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The Development of Minimally Invasive Surgery for Colorectal Resection

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1. Abstract

In the past thirty years, with the development of laparoscopic instruments, the gradual maturity of minimally invasive surgical technology, the popularity of the concept of minimally invasive surgery, and the continuous improvement of people's requirement for postoperative quality of life, laparoscopic and endoscopic colorectal surgery have been widely performed. A series of surgical innovations are emerging and being applied to the field of colorectal surgery. From multi-port laparoscopic surgery to natural orifice transluminal endoscopic surgery and single-port laparoscopic surgery, and from natural orifice specimen extraction surgery to transanal total mesorectal excision, an unprecedented "revolution" of minimally invasive surgery is taking place in the field of colorectal surgery. This paper introduces the development of several common minimally invasive surgical innovations for colorectal resection. In addition, we compare the advantages and disadvantages of various surgical innovations by review the previous representative literature, aiming to provide reference for surgeons in the area of colorectal surgery.

2. Introduction

The world's first laparoscopic cholecystectomy, performed by Mouret in 1987, was a great breakthrough in surgery, and it was also a product promoted by the concept of minimally invasive surgery [1]. In 1991, Jacobs *et al* reported the first case of laparoscopic colectomy [2]. Subsequently, several multicenter Randomized Controlled Trials (RCT) were conducted to compare laparoscopic versus open surgery for colorectomy such as COST study, CLASICC study and COLOR II study proved the better short-term outcomes and similar long-term outcomes, providing data support for laparoscopic colorectal resection [3-6]. In 2009, National Comprehensive Cancer Network (NCCN) listed laparoscopic colorectomy as a standard routine procedure [7]. With the popularization of the concept of minimally invasive surgery, various new methods of colorectal surgery have been created and developed to reduce surgical trauma, reduce postoperative pain, promote postoperative recovery, and increase cosmetic effects by reducing the incisions. In recent years, various new methods were widely studied and applied in the field of colorectal surgery, including Natural Orifice Transluminal Endoscopic Surgery (NOTES), Single-Port Laparoscopic Colorectomy (SPLC), natural orifice specimen extraction surgery (NOSES), transanal total mesorectal excision (TaTME), etc [8-12].

3. Notes

NOTES refers to a new type of surgery that is performed through the body's natural cavities, such as the mouth, anus, rectum, vagina, bladder and so on, in order to eliminate surface incisions. On March 13, 2007, Zorrón *et al* [13] preformed the first transvaginal

cholecystectomy. This approach had overturned the traditional concept of surgery, allowing minimally invasive surgery to enter a higher level. However, NOTES technique for colectomy is still almost not feasible because of the anatomic location and the large size of colorectum, while transgastric appendectomy and transvaginal cholecystectomy have been successful in humans [14-15]. NOTES has high requirements on equipment and technologies, including the assistance of special soft endoscope equipment. And it is quite difficult to complete the ligation, dissection, extraction and anastomosis of the intestine with pure NOTES [16-19]. So, how to perform a colorectal resection with as little risk or complexity as possible, but with a smaller incision? Many surgeons have created a variety of surgical procedures same as NOTES, such as Single-Port Laparoscopic Colorectomy (SPLC), hybrid NOTES, TaTME, etc.

4. Hybrid Notes (NOSES)

Hybrid NOTES is also known as NOSES or total laparoscopic surgery; it is a hybrid technique combing laparoscopic assistance with NOTES. In colorectomy, NOSES eliminating the need of an abdominal assisted incision of several centimeters for specimen extraction, that is expected to reduce postoperative pain and some postoperative complications. In NOSES for colorectomy, the site of specimen removal is usually anus and vagina, which can be selected according to the patient's gender, fertility, tumor size and individual wishes [20].

In 2008, Palanivelu *et al* [21] retrospectively studied seven women patients who underwent transvaginal NOSES laparoscopic proctocolectomy for familial polyposis coexisting with adenocarcinoma of the upper rectum, which showed this new procedure could prevent wound-related complications effectively. In 2009, Akamatsu *et al* [22] reported a series of cases that sixteen patients with colon cancers were treated by transanal NOSES sigmoid colectomy and all the patients were undergoing the operations smoothly without mortality and serious postoperative complications. In 2009, Cheung *et al* [23] used laparoscopy combined with transanal endoscopy to perform NOSES on 10 patients with left colon cancer, and satisfactory postoperative results were obtained in all patients, including short length of stay and mild pain. The initial success has brought more attention to NOSES. It is also because of the combination of minimally invasive effect and the convenience of laparoscopic surgery, that NOSES is carried out in some large medical centers.

Wolthuis *et al* [24] reported a systemic review in 2014, involving 12, 134 patients who underwent NOSES colorectomy. The study shown that NOSES colectomy still serves as a bridge between conventional laparoscopic(CL) and pure NOTES procedures, although it has some shortcomings.

In 2013 Leung *et al* [25] reported a prospective RCT involving seventy patients diagnosed with left-sided colorectal tumor from the splenic flexure to the upper rectum with tumor size ≤ 4 cm. The study showed that NOSES was safe and feasible with less postoperative pain. More importantly, NOSES eliminated the complications related to mini-laparotomy. In 2015, Wolthuis *et al* [26] also reported a RCT of laparoscopic colectomy for forty patients (NOSES, n = 20; CL surgery, n = 20). The result showed NOSES colectomy had less pain and lower analgesia requirements than the CL surgery. In 2017, a large multicenter retrospective study involving 718 patients led by Wang *et al* [27] reported that NOSES colorectomy conformed to the requirements of radical surgery for tumors and has good short-term effects. Then, in 2019, Liu *et al* [28] reported a meta-analysis of 14 studies including 1,435 patients. The study showed that proximal margin, distal margin, lymph node harvest and 5-year disease free survival (DFS) had no significant differences between the NOSES and CL surgery groups.

In terms of excision of lesions, NOSES colorectomy can get same effects as CL surgery. Compared with CL surgery, NOSES has better outcomes including faster recovery of intestinal function, shorter postoperative length of stay, less incision pain, lower incidence of postoperative complications and good cosmetic effect [29-31]. Shortly, the safety and feasibility of laparoscopic surgery have been determined. But, further multicenter, large-sample, prospective randomized controlled, and long-term follow-up studies are needed [32].

5. SPLC

Single-Port Laparoscopic Surgery (SPLS) is a procedure in which multiple cannula are inserted through an incision on the abdominal wall, one with the laparoscope and others with the operating instruments. In most cases of SPLS, a 2–7cm incision is made around the umbilicus, and the wrinkles of the umbilicus are used to cover up the scar of the surgical incision, avoiding multiple surgical scars on the abdominal wall and greatly increasing the cosmetic effect. So, SPLS can be understood as a special type of NOTES that uses the umbilicus, a natural hole in the abdominal wall of the human body, to perform operation.

The SPLS does not yet have a unified international name, other common names including single port access (SPA) surgery, Laparo-endoscopic Single-Site Surgery (LESS), single incision laparoscopic surgery (SILS), Minimal Invasive Single-Site Surgery (MISS) etc. For colorectomy, another great advantage of SPLC is that specimen can be extracted through the incision around umbilicus, avoiding another incision or nature orifice for specimen extraction. In 2008, Bucher *et al* [12] performed the first single-port laparoscopic right hemicolectomy using traditional surgical instruments. In the same year, Remzi *et al* [33] reported a single-port laparoscopic right hemicolectomy for a caecal polyp patient by using Uni-X™ single-port access laparoscopic system (Pnavel Systems, USA) with a multi-channel cannula and specially designed curved laparoscopic instrument. Then, in 2009, Bucher *et a*l [34] firstly reported transumbilical single-port laparoscopic sigmoidectomy for sigmoid stenosis and radical left colectomy for sigmoid colon adenocarcinoma. About systemic review, Diana *et al* [35] reported a systemic review including 149 patients with colorectal diseases in 2011. The results in the colorectal onco-

logical pathology showed the feasibility of SPLC, including sufficient negative margins and lymph nodes dissection. In addition, the study showed that in some cases who planning to undergo ileostomy, single-port surgery may be an ideal selection.

In recent years, a variety of commercial single-port operation platforms have been developed rapidly, such as Triport (Olympus, Japan), Gelport (Applied Medical, USA), SILS Port (Covidien, USA), X-cone (Karl Storz, Germany) etc. In addition, the homemade operation platforms composed of the incision protectors, gloves, trocar and so on have been well received by surgeons because of the economy and accessibility. SPLC has been compared to MPLC colectomy in several multicenter, prospective RCTs. In 2012, Takemasa *et al* [36] reported a prospective RCT involving 300 patients (SPLC, n = 150; MPLC, n = 150) who underwent laparoscopic colorectal resection. The results showed that SPLC got similar oncologic clearance to MPLC. What's more, patients who underwent SPLC got better cosmetic result and less postoperative pain. In 2016, Watanabe *et al* [37] reported a multicenter RCT enrolled 200 patients with colon cancer (SPLC, n = 100; MPLC, n = 100), and the research showed there was no significant difference in operation time, blood loss, conversion to open laparotomy, reoperation rate, time to first flatus, and postoperative hospital stay, median duration of analgesia and overall complication rate between SPLC and MPLC groups. But the total skin incision length was significantly shorter in the SPLC arm. In the same year, Weiss *et al* [38] conducted a prospective multicenter registry involving 1,769 patients in 11 European medical centers for SPLC. Among them, there were 92.0 per cent patients underwent SPLC without additional trocar and 4.2 per cent patients converted to open surgery. And the conversion was related to male sex and ASA fitness grade exceeding I. Independent predictors of complications included male sex, high ASA grade and rectal procedures. The overall 30-day mortality rate was 0.5 per cent. In 2020, Lee *et al* [39] reported the SIMPLE trial, a multicenter RCT that to compare the short- and long-term outcomes of SPLS and MPLS. The result showed that the rate of postoperative complications and total incision length in the SPLS group were significantly lower than those in the MPLS group, but there is no significant difference in other outcomes.

There have also been many reports of retrospective research or systemic reviews. In 2016, a retrospective cohort study of Katsuno *et al* [40] involving 200 patients with colorectal cancer revealed that there was no significant difference in operation time, bleeding volumes, starting time of liquid diet, length of hospital stay between the SPLC and MPLC groups. Plus, two groups also had similar 5-year overall survival rates and 5-year disease-free survival rates in stages 0–III. But SPLC also has the advantages of less analgesic requirement and shorter length of incision. Kim *et al* [41] also reported a retrospective research and conclude that so long as surgeons have overcome the learning curve associated with single-port laparoscopic techniques, SPLC could be a safe and effective method, even in emergency situations. In 2017, Masaaki *et al* [42] reported there was no significant difference in intraoperative morbidity, postoperative complications, rates of 3-year disease-free and overall survival between SPLC and MPLC in a retrospective research.

Although different studies had reported different results, the advantages of SPLC in improving cosmetic effect over MPLC have been well established. In addition, SPLC has same short-term and long-term safety as MPLC. There is no denying that there are still some disadvantages of SPLC related to technology, such as off-axis vision, conflict of instruments and lack of anti-traction during operation [37-38, 43]. But the technological difficulties will not stop the development of SPLC, and more innovations are expected to improve these difficulties.

6. TaTME

TaTME mixed the concept of NOTES, Transanal Endoscopic Microsurgery (TEM) and total mesorectal excision (TME), so, some surgeons call this type of procedure single-port surgery. Depending on whether there is laparoscopic assistance, TaTME can be divided into laparoscopy assisted TaTME (hybrid TaTME) and pure TaTME. Conceptually, hybrid TaTME belongs to hybrid-NOTES (NOSES), and pure TaTME belongs to pure NOTES.

Because TaTME, a down-to-up approach, makes anal preserving surgery less difficult, improves oncological and functional outcomes of patients with mid and low rectal cancer, and gives consideration to the minimally invasive effect same as NOTES, TaTME was noticed by many surgeons [44]. In 2010, Fajardo *et al* [45] conducted the first pure TaTME in a human cadaver by using TEM system. In rapid sequence, Sally *et al* [46] reported the first TaTME with the assistance of TEM and laparoscopy, which successfully operated for a 76-year-old patient with rectal cancer with satisfactory short-term results, including enough negative lymph nodes and negative margins. Zhang *et al* [47] reported the first case of pure TaTME for a patient with rectal cancer and got well effect including well oncologic outcomes, and the procedure was accomplished on October 6, 2011. In 2015, Kang *et al* [48] reported a study involving 20 patients who underwent TaTME (pure TaTME, n = 11), and the study demonstrated that TaTME in rectal cancer was safe and feasible. However, of the 15 patients who planned to have pure TaTME, four converted to open hybrid TaTME. Hence, it reminds us to choose surgical method flexibly during operation.

Although TaTME has many advantages, its disadvantages are also obvious. First of all, TaTME tends to cause injury to surrounding tissues and organs due to narrow operating space. Secondly, although pure TaTME ensures no scar on the abdomen, it cannot probe into the abdominal cavity thoroughly, which is a great risk of missed abdominal lesions and concomitant injuries. TaTME has also been reported to cause carbon dioxide embolism during operation [48-52]. In 2016, Dejin *et al* [52] reported a systemic review including 794

patients. The results showed that the conversion rate was 4.3 versus 2.7%, and major complication rates were 12.2 versus 10.5% (low volume *versus* high volume centres). TME quality was "complete" in 80.5 versus 89.7%, and Circumferential Resection Margin (CRM) involvement was 4.8 and 4.5% in low- *versus* high-volume centres. In addition, of the 302 patients followed up for 12 months or longer (overall time of follow-up was 18.9 month), long-term local recurrence rate was relatively high (8.9 % in low-volume center *versus* 2.8% in high-volume center). In 2018, Norway even called for a moratorium on TaTME because of the concern off unexpected recurrences pattern that occurred early after TaTME [53]. What is indisputable is that a new type of surgery must undergo the test of time. The long-term outcomes of TaTME depends on more multi centre, randomized trial with large simple. Hopefully, in 2015, a multicenter randomized clinical trial named COLOR III intended to compare TaTME versus laparoscopic TME for mid and low rectal cancer was started [54]. In 2017, similar trial named ETAP-GRECCAR II was also started [55].

7. Conclusion

The above-mentioned surgical innovations are developed under the guidance of the minimally invasive concept, and there is no strict sequence or attachment. One type of surgery does not replace another completely, and each has its suitable patients. In the actual clinical work, we need to fully evaluate the indicators of patients and select specific surgical methods. And, no matter which surgical procedure is chosen, the principle of radical resection should be followed.

The benefits of minimally invasive surgery are not only the reduction of surgical incisions, but more importantly, the faster postoperative recovery, less postoperative complications and less psychological burden. As the saying goes, surgery is not only a technique, but also an art. Under the guidance of the concept of minimally invasive surgery and the concept of enhanced recovery after surgery, surgeons will pay more attention to the quality of life, mental health and temperament of patients. It is the common pursuit of every doctor to make patients, especially malignant tumor patients, face their postoperative life with a more positive attitude.

8. Acknowledgement

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