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

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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 in 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.

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. The first laparoscopically-assisted colectomy was reported by Jacobs et al. 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. It has been suggested that the short-term advantages of laparoscopy are related to a decreased inflammatory response. Several studies 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. 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.

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. 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. Based on these results, some maneuvers were proposed to reduce or avoid the port site metastasis. 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. Furthermore, a subset analysis of a randomised trial even showed a lower recurrence rate and better survival in patients with stage III colon cancer undergoing laparoscopic resection as compared with laparotomy although these results have not been confirmed afterwards. The use of laparoscopy for the management of colorectal cancer is currently accepted worldwide.

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 or inflammatory disease, 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.
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\(^\text{[30]}\).

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 ileocolic 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\(^\text{[30]}\). 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\(^\text{[31,32]}\). Maartense \textit{et al}\(^\text{[33]}\) 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\(^\text{[34,35]}\). 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\(^\text{[36]}\).

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\(^\text{[30,37]}\). 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\(^\text{[38]}\). 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\(^\text{[39]}\).

In order to decrease the technical difficulty of laparoscopic colectomy and compensate the lack of tactile feedback, hand-assisted laparoscopic surgery (HALS)\(^\text{[40]}\) 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\(^\text{[40-44]}\), and also HALS with conventional laparoscopic surgery\(^\text{[4,40,45-47]}\). 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\(^\text{[46]}\). 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\(^\text{[48]}\). It may also be a better option for surgeons early in their laparoscopic careers\(^\text{[42]}\).

**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\(^\text{[49,50]}\). 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%\(^\text{[51]}\). 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\(^\text{[52]}\). 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[51] 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[42] 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[46,56].

RECENT CONTROVERSIES

Although the feasibility, short-term benefits and 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[25]. 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[43] 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...
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 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].

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<th>Table 1  Summary of key studies comparing the use of laparoscopy and open surgery in patients with cancer</th>
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| Guillou et al[61] 2005 | 794 (268/526) | RCT multicentre | Short term
Similar results |
| Lujan et al[62] 2009 | 204 (103/101) | RCT unicentre | Short term
Similar results |
| van der Pas et al[63] 2013 | 1103 (964/379) | RCT multicentre | Short term
Similar results |
| Arezzo et al[64] 2015 | 10861 | Systematic | Short term
Similar results |
| Chen et al[65] 2014 | 953 | Meta-analysis | Short term
Similar results |
| Ng et al[66] 2014 | 278 (142/136) | 3 RCT | Long-term
Similar results |
| Trastulli et al[67] 2012 | 1544 (703/841) | Meta-analysis | Short term
Similar results |
| Xiong et al[68] 2012 | 624 (316/308) | 9 RCT | Similar results |
| Xiong et al[69] 2012 | 624 (316/308) | Meta-analysis | Short term
Similar results |

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<th>Table 2 Intracorporeal vs extracorporeal anastomosis in right laparoscopic colectomy</th>
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<td>Milone et al[70] 2015</td>
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<td>Grams et al[71] 2012</td>
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<td>Scatizzi et al[72] 2010</td>
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<td>Hellan et al[73] 2009</td>
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<td>Carnuccio et al[74] 2014</td>
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IA: Intracorporeal anastomosis; EA: Extracorporeal anastomosis.

**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 inno-
vation, SILS has to be associated with the development
of new skills by the surgeon and of new surgical
instruments specifically designed for this procedure.
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. Some
technical options have been described to facilitate work
in parallel in SILS such as the use of magnets for
specific instruments 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.

SILS was first reported in 1992 by Pelosi et al. 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. However, the first colonic
resection procedures via SILS would not have been
published until ten years later. 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
correlation of cases, focused their interest in confirming
the safety of SILS as compared to standard laparo-
sCOPY. Later on, comparative non-randomised
studies were published. 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
of the studies that included only 32 colon cancer patients,
Huscher et al., concluded that SILS for colon cancer
was feasible and safe as conventional laparoscopy,
but with the increased in development of new trocars and
new instruments. This fact has been confirmed by
some authors but with the increased in develop-
ment 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.

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[110,120], 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, 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 rectosigmoid resection assisted by laparoscopy was reported in 2010 by Sylla and Lacy[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 compared 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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