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Editorial Board Member of *World Journal of Gastrointestinal Surgery*, Manuela Cesaretti, MD, PhD, Assistant Professor, Surgeon, Department of HPB Surgery and Liver Transplantation, Department of Nanophysics, Italian Institute of Technology, Hôpital Beaujon, Clichy 92110, France. manuela.csr@hotmail.it

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WJGS mainly publishes articles reporting research results and findings obtained in the field of gastrointestinal surgery and covering a wide range of topics including biliary tract surgical procedures, biliopancreatic diversion, colectomy, esophagectomy, esophagostomy, pancreas transplantation, and pancreatectomy, etc.

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Role of minimally invasive techniques in gastrointestinal surgery: Current status and future perspectives

Shan-Ping Ye, Wei-Quan Zhu, Zhi-Xiang Huang, Dong-Ning Liu, Xiang-Qiong Wen, Tai-Yuan Li

ORCID number: Shan-Ping Ye 0000-0002-3588-7559; Wei-Quan Zhu 0000-0002-5579-9468; Zhi-Xiang Huang 0000-0002-9564-9923; Dong-Ning Liu 0000-0002-9496-9458; Xiang-Qiong Wen 0000-0002-3084-279X; Tai-Yuan Li 0000-0003-2623-4211.

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Shan-Ping Ye, Dong-Ning Liu, Tai-Yuan Li, Department of General Surgery, The First Affiliated Hospital of Nanchang University, Nanchang 330006, Jiangxi Province, China

Shan-Ping Ye, Tai-Yuan Li, Institute of Digestive Surgery, The First Affiliated Hospital of Nanchang University, Nanchang 330006, Jiangxi Province, China

Wei-Quan Zhu, Zhi-Xiang Huang, Xiang-Qiong Wen, Jiangxi Medical College of Nanchang University, Nanchang 330006, Jiangxi Province, China

Corresponding author: Tai-Yuan Li, MD, PhD, Chief Doctor, Department of General Surgery, The First Affiliated Hospital of Nanchang University, No. 17 Yongwaizheng Street, Nanchang 330006, Jiangxi Province, China. litaiyuanyfy@sina.com

Abstract

In recent years, the incidence of gastrointestinal cancer has remained high. Currently, surgical resection is still the most effective method for treating gastrointestinal cancer. Traditionally, radical surgery depends on open surgery. However, traditional open surgery inflicts great trauma and is associated with a slow recovery. Minimally invasive surgery, which aims to reduce postoperative complications and accelerate postoperative recovery, has been rapidly developed in the last two decades; it is increasingly used in the field of gastrointestinal surgery and widely used in early-stage gastrointestinal cancer. Nevertheless, many operations for gastrointestinal cancer treatment are still performed by open surgery. One reason for this may be the challenges of minimally invasive technology, especially when operating in narrow spaces, such as within the pelvis or near the upper edge of the pancreas. Moreover, some of the current literature has questioned oncologic outcomes after minimally invasive surgery for gastrointestinal cancer. Overall, the current evidence suggests that minimally invasive techniques are safe and feasible in gastrointestinal cancer surgery, but most of the studies published in this field are retrospective studies and case-matched studies. Large-scale randomized prospective studies are needed to further support the application of minimally invasive surgery. In this review, we summarize several common minimally invasive methods used to treat gastrointestinal cancer and discuss the advances in the minimally invasive treatment of gastrointestinal cancer in detail.

Key Words: Gastrointestinal neoplasms; Laparoscopy; Minimally invasive surgical procedures; Robotic surgical procedures; Therapeutics

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Core Tip: The incidence of gastrointestinal tumors is high. Minimally invasive surgery has changed the traditional treatment of these patients. Minimally invasive surgery is a revolutionary treatment for gastrointestinal tumors that can reduce surgical complications and accelerate postoperative recovery. Here, we discuss the role and prospect of minimally invasive surgery in the treatment of gastrointestinal tumors.

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INTRODUCTION

With the development of science and technology, minimally invasive surgery is a new option for the radical treatment of tumors. Minimally invasive surgery is gaining increasing popularity for the treatment of gastrointestinal cancer, including endoscopic resection, laparoscopic resection, and da Vinci surgical system resection. Minimally invasive techniques have resulted in less blood loss and fewer complications than conventional surgery.

Minimally invasive surgery is not just about minimizing trauma but also about achieving a complete radical tumor removal. To achieve this goal, high-definition, high-magnification devices have been developed for use in gastrointestinal cancer surgery, allowing surgeons to perform more accurate resection and avoid unnecessary damage compared with traditional surgery because the tumor and surrounding structures can be better visualized.

For any minimally invasive technique, there is always a learning curve to overcome and sufficient evidence to substantiate its effectiveness; equally important is whether the benefits of these techniques are worth the added cost and time.

ENDOSCOPY TECHNOLOGY IN GASTROINTESTINAL CANCER

Endoscopic resection of early gastric cancer

Endoscopic resection may be presently thought of as an option for the majority of early gastric malignancy cases and could be recognized as a definitive treatment unless it is thought that there is a significant risk of lymph node metastasis[1-3]. The most risky component of lymph node metastasis is lymphatic vessels in the vicinity of the tumor. Other risk factors include submucosal intrusion (T1b), poor differentiation, ulceration, and a large tumor[1]. Several studies have reported no significant difference in long-term overall survival or tumor-specific survival between patients with early gastric cancer treated endoscopically and those who underwent conventional surgical resection[4,5].

There are currently two primary endoscopic resection techniques: Endoscopic mucosal resection (EMR) and endoscopic submucosal dissection (ESD). EMR is robust and technically reproducible with a short learning curve, whereas ESD is technically more demanding and therefore has a much longer learning curve. However, ESD normally brings about *en bloc* specimens, higher extent of complete resections, and fewer nearby recurrences[6,7]. Asian and European guidelines recommend ESD as the endoscopic resection method of choice for early gastric cancer[1,8,9].

Endoscopic resection in early colorectal cancer

The detection rate of early colorectal cancer has increased due to the improvements in quality of life and the emphasis on medical check-ups. Early (T1) colorectal cancers with a low risk of lymphatic metastasis can be treated by endoscopic techniques[10-12]. Unfortunately, most patients with early-stage colorectal cancer do not receive adequate endoscopic treatment evaluation and still undergo surgical treatment[13,14].

Endoscopic resection of stage T1 colorectal cancer depends on the tumor size and the depth of invasion. When submucosal invasion is highly suspected, ESD and endoscopic full-thickness resection are better choices than EMR[15-17]. A number of studies have shown that endoscopic treatment of patients with stage T1 colorectal cancer is safe and feasible, and there is no significant difference between the results of endoscopic treatment and surgical treatment[18-21]. Although endoscopic treatment requires adequate physician proficiency and proper assessment of the tumor stage, the advantages of endoscopic treatment in terms of a lower cost and faster postoperative recovery are enormous. Therefore, doctors should properly recognize the advantages of endoscopic treatment and should consider whether endoscopic treatment can benefit their patients with early colorectal cancer.

LAPAROSCOPIC TECHNIQUES IN GASTROINTESTINAL SURGERY

Laparoscopy is a landmark advance in the history of minimally invasive surgery, and its use is intended to help minimize surgical trauma, reduce pain, and accelerate recovery of bowel function and general mobility after surgery. All of these factors have the potential to shorten the length of hospital stay and reduce patient suffering.

Laparoscopic gastric cancer surgery

Since Kitano *et al*[22] first reported laparoscopic-assisted gastrectomy for early gastric cancer in 1994, laparoscopic gastric cancer surgery has developed rapidly, especially in East Asian countries with a high incidence of gastric cancer, such as China, Japan, and Korea. Despite the rapid development of laparoscopic gastric cancer surgery, the clinical issues surrounding laparoscopic gastric cancer surgery still require more solid medical evidence, mainly due to insufficient evidence of its long-term oncologic efficacy and the optimal extent of lymph node dissection[23].

The KLASS-02-Randomized Clinical Trial of Korean[24] followed and observed 1050 patients in terms of the 3-year relapse-free survival rate. A total of 492 patients underwent laparoscopic surgery and 482 patients underwent open surgery. The 3-year relapse-free survival rate of the laparoscopy group was 80.3%, and this rate of the open group was 81.3%. It was concluded that for patients with locally advanced gastric cancer, the recurrence-free survival rate of laparoscopic distal gastrectomy combined with D2 lymphadenectomy is similar to that of open surgery.

The Chinese Laparoscopic Gastrointestinal Surgery Study (CLASS) Group established the largest multicenter cohort of laparoscopic gastric cancer, the CLASS-01 Randomized Clinical Trial Effect of Laparoscopic *vs* Open Distal Gastrectomy on 3-Year Disease-Free Survival in Patients With Locally Advanced Gastric Cancer[25]. This study showed that the 3-year disease-free survival rate of laparoscopic distal gastrectomy was not less than that of open distal gastrectomy.

These studies are inadequate and have limitations, such as geographical differences between the East and the West, but they provide a scientific basis and clinical experience for the promotion of laparoscopic gastric cancer surgery[24-32] (Table 1).

Laparoscopic colorectal cancer surgery

Surgery is the main treatment for colorectal cancer, and minimally invasive surgery is the mainstream developmental direction of surgery in recent years. Laparoscopic colorectal cancer surgery has become the standard technique for the treatment of colon cancer in many countries around the world and has been shown to be safe and feasible in randomized trials and population-based studies due to its short-term efficacy[33-44]. However, more evidence is needed to determine its long-term efficacy, especially for advanced colorectal tumors[45] (Table 2).

The operation for rectal cancer is very complicated and is related to the accessibility of the pelvis and its complex anatomical structure. The surgical treatment of rectal cancer has a greater technical challenge than colon cancer, mainly due to the anatomical limitations of the pelvis and the protection by the pelvic plexus[46]. However, laparoscopic surgery has significant advantages compared to open surgery. Although most studies show no difference in short- and long-term outcomes between laparoscopic and open surgery for rectal cancer, it is still a debated issue. Some studies suggest that the long-term efficacy of laparoscopic rectal cancer resection is yet to be determined and is not superior to that of open surgery[47]. In general, an increasing number of studies have confirmed the efficacy and advantages of laparoscopy in colorectal cancer surgery, and it has been widely used.

Table 1 Studies on laparoscopic surgery in gastric cancer

Ref.	Study type	Comparison	Group	Endpoints	Results
Kim <i>et al</i> [31], KCLASS-01-RCT, 2019	Randomized clinical trial	Laparoscopic distal gastrectomy <i>vs</i> open distal gastrectomy on long-term survival among patients with stage I gastric cancer	LADG (<i>n</i> = 706); ODG (<i>n</i> = 711)	5-yr overall survival rate and 5-yr cancer-specific survival rate	No significant difference between the two groups in the 5-yr overall survival rate (94.2% <i>vs</i> 93.3%) or 5-yr cancer-specific survival rate (97.1% <i>vs</i> 97.2%)
Lee <i>et al</i> [30], KCLASS-02-RCT, 2019	Multicenter randomized controlled trial	Laparoscopic distal gastrectomy (LDG) <i>vs</i> open distal gastrectomy (ODG) for D2 lymphadenectomy	LADG (<i>n</i> = 526); ODG (<i>n</i> = 524)	Thirty-day morbidity, 90-d mortality, postoperative pain, and recovery	Laparoscopic distal gastrectomy was associated with a lower complication rate, faster recovery, and less pain (<i>P</i> < 0.05), and there was no significant difference in mean number of totally retrieved lymph nodes (46.6 <i>vs</i> 47.4, <i>P</i> = 0.451)
Hyung <i>et al</i> [24], KCLASS-02-RCT, 2020	Randomized clinical trial	Laparoscopic distal gastrectomy surgery <i>vs</i> open distal gastrectomy surgery for locally advanced gastric cancer	LADG (<i>n</i> = 492); ODG (<i>n</i> = 482)	3-yr relapse-free survival rate	No significant difference between the two groups in the 3-yr relapse-free survival rate (80.3% <i>vs</i> 81.3%)
Yu <i>et al</i> [25], The CLASS-01 RCT, 2019	Randomized clinical trial	Laparoscopic distal gastrectomy surgery <i>vs</i> open distal gastrectomy for early-stage gastric cancer	LADG (<i>n</i> = 519); ODG (<i>n</i> = 520)	3-year disease-free survival rate	No significant difference between the two groups in 3-year disease-free survival rate (83.1% <i>vs</i> 85.2%)
Liu <i>et al</i> [27], The CLASS-02, 2020	Multicenter randomized clinical trial	Laparoscopic total gastrectomy (LTG) <i>vs</i> open total gastrectomy (OTG) for patients with clinical stage I gastric cancer	LTG (<i>n</i> = 105); OTG (<i>n</i> = 109)	Morbidity and mortality within 30 d following surgeries; recovery courses; postoperative hospital stays	No significant difference in morbidity and mortality within 30 d following surgeries
Katai <i>et al</i> [26], JCOG0912, 2020	A multicenter, non-inferiority, phase 3 randomized controlled trial	Laparoscopy-assisted distal gastrectomy (LADG) <i>vs</i> open distal gastrectomy (ODG) for patients with clinical stage I gastric cancer	LADG (<i>n</i> = 462); ODG (<i>n</i> = 459)	Relapse-free survival	LADG was non-inferior to ODG for relapse-free survival (94% <i>vs</i> 95.1%, <i>P</i> < 0.05), and LADG should be considered a standard treatment option
Kinoshita <i>et al</i> [28], LOC-A Study, 2019	Multicenter cohort study	Laparoscopic gastrectomy (LC) <i>vs</i> open gastrectomy (OP) for locally advanced gastric cancer	LC (<i>n</i> = 305); Op (<i>n</i> = 305)	5-yr overall survival; recurrence rate; hazard ratio for recurrence (HR)	No significant difference between the two groups in the 5-yr overall survival (53.0% <i>vs</i> 54.2%) and recurrence rate (30.8% <i>vs</i> 29.8%)
Park <i>et al</i> [29], COACT 1001, 2018	Randomized phase II multicenter clinical trial	Laparoscopy-assisted distal gastrectomy (LADG) with D2 lymph node dissection <i>vs</i> open distal gastrectomy (ODG) for the treatment of advanced gastric cancer	LADG (<i>n</i> = 105); ODG (<i>n</i> = 99)	Noncompliance rate of the lymph node dissection; 3-yr disease-free survival (DFS), 5-yr overall survival, complications, and surgical stress response	No significant difference between the two groups in the noncompliance rate of lymph node dissection (47.0% <i>vs</i> 43.2%) and 3-yr DFS (80.1% <i>vs</i> 81.9%)

LADG: Laparoscopy-assisted distal gastrectomy; ODG: Open distal gastrectomy; LC: Laparoscopic gastrectomy; OP: Open gastrectomy; DFS: Disease-free survival; HR: Hazard ratio; LTG: Laparoscopic total gastrectomy; OTG: Open total gastrectomy; LDG: Laparoscopic distal gastrectomy.

Three-dimensional laparoscopic imaging systems

Minimally invasive laparoscopic techniques are now rapidly gaining popularity, but conventional laparoscopy provides only a two-dimensional (2D) view. Three-dimensional (3D) laparoscopy overcomes this disadvantage and offers the advantage of a greater field of view[48]. Some studies have shown that 3D laparoscopic surgery provides better depth perception, significantly reduces the operative time and intraoperative blood loss, and shortens the surgeon's learning curve[48-51]. However, there is a lack of prospective evidence on the safety and efficacy of 3D technology in the long term. Despite the controversy, the benefits of 3D laparoscopy are undeniable and it has a promising future.

APPLICATION STATUS OF ROBOTIC SURGICAL SYSTEMS IN GASTRO-INTESTINAL SURGERY

To overcome the shortcomings of laparoscopic techniques, especially when working in confined spaces such as the pelvis, da Vinci robotic surgery system robots, which are precise, stable, and flexible and can be operated remotely and gradually, are becoming a new option for minimally invasive surgery. The da Vinci robotic surgery system developed by the US Intuitive Surgical Company received US FDA marketing

Table 2 Studies on laparoscopic surgery in colorectal cancer

Ref.	Study type	Comparison	Group	Endpoints	Results
Bonjer <i>et al</i> [44], 2015	Randomized clinical trial	Laparoscopic <i>vs</i> open surgery for rectal cancer	LC (<i>n</i> = 699); OP (<i>n</i> = 345)	Locoregional recurrence 3 yr after index surgery, and disease-free and overall survival	No significant difference between the two groups in locoregional recurrence 3 yr after index surgery, or disease-free and overall survival (86.7% <i>vs</i> 83.6%)
Fleshman <i>et al</i> [43], ACOSOG Z6051 Randomized Controlled Trial, 2019	Randomized clinical trial	Laparoscopic-assisted resection <i>vs</i> open resection of stage II or III rectal cancer	LC (<i>n</i> = 243); OP (<i>n</i> = 243)	Disease-free survival and local recurrence	No significant difference between the two groups in disease-free survival and local recurrence
Park <i>et al</i> [39], 2020	Multicenter comparative study	Laparoscopic <i>vs</i> open surgery for small T4 colon cancer	LC (<i>n</i> = 149); OP (<i>n</i> = 300)	Blood loss, length of hospital stay, postoperative morbidity, and overall survival or disease-free survival	No significant difference between the two groups in overall survival or disease-free survival, and LC was associated with favorable short-term oncologic outcomes in patients with tumors \leq 4.0 cm
Li <i>et al</i> [40], 2021	Multicenter comparative study	Laparoscopic <i>vs</i> open surgery for transverse colon cancer	LC (<i>n</i> = 181); OP (<i>n</i> = 235)	Operation time, postoperative hospitalization, lymph node retrieval, 5-yr overall survival	LC was associated with statistically longer operation time (209.96 <i>vs</i> 173.31 min, <i>P</i> = 0.002) and shorter postoperative hospitalization (12.05 <i>vs</i> 14.44 d, <i>P</i> = 0.001), but there was no significant difference in lymph node retrieval and 5-yr overall survival
Garbarino <i>et al</i> [42], 2021	Propensity score-matched analysis	Laparoscopic <i>vs</i> open surgery for rectal resection	LC (<i>n</i> = 181); OP (<i>n</i> = 235)	Operative time, postoperative morbidity, hospital stay, safe oncological adequateness	LC was associated with shorter hospital stay (<i>P</i> < 0.001), but there was no significant difference in safe oncological adequateness

LC: Laparoscopic gastrectomy; OP: Open gastrectomy.

approval in July 2000 and began to be used in clinical applications. In 2002, Weber *et al* [52] reported the first robotic system-assisted surgery for benign colonic disease, and in the same year, Hashizume *et al*[53] also reported robotic colorectal surgery for malignant disease. With the development of the technology, it has been widely used in gastrointestinal surgery, hepatobiliary surgery, urology, gynecology, *etc.*[54]. However, the high cost and a lack of evidence of efficacy are limitations.

Robotic surgery in gastric cancer

Despite the lack of more robust multicenter evidence, robotic surgery has been increasingly used as a minimally invasive means for treating gastric cancer because of the potential surgical advantages that it may have over conventional laparoscopy. However, Kim *et al*[55] showed that there was no significant difference between the two in terms of surgical blood loss, number of intermediate openings, time to oral feeding, or the length of hospital stay. At the same time, Uyama *et al*[56] showed that robotic gastric cancer surgery is safe and effective for stage I/II gastric cancer and can reduce the incidence of early postoperative complications compared to laparoscopic surgery. The short-term efficacy of robotic gastric cancer surgery is therefore good, but more evidence is still needed to prove it.

Robotics surgery in colorectal cancer

Current evidence suggests that the short-term efficacy of robotic-assisted colorectal cancer surgery is good and it may have potential minimally invasive advantages[57-61]. Robotic surgery for rectal cancer has been promoted as an improved minimally invasive procedure due to the flexibility of the da Vinci robot for operating in confined spaces such as the pelvis. Some prospectively randomized studies have shown that the clinical outcomes of robotic surgical resection of rectal cancer are similar to those of laparoscopic and open surgery[62-69]. There is also literature confirming that robotic rectal cancer surgery is closely associated with better short-term outcomes than laparoscopic surgery, and it has advantages in protecting the pelvic nerves, resulting in fewer short-term postoperative complications and shorter hospital stays[70,71].

Crippa *et al*[71] analyzed 600 patients. The number of patients undergoing robotic surgery was 317 (52.8%), and the laparoscopic group consisted of 283 (47.2%) patients. Both groups were similar in terms of age, sex, and body mass index (BMI). The overall incidence of short-term complications in patients undergoing robotic surgery was lower than that in the laparoscopic group (37.2% *vs* 51.2%; *P* < 0.001). However, larger

prospectively randomized trials are needed to support its use. There is no denying that robotic flexibility may be more promising than laparoscopy in rectal cancer surgery.

NATURAL ORIFICE SPECIMEN EXTRACTION SURGERY

The aim of minimal invasiveness is to reduce trauma. To avoid the need for an auxiliary abdominal incision, natural orifice specimen extraction surgery (NOSES) is a newly developed method that extracts specimens through natural orifices *via* the trans-anal or transvaginal route to reduce trauma and to avoid auxiliary abdominal incisions[72]. Trans-anal removal of specimens is mainly used for left-sided colectomies and rectal procedures, and transvaginal removal is used for all colonic procedures, especially right-sided colectomies and large specimens[73,74]. It is seldom used for operations on the stomach, but the study by Jeong *et al*[73] concluded that in carefully selected elderly women with early gastric cancer, transvaginal specimen collection may be a safe and feasible procedure.

The NOSES technique is currently used mainly in colorectal cancer surgery, especially rectal surgery. Many studies have shown that the NOSES technique is safe and feasible for colorectal cancer; although it may increase the probability of contamination of the surgical area, this does not appear to translate into a higher incidence of infection[75-81]. Colorectal resection with NOSES is more advantageous in terms of postoperative recovery, postoperative pain, esthetics, and complications (Figure 1). However, not every patient is suitable for NOSES. Patients with stage T4 tumors and large tumors should not undergo NOSES. Trans-anal specimens are suitable for both men and women, but the tumor size should be less than 3 cm, whereas transvaginal specimens are suitable for women and the tumor size should be no larger than 5 cm. In addition, the BMI of the patient should be less than 30 kg/m² for anal specimens and less than 35 kg/m² for transvaginal specimens[82,83]. Hence, the NOSES procedure indications should be strictly observed.

CONCLUSION

Advances in minimally invasive techniques have opened a new era in gastrointestinal treatment. For gastrointestinal tumors, the most important treatment is surgical resection. However, it is often overlooked that early-stage gastrointestinal cancer can be treated endoscopically with a good result. To obtain the best prognosis and minimal trauma, it is very important to choose an appropriate surgical method.

For advanced tumors, total resection including regional lymph nodes should be performed. The emergence of laparoscopic surgery has brought innovation to minimally invasive surgery. As laparoscopic techniques continue to mature and surgeons become more skilled, surgeons can do even more with a laparoscopic view. There are many reported studies showing that the efficacy of total laparoscopic surgery is positive; completely laparoscopic surgery reduces the size of the secondary incision and reduces trauma[84-90].

A 3D laparoscopic imaging system is a further improvement on conventional laparoscopic techniques, and with improved laparoscopic views, it may help to shorten the learning curve of surgeons. Laparoscopic surgery has been recognized in the early treatment of gastrointestinal cancer, and its use in the treatment of most advanced tumors has also been affirmed. We look forward to international multicenter research evidence.

To improve the inadequacy of laparoscopic techniques, especially when operating in a narrow space, such as the pelvis and at the superior margin of the pancreas, surgeons started using robotic surgery systems. Among them, the da Vinci robot surgery system is used most often, and its technology is relatively mature, which offers the advantages of anti-shaking, three-dimensional vision, and operational flexibility, taking minimally invasive surgery to new levels of precision[91,92]. At present, the research on da Vinci robots is mainly retrospective. From the results, some short-term curative effects are better than those of laparoscopy, and the long-term curative effect is equivalent. However, these results need further confirmation in randomized clinical trial results. Additionally, one of the greatest drawbacks of the da Vinci robotic surgical system is its cost. The da Vinci surgical system is the only surgical robot available on the market today, and it has a high upfront cost. At the same time, surgeons need to go through a long learning curve to use the robotic system, meaning that the da Vinci system costs considerable time and money upfront,



Figure 1 Rectal cancer resection by natural orifice specimen extraction surgery without incision.

which is a major reason for its need for further development. Hence, before large-scale randomized clinical trial research is confirmed, we recommend that gastrointestinal surgery with rich experience in laparoscopy be carried out.

The future of surgical robots will move toward miniaturization and intelligence, and with the maturity of 5G technology, artificial intelligence technology and 5G technology have the potential to be combined with robotic surgical systems to help surgeons operate remotely, improve medical conditions, reduce healthcare costs, and benefit more patients.

In summary, minimally invasive surgery is the goal of surgeons. Combined with our experience, robotic surgery systems may be used increasingly widely. As interest and research in minimally invasive surgery continue to grow, the role of minimally invasive techniques in gastrointestinal surgery will become increasingly important.

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