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EDUCATIONAL MODELS FOR TRAINING IN MINIMALLY INVASIVE COLORECTAL SURGERY*

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Abstract

Colorectal cancer (CRC) is the third most commonly diagnosed malignancy and the fourth most deadly cancer in the world for which surgery is the main treatment. Colorectal surgery can be performed through a wide incision in the abdomen or using minimally

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invasive surgical (MIS) techniques. Some of these techniques include transanal endoscopic microsurgery (TEM), transanal minimally invasive surgery (TAMIS), transanal total mesorectal excision (TaTME), and robot-assisted surgery. Studies increasingly confirm that resections using MIS techniques are safe, oncologically equivalent to open surgery and have better short-term results. These surgical approaches are, however, technically demanding and result in a steep learning curve. The main objective of this study is to review the different MIS techniques for colorectal surgery, as well as the training tools and programs designed to achieve the necessary surgical skills. Different training programs in colorectal surgery have been reported for the different surgical techniques analyzed. Most of these programs are based on training tools in the form of surgical simulators, physical and virtual, as well as the use of experimental and cadaveric models. However, structured training programs in minimally invasive colorectal surgery remain scarce, and there should be a consensus on the fundamental training aspects for the various surgical techniques presented. These training programs should ensure that surgeons acquire sufficient surgical skills to be competent in the development of these surgical techniques, improving the quality of the patient's surgical outcomes.

Key words: surgical simulation, colorectal surgery, medical training, minimally invasive techniques, colorectal cancer

Introduction

Colorectal cancer (CRC) is the third most commonly diagnosed malignant neoplasm and the fourth deadliest cancer in the world [1,2]. By the year 2035 this type of cancer is expected to affect a total of 2.5 million people worldwide [2]. Adenocarcinoma is the most common histopathology for CRC. This cancer is usually diagnosed in the proximal colon (41%), followed by the rectum (28%) and the distal colon (22%), respectively [3]. Approximately 80% of newly diagnosed cases require surgery. Surgery remains the treatment of choice for most cases of CRC, both as a treatment with a curative intent and as palliative therapy [4].

There are different risk factors which play a role in the development of this cancer, such as genetics (hereditary), gender, age, and environmental factors [1,3]. Patients have a high-risk factor if they are male and have a positive family history. Additionally, elderly people are more prone to CRC [1]. It is known that environmental factors, such as alcohol and processed meat consumption, a sedentary lifestyle, and obesity, etc. increase the risk of colon cancer pathology. On the other hand, balanced nutrition (fruit, vegetables, fiber, fish, among others) and physical activity prevents the appearance of this type of cancer [3].

Patients with CRC usually have a wide range of clinical symptoms, such as anemia or abdominal pain. These patients also tend to have occult blood in the stool. However, these symptoms are generally present in advanced stages of cancer, therefore CRC commonly develops with asymptomatic clinical signs [1].

For this reason, endoscopy is the primary choice in the diagnosis of CRC. Colonoscopy facilitates the identification of the different degrees of injury; therefore, a careful and complete examination of the colon allows this pathology to be diagnosed [1,3]. Endoscopic treatment is feasible in some early cancers with lesions located on the surface (mucosa or submucosa) [1].

Nowadays, surgical resection is the gold standard in the treatment of CRC [1,3,5]. Colon surgery aims to resect a portion of the large intestine that includes the tumor and subsequently anastomose the intestine, thus maintaining intestinal function. Furthermore, it must include minimum margins to minimize the chances of recurrence of the tumor in the operated area as far as possible, and, thus, the reproduction of the tumor both locally and at a distance (metastasis). Some patients have lymph node metastases, so colectomy with lymph node dissection is required [6]. There are some patients who have distant metastases in the lungs or liver [5], so neoadjuvant chemotherapy becomes necessary [3,5].

Colorectal surgery can be performed through a wide incision in the abdomen or via minimally invasive surgery (MIS). Some of these MIS techniques include transanal endoscopic microsurgery (TEM), transanal minimally invasive surgery (TAMIS), transanal total mesorectal excision (TaTME), and robot-assisted surgery. Studies increasingly confirm that resections using MIS techniques are safe, oncologically equivalent to open surgery and have better short-term results [7]. However, these surgical approaches are technically demanding and result in a steep learning curve, which requires appropriate structured training programs for adequate learning. Therefore, the main objective of this study is to review the various MIS techniques for colorectal surgery, as well as the training tools and programs designed to achieve the necessary surgical skills.

Technology description

Training tools and programs for colorectal surgery

Surgical outcomes are highly dependent on the surgeon's skills [5]. The use of MIS brings benefits to patients due to a decrease in tissue trauma, fewer perioperative complications and faster postoperative recovery than conventional surgery [8]. Nevertheless, the acquisition of surgical skills in certain MIS techniques, as well as particular surgical procedures, is sometimes a complex process and results in a steep learning curve [9]. Various surgical skills, such as technical and cognitive skills and judgment abilities, are needed to become a proficient surgeon [10]. Minimally invasive colorectal surgeries are challenging since surgeons have to perform complex procedures with limited tactile sensitivity, such as anastomosis of colorectal sections, dissection of a wide variety of tissue located at different surgical quadrants and control of the hemostasis [11]. Furthermore, surgeons should have the capacity to identify the different anatomical areas by means of two-dimensional (2D) images and performing the surgery using MIS tools at a distance [8]. For this reason, training tools and programs for colorectal surgery have been developed in order to facilitate the process of acquiring these surgical skills and, consequently, improve surgical outcomes [12]. The knowledge and skills acquired by the trainees through these training tools and programs will be applied later in actual surgeries. Therefore, in addition to technical and cognitive skills, they should provide the surgeon with the ability to resolve possible adversities (judgment skills) during the course of the surgical intervention. In order to meet these aims, these training programs have to be structured, organized and taught by minimally invasive surgery professionals.

The first MIS training programs were carried out in a similar way to conventional surgery, so that an experienced surgeon supervised the surgery of the trainee [10]. This method was based on Halsted's classic "see one, do one, teach one" scheme [10,13,14]. Nonetheless, this training method has certain limitations in MIS since it requires a new way of learning, focused on the acquisition of new surgical skills to cope with the lack of three-dimensional (3D) images, depth perception, tactile sensation, inverted (fulcrum effect) and limited movements, among others [10,13,15]. Subsequently, surgical simulators emerged as an effective training complement, mainly during the initial phases of MIS education [16–18]. Surgical simulators offer the students a tool to practice as long as they need and without putting a patient's life at risk [19]. Nowadays, there are a great variety of simulators, with physical (box trainers) and virtual simulators being the most frequently used [20].

Box trainers are an affordable solution for learning basic surgical skills and acquiring sufficient dexterity in handling surgical instruments. In general, they can be adapted for the training of different types of surgical tasks and procedures and with different levels of difficulty. Box trainers can be used with both artificial and *ex vivo* training models. They usually reproduce the abdominal and pelvic cavity, so basic training programs for colorectal surgery can be carried out [18]. There are different types of box trainers designed for a wide variety of training programs. An example is the SIMULAP® (CCMIJU, Cáceres, Spain), which is a box trainer that simulates the abdominal and pelvic cavity, which can be used to practice various laparoscopic techniques, including those related to colorectal surgery [18] (Figure 1).

Another extended box trainer for colorectal surgery is the Tübinger MIC Trainer (Richard Wolf GmbH, Knittlingen, Germany), which has an anatomical design with an inbuilt facility for restructuring the anus. This was used by Bhattacharjee *et al*. to prove the feasibility of performing a single-port technique for transanal rectosigmoid resection and colorectal anastomosis on an *ex vivo* experimental model [21]. This simulator was also used to investigate the feasibility of transrectal robotic natural orifice translumenal endoscopic surgery (NOTES), requiring intracorporeal small intestinal anastomosis and closure of the rectal anterior wall incision [22].

Nevertheless, box trainers are mainly limited to basic surgical skills, such as psychomotor skills, and they lack objective and automatic evaluation systems and therefore require the supervision of an experienced tutor [13,20].

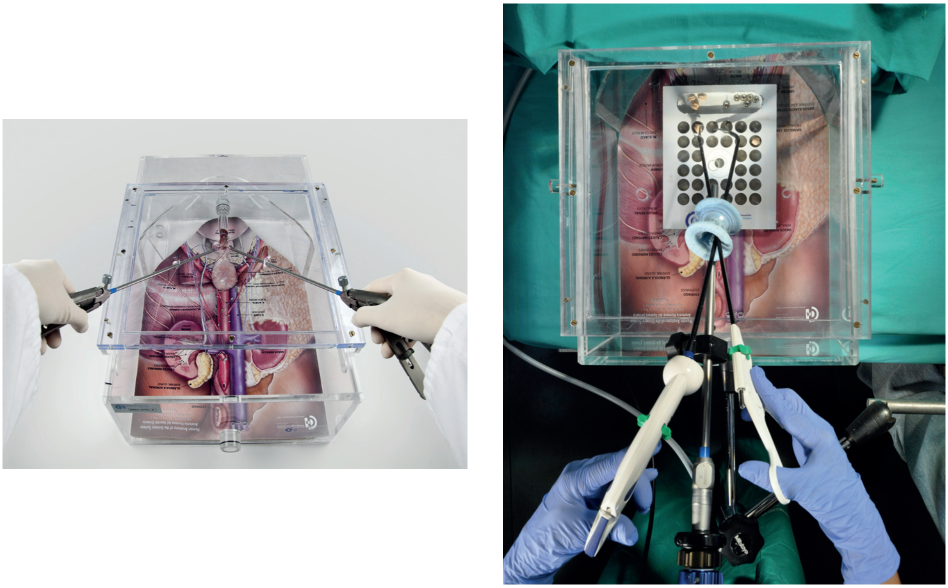

Figure 1. Use of SIMULAP® laparoscopic box trainer during a urethrovesical anastomosis (left) and a single--site approach (right). Source: Jesús Usón Minimally Invasive Surgery Centre.

There are other types of surgical simulators based on virtual reality (VR). These training tools provide realistic virtual representations of a surgical scenario in which trainees can perform complete surgical procedures [13]. Apart from practical surgical scenarios, some of them use haptic devices that provide tactile feedback on the tissue interaction. These devices allow one to objectively measure the learning curve, including the analysis of errors, execution time in surgery, and the quality of the technique, among other parameters [13]. Nowadays, there are different simulators based on virtual reality, such as LAP Mentor™ (Simbionix, Cleveland, Ohio, USA) or LapSim™ (Surgical Science, Gothenburg, Sweden) (Figure 2), which could help improve safety during colorectal surgery. They allow the trainee to learn anatomical details more thoroughly [23]. According to a study by Beyer-Berjot *et al*. using the LAP Mentor™ VR simulator, training with these systems may reduce learning curves and improve patient safety in the operating rooms [24]. In addition, Palter *et al*. designed a VR curriculum using LapSim™ for colorectal surgery and the Delphi methodology [25]. However, the main disadvantage is that these systems are expensive when compared to box trainers [20].

Figure 2. Use of the laparoscopic simulator LAP Mentor™ for laparoscopic training. Source: Jesús Usón Minimally Invasive Surgery Centre.

A more advanced and realistic option for surgical training is the use of experimental models, which can be *in vivo* and anesthetized models, or cadavers [13]. They are the best training option for colorectal surgery due to their high degree of resemblance to actual surgery [26]. Surgical training programs often use the porcine model because of its anatomical and physiological similarities to humans. The size of the abdomen of the porcine is equivalent to that of a human [20]. In addition, the experimental models allow one to simulate a surgery to a great extent, so that the trainee can create the peritoneum, experience a real simulation of the possible surgical complications and carry out the complete surgical technique [26,27].

On the other hand, the use of cadavers is the closest thing to human colorectal surgery training because of the clear anatomical similarities, the location of the ports and the configuration of the surgical environment [26]. However, for both ethical and economic reasons, experimental and cadaveric models are far less accessible than simulators for surgical training [13,26].

Minimally invasive techniques

Colonoscopy may be used to perform a polypectomy in some early stages of colon cancer and when lesions are located on the surface (mucosa or submucosa) [1]. However, the gold standard in the treatment of CRC is colectomy [1,3,5]. Surgical treatment can be provided via conventional or minimally invasive surgery.

In the case of minimally invasive surgery using a laparoscopic approach, the surgery is performed through incisions in the abdominal wall by which the trocars are introduced to handle the surgical instruments and the laparoscope. This surgical technique has transformed the way surgeons practice colorectal surgery and it has resulted in reduced hospitalization time and a remarkable decrease in wound infections, showing evidence of an overall lower complication rate in comparison to open surgery [28]. Nevertheless, this type of approach also implies some limitations for the surgeon because of the need to manipulate the instruments and devices at a distance using a 2D image displayed through screens or monitors and restriction of movements during surgery. Hence, appropriate training is imperative before this type of surgical technique is performed in a real surgical scenario [29].

A good patient position is essential in this type of surgery due to the surgeon having to perform the surgery in different quadrants. A Trendelenburg position is optimal for colorectal surgery using the laparoscopic approach. Once the pneumoperitoneum has been created, the optic will be placed above the umbilicus. The position of the ports will vary depending on the size and location of the tumors (right or left colectomy). According to Parker *et al*., port placement is at the discretion of the surgeon [30]. Colorectal surgery requires a series of complex techniques, so normally four ports are used, two for the surgical instruments, and the rest to place the camera and an auxiliary port for the assistant. The next step is to locate the areas affected by cancer and carry out a colectomy, in which the surgeon removes the affected areas of the colon and performs an anastomosis with the healthy areas [30].

Laparoscopic colorectal surgeries are challenging. The learning process in the initial stages focuses mainly on the acquisition of adequate skills in the laparoscopic maneuvers of grasping, dissection, cutting, and suturing, which are indispensable in any surgical procedure. For this purpose, the repetition of maneuvers is fundamental. In this regard, laparoscopic simulators allow surgeons to acquire sufficient dexterity and skills in the handling of new surgical instruments before moving to experimental training programs or clinical situations.

Various laparoscopic colorectal surgery training programs have been reported. La Torre *et al.* evaluated the experience of senior residents (n = 50) in a training program for laparoscopic colorectal surgery using a porcine model [31]. Some surgeons (n = 20) used a box trainer before surgery to improve their psychomotor skills. During the training program, the tutors evaluated the execution time and trainees' level of expertise and confidence in their laparoscopic skills in performing different colorectal procedures such as anterior colorectal resection, ileocolic resection, manual and mechanical intestinal resections, and anastomosis. The authors concluded that surgeons were not skilled enough to perform colorectal surgery safely. On the other hand, Alba Mesa *et al*. studied the application of a failure training model for laparoscopic colon surgery. This training program consisted in the performance of a laparoscopic sigmoidectomy using the porcine model during three courses. Each course lasted three days, in which one laparoscopic sigmoidectomy was performed per day. Prior to surgery, participants were taught the anatomy of the porcine model. On the first day, surgeons performed the laparoscopic sigmoidectomy without help. On the second and third days, the students received help from tutors to avoid or eliminate failures. After each session, the failures were discussed and the "risk priority number" was calculated. If this parameter was higher than 300, surgery was not safe to perform in human patients. The authors demonstrated that this laparoscopy training program could improve non-technical surgical errors [32].

In addition to laparoscopic surgery, there are a wide variety of minimally invasive colorectal surgical techniques, such as TEM, TAMIS, TaTME and robotic assisted-surgery.

Transanal Endoscopic Microsurgery (TEM)

TEM, initially described by Buess in 1984 [33], is a minimally invasive endoluminal method that has been adopted as the standard for rectal tumor resection [34,35]. Benign and malignant rectal tumors are highly prevalent in Western countries. The ideal treatment for benign lesions is complete local resection, offering the pathologist a suitable specimen for study. Many authors consider local excision as not only a palliative but also a curative method in selected cases of carcinoma [36]. Only the early and complete excision of colorectal neoplasms meets the requirements for cancer treatment and prevention [37].

The location of the tumor will determine the position of the patient [34]. The patient should be arranged in such a way that the tumor is always in the lower part of the operating field. Thus, for posterior lesions, the patient will be placed in the gynecological position; in the prone position if the lesion is anterior and in the right or left decubitus if the lesion is lateral [36].

TEM is a particularly challenging technique; it involves the use of uncommon surgical instrumentation and requires a different eye-hand coordination compared to conventional laparoscopy due to the parallel working plane [35]. In this sense, a learning system based on levels has been developed, so that the student progressively makes contact with the special instruments, equipment and technique. The first contact with the equipment is usually made by using an open simulator and a transparent plastic rectoscope with a window for better visualization of what is being done. Scissors and dissectors are used and the dissection and suture are performed on an open piece of *ex vivo* intestine (e.g. cow intestine, Figure 3). Then, training in the use of the stereoscopic optic and the electric scalpel is conducted. In this regard, the area to be extracted is marked with coagulation points and the dissection is carried out from right to left using a full thickness technique. Once the exeresis has been performed, the transversal suture is performed [36].

The University Hospital of Tübingen developed the Tübinger MIC-Trainer for TEM training in cooperation with Richard Wolf GmbH. This box trainer has been used in different training programs and studies since 2005. This consists of four parts: fluid reservoir, dorsal abdominal form, abdominal wall and neoprene cover. The form of this simulator allows *ex vivo* organs to be hosted and replicates the anatomy of the human body [38].

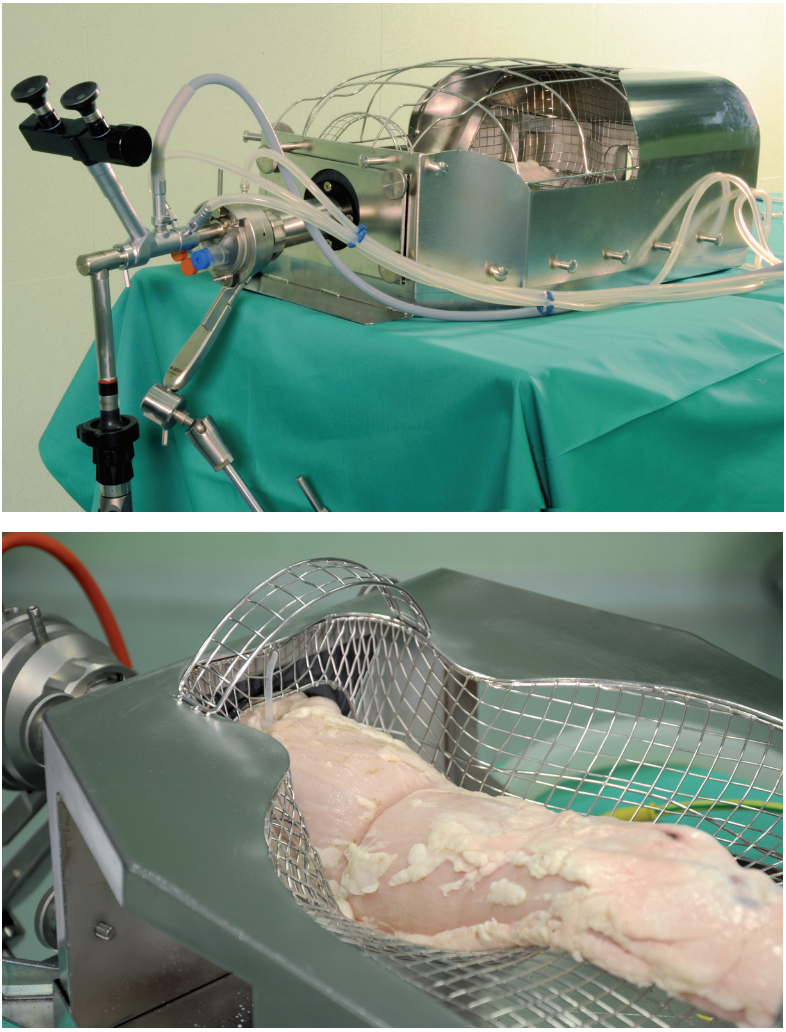

Figure 3. Training setting for TEM using a box trainer and an *ex vivo* cow intestine. Source: Jesús Usón Minimally Invasive Surgery Centre.

TEM is an effective, safe and precise technique, with a learning curve, which has demonstrated a significant reduction in operating time, total length of hospitalization and complication rate over years [39].

Transanal minimally invasive surgery (TAMIS)

The concept of TAMIS was first developed and reported by Atallah *et al*. in 2010 [40]. This technique uses single-port technology to operate within the rectum, which would have a profound effect on the way colorectal surgeons resect rectal neoplasms. This can be considered a hybrid technique between TEM and single-port laparoscopy.

TAMIS offers several applications, in which surgery can be used to perform local excision of benign rectal neoplasms, T1 cancers with histologically favorable features and radical proctectomy for rectal cancer [41]. In addition, this surgical technique has been used in various non-neoplastic conditions such as recto-urethral fistulas, foreign body removal and the indication for TAMIS can also be extended to cT0 lesions in patients with rectal cancer after neoadjuvant therapy [41–45]. The key to the technical success of this procedure is based on the selection of patients, so all must undergo an appropriate preoperative evaluation. In addition, complete mechanical bowel preparation and parenteral antibiotics are recommended [46].

As for the TAMIS training programs, some authors have described the use of an *ex vivo* porcine training model [47]. This training program uses the porcine rectum and anus with intact perianal skin in a box trainer by holding the distal end to a ringed clamp and the proximal end to the box (Figure 4). All participants are accompanied by an assistant and they are asked to remove several pseudopolyps through several transanal excisions via the TAMIS technique, using electrocautery, rays and laparoscopic harmonic devices. Although the learning curve of TAMIS has not yet been adequately defined, there are studies that determine that a minimum of 14 to 24 cases is required to achieve an acceptable resection rate and reduce the duration of the operation [48].

TAMIS is rapidly gaining in popularity; this is due to its reduced cost, simple configuration and use of traditional laparoscopic equipment [49]. In addition, this surgical technique represents an alternative option for advanced transanal access for surgeons and hospital systems. Its worldwide adoption has been reflected in the growing number of publications and citations since its origins [40].

Figure 4. Surgical training course in TAMIS using a box trainer. Source: Jesús Usón Minimally Invasive Surgery Centre.

Transanal total mesorectal excision (TaTME)

Total mesorectal excision (TME) is the standard surgical treatment for rectal cancer, with the objective of negative circumferential and distal resection margins and excision of the associated lymph nodes. High-quality TME is associated with lower locoregional recurrence rates and improved patient outcomes [50]. The development of laparoscopic and robotic techniques has brought TME to a new stage [51], although in the presence of bulky tumors, narrow male pelvis or obesity, the surgical scenario is more challenging, with reported high morbidity rates and lower rates of clear surgical margins [52,53].

TaTME was first described by Sylla *et al.* in 2010 [54]; this technique is a combination of TEM, TAMIS and NOTES [55]. Initial results suggested that the transanal approach improves the ability to perform minimally invasive TME dissection. The first 720 patients entered into the international TaTME database had a conversion rate of 6.4% [56]. TaTME also had a significantly lower rate of conversion to open when compared to laparoscopic TME as reported in a meta-analysis of 573 patients [57].

Surgeons, nevertheless, have experienced different intraoperative difficulties in about 40% of cases, such as urethral injury, incorrect plane dissection, pelvic bleeding, and unstable pneumopelvis with excessive smoke and visceral injuries [58]. Over the last years, some workshops, cadaveric training models, courses and training programs have been developed by several authors, along with the use of the Global Assessment Scale as a tool that assists training [59–63]. In 2017, Francis *et al.* reached a consensus on the structure of a TaTME training curriculum, seeking the views of 207 surgeons across 18 different countries, including 52 international experts in TaTME. The proposed curriculum includes clear guidance on case selection, teaching methods, including online modules, dry lab purse-string simulators, cadaveric training and clinical proctoring, as well as assessment and data collection [58]. As a training model for this technique, some authors have proposed the use of frozen porcine rectum and anus with intact perianal skin in a box trainer [47]. For dissection and suture training in a simulator, the transverse and descending colon of the ovine species are useful, which is also a good experimental model for TaTME training [64] (Figures 5 and 6).

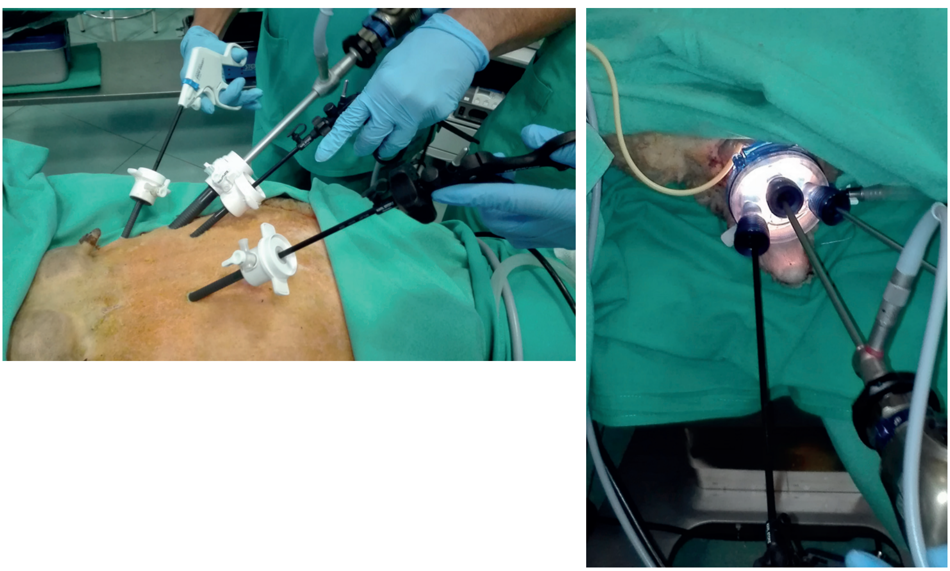

Figure 5. Surgical training course in TaTME using an experimental model, including both laparoscopic and transanal approaches. Source: Jesús Usón Minimally Invasive Surgery Centre.

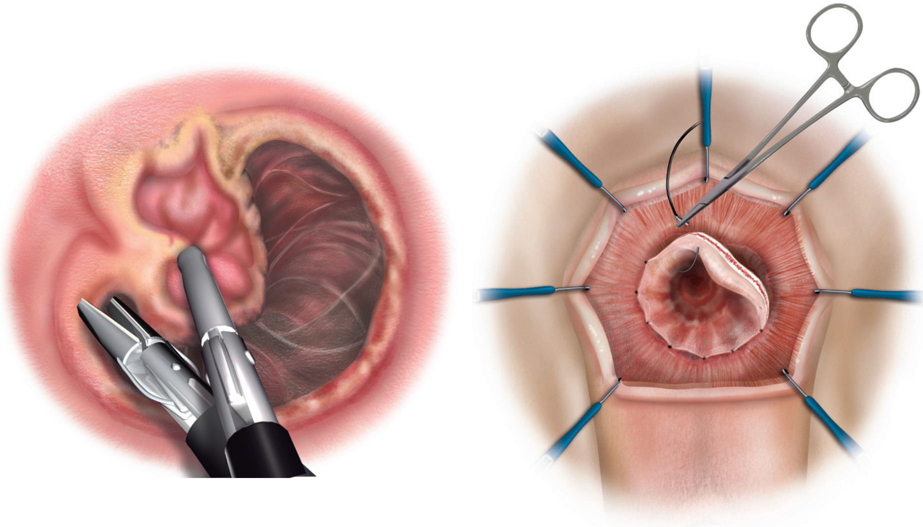

Figure 6. Dissection of the posterior and lateral mesorectum through single-port access. Once the mesorectal excision has been performed via the transanal route, the term-terminal anastomosis is performed [64: 159, 160]

On the other hand, TaTME results in a steep learning curve, even for expert surgeons [65,66], so this technique needs to be standardized due to its heterogeneity in several aspects, such as the surgical procedure, the type of platform, the surgical instruments and equipment, the indications, the selection of patients, and the distance from the tumor to the anus [67]. Recently, another international consensus was reached, in which a total of 56 experienced surgeons and tutors in TaTME participated in this project in an attempt to provide a framework of best practices related to the implementation of TaTME, which will subsequently be updated to reflect new evidence as it emerges. This framework focused mainly on training, establishing that before TaTME is implemented, a formal structured training pathway should be completed as well as an annual institutional volume of at least 30 rectal resections. This structured TaTME training curriculum should include didactic learning, such as patient selection, anatomy, operative setup, techniques and detailed procedural steps, observation of live TaTME procedures, a hands-on cadaver workshop, and a formal proctorship programme. Clinical training on TaTME should commence as soon as possible and should continue until safe independent performance is achieved. The whole training process should be reviewed and assessed regularly. Other recommendations are that at least two surgeons per institution and a multidisciplinary dedicated operative theatre team are needed for TaTME [68].

Robot-assisted surgery

Robotic surgery can be also considered as computer-assisted surgery, in which the robot is defined as a computer-processed tele-operated system that works indirectly through electrical signals, at the command of a surgeon located in a remote console. The surgeon, who is provided with visual information about the surgical field, has the ability to evaluate the condition of the patient and handle the robotic surgery. There are different types of robotic surgical equipment in the world. However, the most extended surgical robot is the da Vinci™ Surgical System (Intuitive Surgical, Sunnyvalley, CA, USA). It is a multi-arm master-slave manipulator system that makes it possible to perform complex endoscopic procedures [69].

Robotic surgery for rectal cancer has some benefits over conventional laparoscopic surgery such as a lower conversion rate, shorter hospital stays and better distance to the distal margin outcomes [70]. In addition, this technique has several potential advantages, including an immersive 3D view of the surgical field, improved dexterity and ambidextrous capability, and a stable camera shape [70]. Apart from this, none of the new surgical procedures should be performed without sufficient surgical planning and training. The surgeon's training should include both learning how to operate the robot and learning about emergency surgical procedures [71]. The da Vinci Surgical Skills Simulator™ (Intuitive Surgical, Sunnyvalley, CA, USA) allows novice surgeons in robotic surgery to significantly improve their overall performance in an environment similar to real surgery using the da Vinci surgical platform [72,73].

Most published curricula in robotic surgery are similar. Although the details and sequence may vary slightly, each involves successive progression through dry lab exercises, video review, simulation exercises, bed assistance, wet lab sessions with animal or cadaveric models, and console training [71] (Figure 7). The Association of Directors of Colon and Rectal Surgeons Programs (APDCRS) has developed and systematically implemented a colorectal robotic surgery training curriculum that has continued to evolve since 2010 for the training of colorectal residents in the United States and Canada [74]. This training curriculum includes online and face-to-face modules on how the da Vinci™ system works; completion of skill simulator modules (Thread the Rings, Matchboard, Camera Targeting, Energy Switching, and Suture Sponge) using the da Vinci™ Surgical Skills Simulator; participation in surgeon-led web seminars; and finally, participation in five da Vinci™ cases as a console surgeon.

Figure 7. Surgical training activity with the da Vinci™ robotic system. Source: Jesús Usón Minimally Invasive Surgery Centre.

The European Academy of Robotic Colorectal Surgery (EARCS) has designed a training program for robotic-assisted colorectal surgery. This training program involves familiarization with the robotic system, attendance at animal and cadaveric courses, case observations, and hands-on training using a modular approach, with the aim of performing surgeries solo [75]. Furthermore, during the 6th Clinical Robotic Surgery Association (CRSA) congress in San Francisco (October 2014), a consensus was reached on the general characteristics and structure of training programs for robotic-assisted colorectal surgery. It was suggested that specific skills in laparoscopic colorectal surgery are needed prior to accessing a training program. In addition, training programs should be divided into training modules that consist of three sequential steps: basic module, advanced module and tutored clinical practice. Participants have to successfully attend previous steps to access the following module. Each module has an objective evaluation system for various criteria that score each task or competence acquisition from 1 (lack of competence) to 3 (high-skill) [76].

The main objectives of the basic module are to learn about robotic platform functioning, robot docking, port placement for different colorectal procedures, theoretical principles of arm collision avoidance, and pedal coordination. Experts consider that virtual simulators should be the main teaching method for reaching these objectives. The next step is the acquisition of competence in performing surgical steps in colorectal procedures, such as vessel dissection, bowel resection, intracorporeal anastomosis, and pelvic dissection. The aim of the advanced module is the acquisition of specific capacities to safely perform a colonic or rectal resection. Recommended teaching methods include a theoretical discussion with experts, video tutorials and cadaver lab (if available). Finally, tutored clinical practice should be conducted, performing colorectal procedures of increasing complexity such as left colectomy for cancer, sigmoidectomy for diverticular disease, right colectomy for cancer with intracorporeal anastomosis, rectal resection with partial mesorectal excision, rectal resection with total mesorectal excision, and rectal intersphinteric resection with colo-anal anastomosis [76].

However, nowadays most training takes place as part of proctorships and international collaborative groups. Standardization of techniques and teaching methods and materials are more relevant now than before robotic surgery had become fully established [77]. In robotic CRC surgery, reaching mastery for each surgeon depends on the establishment of a program in each institution with a dedicated team that addresses the many aspects of robotic surgery that extend beyond sitting at the console. There are many phases in this learning curve, which can be shortened by means of a well-established and systematic training program [78].

Discussion

Colorectal cancer (CRC) is one of the most frequently diagnosed and deadliest cancers in the world [1,2]. Although its diagnosis and, in some cases, treatment is performed through a colonoscopy, the gold standard for its treatment is surgery [1,3,5]. The surgical therapy of CRC is complex because surgeons have to master different surgical skills such as dissection of a wide variety of tissue at different planes and perform complex procedures such as colectomy and anastomosis of colorectal sections [11]. In this regard, both theoretical and practical training for the acquisition of these surgical skills are fundamental if one is to become a surgeon who is competent at performing these surgeries. To this end, training simulators and structured programs are essential tools for the training of surgeons in minimally invasive colorectal surgery.

Surgical simulators focus primarily on the training of basic psychomotor skills, which is crucial during the early stages of surgical education. Among these systems, there are physical, VR and hybrid simulators [20,23,79]. Unlike box trainers (physical simulators), VR simulators allow the recreation of a wider variety of surgical procedures and tasks [13,23]. This technology offers increasingly greater realism thanks to advances in 3D modelling techniques, computing and force feedback technology. In the field of colorectal surgery, some authors have designed a proficiency-based training curriculum in colorectal surgery using the LapSim™ VR simulator [25]. They have used the Delphi method to determine a consensus among experts according to which VR tasks were relevant to laparoscopic colorectal surgery training. A consensus was reached for seven basic tasks (coordination, grasping, cutting, clipping, lifting and grasping, handling intestines, and fine dissection) and one advanced suturing task (stitch and square knot). Nevertheless, one of the main limitations of VR simulators is their frequently high price, which means they are not affordable for everyone.

Apart from surgical simulators, experimental and cadaveric models are more advanced and realistic options for surgical training [13]. Depending on the training objective, each model has its advantages. It is evident that the use of human cadavers is a better option with respect to anatomical training during surgery [26,80]. However, the use of experimental models, which must be anesthetized and not experience any pain or discomfort, allows the trainee to reproduce the specific conditions of real surgery, such as the control of peritoneum and bleeding, not present in cadaveric models [26,27].

Colorectal surgery using the laparoscopic approach leads to high surgical complexity, for which several authors have designed, validated and implemented various training programs using different training tools such as box trainers or experimental models [81]. These studies showed the importance of acquiring technical and non-technical surgical skills in colorectal laparoscopic surgery through training programs [31,32]. However, there are few articles that study the efficacy of these training programs in actual colorectal surgery. Some of these authors stated that training activities in laparoscopic colorectal surgery remain limited and that clear training guidelines for resident surgeons or assessment criteria for the level of acquired skills are needed [31]. Therefore, more training programs and a clearer consensus on the training aspects of laparoscopic colorectal surgery need to be designed and implemented in order for surgeons to acquire sufficient surgical skills and ensure the quality of surgical outcomes.

TEM is an effective, safe and accurate technique and the treatment of choice for benign lesions and stage T1 rectal carcinomas in selected patients [39]. Nevertheless, TEM is a technically difficult surgical technique as it requires different eye-hand coordination skills compared to conventional laparoscopy mainly due to the working plane during surgery. This implies the use of a specialized set of surgical instruments, which entails a steep learning curve [35,82]. One aspect to be considered in this surgical technique is that the location of the tumor determines the patient's position during surgery [34], so that the patient is arranged in such a way that the tumor is always in the lower part of the operating field [36]. In general terms, we can define TEM as the standard treatment for the resection of rectal tumors, but it has a pronounced learning curve, and it is limited to local rectal neoplasms. Wider adoption of TEM has been limited due to the cost of surgical instruments, the long learning curve, and the relative scarcity of training programs. On the other hand, its training programs seem to be limited to theoretical instruction and *ex vivo* practice under expert supervision [35].

As for TAMIS, it is a surgical technique that is described as an affordable and easily configured technique, allowing the use of traditional laparoscopic equipment, and which can be used for various applications [41–45,49]. It is considered a hybrid technique between TEM and single-port laparoscopy, and therefore specialized training is required to master the nuances of this surgical approach. However, it seems that the TAMIS technique does not have such a steep learning curve as is the case with the TEM technique [40], although the lack of training programs means that the TAMIS learning curve has not yet been adequately analyzed and defined [47,48]. This shorter learning curve and ease of implantation have led to a fast adoption of TAMIS compared to other surgical modalities for colorectal surgery in the last decade.

A steep learning curve and intraoperative difficulties have been reported for TaTME [58,65,66] along with a lack of quality evidence to support the recommendations from experts [68]. Studies report that this technique requires a minimum of 45–51 cases to reach an acceptable incidence of high-quality TME and lower operative duration [65]. Although there are several training programs and expert consensus on TaTME [58–63], these programs are not accessible to most surgeons who wish to learn the TaTME surgical technique. Hence, there is a clear need to develop structured training programs worldwide [68]. We believe that the standardization of this technique, the definition of adequate training programs, mentoring and proctoring are needed to overcome its difficulties, together with solid studies supporting the safety and benefits of TaTME in the treatment of CRC.

The introduction of robot-assisted surgery has made it possible to improve some aspects with regard to the conventional laparoscopic approach, such as a reduction in the conversion rate, hospitalization, and increased precision during surgery. In addition, in CRC surgery, the pathological results of the robotic approach are comparable to those obtained by conventional laparoscopic surgery [70]. Nevertheless, this technique has some limitations with respect to conventional laparoscopic surgery such as the high cost, the size of the surgical platforms, the complexity of the systems configuration, and the need for specific surgical skills [76]. The development of preoperative simulation equipment is an important aspect to consider in robot-assisted surgical training, so that these training systems provide surgeons with a virtual experience in robotic surgery before proceeding to the actual clinical situation [69]. Although several virtual training platforms have been implemented for robotic surgery, educational opportunities for robotic-assisted colorectal surgery are still scarce. In this sense, the definition of the training requirements in colorectal robotic surgery, the delineation of structured training programs and the objective evaluation of the acquired surgical skills are basic pillars for the safe and efficient acquisition of robot-assisted colorectal surgical skills [76].

Conclusions

Minimally invasive colon and rectal surgery entails challenging surgical techniques, which require a long and steep learning curve. Surgical simulators, both physical and virtual, are presented as efficient learning solutions that allow trainees to acquire, without risk to the patient, basic surgical skills in the different techniques of minimally invasive colorectal surgery. The subsequent learning steps should transfer the surgical abilities acquired from inanimate models to experimental or cadaveric ones, for subsequent application in actual surgical practice.

Structured training is a key element for the learning of surgical techniques with a level of complexity as high as that of minimally invasive colorectal surgery. However, training programs in this surgical discipline remain limited. It is necessary to implement more structured training programs and reach a clearer consensus on the training aspects for the different techniques presented, such as laparoscopic surgery, TEM, TAMIS, TaTME and robotic-assisted surgery. These training programs and tools should ensure that surgeons acquire sufficient surgical abilities for them to be competent in the development of these surgical techniques, ensuring the quality of the patient's surgical outcomes.

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Modele szkoleniowe w chirurgii minimalnie inwazyjnej jelita grubego

Streszczenie
Rak jelita grubego (RJG) jest trzecim co do częstotliwości rozpoznawania nowotworem złośliwym na świecie, a także czwartą przyczyną zgonów na nowotwory złośliwe. Głównym elementem leczenia RJG jest operacja, którą można wykonać przez rozległe nacięcie powłok lub za pomocą technik minimalnie inwazyjnych. Do tych drugich należą: endoskopowa chirurgia transanalna (TEM), przezodbytowa chirurgia minimalnie inwazyjna (TAMIS), przezodbytowe całkowite wycięcie mezorektum (TaTME) oraz chirurgia wspomagana robotowo. Analizy danych potwierdzają, że techniki minimalnie inwazyjne są bezpieczne, równie skuteczne onkologicznie co techniki tradycyjne, a także wiążą się z szybszym powrotem chorych do pełnej sprawności. Ich wspólną cechą są niestety wysokie wymagania techniczne oraz długa krzywa uczenia. W artykule omówione zostały różne techniki minimalnie inwazyjne stosowane w leczeniu RJG oraz metody nauczania tych technik. Jak dotąd opracowano wiele sposobów szkolenia dla różnych technik operacyjnych. Większość opiera się na symulatorach chirurgicznych zarówno rzeczywistych, jak i wirtualnych oraz na wykorzystaniu modeli eksperymentalnych i preparatów z ludzkich zwłok. Niestety usystematyzowane modele szkolenia w minimalnie inwazyjnej chirurgii RJG są nadal rzadkością. Widać wyraźnie potrzebę opracowania

konsensusu dotyczącego szkolenia w poszczególnych metodach operacyjnych. Tego rodzaju programy powinny zapewnić uczestniczącym w nich chirurgom zdobycie wiedzy pozwalającej na skuteczne wykonywanie zabiegów w celu zapewnienia pacjentom jak najlepszych efektów leczenia.

Słowa kluczowe: symulacja chirurgiczna, chirurgia kolorektalna, szkolenie medyczne, techniki minimalnie inwazyjne, rak jelita grubego