts).	Construct validity of superficial and deep suture hemostasis stitch. Superior educational value compared to a typical box trainer.	NA	No
Biliary surgery	Benchtop model for common bile duct exploration.	Santos et al. [44]	2012	16 novices, 5 experienced surgeons	Construct validity, concurrent validity, internal consistency, and interrater reliability Low cost.	$465	No
	3D printed model with benchtop simulator for choledochal surgery.	Burdall et al. [45]	2016	10 senior pediatric surgical trainees	Tactile likeness was rated as good. Participants found the model useful.	NA	No

NA: Not Available.

Table 5.
Methods of simulation in hepatopancreaticobiliary (HPB) surgery.

the overall assessment for training sessions being excellent in 43% of cases, good in 32%, and fair in 25% of situations. Rashidian et al. [38], assessed participant feedback after a laparoscopic liver surgery course on THCs. Participants found training on Thiel cadavers was superior (49%) to other training modalities, including proctoring in the operating room (35%), virtual reality (6%), video training (5%), and practicing on pigs (5%).

ProMIS augmented reality surgical simulator (Haptica, Dublin, Ireland) and an *ex vivo* ovine liver is another model for learning the technical skills required for LLR [18] and could also be used to assess and measure surgical performance. The model was put to the test by twenty candidates with varying levels of laparoscopic surgery experience. Candidates had to identify a liver tumor via ultrasound, mark and transect the *ex vivo* liver, and place two laparoscopic stitches with intracorporeal knots to control bleeding from the liver. The performance data was recorded by the simulator, which included instrument path lengths and time. For time and path length, all four tests indicated construct validity (confirms that based on performance score, the simulator can discriminate between skilled and novice surgeons) [46].

Several groups have attempted to find a meaningful animal model with educational value in LLR. Komorowski et al. [41] showed that an anesthetized pig provided a realistic learning environment in which exposure of the liver, Pringle maneuver mobilization, and management of surgical injuries could be taught. Teh et al. [42] carried out surgical dissection and contrast studies to show the inflow and outflow structures of the sheep liver were similar to human liver anatomy. This information can be used to simulate an accurate laparoscopic left hepatic resection in anesthetized sheep. An *ex vivo* ovine liver model with portal veins perfused with a red-dyed liquid gelatin solution was used to simulate bleeding [43]. Construct validity was evaluated in 33 participants (from novices to experts) who were instructed to execute one superficial and one deep suture for hemostasis. The educational value was compared to that of a typical box trainer, and the results were determined to be superior.

5.2 Pancreas surgery

Laparoscopic pancreatic surgery has evolved over the last three decades and is now utilized more frequently in the management of tumors and other conditions. There are no peer-reviewed publications on simulation specifically to perform laparoscopic distal pancreatectomy and laparoscopic pancreaticoduodenectomy. However, there are publications on simulation in robotic-assisted pancreatic surgery although robotic-assisted surgery is not the focus of this chapter [47].

Training programs have been developed to facilitate training in minimally invasive pancreatic surgery [48, 49]. Biotissue exercises are a useful model to hone reconstructive abilities for a specific treatment. The pancreaticojejunostomy (PJ), hepaticojejunostomy (HJ), and gastro-/duodenojejunostomy (GJ) are all examples of procedures that can be carried out on biotissue models. Biotissue drills are especially important for the PJ and HJ since porcine models often have a different pancreas shape and a smaller pancreatic duct. Training on human cadavers is problematic owing to fast tissue deterioration and autophagy of the pancreatic tissue [50].

5.3 Biliary surgery

There are limited simulators to assist with complex bile duct surgery. Simulation for laparoscopic cholecystectomy will not be discussed in this chapter as it is not defined as a complex laparoscopic surgery (see **Table 1**). Laparoscopic common bile duct exploration (LCBDE) is an effective treatment for choledocholithiasis. LCBDE requires specific technical skills. A simulator for LCBDE was developed and evaluated using latex tubing for cystic and common bile ducts and a plastic bead to represent the gallstone [44]. A procedure algorithm was developed for key steps of the operation. Sixteen novices and five experienced surgeons trialed the model. Novices scored less on the technical skills in both transcystic and transcholedochal exploration. The LCBDE simulator is a low-cost, realistic physical model that enables the performance and evaluation of technical skills needed for LCBDE.

Three-dimensional (3D) printing has been used to simulate surgery for choledochal cysts. Hepatic anatomy images were used to 3D print a model of a liver. This mold was then used to create a silicone model of the liver and combined with a surgical glove finger to simulate dilated bile duct and an electrical wire-insulating tube to represent the common bile duct and pancreatic duct [45]. This model was placed in a laparoscopic trainer. Ten senior pediatric surgical trainees trialed the model and felt the tactile likeness was good and the model was useful. This model highlights the potential use of 3D printing to simulate a rare and complex operation.

6. Simulation in colorectal surgery

Over the last three decades, laparoscopic colorectal surgery (LCS) has grown in popularity, with Jacobs et al. credited with performing the first laparoscopic-assisted colectomy in 1991 [51]. There are several modalities for simulation training in LCS (**Table 6**).

6.1 Right-sided colectomy

An *ex vivo* porcine model has been developed to aid in training with laparoscopic right hemicolectomies [19]. A box trainer was used to house the animal model. Porcine bowel was used to replicate the right colon, ileocaecal junction, omentum, and peritoneal attachments. The ileocolic pedicle was simulated with a porcine ureter filled with red dye. A limitation of this model is a lack of simulated bleeding so learners could not practice vascular control and hemostasis. Also, porcine bowel is thinner than human bowel so places different demands on the operating surgeon for human tissue. The model for right hemicolectomy costs $95 USD. The feedback from 16 colorectal trainees who used the model was positive. However, this model has not been validated to assess the effect on the learning curve and performance in the operating theatre.

6.2 Left-sided colectomy

Laparoscopic sigmoid colectomy has a long learning curve and simulation has been shown to improve this [16]. LeBlanc et al. [52] performed sigmoid colectomies on a cadaver and on an AR simulator. Technical skill scores on the simulator were significantly higher than on the cadaver for trainers and trainees. The cadaver model received higher overall satisfaction than the simulator model.

A high anterior resection laparoscopic trainer was developed using porcine tissues [19]. Human colon, omentum, peritoneal attachments, retroperitoneum, ureters, and the inferior mesenteric artery are all modeled using porcine tissue. The tumor position in the distal colon is marked with ink and the aortic bifurcation and bladder

Procedure	Simulation devices	Author	Year	Participants	Assessment of the simulation	Cost (USD)	Commercially available
Right hemicolectomy.	*Ex vivo* porcine model.	Ansell et al. [19]	2014	16 colorectal trainees.	Positive feedback on subjective increased practical skills. Well accepted by participants.	$95	No
High anterior resection.	*Ex vivo* porcine model.	Ansell et al [19]	2014	12 colorectal trainees		$120	No
Sigmoid colectomy	Cadaver and ProMIS simulator (AR).	LeBlanc et al. [52]	2010	Not specified	Technical skills scores on the simulator were significantly higher than on the cadaver. The cadaver model received higher overall satisfaction than the simulator model.	NA	No
	LAP Mentor™ [33] (VR)	Wynn et al. [13]	2017	14 trainees	Performance metrics showed evidence of validity and distinct learning curves.	NA	Yes
	Lap-PASS LP-100 [53] (VR)	Mori et al. [54]	2022	44 surgeons, 6 non-medical professionals	Validity in assessment of efficiency, depth perception, bimanual dexterity, efficiency, and tissue handling. May be individualized to patient using computed tomography or magnetic resonance imaging data.	NA	Yes

NA: Not Available.

Table 6.
Methods of simulation in laparoscopic colorectal surgery (LCS).

are also simulated. The *ex vivo* porcine tissue is mounted on an internal tray held in place by a plastic bowl, which models the sacral promontory and pelvis. Neoprene is used to replicate the anterior abdominal wall. During the simulation, three to four laparoscopic ports are employed. The distal end of the box features a hole to replicate the anus and allows the circular stapler for bowel anastomosis to enter. This simulator costs a total of $120 USD to make and additional porcine tissue costs $30 USD.

An increasing number of VR simulators are available to assist with training in LCS. Commercially available VR simulators, such as LapSim^{TM} (Surgical Science, Göteborg, Sweden) [55], provide modules to learn basic laparoscopic surgery skills (**Figure 2**). LapMentor^{TM} (Simbionix Corporation, Cleveland, Ohio, USA) [33] offers comprehensive laparoscopic sigmoidectomy training via two modules [13]. The first module covers medial peritoneal dissection, inferior mesenteric vascular division, medial to lateral colonic mobilization, and colonic transection with a laparoscopic stapler. The development of an intraperitoneal circular stapled colorectal anastomosis is required in the second module. Wynn et al. [13] assessed the validity and effects of a structured VR laparoscopic sigmoid colectomy curriculum. A median of 14 attempts was required to complete the curriculum. Metrics, including time to finish the process, number of movements of the right and left instruments, and total route length of right and left instrument movements all showed evidence of validity and distinct learning curves.

More recently, a VR simulation system, Lap-PASS LP-100 (Mitsubishi Precision Co., Ltd, Tokyo, Japan) [53], focuses on training to create proper tension on the tissue in laparoscopic sigmoid colectomy dissection (**Figure 3**) [54]. This system was validated by asking 44 surgeons (ranging from expert to novice) and six non-medical professionals to carry out a medial dissection of the sigmoid mesocolon on the simulator. There were significant differences in depth perception, bimanual dexterity, efficiency, and tissue handling, between the non-medical professionals and surgeons.

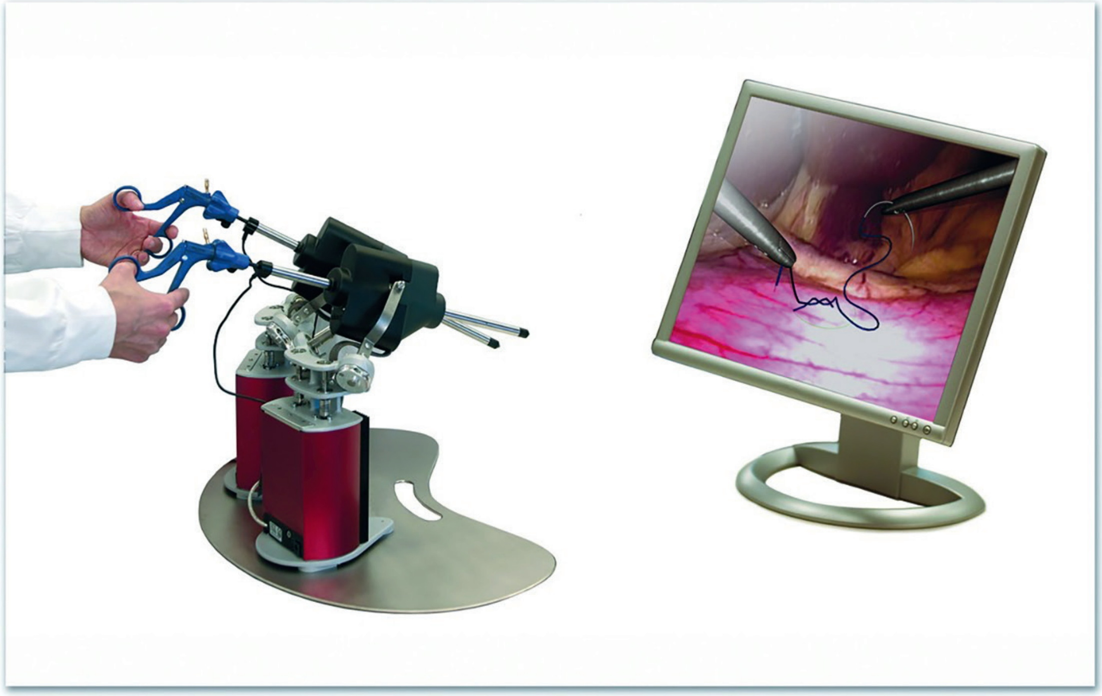

Figure 2.
Intracorporal knotting. LapSim® basic tasks module ([56], with permission).

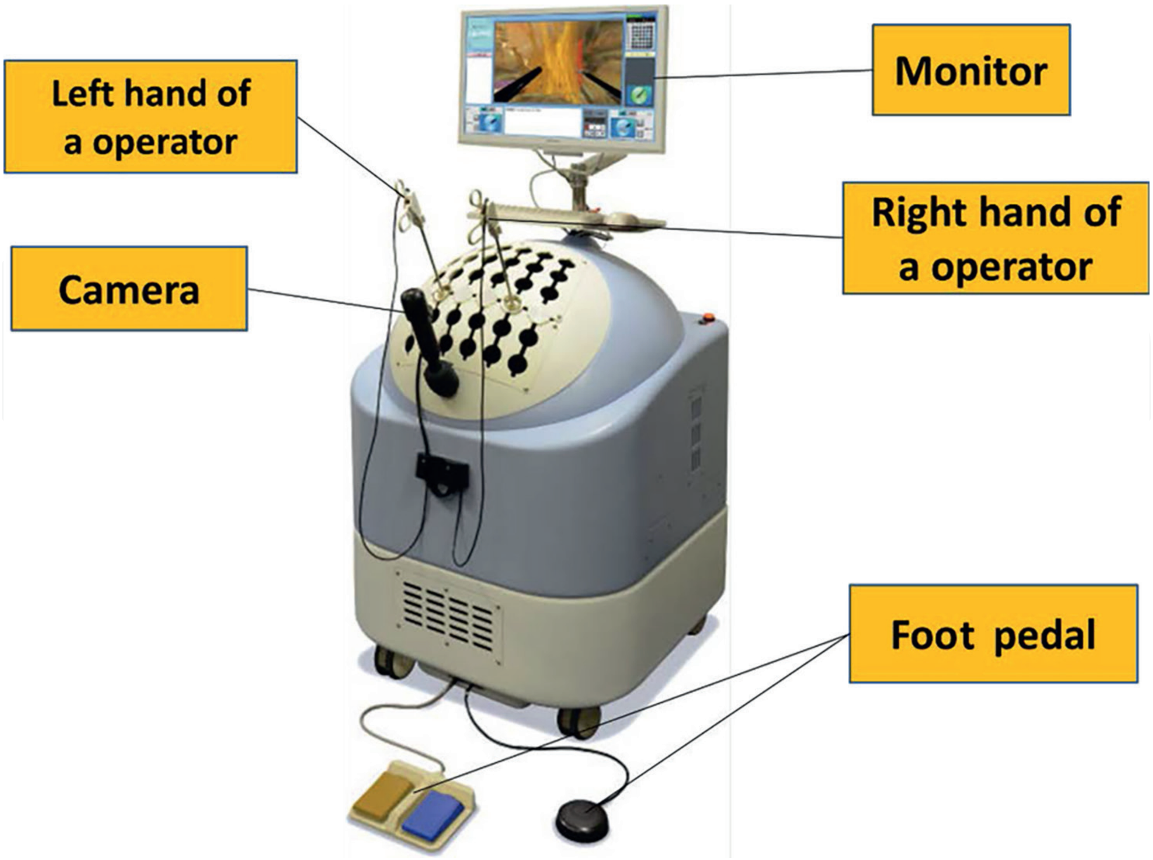

Figure 3.
Lap-PASS LP-100 simulator ([54], with permission).

This system can also produce patient-specific models using actual computed tomography (CT) or magnetic resonance imaging (MRI) data, allowing users to engage in surgical training for specific patients and their procedures.

At Bournemouth University, a virtual colorectal surgery simulator for laparoscopic colectomies was developed [57]. Anatomical models were created using MRI images, and realistic soft tissue deformation was achieved using a hybrid mechanical model of the intestine. The user could also receive haptic feedback from the simulator. Another study from Beihang University used real-time simulation of soft tissue deformation and electro-cautery simulation with smoke and haptic feedback to create a VR simulator for laparoscopic radical rectal cancer surgery [58]. Both simulators have yet to be tested in a clinical setting.

Currently, VR simulation lacks realism and the learning curve is less challenging. This suggests that cadaver and animal models play an important role in simulation in laparoscopic colorectal surgery [59]. Virtual reality simulator training alone may not be sufficient to meet training demands, at least until more realistic training models are developed. VR training should be supplemented with cadaveric or animal models to obtain optimal learning curve reductions.

7. Future direction and research

Modern technological advancements have permitted the development of surgical simulators that mimic complex operations specific to the anatomical demands of individual patients. By allowing surgeons to rehearse the precise case they

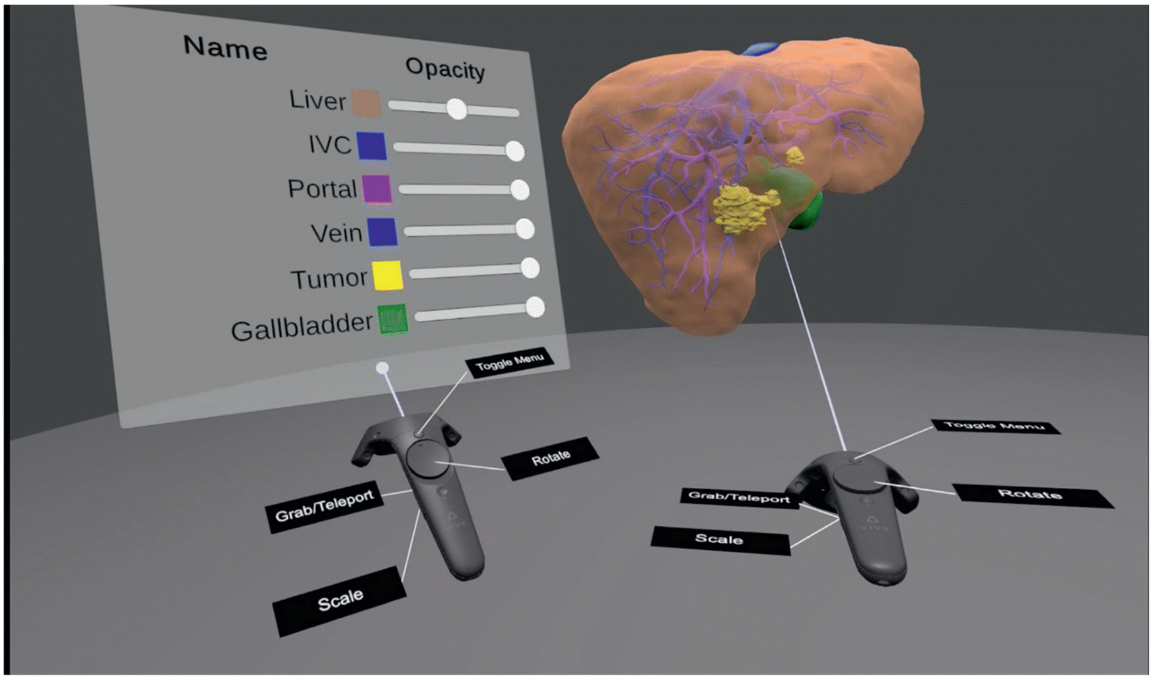

Figure 4.
VR application for the preoperative demonstration of 3D liver models [62].

will be conducting on models that accurately mimic their patients, these patient-specific surgical simulators reach the maximum level of realism. Furthermore, telesurgery is developing into a genuine tool for skilled surgeons to mentor novice surgeons in complex surgical procedures thanks to augmented reality and wireless technology [60].

Three-dimensional printing technology is also evolving with new applications in surgery being developed. For instance, in liver surgery, anatomy data can be extracted from the CT or MRI scans of a patient with a liver tumor and converted into a digital 3D model which can be 3D printed. The final model can show the surgeon the relationship between the tumor and surrounding structures aiding with surgical planning [61]. Future techniques of printing into deformable biosynthetic materials may facilitate its use in high-fidelity simulators.

Patient-specific simulators have also been developed. A virtual 3D model can be created using a patient's CT data. This allows the surgeon to practice laparoscopic operations in a virtual environment with realistic representations of the patient's anatomy before performing them on the real patient (**Figure 4**) [62]. The simulator's overall accuracy is high, allowing the tumor, arteries, and veins to be visualized. The time it takes to develop these simulations is short, with the hepatectomy and pancreatectomy simulators needing approximately 2.5 hours [63]. As a result, these technologies may have a role in preoperative planning and preparation for complex procedures. However, because patient-specific VR simulators are a novel technology, further research is needed to validate them.

With all models of simulation, an appropriate educational program or curriculum needs to complement its utility. Therefore, research into the applicability of models to facilitate acquiring or mastering procedural skills needs to involve an entire educational program and not just simply time spent on a simulation model. Furthermore, future evidence should focus on measuring and obtaining clinical outcomes associated with high-quality patient care to ultimately demonstrate simulations' effectiveness.

8. Conclusion

Laparoscopy presents the surgeon with multiple challenges, including ergonomics, tactile feedback, obtaining an adequate and stable field of vision, and efficient teamwork. There is a significant learning curve for complex laparoscopic digestive surgery. Simulation is a useful method to train surgeons in complex procedures and has been suggested to decrease the duration of the learning curve. Simulation has become an integral part of surgical education and training. Technical abilities no longer need to be primarily gained in the operating room through a conventional apprenticeship form of training. Instead, new skills can be acquired and refined, and fundamental surgical competency developed in a simulated setting. Basic surgical activities, as well as certain advanced surgical methods, may be recreated in simulation, allowing trainees, and practicing surgeons to build and maintain expertise.

Conflict of interest

The authors declare no conflict of interest.

Notes

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Author details

Asanga Gihan Nanayakkara[1,2]*, Phillip Chao[1,2], Jonathan B. Koea[1,2]
and Sanket Srinivasa[1,2]

1 Upper Gastrointestinal Unit, Department of Surgery, North Shore Hospital, Auckland, New Zealand

2 Department of Surgery, School of Medicine, Faculty of Medical and Health Sciences, The University of Auckland, Auckland, New Zealand

*Address all correspondence to: asanga.nanayakkara@gmail.com

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