Cite as: Wang Y, Nan HO, Ge MM, Wang HF, Pan HF, Sun CH, Wang G, Jiang ZW. Prevention and management of complications in robotic radical gastrectomy [J]. Chin J Clin Res, 2026, 39(2):173-177.
DOI: 10.13429/j.cnki.cjcr.2026.02.002

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Prevention and management of complications in robotic radical gastrectomy

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Abstract: With the extensive development of minimally invasive technology in gastric cancer surgery, Da Vinci robot-assisted radical gastrectomy has also attracted increasing attention. The application of robotic technology in gastric cancer surgery can not only complete the endoscopic reconstruction of digestive tract, but also has the advantages of less intraoperative bleeding and more thorough lymph node dissection. However, the new technology cannot avoid complications and technical difficulties. The incidence of complications related to robotic gastric cancer surgery is one of the effective indicators to evaluate its safety and feasibility. Common complications of robotic radical gastrectomy mainly include abdominal hemorrhage, abdominal infection, anastomotic complications, postoperative ileus, duodenal stump fistula, pancreatic fistula and pancreatitis, pneumoperitoneal-related complications, and complications related to trocar puncture and auxiliary incision. Strict adherence to the indications for robotic radical gastrectomy and careful operation by surgeons with extensive experience in robotic operation do not increase the incidence of complications and conversion to laparotomy. The purpose of this paper is to summarize and analyze the common complications found in the clinical practice of Da Vinci robot-assisted radical gastrectomy, and summarize the current effective measures for the prevention and treatment of such complications, so as to provide references for clinical work.

Keywords: Da Vinci robot; Radical gastrectomy; Surgical complications; Pneumoperitoneum; Abdominal bleeding; Pancreatic fistula; Lymphatic leakage; Iatrogenic injury

Fund program: Revitalization and Development Project of Jiangsu Provincial Association of Chinese Medicine (ZXFZ2024001); Leading Talents in Chinese Medicine of Jiangsu Provincial Administration of Chinese Medicine (SLJ0311); Hospital-level Research Project of Jiangsu Province Hospital of Chinese Medicine (Y21024)

Since Hashizume *et al.* [1] first applied robotic surgical systems to gastric cancer treatment in 2002, the Da Vinci robot-assisted system has demonstrated unique value in radical gastrectomy due to its technical advantages including three-dimensional visualization, flexible articulating arms, and tremor filtration. Compared with conventional laparoscopy, robotic radical gastrectomy can significantly improve lymph node dissection rates, particularly for lymph nodes in complex anatomical locations such as the distal splenic artery lymph nodes (No.11d) and celiac trunk lymph nodes (No.9). It relatively reduces intraoperative blood loss, decreases the incidence of complications such as pancreatic fistula, and lowers the risk of anastomotic leakage through precise suturing during digestive tract reconstruction [2-4]. Compared with conventional laparoscopic gastrectomy, robotic radical gastrectomy combined with enhanced recovery after surgery (ERAS) management demonstrates greater advantages in shortening the time to postoperative ambulation, duration of postoperative pain, time to catheter removal, time to first flatus, and time to liquid diet intake [5-6]. However, as an emerging technology dependent on mechanical arm operation, its complication spectrum shares commonalities with conventional laparoscopic surgery while also presenting unique characteristics due to differences in operative modalities. This article, based on the latest domestic and international research, systematically elucidates the pathogenesis, prevention strategies, and management approaches of common complications from the perspective of robotic surgical technical characteristics, providing reference for clinical practice.

1 Current Status of Complications in Robotic Radical Gastrectomy

1.1 Classification and Specificity of Complications in Robotic Radical Gastrectomy

Complications of robotic radical gastrectomy can be broadly categorized into common complications and specific complications. Common complications refer to those with mechanisms similar to conventional laparoscopic surgery cases since the advent of minimally invasive techniques, such as intraperitoneal hemorrhage, anastomotic leakage, and duodenal stump leakage, though actual incidence rates may differ due to variations in surgical precision. Specific complications include tissue crush injuries caused by robotic arm manipulation, collateral damage resulting from blind spots in the camera field of view, and technical complications associated with the coordinated operation of the pneumoperitoneum system and robotic arms, such as trocar displacement and robotic arm collision.

The impact of robotic radical gastrectomy on postoperative complication rates remains controversial. Some meta-analyses have demonstrated that robotic and laparoscopic radical gastrectomy have comparable complication rates (12.75% *vs* 13.62%) [2]. Another multicenter prospective comparative study showed that among 152 patients undergoing robotic radical gastrectomy and 1,020 patients undergoing laparoscopic radical gastrectomy, the incidence of ≥Clavien-Dindo grade III postoperative complications was 1.3% (2/152) in the robotic group *vs* 7.1% (72/1,020) in the laparoscopic group, suggesting that robotic surgery offers certain advantages in reducing severe complication rates [7]. The study by Feng *et al.* [8] similarly validated the reliability of this conclusion.

1.2 Core Differences Between Robotic Radical Gastrectomy and Conventional Laparoscopic Surgery

The technical advantages of robotic surgery generally affect occurrence of complication through three mechanisms. (1) Three-dimensional visualization: provide a clear surgical field with 10-15× magnification, enhancing the identification of fine anatomical structures such as the left gastric artery and splenic artery, thereby reducing vascular injury; (2) Multi-degree-of-freedom robotic arms: enable complex maneuvers such as rotation, grasping, and suturing in confined spaces (e.g. the superior pancreatic margin and pericardial region), reducing tissue traction tension; (3) Precise energy control: coordinate use of bipolar electrocoagulation and ultrasonic scalpel reduces thermal conduction injury to the pancreas and duodenum, lowering the risk of pancreatic fistula and intestinal fistula [2]. Based on multiple research findings, current conclusions regarding complication rates between robotic and laparoscopic radical gastrectomy remain inconsistent, which may be related to various factors including sample size, disease staging, and surgeon proficiency across studies.

2 Management Strategies for Common Complications in Robotic Radical Gastrectomy

This article primarily summarizes the most common and specific surgical complications in robotic radical gastrectomy, including intraperitoneal hemorrhage, anastomotic complications, duodenal stump leakage, pancreatic-related complications, and pneumoperitoneum and robotic arm-related complications, aiming to provide references for the prevention and management of surgical complications.

2.1 Intraperitoneal Hemorrhage

2.1.1 Intraoperative Intraperitoneal Hemorrhage

In actual clinical practice and research, intraoperative intraperitoneal hemorrhage is typically defined as the occurrence of obvious, visible, and persistent blood seepage or gushing within the abdominal cavity during surgery, reaching a level requiring additional hemostatic measures (such as using titanium clips or vascular clips for clamping, or employing high-power electrosurgical knives or ultrasonic scalpels for hemostasis). The median intraoperative blood loss in robotic radical gastrectomy is approximately 98.77 mL [9], with causes primarily attributed to unclear anatomical layers leading to injury of the right gastroepiploic artery, right gastric artery, gastroduodenal artery, left gastric vein, splenic artery, left gastroepiploic artery and vein, short gastric veins, and perigastric parenchymal organs [2]. Particularly, excessive traction on the vascular sheath causing injury to the left gastric artery trunk, improper robotic arm manipulation angle during No.11d lymph node dissection leading to splenic artery laceration, incomplete closure by cutting staplers or tissue clip detachment resulting in gastroduodenal artery stump hemorrhage are high-risk factors for intraperitoneal hemorrhage [10], most likely to occur during the early phase of the robotic learning curve.

The Da Vinci robot-assisted system has specific preventive measures for intraoperative hemorrhage. First, the flexibility of the robotic arm "wrist" can be utilized to employ the "vertical-axis dissection technique" for separating perivascular adipose lymphatic tissue, avoiding transverse traction, Second, for vessels with diameter >3 mm, vascular clips should be preferentially used for clamping rather than relying solely on energy device coagulation. Furthermore, maintaining the camera at a distance of 15-20 cm from the operative area to ensure precise localization of bleeding points is also an effective approach [11].

When intraoperative hemorrhage cannot be avoided, the corresponding management protocol can be classified according to specific circumstances. (1) For small vessel bleeding, bipolar electrocoagulation can be used for precise coagulation (power setting at 40-50 W to avoid expansion of thermal injury); (2) For medium-sized vessel bleeding, the robotic arm can be used to hold disposable tissue closure clips (Hem-o-lok) for clamping, or conversion to laparoscopic titanium clip application may yield better results; (3) For massive hemorrhage, pneumoperitoneum pressure should be immediately reduced to 8 mmHg, and after compressing the bleeding point, evaluation for conversion to laparotomy should be performed. The conversion rate to laparotomy in robotic surgery is approximately 1.2%-3.5%, primarily related to vascular injury [12].

2.1.2 Postoperative Intraperitoneal Hemorrhage

Postoperative intraperitoneal hemorrhage refers to the phenomenon of internal bleeding caused by rupture of intraperitoneal vessels or oozing from surgical wounds after surgery [13-14]. The incidence of postoperative intraperitoneal hemorrhage after robotic radical gastrectomy is 1%-4% and can be classified into early hemorrhage and delayed hemorrhage [15]. Generally, hemorrhage occurring within 24 hours postoperatively is termed early hemorrhage, encompassing anastomotic bleeding and remnant stomach bleeding, mostly caused by ineffective control of bleeding points during surgery. Postoperative intraperitoneal hemorrhage typically presents in two forms: intraperitoneal hemorrhage and gastrointestinal hemorrhage.

Early postoperative hemorrhage is mostly caused by incomplete intraoperative hemostasis or insecure vascular clamping, and can also result from inadvertent inclusion of mesentery or epiploic appendages during anastomosis, with postoperative blood pressure elevation triggering hemorrhage. Anastomotic or remnant stomach stump bleeding may present as gastrointestinal hemorrhage (hematemesis, melena) or intraperitoneal hemorrhage (bloody drainage fluid). Therefore, close postoperative monitoring of vital signs and hemoglobin changes is essential, and if abnormal fluctuations are detected, timely evaluation and management should be initiated. Meanwhile, reasonable use of hemostatic and acid-suppressive medications is important; prophylactic application of intravenous hemostatic agents in the early postoperative period can enhance coagulation function; use of acid-suppressive medications, such as proton pump inhibitors, can reduce gastric acid secretion and decrease gastric acid stimulation of the anastomosis and remnant stomach stump, helping to prevent hemorrhage [16]. Additionally, maintaining drainage tube patency is also crucial. If conservative treatment is ineffective or hemodynamic instability occurs, prompt gastroscopic examination with direct visualization for hemostasis should be performed [17].

Delayed hemorrhage is often caused by rupture and bleeding of intraperitoneal vessels, including the splenic artery, common hepatic artery, gastroduodenal artery and their branches, and can also occur in the transverse colonic mesentery and mesenteric vessels of the anastomosed intestinal segment. The primary cause is the formation of pseudoaneurysm rupture due to vascular sheath thermal injury caused by surgical electrosurgical instruments, followed by rupture and hemorrhage. Typical manifestations include sudden increase in peritoneal drainage fluid or poor drainage, accompanied by palpitations, irritability, abdominal pain, and blood pressure decrease; severe cases may present with shock. For pseudoaneurysm hemorrhage, interventional treatment can be performed after stabilization with conservative therapy [18]. If the hemorrhage volume is large with rapid disease progression, hemorrhagic shock may occur within a short period, and decisive secondary surgery should be undertaken [15].

2.2 Anastomotic Complications

Anastomotic complications, in addition to the aforementioned anastomosis-related hemorrhage, also include anastomotic leakage and anastomotic stenosis, with an incidence rate of 0.4%-4.0% [19-20].

During robotic surgery, when performing suturing under the microscope, the robotic arms can accomplish operations that are difficult to achieve with conventional laparoscopy, such as "vertical needle insertion" and "reverse knot tying," which are particularly suitable for esophagojejunostomy (such as the Overlap technique); with the aid of indocyanine green fluorescence angiography for real-time assessment of anastomotic blood flow, the risk of anastomotic leakage due to postoperative ischemia can also be reduced [21]. Most anastomotic leakages are minor leaks that generally respond to conservative treatment. For severe anastomotic leakage complicated by intra-abdominal abscess, ultrasound or CT-guided puncture drainage should be performed, with the option of placing a nasojejunal tube for enteral nutritional support. Ensuring adequate blood supply and tension-free anastomosis is key to preventing anastomotic leakage; if treatment outcomes are unsatisfactory, reoperation may be considered [11].

Patients with anastomotic stenosis often present with systemic nutritional impairment and remnant stomach dilation and edema. The etiology may include excessively short proximal jejunum during gastrojejunostomy, causing upward traction and angulation of the Braun anastomosis, resulting in anastomotic obstruction [21]. In robotic radical gastrectomy, the "precise cutting" achieved by robotic arm manipulation may lead to excessively regular anastomotic margins, with symmetrical granulation tissue hyperplasia during the healing process, forming circumferential stenosis [20]. A stepped approach is advocated: first, gastrointestinal decompression and isotonic saline irrigation, followed by endoscopic placement of a jejunal nutrition tube through the stenotic anastomosis to provide enteral nutritional support, and finally, endoscopic balloon dilatation. For refractory stenosis, stent placement may be considered, generally with a fully covered self-expanding stent for approximately 4-6 weeks [22]; only a very small number of patients with anastomotic stenosis require repeat digestive tract reconstruction surgery.

2.3 Duodenal Stump Leakage

Duodenal stump leakage is one of the serious complications following robotic radical gastrectomy, with literature reporting an incidence of 0.37%-1.8% [23-24]. The most common cause of this complication is obstruction of the afferent or efferent jejunal loop, though it may also result from inadvertent injury to the intestinal wall by the ultrasonic scalpel during dissection of the duodenal bulb, or from excessive tension when applying the cutting stapler to close the duodenal stump. This may erode surrounding tissues and vessels, causing intraperitoneal hemorrhage or intra-abdominal abscess, and in severe cases, may lead to serious consequences such as multiple organ failure [15].

When duodenal stump leakage occurs, most cases can be managed conservatively through peritoneal drainage, parenteral nutrition, and administration of somatostatin. Surgical intervention is considered only when the aforementioned measures are ineffective or when complicated by other conditions (such as intraperitoneal hemorrhage) [25-26]. Additionally, there have been reports of endoscopic clipping for duodenal stump leakage; however, its clinical indications are strict, and its reliability and safety require further clinical validation [27].

2.4 Pancreatic Fistula and Pancreatitis

The direct causes of pancreatic fistula and pancreatitis are intraoperative pancreatic injury, specifically including: compression by surgical clamps, thermal conduction from ultrasonic scalpels, and excessive friction of the pancreatic capsule by robotic arms during dissection of lymphatic tissue adjacent to the distal splenic artery [28]. To better prevent such complications, surgeons adopt the "no-touch principle" when dissecting the superior pancreatic margin, with robotic arms grasping adipose tissue surrounding lymph nodes rather than directly tractioning the pancreas; for vessels in the pancreatic tail region, preferential use of the LigaSure vessel sealing system to reduce the extent of thermal injury are effective measures for preventing pancreatic injury [29].

Although the incidence of pancreatic fistula is low, the consequences are serious, easily leading to secondary intra-abdominal infection, abscess, and even fatal massive hemorrhage, requiring high vigilance. Once it occurs, patency of the abdominal double-lumen tube irrigation should be ensured, and medications to inhibit pancreatic secretion should be administered, with surgical intervention when necessary [30].

2.5 Postoperative Ileus (POI)

POI is a common early complication following abdominal surgery, and its occurrence is related to gastrointestinal hormone disturbances, inflammatory responses, and autonomic nervous system dysfunction caused by surgical stress, which subsequently reduces intestinal peristalsis, with clinical manifestations including abdominal pain, abdominal distension, nausea, and vomiting [31]. Additionally, the use of certain analgesic medications, particularly opioid analgesics, is also considered to be associated with slowed postoperative intestinal peristalsis [32].

In response to the aforementioned causes, effective methods for preventing POI include adequate preoperative gastrointestinal preparation, meticulous and gentle intraoperative manipulation, thorough hemostasis with minimal trauma; encouraging early postoperative mobilization and oral intake; and employing postoperative multimodal analgesia to reduce opioid dosage while ensuring analgesic efficacy, thereby lowering the risk of POI [15].

Most cases of postoperative POI show significant improvement after conservative treatment including continuous gastrointestinal decompression, fasting, enema administration, enhanced parenteral nutrition, and administration of digestive enzymes. The use of certain anti-inflammatory medications has also been confirmed to be beneficial in alleviating POI [33], though their specific mechanisms of action require further investigation. For patients with progressively worsening strangulating abdominal pain and recurrent adhesive intestinal obstruction, active surgical exploration should be undertaken to prevent delay in treatment.

2.6 Lymphatic Leakage

Due to the primary use of ultrasonic scalpels for anatomical dissection in robotic radical gastrectomy, the incidence of postoperative lymphatic leakage is relatively low. However, vigilance during the surgical procedure remains essential, as the primary cause of lymphatic leakage is neglecting the management of lymphatic duct stumps during lymph node dissection for gastric cancer. During robotic radical gastrectomy, surgeons should leverage the advantages of the robotic camera and instrumentation to perform more thorough lymph node dissection [34]. After completing lymph node dissection and achieving hemostasis of the surgical field, careful inspection for milky lymphatic fluid exudation should be performed, with coagulation or suture ligation applied to suspicious areas, and measures such as extending coagulation time during dissection around the celiac trunk and near the midline of the trunk should be implemented to reduce lymphatic leakage occurrence [35]. Postoperative proper drainage is highly beneficial for preventing lymphatic leakage. Once lymphatic leakage occurs, generally speaking, it can be cured in most cases by ensuring the abdominal drainage tube remains patent while maintaining the body's water-electrolyte and nutritional balance.

2.7 Pneumoperitoneum and Robotic Arm-Related Complications

2.7.1 Pneumoperitoneum-Related Complications

Hypercapnia, subcutaneous emphysema, and gas embolism are common pneumoperitoneum-related complications in robotic gastric cancer surgery. For preventive purposes, pneumoperitoneum pressure should be continuously monitored intraoperatively, typically maintained at 10-15 mmHg (1 mmHg=0.133 kPa) to minimize the carbon dioxide pressure gradient between the peritoneal cavity and blood [30]. Additionally, operative time should be minimized as much as possible; in the field of robotic gastric cancer surgery, achieving this requires excellent instrument preparation and high surgeon proficiency.

Studies have demonstrated that gasless laparoscopic radical gastrectomy, utilizing a suspension device, can partially replace conventional pneumoperitoneum and expand the indications for laparoscopic surgery [36]. It may be worth considering whether this technique can be combined with robotic technology to create a new approach of robotic gasless radical gastrectomy, thereby avoiding pneumoperitoneum-related complications.

2.7.2 Robotic Arm-Induced Iatrogenic Injury

Robotic surgery carries the risk of iatrogenic injury due to the operational characteristics of robotic arms, with primary causes including inadequate surgical technique proficiency, equipment malfunction, and limited surgical field visualization. Prevention of robotic arm-induced iatrogenic injury requires a multidimensional approach spanning preoperative and intraoperative phases. Preoperatively, surgeon training should be strengthened, and patient conditions should be rigorously evaluated to develop personalized surgical plans; comprehensive inspection of robotic arm and instrument performance should be performed with preset emergency stop mechanisms to address unexpected malfunctions. Intraoperatively, operative workflow should be optimized, for example, by adopting the "W-shaped" five-port trocar configuration to reduce instrument collision, rational use of the third arm for assisted exposure to enhance surgical field clarity; establishing "safe operative zones" with robotic arm activity maintained at distances greater than 2 cm from intestinal tract and major vessels; utilizing pressure-sensing robotic arms (such as the da Vinci Xi system) for real-time feedback on tissue tension [37].

Once injury occurs, targeted measures should be implemented according to type and severity. For vascular injury, hemostasis can be achieved through electrocoagulation, suturing, or vascular clips; for organ perforation (such as stomach or intestine), timely repair or resection of the damaged area is required. Complex injuries (such as pancreatic fistula or duodenal stump leakage) require multidisciplinary collaboration, combining interventional therapy or secondary surgical repair.

2.8 Trocar Puncture and Auxiliary Incision-Related Complications

Common complications include trocar injury to abdominal wall arteries, uncontrolled puncture leading to retroperitoneal vessel rupture and hemorrhage or intestinal injury [30], which are complications specific to laparoscopic surgery. Accurate preoperative assessment of patient conditions, selection of appropriate puncture sites and proper puncture methods (trocar, Veress needle, or direct incision, etc.) are all reasonable approaches to reduce the occurrence of such complications.

The prevention and management methods for common complications in robotic gastric cancer surgery are generally as described above. Additionally, Li Zhengyan *et al.* [12] found that surgeon experience of ≤30 cases is an independent risk factor for severe complications and local complications. Therefore, during the learning curve phase of robotic surgery, accumulation of surgeon experience and appropriate selection of robotic surgery indications are also important measures for preventing iatrogenic injury.

3 Future Prospects of Robotic Radical Gastrectomy

The application of robotic gastric cancer surgery is increasingly widespread. To standardize surgical procedures and evaluate therapeutic outcomes, there is an urgent need to conduct prospective, multi-center, large-sample randomized controlled studies. The author proposes the following prospects for its development: (1) the new generation Da Vinci robot-assisted system (5th generation) introduces force feedback technology, which can enhance surgical precision and reduce the risk of tissue injury; (2) integrate with artificial intelligence technology to refine the robotic application system, enhance system stability, and reduce failure rates and surgical risks; (3) promote the research and development of domestic surgical robots, leading technological innovation and improving accessibility through technological independence, intelligentization, and grassroots-level dissemination; (4) leverage 5G communication technology to realize robotic telesurgery, reducing latency, improving safety, optimizing healthcare resource distribution, and alleviating patient burden.

In conclusion, although robotic gastric cancer surgery still has limitations such as relatively high maintenance costs and constraints in operative space and time, it has overcome numerous deficiencies of conventional laparoscopic technology, demonstrating clear advantages over traditional laparoscopy, with unique merits in controlling postoperative complication rates, leading the developmental trends of future minimally invasive surgery.

Conflict of Interest None

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Submission Received 2025-06-24/**Revised** 2025-09-19

·学术前沿·

机器人胃癌根治术并发症的预防和处理

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摘要： 随着微创技术在胃癌手术中的广泛应用，达芬奇机器人胃癌根治术也日渐受到关注。将机器人技术应用于胃癌根治术中不仅能完成镜下消化道重建，还具有术中出血更少、淋巴结清扫更彻底等优势。但该技术仍无法避免并发症和技术难题，机器人胃癌手术相关并发症的发生率是评价其安全性和可行性的有效指标之一。机器人胃癌根治术常见并发症主要包括腹腔出血、腹腔感染、吻合口并发症、术后肠麻痹、十二指肠残端瘘、胰瘘和胰腺炎、气腹相关并发症、与穿刺器（trocar）及辅助切口相关的并发症等。严格把握机器人胃癌根治术的适应证，由在机器人操作方面经验丰富的外科医生仔细操作，并不增加并发症和中转开腹的发生率。本文旨在对现有达芬奇机器人胃癌根治手术临床实践中发现的常见并发症作总结分析，归纳现行有效的针对此类并发症的预防和处理措施，为临床工作提供参考。

关键词： 达芬奇机器人；胃癌根治术；手术并发症；气腹；腹腔出血；胰瘘；淋巴漏；医源性损伤
中图分类号： R619　R735.2　**文献标识码：** A　**文章编号：** 1674-8182(2026)02-0173-05

Prevention and management of complications in robotic radical gastrectomy

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Abstract: With the extensive development of minimally invasive technology in gastric cancer surgery, Da Vinci robot-assisted radical gastrectomy has also attracted increasing attention. The application of robotic technology in gastric cancer surgery can not only complete the endoscopic reconstruction of digestive tract, but also has the advantages of less intraoperative bleeding and more thorough lymph node dissection. However, the new technology cannot avoid complications and technical difficulties. The incidence of complications related to robotic gastric cancer surgery is one of the effective indicators to evaluate its safety and feasibility. Common complications of robotic radical gastrectomy mainly include abdominal hemorrhage, abdominal infection, anastomotic complications, postoperative ileus, duodenal stump fistula, pancreatic fistula and pancreatitis, pneumoperitoneal-related complications, and complications related to trocar puncture and auxiliary incision. Strict adherence to the indications for robotic radical gastrectomy and careful operation

DOI: 10.13429/j.cnki.cjcr.2026.02.002
基金项目： 江苏省中医药学会振兴发展项目（ZXFZ2024001）；江苏省中医药管理局中医药领军人才（SLJ0311）；江苏省中医院院级课题（Y21024）
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出版日期： 2026-02-20

QR code for English version

by surgeons with extensive experience in robotic operation do not increase the incidence of complications and conversion to laparotomy. The purpose of this paper is to summarize and analyze the common complications found in the clinical practice of Da Vinci robot-assisted radical gastrectomy, and summarize the current effective measures for the prevention and treatment of such complications, so as to provide references for clinical work.

Keywords: Da Vinci robot; Radical gastrectomy; Surgical complications; Pneumoperitoneum; Abdominal bleeding; Pancreatic fistula; Lymphatic leakage; Iatrogenic injury

Fund program: Revitalization and Development Project of Jiangsu Provincial Association of Chinese Medicine (ZXFZ2024001); Leading Talents in Chinese Medicine of Jiangsu Provincial Administration of Chinese Medicine (SLJ0311); Hospital-level Research Project of Jiangsu Province Hospital of Chinese Medicine (Y21024)

自2002年Hashizume等[1]首次将机器人手术系统应用于胃癌治疗以来，达芬奇机器人凭借三维视野、关节臂灵活操作及震颤过滤等技术优势，在胃癌根治术中展现出独特价值。与传统腹腔镜相比，机器人胃癌根治术可显著提高淋巴结清扫率，尤其是脾动脉远端淋巴结(No.11d)、腹腔干淋巴结(No.9)等复杂部位的淋巴结，相对减少术中出血量，减少胰瘘等并发症发生的同时，通过精准缝合完成消化道重建以降低吻合口瘘风险等[2-4]。相比传统腹腔镜胃切除术，机器人胃癌根治术结合加速康复外科管理，在缩短术后下床时间、术后疼痛时间、管道拔除时间、首次排气时间及进食流质时间方面表现出更大优势[5-6]。然而，作为依赖机械臂操作的新兴技术，其并发症谱既与传统腹腔镜手术存在共性，也因操作模式差异呈现独特性。本文结合国内外最新研究，从机器人手术技术特性出发，系统阐述常见并发症的发生机制、预防要点及处理策略，为临床实践提供参考。

1　机器人胃癌根治术并发症现状

1.1　*机器人胃癌根治术并发症分类及其特异性*　机器人胃癌根治术的并发症大致可分为共性并发症和特异性并发症。共性并发症即作为微创技术开展以来与传统腹腔镜手术病例机制相似的并发症，如腹腔出血、吻合口瘘、十二指肠残端瘘等，但实际发生率可能因操作精度不同而存在差异；特异性并发症指如机械臂操作导致的组织挤压伤、镜头视野盲区引发的副损伤，以及气腹系统与机械臂协同操作相关的技术性并发症[如穿刺器(trocar)移位、机械臂碰撞等]。

机器人胃癌根治术对术后并发症发生率的影响尚存在争议。有荟萃分析显示，机器人和腹腔镜胃癌根治术在并发症发生率上相近(12.75% *vs* 13.62%)[2]。另一项多中心前瞻性对比研究显示，在152例接受机器人胃癌根治术和1 020例接受腹腔镜胃癌根治术的患者中，机器人组≥Clavien-Dindo Ⅲ级术后并发症发生率为1.3%(2/152)，腹腔镜组为7.1%(72/1 020)，提示机器人手术在降低严重并发症发生率上有一定优势[7]，Feng等[8]的研究同样验证了这一结论的可靠性。

1.2　*机器人胃癌根治术与传统腹腔镜手术的核心差异*　机器人手术的技术优势一般通过三种机制影响并发症发生。(1) 三维立体视野：提供10~15倍放大的清晰术野，使胃左动脉、脾动脉等精细解剖结构辨识度提升，减少血管损伤；(2) 多自由度机械臂：可在狭小空间(如胰腺上缘、贲门周围)完成旋转、抓持、缝合等复杂操作，降低组织牵拉张力；(3) 精准能量控制：双极电凝与超声刀的协同使用，减少热传导对胰腺、十二指肠的损伤，降低胰瘘与肠瘘风险[2]。综合多个研究结果来看，目前对于机器人胃癌根治术与腹腔镜胃癌根治术在并发症发生率方面的结论并不完全一致，可能与研究的样本量、患者的疾病分期、手术医生的操作熟练程度等多种因素相关。

2　机器人胃癌根治术常见并发症的处理策略

本文主要归纳机器人胃癌根治术中最为常见和特殊的手术并发症，包括腹腔出血、吻合口并发症、十二指肠残端瘘、胰腺相关并发症和气腹与机械臂相关并发症，以期为手术并发症的预防和处理提供参考。

2.1　*腹腔出血*

2.1.1　术中腹腔出血　实际临床操作和研究中，通常将术中腹腔内出现明显可见的、持续性的血液渗出或涌出，且达到需要采取额外止血措施(如使用钛夹、血管夹夹闭，或使用大功率电刀、超声刀止血等)的情况，认定为术中腹腔出血。机器人胃癌根治术中腹腔出血量中位数约为98.77 mL[9]，发生原因多为解剖层次不清，进而损伤胃网膜右动脉、胃右动脉、胃十二指肠动脉、胃左静脉、脾动脉、胃网膜左动静脉、胃短静脉及胃周实质器官等[2]。尤其是术中过度牵拉血管鞘损伤胃左动脉主干、清扫No.11d时机械臂操作角度不当导致撕裂脾动脉、切割闭合器闭合不完整或组织夹脱落导致胃十二指肠动脉残端出血等，更是腹腔出

血的高危因素[10]，在机器人学习曲线初期最易发生。

达芬奇机器人对术中出血有特殊的预防措施。首先，可以利用机械臂“手腕”灵活性，采用“垂直解剖法”分离血管周围脂肪淋巴组织，避免横向牵拉；其次，对直径>3 mm的血管可优先使用血管夹夹闭，而非单纯能量器械凝固；并且镜头保持与操作区域15~20 cm距离，确保出血点定位精准亦是有效方式[11]。

无法避免发生术中出血时，相应处理流程可根据具体情况分类：(1) 小血管出血时，可采用双极电凝精准凝血（功率设定为40~50 W，避免热损伤扩大）；(2) 中等血管出血时，用机械臂持一次性组织闭合夹（Hem-o-lok）夹闭，或转换为腹腔镜下钛夹处理效果更佳；(3) 大出血时，应立即降低气腹压力至8 mmHg，压迫出血点后评估是否中转开腹，机器人手术中转开腹率约1.2%~3.5%，主要与血管损伤相关[12]。

2.1.2　术后腹腔出血　术后腹腔出血是指手术后腹腔内血管破裂或创面渗血导致的内出血现象[13-14]。机器人胃癌根治术后腹腔出血发生率为1%~4%，可分为早期出血与迟发性出血[15]。一般把发生在术后24 h内的出血称为早期出血，涵盖吻合口出血、残胃出血，多因术中未能有效控制出血点引起。术后腹腔出血通常表现为腹腔内出血、消化道出血两种形式。

术后早期出血多因术中止血不彻底或血管夹闭不牢所致，也可因吻合时误将系膜或肠脂垂一并吻合，术后血压升高引发出血。吻合口或残胃断端出血可表现为消化道出血（呕血、黑便）或腹腔内出血（引流液呈血性）。因此，术后需严密监测生命体征及血红蛋白变化，若发现异常波动，及时进行评估和处理。同时合理使用止血药物和抑酸药物，在术后早期预防性应用静脉止血药物，可增强凝血功能；使用抑酸药物，如质子泵抑制剂，可降低胃酸分泌，减少胃酸对吻合口及残胃断端的刺激，有助于预防出血[16]。此外，保持引流管通畅亦至关重要。若保守治疗无效或出现血流动力学不稳定，应及时行胃镜检查并在直视下止血[17]。

迟发性出血往往是由于腹腔内血管破裂出血，包括脾动脉、肝总动脉、胃十二指肠动脉及其分支，也可发生在横结肠系膜及吻合肠管的系膜血管。其原因主要由手术电外科器械造成的血管鞘灼伤形成假性动脉瘤破裂，继而破裂出血。典型表现为腹腔引流液突然增多或引流不畅，伴心悸、烦躁、腹痛及血压下降，严重者可出现休克。假性动脉瘤出血经保守治疗平稳后可行介入治疗[18]。如果出血量较大，病情进展迅速者短期可出现失血性休克，则应果断采取二次手术[15]。

2.2　吻合口并发症　吻合口并发症除外上述提及的吻合口相关出血，还有吻合口瘘及吻合口狭窄，发生率为0.4%~4.0%[19-20]。

机器人手术在镜下缝合时，机械臂可完成传统腹腔镜难以实现的“垂直进针”、“反向打结”操作，尤其适用于食管-空肠吻合（如Overlap法）；借助如吲哚菁绿荧光血管造影技术，实时评估吻合口血运，还可以降低术后缺血导致吻合口瘘的风险[21]。大多数吻合口瘘是微小的渗漏，一般保守治疗即可。严重吻合口瘘合并腹腔脓肿，应该在超声或CT引导下穿刺引流，同时可以选择放置鼻肠管予肠内营养支持。确保吻合口充足的血供和无张力是预防吻合口瘘的关键，效果不佳时可考虑再次手术[11]。

吻合口狭窄患者往往合并全身营养障碍和残胃扩张、水肿，发生原因可能为胃-空肠吻合时近端空肠过短，使Braun吻合口向上牵拉成角，引起吻合口梗阻[21]。在机器人胃癌根治术中，还有可能因机械臂操作的“精准切割”导致吻合口边缘过度整齐，愈合过程中肉芽组织对称性增生，形成环形狭窄[20]。提倡采取阶梯式处理，首先进行胃肠减压以及等渗盐水冲洗，而后内镜下经由狭窄的吻合口放置空肠营养管，以此提供肠内营养支持，最后实施内镜下气囊扩张。对于顽固性狭窄者，考虑选择支架置入，一般放置全覆膜自膨式支架约4~6周[22]，仅有极少量吻合口狭窄患者需要再次行消化道重建手术。

2.3　十二指肠残端瘘　十二指肠残端瘘是机器人胃癌根治术后严重的并发症之一，文献报道其发生率为0.37%~1.8%[23-24]，引起此并发症的最常见原因是空肠输入袢或输出袢的梗阻，也可能是在游离十二指肠球部时超声刀误伤肠壁，或者在应用切割吻合器关闭十二指肠残端时张力过高导致，可能腐蚀周围组织和血管引起腹腔内出血或腹腔内脓肿，甚者发生多器官功能衰竭等严重后果[15]。

发生十二指肠残端瘘时，大部分可通过腹腔引流、肠外营养、使用生长抑素等保守治疗。上述手段无效或合并其他并发症（如腹腔出血等）时才考虑外科手术治疗[25-26]。另外，也有行内镜下夹闭十二指肠残端瘘的相关报道，但其临床适应证严格，可靠性及安全性有待临床验证[27]。

2.4　胰瘘和胰腺炎　胰瘘与胰腺炎的直接原因是术中胰腺损伤，具体包括：手术钳压迫、超声刀的热传导，以及清扫远端脾动脉旁淋巴组织时机械臂过度摩擦胰腺被膜[28]。为了更好地预防此类并发症，术者采取“无接触原则”分离胰腺上缘，机械臂抓持淋

巴结周围脂肪组织，而非直接牵拉胰腺；对胰尾区域血管，优先使用LigaSure血管闭合系统，减少热损伤范围均是预防胰腺损伤的有效措施[29]。

胰瘘发生率虽低，但后果严重，易继发腹腔感染、脓肿乃至致命性大出血，须高度重视。一旦发生，应确保腹腔双套管冲洗通畅，并应用抑制胰液分泌的药物，必要时手术干预[30]。

2.5 *术后肠麻痹*（postoperative ileus，POI） POI是腹部术后早期常见并发症，其发生与手术应激所致的胃肠激素紊乱、炎症反应及自主神经功能紊乱有关，进而使肠蠕动减少，临床表现为腹痛、腹胀、恶心、呕吐等[31]。此外一些镇痛药物，特别是阿片类止痛剂的使用也被认为与术后肠蠕动减缓相关[32]。

针对以上原因，有效预防POI的方法包括术前充分的胃肠道准备、术中精细轻柔操作、彻底止血并减轻创伤；术后鼓励早期活动与进食；采用术后多模式镇痛，在确保镇痛效果的同时，减少阿片类药物用量，从而降低POI发生风险[15]。

术后POI大多数都可经过持续胃肠减压、禁食、灌肠、加强肠外营养、给予消化酶等保守治疗后明显好转，某些抗炎药物的使用也被证实有利于减轻POI[33]，但其具体作用机制有待进一步研究。对于进行性加重的绞窄性腹痛，以及反复发作的粘连性肠梗阻患者，应积极手术探查，以防延误病情。

2.6 *淋巴漏* 机器人胃癌根治术因主要采用超声刀行解剖分离，术后淋巴漏的发生率较低。但手术过程仍不可掉以轻心，淋巴漏发生的主要原因是行胃癌淋巴结清扫时忽视淋巴管断端的处理。机器人胃癌根治术过程中，术者应利用机器人的镜头和操作优势，更彻底地清扫淋巴结[34]。在淋巴结清扫完成后创面止血的同时，仔细检查有无乳白色淋巴液渗出，对可疑创面进行凝闭或缝扎，在腹腔干周围、躯干中轴线附近清扫时采取延长凝固时间等措施，有利于减少淋巴漏发生[35]。术后予以妥善引流，对预防淋巴漏大有裨益。一旦发生淋巴漏，一般而言，只要确保腹腔引流管保持通畅，同时维护好机体水电解质及营养的平衡状态，大多可治愈。

2.7 *气腹与机械臂相关并发症*

2.7.1 气腹相关并发症 高碳酸血症、皮下气肿、气栓等是机器人胃癌手术中常见的与气腹有关的并发症。出于预防考虑，术中应持续监测气腹压力，通常维持在10~15 mmHg（1 mmHg=0.133 kPa），以减小腹腔–血液间二氧化碳的压力梯度[30]。同时，尽量缩短手术时间，在机器人胃癌手术领域，做到这一点需要良好的器械准备和术者的高熟练度。

另有研究证明，免气腹腹腔镜胃癌根治术通过悬吊装置，可在一定程度上替代传统气腹，扩大了腹腔镜手术的适应证[36]。或可考虑该技术是否能与机器人技术结合，创造机器人免气腹胃癌根治术的新方式，从而避免气腹相关并发症的发生。

2.7.2 机械臂医源性损伤 机器人手术因机械臂操作特性存在医源性损伤风险，发生原因主要为操作技术不熟练、设备故障及手术视野受限等。预防机械臂医源性损伤需从术前、术中多维度入手，术前应加强术者培训，并严格评估患者病情以制定个性化手术方案，全面检查机械臂及器械性能并预设紧急停止机制以应对突发故障。术中需优化操作流程，例如采用"W"形五孔法trocar布局减少器械碰撞，合理使用3号臂辅助暴露以增强术野清晰度；建立"安全操作区"，机械臂活动范围与肠管、大血管保持2 cm以上距离；使用压力感应机械臂（如达芬奇Xi系统），实时反馈组织张力[37]。

一旦发生损伤，需根据类型和严重程度采取针对性措施。对于血管损伤，可通过电凝、缝合或血管夹止血；若为脏器穿孔（如胃、肠），需及时修补或切除受损部位。复杂损伤（如胰瘘或十二指肠残端瘘）需多学科协作，结合介入治疗或二次手术修复。

2.8 *与trocar穿刺及辅助切口相关的并发症* 常见并发症包括trocar损伤腹壁动脉、穿刺失控导致腹膜后血管破裂出血或肠管损伤等[30]，属于腹腔镜手术特有并发症，在术前准确评估患者情况，选择合适的穿刺点和适当的穿刺方式（trocar、气腹针或直接切开等），都是减少该并发症发生的合理方法。

机器人胃癌手术常见并发症的预防与处理方法大抵如上。此外，李政焰等[12]发现，术者经验≤30例是发生严重并发症及局部并发症的独立危险因素，因此在机器人手术学习曲线阶段，术者的经验积累和机器人适应证的选择也是预防医源性损伤的重要措施。

3 机器人胃癌根治术的展望

机器人胃癌手术的应用日益广泛。为规范手术流程与疗效评价，亟需开展前瞻性、多中心、大样本的随机对照研究。笔者对其发展提出以下展望：（1）新一代达芬奇机器人（第5代）引入力反馈技术，可提升操作精准度，降低组织损伤风险；（2）结合人工智能技术完善机器人应用体系，增强系统稳定性，降低故障率与手术风险；（3）推动国产手术机器人研发，通过技术自主化、智能化与基层推广，引领技术

革新与可及性提升；(4)借助5G通信技术，实现机器人远程手术，减少延迟，提高安全性，优化医疗资源分布，减轻患者负担。

总之，机器人胃癌手术虽然仍存在使用维护成本偏高、操作空间及时间的局限等不足。但它克服了传统腹腔镜技术的诸多缺陷，较传统腹腔镜有明显的优势，在控制术后并发症发生率方面有其独到之处，引领了未来微创外科的发展趋势。

利益冲突　无

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收稿日期：2025-06-24　**修回日期**：2025-09-19　**编辑**：叶小舟