

2016 Laparoscopic Surgery: Global view

Laparoscopic colorectal surgery: Current status and implementation of the latest technological innovations

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Abstract

The introduction of laparoscopy is an example of surgical innovation with a rapid implementation in many areas of surgery. A large number of controlled studies

and meta-analyses have shown that laparoscopic colorectal surgery is associated with the same benefits than other minimally invasive procedures, including lesser pain, earlier recovery of bowel transit and shorter hospital stay. On the other hand, despite initial concerns about oncological safety, well-designed prospective randomized multicentre trials have demonstrated that oncological outcomes of laparoscopy and open surgery are similar. Although the use of laparoscopy in colorectal surgery has increased in recent years, the percentages of patients treated with surgery using minimally invasive techniques are still reduced and there are also substantial differences among centres. It has been argued that the limiting factor for the use of laparoscopic procedures is the number of surgeons with adequate skills to perform a laparoscopic colectomy rather than the tumour of patients' characteristics. In this regard, future efforts to increase the use of laparoscopic techniques in colorectal surgery will necessarily require more efforts in teaching surgeons. We here present a review of recent controversies of the use of laparoscopy in colorectal surgery, such as in rectal cancer operations, the possibility of reproducing complete mesocolon excision, and the benefits of intracorporeal anastomosis after right hemicolectomy. We also describe the results of latest innovations such as single incision laparoscopic surgery, robotic surgery and natural orifice transluminal endoscopic surgery for colon and rectal diseases.

Key words: Laparoscopy; Inflammatory bowel disease; Surgical innovations; Colorectal cancer; Single incision laparoscopic surgery; Robotic surgery; Natural orifice transluminal endoscopic surgery

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Core tip: The introduction of laparoscopy for the treatment of colorectal pathology is associated with

the same benefits than other minimally invasive procedures with lesser pain, earlier recovery of bowel transit and shorter hospital stay. Although the use of laparoscopy in colorectal surgery has increased in recent years, several studies have shown that minimally invasive techniques are still underused and there are also substantial differences among centres. Thus, its implementation of the laparoscopic approach requires more efforts in teaching surgeons. We here present a review of recent controversies and the results of latest innovations in the use of laparoscopic surgery for colon and rectal diseases.

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INTRODUCTION

The introduction of the laparoscopic approach to cholecystectomy in the past two decades has been followed by rapid implementation of this technique in many areas of surgery. The laparoscopic revolution is an example of surgical innovation with a rapid dissemination of the technique through the academic network^[1]. The first laparoscopically-assisted colectomy was reported by Jacobs *et al*^[2] in 1991. Since then, a large number of controlled studies and meta-analyses have shown that laparoscopic colorectal surgery is associated with lesser pain, earlier recovery of bowel transit and shorter hospital stay as compared to open surgery^[3-7]. It has been suggested that the short-term advantages of laparoscopy are related to a decreased inflammatory response^[8,9]. Several studies^[6,10] have demonstrated lower serum levels of interleukin-6 and other proinflammatory cytokines, which are sensitive markers of tissue damage, after laparoscopic colectomy than after open resection.

However, compared with cholecystectomy, appendectomy or Nissen fundoplication, laparoscopic colonic surgery is a significantly more challenging operation as it frequently involves often more than one abdominal quadrant, identification and transection of vascular structures, mobilisation and resection of the bowel, retrieval of the surgical specimen and performing an anastomosis. The greater complexity of laparoscopic colectomy has been associated with longer operative times and a long learning curve. For these reasons, despite its advantages, laparoscopic colectomy has taken several years to start becoming a popular technique.

Laparoscopy and colon cancer

The impact of laparoscopy on long-term oncological outcome was a subject of controversy for many

years, especially because of port-site metastasis and concerns regarding lower number of lymph nodes retrieved^[11]. This was another factor that influenced its slow uptake in colorectal surgery. Wound recurrence of gastrointestinal cancer after open surgery has been traditionally considered an infrequent finding, with an incidence of less than 1% for colorectal cancer. The largest number of metastases in the abdominal wall, and in particular into laparoscopic ports, described in some of the first series of laparoscopic surgery published in the 1990s caused widespread concern regarding the indication of minimally invasive techniques in the treatment of gastrointestinal tumours. In fact, some series reported port site metastases and peritoneal dissemination in 10%-20% of patients^[11-14].

The relationship between different factors related to the laparoscopic technique (pneumoperitoneum) to the tumour (manipulation, degree of differentiation, stage) and the host (immune and inflammatory factors) were investigated in several experimental studies^[15,16]. The so-called "chimney effect" referring to leakage of CO₂ alongside trocars causing a high local gas flow at the trocar sites and aerosolisation of tumour cells has been proposed as a causative factor^[17]. Based on these results, some maneuvers were proposed to reduce or avoid the port site metastasis^[17-19]. These included the avoiding manipulation of the tumour to prevent exfoliation of tumour cells, the use of povidone-iodine solutions, empty the CO₂ through the trocars, using a device to protect wall incision and closing all trocars holes.

However, despite this initial concern regarding the oncological safety of the laparoscopic approach, well-designed prospective randomised multicentre trials have demonstrated no differences in the incidence of metastasis in the surgical wound as well as in oncological outcomes when the laparoscopic approach was compared to open surgery^[5,20-24]. Furthermore, a subset analysis of a randomised trial even showed a lower recurrence rate and better survival in patients with stage III colonic cancer undergoing laparoscopic resection as compared with laparotomy^[25] although these results have not been confirmed afterwards. The use of laparoscopy for the management of colorectal cancer is currently accepted worldwide^[26].

Laparoscopy and inflammatory bowel disease

The development of laparoscopic procedures for benign conditions has met with technical difficulties, even higher than in patients with cancer, particularly when treating patients with inflammatory disorders such as diverticular disease^[27] or inflammatory disease^[28], which frequently involves adjacent structures. This technical challenge for the colorectal and laparoscopic surgeons has been reflected in evidence provided by large trials supporting laparoscopic resections for these indications lagging behind those related to surgical oncology^[29].

With regard to inflammatory bowel diseases, we have to distinguish between Crohn's disease and ulcerative colitis because the indications and operative procedures are different. In Crohn's disease there is a wide range of potential procedures, whereas in ulcerative colitis, restorative proctocolectomy is the standard technique in the elective setting^[30].

Early reports of the introduction of laparoscopy in the treatment of patients with Crohn's disease demonstrated the feasibility of the laparoscopic approach for the formation of stomas and ileocecal resections. However, the widespread use of laparoscopy in Crohn's disease has been limited because it is a technically demanding surgery. Complicated cases of Crohn's disease continue to be challenging even for surgeons with great experience in surgery of inflammatory bowel disease and minimally invasive techniques^[30]. Despite these difficulties, several case-control studies and randomised trials have demonstrated that a laparoscopic approach for ileocolic and also for colonic disease is as effective as open surgery with many short-term benefits^[31,32]. Maartense *et al.*^[33] reported the results of a multicentre randomised controlled trial comparing laparoscopic or open approach for ileocolic Crohn's disease. Although laparoscopy was associated with longer operative times, postoperative recovery was shorter. The authors also found decreased morbidity and reduced costs in patients undergoing laparoscopic ileocolic resection. Two meta-analyses have reported lower postoperative morbidity, a faster return to bowel function and a shorter postoperative hospital stay after laparoscopic surgery as compared to open approach^[34,35]. Another meta-analysis published by the Cochrane Collaboration Group found no significant differences in perioperative outcomes between laparoscopic and open surgery for Crohn's disease, although only two randomised controlled trials were included in the review^[36].

The initial results of laparoscopic restorative proctocolectomy and ileal pouch-anal anastomosis were not very promising. The laparoscopic technique appeared to be difficult to apply and time consuming. Years later, with the availability of new instruments and technical innovations as well as increased experience and concentration of cases in specialised centres, more favourable results were obtained^[30,37]. Several studies have compared the short-term postoperative outcomes of laparoscopic and open surgery for ileal pouch-anal anastomosis, but the results are controversial. A recent meta-analysis included 27 comparative studies with 2428 patients, 1097 (45%) of which underwent laparoscopic surgery^[38]. The laparoscopic approach was associated with a significantly longer operative time, reduced intraoperative blood loss and lower incidence of wound infection. No significant differences were observed in the rate of pouch failure. The authors concluded that for restorative proctocolectomy, laparoscopic and open approaches were associated with similar adverse event rates and

long-term functional results, although the evidence might be underpowered. It has been suggested that although the procedure is feasible and safe, since the short-term advantages are mainly cosmetic the clinical significance of this procedure is arguable^[39].

In order to decrease the technical difficulty of laparoscopic colectomy and compensate the lack of tactile feedback, hand-assisted laparoscopic surgery (HALS)^[4] has been appeared as an alternative. HALS is a hybrid approach by which the surgeon inserts a hand into the abdomen through a small incision to facilitate exposing the colon and dissection while keeping the pneumoperitoneum.

A few controlled studies, systematic reviews and meta-analysis have compared HALS with open surgery^[40-44], and also HALS with conventional laparoscopic surgery^[4,40,45-47]. These studies generally conclude that this combined approach has the advantages of minimally invasive surgery (lower blood loss, shorter incision length, faster recovery, shorter hospital stay) over open surgery while reducing some of the disadvantages of laparoscopic surgery (shorter operative time, lower conversion rates). However, there is no strong evidence to suggest that HALS will result in better or worse operative outcomes vs conventional laparoscopic approach^[46]. In this regard, HALS may be considered an interesting alternative for laparoscopic colectomy, particularly in more difficult cases such as complex diverticular disease or total colectomy^[48]. It may also be a better option for surgeons early in their laparoscopic careers^[42].

CURRENT STATUS

Although the use of laparoscopic colorectal surgery has been increasing in recent years, the percentage of patients who undergo surgery using minimally invasive techniques is still limited and there are also significant differences among centres^[49,50]. In recent years, there have been several reports of the implementation of laparoscopy in colorectal surgery. According to the National Institute for Health and Clinical Excellence (NICE) implementation uptake report the percentage of colorectal resections performed laparoscopically in England in 2009 was 22% while in 2007 it was only 8.8%^[51]. The rates ranged from 10% for total colectomy procedures to 25% in patients undergoing sigmoid colectomy. The level of uptake was higher than the future forecast made previously by NICE which estimated a rate of 13% would be completed laparoscopically.

The Surgical Care and Outcomes Assessment Program evaluated the use of laparoscopy for elective colorectal resection at 48 hospitals in the United States from 2005 to 2010. The use of laparoscopic procedures increased from 23.3% in 2005 to 41.6% in 2010^[52]. The authors found that hospital characteristics (urban location and less than 200 beds), diverticular disease, and right hemicolectomies were factors associated

with the laparoscopy use. They also found the greatest increase in the total number of colorectal operations among hospitals with the highest laparoscopy adoption rates.

In another recent study using the University Health System Consortium administrative database, which includes more than 300 academic hospitals, laparoscopic colorectal resection was attempted in 36228 (42.2%) out of 85712 patients, with 15.8% requiring conversion to open surgery. The authors concluded that there is a trend of increasing use of laparoscopy in colorectal surgery, across hospital in the United States in the recent years^[53] with acceptable conversion rates

The use of laparoscopy in colorectal surgery should be calculated in relation to the number of patients who are candidates for minimally invasive surgery. Although the number of absolute contraindications is currently almost negligible, it is important to properly select patients to maintain conversion rates below 10%. Thus preoperative selection of patients with colorectal disease allows optimum use of the advantages of laparoscopy. It has been estimated that an appropriate indication for patients with colorectal disease ranges between 60% and 80%^[47]. In this regard, although the use of laparoscopy is increasing, the figures mentioned above show that laparoscopic colorectal surgery is still underused. It has been suggested that the limiting factor for the implementation of this procedure is the number of surgeons capable of performing a laparoscopic colectomy, rather than the characteristics of the tumour or patient^[51]. Recent studies have demonstrated the positive effect of a standardized technique, training courses and surgical simulation on the implementation of laparoscopic colorectal procedures^[54,55]. Manuel Palazuelos *et al*^[55] measured the impact on clinical practice of a laparoscopic colorectal resection training programme based on surgical simulation. In a prospective study, 163 surgeons participated in 30 courses of 35 h (18 h in the operating room, 12 h practicing with animal models and 4 h in seminars). Afterwards, participants were asked *via* an on-line survey about the degree of implementation of the techniques in their day-to-day work. Average time elapsed after the course was 11.5 mo (2-60 mo). Interestingly, a total of 75% of participants initiated or increased the number of laparoscopic surgeries performed after the training experience. Future efforts to increase the use of laparoscopic techniques in colorectal surgery will require novel opportunities for learning among surgeons. As it has occurred before with other surgical techniques, the use of workshops, symposia and video demonstrations are important resources to increase the implementation of colorectal laparoscopic surgery in daily practice^[49,56].

oncological safety of laparoscopic colonic resection in patients with colon cancer was demonstrated and widely accepted more than 10 years ago, the use of laparoscopy in patients with rectal cancer has raised questions regarding the safety and effectiveness of this approach^[57,58]. The need to perform a total mesorectal excision in a deep and narrow pelvis increases the technical complexity of this procedure and the risk of oncological compromise.

The CLASSIC study was one of the first trials comparing laparoscopic-assisted surgery with conventional open surgery, not only for colon cancer patients, but also for patients with rectal cancer^[5]. It is important to note that patients were recruited between 1996 and 2002 and the lack of experience in laparoscopic anterior resection in the early years of the study had a significant influence on the reported conversion rate, which was higher than 30%. The mean hospital stay was 2 d shorter for laparoscopy than for open surgery, but for successful laparoscopic excisions, hospital stay was 3 d shorter than for converted patients. Circumferential resection margin positivity was greater in the laparoscopic than in the open surgery group (12% vs 6%), although the difference was not statistically significant. On the other hand, converted patients had the highest rates of surgery-related complications and death than open or laparoscopy patients. The high conversion rate and the worse outcomes in this group of patients raised some concerns about the unselected indication of laparoscopy in patients with rectal cancer and the impact of the learning curve. In fact, the authors concluded that routine use of laparoscopy does not appear to be justified in patients with rectal cancer.

Thereafter, several others randomised controlled trials and meta-analyses have compared short-term clinical outcomes between laparoscopic and open surgery approaches in rectal cancer. See Table 1. In a recent single centre randomised trial, Lujan *et al*^[59] compared surgical outcomes after laparoscopy and open surgery in patients with mid and low rectal cancers. Blood loss was significantly greater for open surgery, operating time was significantly greater for laparoscopic surgery, and return to diet and hospital stay were longer for open surgery. Complication rates and involvement of circumferential and radial margins were similar for both procedures. In relation to other studies, we would like to highlight the European multicentre COLOR II trial^[60] conducted in 30 hospitals, in which 1103 patients were randomised. Again, the study showed reduced blood loss, earlier return of bowel function and shorter hospital stay in the laparoscopic group than in the open surgery group^[60]. There were no differences in postoperative morbidity and mortality. The long-term oncological results of this multicentre trial have been recently published, showing that laparoscopic surgery in patients with rectal cancer is oncologically safe, with rates of locoregional recurrence, disease-free survival and overall survival

RECENT CONTROVERSIES

Although the feasibility, short-term benefits and

Table 1 Summary of key studies comparing the use of laparoscopy and open surgery in patients with cancer

Ref.	n (open vs lap)	Study	Results
Guillou <i>et al</i> ^[65] 2005	794 (268/526)	RCT multicentre	Short term Similar results
Lujan <i>et al</i> ^[69] 2009	204 (103/101)	RCT unicentre	Short term Similar results
van der Pas <i>et al</i> ^[60] 2013	1103 (364/739)	RCT multicentre	Short term Similar results
Arezzo <i>et al</i> ^[62] 2015	10861	Systematic review	Short term Similar results
Chen <i>et al</i> ^[64] 2014	953	Meta-analysis	Short-term Similar results
Ng <i>et al</i> ^[65] 2014	278 (142/136)	3 RCT 3 yr follow-up	Long-term similar results
Trastulli <i>et al</i> ^[66] 2012	1544 (703/841)	Meta-analysis 9 RCT	Short term Similar results
Xiong <i>et al</i> ^[67] 2012	624 (316/308)	Meta-analysis 4 RCT	Short term Similar results

RCT: Randomised controlled trial.

similar to those of open surgery^[61]. Several systematic reviews and meta-analyses have recently confirmed the short-term benefits and oncological safety of minimally-invasive approach for rectal cancer surgery^[62-67].

Another recent controversy on laparoscopic colorectal surgery relates to complete mesocolon excision. There are three essential components to complete mesocolon excision: dissection between the mesenteric plane and the parietal fascia and removal of the mesentery within a complete envelope of mesenteric fascia and visceral peritoneum that contains all lymph nodes draining the tumour area, central vascular tie, and resection of an adequate length of bowel to remove involved pericolic lymph nodes in the longitudinal direction. It has been suggested that complete mesocolic excision is associated with increased lymph node yield, reduced locoregional recurrences and increased disease-free survival in patients with colorectal cancer^[68,69]. However, a concern has arisen about the possibility of reproducing this more extensive dissection by laparoscopy. A recent systematic review included 34 retrospective, prospective and observational studies. Of the prospective studies, four reported an increased lymph node harvest and a survival benefit. The authors concluded that laparoscopic complete mesocolic excision has the same oncological outcome as open surgery, although completeness of excision during laparoscopy may be compromised by tumours in the transverse colon^[70]. Although several reports have demonstrated that laparoscopic resection for transverse colon cancer is feasible and safe with short- and long-term outcomes comparable to open surgery^[71,72], the evidence for laparoscopic complete mesocolon excision is still limited^[73].

Finally, the advantages of intracorporeal (vs extracorporeal anastomosis in patients undergoing laparoscopic right colectomy is also a matter of controversy. See Table 2. Although totally laparoscopic

Table 2 Intracorporeal vs extracorporeal anastomosis in right laparoscopic colectomy

Ref.	n (IA/EA)	Study	Results
Milone <i>et al</i> ^[74] 2015	512 (286/226)	Multicentre Observational	Similar results
Grams <i>et al</i> ^[75] 2012	105 (54/51)	Retrospective	Better for IA
Scatizzi <i>et al</i> ^[76] 2010	80 (40/40)	Case-control	Similar results
Hellan <i>et al</i> ^[77] 2009	80 (23/57)	Prospective	Similar results
Carnuccio <i>et al</i> ^[78] 2014	484 (272/212)	Systematic review	Similar results

IA: Intracorporeal anastomosis; EA: Extracorporeal anastomosis.

right colectomy with intracorporeal functional end-to-end anastomosis has been shown to be feasible and effective in terms of short- and long-term results and oncological radicality, this technique is still performed by a relatively small number of surgeons^[74]. In a retrospective study including 105 patients, Grams *et al*^[75] found that resection and creation of the anastomosis intracorporeally produces superior results with earlier return of bowel function, decreased postoperative narcotic use, and decreased length of stay and morbidity in comparison to the extracorporeal technique. Other reported advantages of intracorporeal anastomosis are improved cosmesis and higher rates of early regular diet tolerance^[76]. However, these advantages have not been confirmed in other non-controlled clinical studies^[77].

A recent meta-analysis of observational studies included six case-control studies with 484 patients undergoing right laparoscopic colectomy, 272 with intracorporeal anastomosis and 212 with extracorporeal anastomosis. The best outcomes were associated with intracorporeal anastomosis especially in terms of return of bowel function, length of hospital stay and cosmetic results. However, the meta-analysis did not show a significant difference between the two techniques for anastomotic leaks or overall short-term morbidity. The authors concluded that the meta-analysis did not allow to draw definitive conclusions^[78]. Several other meta-analyses have also failed to solve this controversy. Future randomised, controlled trials are needed to further evaluate different surgical anastomosis after laparoscopic right hemicolectomy^[79,80].

LATEST TECHNOLOGICAL INNOVATIONS

Over the last decades, different minimally invasive surgery techniques have emerged. The combination of new technology with the improvement of skills and knowledge of surgeons has encouraged many groups to converge techniques and technology to develop new strategies.

Single incision laparoscopic surgery

After the great development of laparoscopic surgery for the treatment of colorectal diseases over the two

past decades, a new procedure emerged in order to improve even more its results. In single incision laparoscopic surgery (SILS), a unique port is used, usually in the umbilicus or at the site where a stoma is planned. The development of this approach is primarily intended to achieve two main objectives: on the one hand, to minimise the potential risks of trocar-related complications, and therefore to improve cosmetic results, and on the other, to reduce the inflammatory response to surgical trauma.

However, as any other example of surgical innovation, SILS has to be associated with the development of new skills by the surgeon and of new surgical instruments specifically designed for this procedure^[81,82]. SILS involves the handling of straight instruments in parallel and the decreased in the freedom of movement for the surgeon. Some authors have shown that SILS causes more physical workload for the surgeon compared to conventional laparoscopy^[83]. Some technical options have been described to facilitate work in parallel in SILS such as the use of magnetics forceps^[84] that permits better triangulation of instruments and the "colon-lifting technique" that consist in the suspension of the colon to the abdominal wall with a suture string^[85].

SILS was first reported in 1992 by Pelosi *et al*^[86]. They were the first authors who described the technique as transumbilical approach for appendectomy, some years later after the first transumbilical cholecystectomy described by Navarra *et al*^[87]. However, the first colonic resection procedures *via* SILS would not have been published until ten years later^[88-90]. In the last 5 years there have been an exponential growth of published papers on this topic, reporting increasingly complex procedures performed by SILS technique and showing that this technique can be applied to both, benign and malignant colorectal diseases.

The first case series, mostly involving a small number of cases, focused their interest in confirming the safety of SILS as compared to standard laparoscopy^[81,91-93]. Later on, comparative non-randomised studies were published^[85,94-98]. Altogether, these studies showed that SILS was as similar to conventional laparoscopy in terms of early complications such as postoperative bleeding, wound complications, lymph node retrieval and mortality. Regarding other possible benefits of SILS such as reduced postoperative pain or peritoneal adhesions there is no sufficient evidence of the superiority of SILS vs conventional laparoscopy.

It is important to note that the studies published to date have a number of biases limiting the value of their conclusions. Limitations include important selection bias regarding the patients' body mass index (BMI) as well as the size and location of tumours. Moreover, patients undergoing SILS surgical procedures are operated by select groups of surgeons with special interest and skills in laparoscopic surgery; this could be a limitation in order to reproduce the same results in other institutions.

In 2012, two randomised studies were published

comparing SILS with conventional laparoscopy. In one the study that included only 32 colon cancer patients, Huscher *et al*^[99], concluded that SILS for colon cancer was feasible and safe as conventional laparoscopy, by they found no differences of SILS in terms of postoperative morbidity, first time of oral intake and length of hospital stay. By contrast, in a randomised study including 25 patients per group, Poon *et al*^[100], showed that SILS was associated with lesser pain and shorter hospital stay. In the same year, the first meta-analysis including 14 studies^[101], only one randomised, reported the same conclusions; there were no significant differences between two approaches, so the authors considered that SILS was just an alternative for colorectal cancer surgery. The meta-analysis published by Maggiori *et al*^[28] is important because more than 1000 patients operated on by SILS were included. According to the results of this systematic review and meta-analysis suggest that single-incision laparoscopic colorectal surgery is feasible and safe.

Another systematic review published in 2012^[102] confirmed the lack of superiority of SILS over conventional laparoscopy. Results of this review, however, should be interpreted taking into account some limitations including, selection bias in SILS patients and surgical expertise as well as heterogeneity among studies and differences in the primary endpoints.

One year later, in another meta-analysis with more than 500 patients per group Yang *et al*^[103] that patients undergoing SILS had shorter length of stay, shorter incision length, less estimated blood loss and more lymph nodes harvested, with the same number of postoperative complications and the same operative time. In the conclusions of this study the authors also admitted that SILS was performed only by experienced surgeons. Similar conclusions have been reached in more recent meta-analysis^[104].

Two special topics merit to be mentioned apart. One of the supposed advantages of SILS is cosmesis but, this topic has been refuted by some authors^[95,98,105]. Although many studies have demonstrated, obviously, that SILS is associated with a shorter incision^[28,102,103], the majority of authors agree that there is a lack of consensus on how to evaluate the cosmetic results and that cosmetic evaluation should only be performed after completion of the healing process and by an independent clinician.

Another special issue of SILS is cost. In the early years, SILS was more expensive than conventional laparoscopy due to development of new trocars and new instruments. This fact has been confirmed by some authors^[106] but with the increased in development of instruments and the competition between providers, both techniques have equalized in costs; today the cost of SILS port is just a little higher than the four conventional laparoscopy ports^[94,96].

Based on the available evidence it cannot be concluded that SILS is better than conventional laparoscopy. In our opinion, this approach should be

reserved to selected patients, (with low BMI, small size tumours and preferably localised in right colon) and selected surgeons. Data regarding long-term oncological results for malignant diseases cannot be presented given the lack of long-term follow-up studies.

Robotic laparoscopic colorectal surgery

One step beyond minimally invasive surgery is robotic surgery. Robotics were applied to surgery in 1970s in the military setting; the first robot entering in an operating room was designed in 1985 and, since then, multiple tele-manipulators have been proven until the introduction of the da Vinci robotic surgical system (Intuitive Surgical, Inc, Sunnyvale, Calif) that has revolutionised this field.

This new approach provides three-dimensional image, diminishes surgeon tremor, allows dexterity and ambidextrous capability, is associated with shorter learning curve, and provides human wrist-like motion for the instruments^[107]. All these advantages are particularly useful in operations performed in small fields in which high precision is crucial^[108].

However, despite the growing number of published articles on this topic there is lack of evidence about long-term oncological safety or its clinical benefits over conventional laparoscopy. Moreover this technique is expensive, which is a major drawback to the widespread adoption of robotic surgery in the present time of budget constraints^[109].

Evidence of the usefulness of robotic surgery was firstly reported in prostate, gynaecological and cardiac surgery but no was until 2002 when Weber *et al*^[110] published the first two cases of robotic colectomies. Since then, there has been a rapid growing of evidence about colon and, specially, rectal cancer. Araujo *et al*^[111] found only two publications between 2006 and 2007 and more than 20 manuscripts published between 2010 and 2013 regarding this topic. It is important to note that the evidence available until today about robotic surgery shows a great difference between colon and rectal surgery. In the development of this new approach different difficulties and challenges have been described and this is why deserved to be considered separately.

Robotic colon surgery differs from robotic rectal surgery because one of the most important disadvantages of this technique is limited intracorporeal possibility of motion. Surgery of the colon requires access to more than one quadrant of the abdomen. This fact needs repositioning of the robotic arms, increasing the operative time. The first case series^[108,112-115] reported the benefit of the new approach in specific steps of the surgical procedure, such as take down of the splenic flexure or hand sewn anastomosis, but stressed major drawbacks regarding higher cost and longer operative times. Another steps of laparoscopic colectomy where robotic colorectal surgery has shown

superiority compared with conventional laparoscopy is are accurate lymphadenectomy around major vessels and the ability to perform intracorporeal anastomosis^[113]. In a randomised controlled trial with right-sided colonic cancer patients undergoing right hemicolectomy the duration of surgery was longer and the overall cost greater in the robotic group compared with the conventional laparoscopic group^[116]. In summary, robotic colorectal surgery is a safe and feasible technique but is associated with higher costs and longer operative times. The long-term results in patients with colon cancer are still to be determined.

Special mention should be made of the use of robotics in patients with rectal cancer, where robotic surgery permits the access to a narrow pelvic cavity with an excellent surgical view. As previously mentioned, the need to perform a total mesorectal excision in a deep and narrow pelvis increases the technical complexity of this procedure and the risk of oncological compromise^[117]. In this regard, robotic surgery allows for a very precise dissection. With robotics total mesorectal excision and preservation of urinary and sexual functions can be achieved with more security^[108]. Even more, some studies suggest that robotic surgery may attenuate the learning curve for laparoscopic rectal resection^[109].

The first evidence described for treatment of rectal cancer with total mesorectal excision was in 2010^[118,119]; two studies with a small number of patients confirmed that robotic surgery was as safe and feasible technique as conventional laparoscopy. During the last years, a large number of studies have been published including clinical series^[119,120], comparative studies^[121,122] and one randomised controlled trial^[123]. The results of all of them agree that robotic surgery is safe and can be reproduced, with a higher cost and longer operative time; similarly, these studies pint out the absence of evidences about oncological outcomes.

In a recent review of Araujo *et al*^[111], a total of 1776 patients with rectal cancer that underwent minimally invasive robotic surgery in 32 studies were evaluated. In this study the authors found no differences between robotic and laparoscopic surgery regarding morbidity and anastomotic complications. Robotic surgery was better in short-term oncological results, larger number of lymph nodes harvested and greater distance of resection margin. However, the authors insist in the fact that this new approach is associated with increased costs and longer operative times. Other meta-analyses have obtained similar results^[124-126]. More recently, Park *et al*^[127] have published the first study of long-term oncologic outcomes of rectal cancer patients undergoing robotic surgery compared with conventional laparoscopy. In this prospective study, no significant differences were found in the 5-year overall, disease-free survival and local recurrence rates between robotic and laparoscopic surgical procedures and, once again, robotic surgery was associated with

higher costs.

Other systematic reviews and meta-analyses have investigated the impact of robotic surgery including together patients undergoing colon and rectal surgery^[124,128-130] and have confirmed the results of previous studies: robotic colorectal surgery is a safe and feasible option and show comparable short-term outcomes compared to conventional laparoscopic surgery.

In summary, there is no evidence supporting the superiority of robotic surgery over standard laparoscopy in procedures for colon or rectal cancer. Further studies are required to evaluate oncologic safety and functional results. Moreover, the aforementioned drawbacks, longer operative time and higher costs, are factors associated with a slow implementation of this technology.

Natural orifice transluminal endoscopic surgery

Natural orifice transluminal endoscopic surgery (NOTES) appeared as a further step of the laparoscopic approach with a preservation of the abdominal wall integrity. It proposes the access to the peritoneal cavity with flexible endoscopic or rigid laparoscopic instruments using natural openings such as the mouth (transgastric), the urethra (transvesical), the vagina (transvaginal) and the anus (transcolonic)^[131]. Theoretically, NOTES offers a reduction of pain and wound-related complications as it is also defined as "scarless" surgery.

In the field of colorectal surgery, transrectal NOTES has been accepted as a hybrid procedure assisted by laparoscopy, and also as a pure access to resect a rectal and also a colon specimen. In 2007, Whiteford *et al*^[132] published the first successful pure transanal NOTES sigmoidectomy using transanal endoscopic microsurgery (TEM) instrumentation in a cadaveric model with success. Later on, in 2009, Velhote *et al*^[133] published a pure NOTES in a patient in which they performed a transanal endorectal pull-through sigmoidectomy. Although there are few case reports describing the results of pure colon resection NOTES, nowadays, the hybrid technique using laparoscopic trocars and transvaginal^[134] or transanal approach^[135] to excise the specimen seems to be more accepted among colorectal surgeons. Recently, The German NOTES registry analysed the first 139 colonic NOTES procedures showing that transvaginal or transrectal NOTES colectomy is feasible and can be performed safely^[136].

In the last years, different colorectal surgery groups have used NOTES approach for total mesorectal excision (TME) through the anus assisted by laparoscopy to treat low and medium rectal cancer. It is known under different names in the literature: Transanal NOTES for TME, Perirectal NOTES, Transanal endoscopic TME and transanal minimally invasive surgery (TAMIS)-TME. NOTES for TME is a combination of the benefits of TEM,^[137] the improvements achieved

with TAMIS and the principles of NOTES. The purpose is to give a safe and feasible alternative to the open and laparoscopic TME.

Since its introduction in 1983, TEM^[137] has become an effective and well-established surgical approach to excise benign rectal adenomas and early stage rectal cancer. This minimally invasive technique offers the advantage of better controlled full-thickness rectal wall excision in a narrow operative field compared to endoscopic submucosal dissection^[63] or transanal local excision^[138]. In addition, TEM approach is a feasible alternative to radical excision of the rectum with lower morbidity and mortality^[139] in low risk T1 adenocarcinoma^[140]. Furthermore, TEM has a role as a palliative technique in patients who refuse radical excision or are medically unfit for radical resection.

A modification of this technique named TAMIS and was first described in 2010 by Atallah *et al*^[141]. This new technique is characterised by a different platform. They proposed to use a single port laparoscopic device transanally to excise rectal tumours instead of the rigid and longer rectoscope of the TEM. These authors showed that TAMIS is a feasible and safe alternative to TEM, with technical advantages, quicker settling of the operative field and less expensive. Transanal NOTES is a well-known "hybrid" procedure combining laparoscopic instruments with TEM skills and TAMIS technique.

The first case report of a Transanal NOTES recto-sigmoid resection assisted by laparoscopy was reported in 2010 by Sylla and Lacy groups^[142]. Since then, several case reports and also some small clinical series^[143-146] of TME for rectal cancer using transanal NOTES approach with laparoscopic assistance have been published. Emhoff *et al*^[147] have recently reviewed the first published series and reported favourable short-term outcomes in selected patients. Also, Tuech *et al*^[148] published good short-term outcomes in a multicentre prospective study of 56 unselected consecutive patients with no intraoperative complications, a postoperative morbidity rate of 26% and no postoperative mortality. They demonstrate that endoscopic transanal proctectomy is a safe and reproducible procedure and does not negatively impact the oncological dissection or functional outcomes^[148]. Recently, Fernandez *et al*^[149] have published the first prospective cohort study of patients treated by transanal NOTES assisted by laparoscopy compared to a retrospective historical cohort treated by laparoscopic TME. This study confirms that transanal TME is a feasible and safe technique associated with a shorter surgical time and a lower early readmission rate compared to laparoscopic TME^[149]. However, randomised controlled trials are necessary to evaluate the short-term outcomes and long-term functional and oncological results.

Transanal NOTES for rectal cancer offers the possibility to avoid an extra viscerotomy compare to other NOTES approaches. The proctotomy used to

remove the specimen would be incorporated in the final colorectal or coloanal anastomosis. Moreover, this is not the only advantage; experienced colorectal surgeons with this approach point out to a better visualisation of the tumour distal edge so that a clear negative distal resection margin could be done. It seems particularly indicated in patients with unfavourable characteristics such as male gender obesity, narrow pelvis and bulky tumours^[148-150]. In summary, transanal NOTES is a "hybrid" procedure combining laparoscopic instruments with TEM skills and TAMIS technique. It will play an important role in minimally invasive colorectal surgery allowing to perform the transanal TME after the abdominal approach.

CONCLUSION

Although the use of laparoscopy in colorectal surgery has increased in recent years, several studies have shown that minimally invasive techniques are still underused and there are also substantial differences among centres. Thus, its implementation of the laparoscopic approach requires more efforts in teaching surgeons. This review of recent controversies and latest innovations in the use of laparoscopic surgery for colon and rectal diseases, allows us to know more about this approach and its implementation.

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