Review Article

Robotic surgery for gastric tumor: current status and new approaches

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Abstract: Surgical techniques have evolved tremendously over this past century. To maximize the efficacy and minimize the invasiveness of laparoscopic surgery, researchers have sought to implement wider application of robotics. Nevertheless, both optimism without sound evidence and fear of new technology obscure the appropriate uses of robotic surgery. In the present review, we attempted to provide a balanced perspective on the current state of robotic gastrectomy, outlining evidence and opportunities for the use thereof. Although evidence is limited, the use of robotics is feasible for gastric cancer surgery, and less than 10 cases of robotic surgery are needed to become proficient therein. Compared to the clinical impact of laparoscopy on gastric cancer surgery, the additional benefits of robotic surgery to patients seem to be limited. Despite additional costs and longer surgeries, robotic surgery reportedly does not offer surgical outcomes superior to those for laparoscopic surgery, according to a recent multicenter study. Meanwhile, however, our in-depth review of retrospective and prospective reports revealed that robots could expand the indications of minimally invasive gastrectomy for patients requiring total gastrectomy and D2 lymph node dissection. Moreover, we found that robotic gastrectomy is associated with a higher number of retrieved lymph nodes, less bleeding, fewer complications, and shorter hospital stay, compared to laparoscopic gastrectomy. Accordingly, new surgical approaches using advanced technologies, such as near infrared detectors, the Tilepro® multi-input display, dual consoles, and the Single-Site® system, are under investigation. In conclusion, measuring the additional benefits of robotic over laparoscopic surgery would be difficult and clinically insignificant. Thus, developing new surgical procedures that extend the benefits of conventional laparoscopic surgery to patients in whom minimally invasive surgery would not be possible is necessary to justify the greater use of robotic surgery.

Keywords: Robotic surgery; gastrectomy; fluorescence imaging; learning curve; feasibility

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Introduction

Despite initial concerns with oncological safety, laparoscopic surgery has penetrated various fields of surgery, owing to improved surgical outcomes of good cosmesis, early bowel recovery, and better quality of life. To maximize the benefits of laparoscopic surgery, clinicians and researchers have sought to advance instruments important to performing laparoscopic procedures. Among such advances, robot systems have been introduced to minimize the limitations of laparoscopic surgery by providing technical advantages

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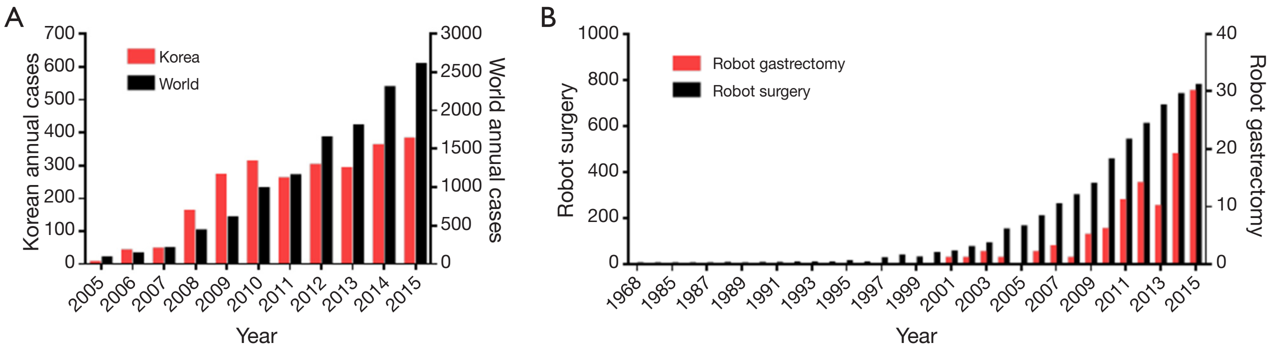

Figure 1 Increasing number of robotic surgeries and reports thereon.

of a high-resolution 3D surgical view, instrumentation with a higher degree of freedom in movement, and a more ergonomic posture for the surgeon. Indeed, with these advantages, the use of robotic systems has permeated various surgical fields, including gastrectomy, on which clinical application and investigations are increasing (*Figure 1A,B*).

Nevertheless, studies have yet to show that the technical superiority of robotic systems provides superior surgical outcomes in gastrectomy. In the meantime, overestimation of the benefits of technological advances without sound evidence can increase the cost of medical services without improvement in outcomes. Underestimation, however, in the early phases of implementing new technology can deprive researchers the opportunity to validate the benefits thereof.

In the present review, we attempted to provide a balanced perspective on the current state of robotic gastrectomy, outlining evidence and opportunities for its use.

Current evidence

Feasibility

The feasibility and safety of robotic gastrectomy have been extensively tested (1-5). Most studies have been designed as single-arm case series, focusing on short-term surgical outcomes. Currently, only one prospective study on the feasibility of robotic surgery has been reported (1); it showed excellent surgical outcomes with a median hospital stay of 8 days and no major complications or mortality. Indeed, most studies have found the feasibility and safety of robotic gastrectomy to be acceptable.

Learning curve

The learning curve associated with robotic surgery could be of great concern, as robot surgery can be regarded as a variant of laparoscopic surgery, which has a long learning curve. Thus, adaptation of robot systems has been extensively analyzed: According to a learning curve analysis of three surgeons, operation times were stabilized after 9.6, 9.6, and 6 cases of robotic gastrectomy, respectively (6). Another report comparing an initial 20 robotic gastrectomies with 80 thereafter showed satisfactory surgical outcomes in the latter robotic gastrectomies (7). A report applying multi-dimensional analysis showed that operation times stabilize after 95 and 121 cases, according to moving average and non-linear regression analysis (8). In that report, a fewer number of robotic cases than laparoscopies was required to reach stabilized operation times. Also, a CUSUM analysis showed that robotic surgeries are successful even for initial cases. In the report, surgical failure was defined as conversion to laparoscopic or open surgery, failure to harvest an adequate number of lymph nodes for staging, resection margin involvement, and major postoperative complications including mortality. Thus, the literature suggests that a fewer number of cases is needed to stabilize operation times for robotic surgery than for laparoscopy and that surgical outcomes following robotic gastrectomy are acceptable even during its initial implementation.

Comparison of surgical outcomes

The most important and frequently asked questions concerning robotic surgery are related to its benefits over laparoscopic surgery. Laparoscopic surgery provided tremendous advantages over open surgery, such as good cosmesis, reduced pain, and shorter hospital stay. On the contrary, studies seem to suggest that no perceptible benefit is provided by robotic surgery over laparoscopic surgery, especially to patients (9-14). A recent multicenter prospective

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trial comparing robot and laparoscopic gastrectomy confirmed the lack of substantial benefits (15). Despite longer operation time and higher costs, which are the major pitfalls of robotic surgery, perioperative surgical outcomes, such as bleeding, number of retrieved lymph nodes, gas passing, and hospital stay, as well as all complications and major complications rates, are not greatly different.

Opportunities

Advantages of robotic surgery in relation to classical perioperative parameters

Figure 2 compares robotic gastrectomy versus laparoscopic gastrectomy and laparoscopic gastrectomy versus open gastrectomy. Parameters in which the newer technology shows statistical benefit over the older are noted in blue, while statistical detriments are noted in red. Other parameters that were not statistically analyzed are noted as weak blue or weak red. Although operation time and cost show no benefit, other parameters highlight areas in which robotic gastrectomy can be of benefit.

Higher number of retrieved lymph nodes

Compared with open surgery, laparoscopy exhibits comparable or poorer retrieval of lymph nodes (31,36). On the contrary, robotic surgery shows comparable or better retrieval of lymph nodes than laparoscopy (16,17,19,21,23,25). The reduced number of retrieved lymph nodes is the one single weakness of laparoscopic surgery, compared with open surgery, for which robotic systems can compensate. This strength of robot systems is especially apparent in difficult operations requiring total gastrectomy or D2 dissection (16,19,21). The working space within the supra-pancreatic area, hiatus, and splenic hilum is quite far from the trocar site in laparoscopic surgery. This introduces problems with physiologic tremor. Meanwhile, robotic systems automatically compensate for any physiologic tremors and provide enhanced dexterity of surgical instruments, facilitating retrieval of a higher number of lymph nodes.

Less bleeding

A well-known feature, less bleeding is typically recorded for laparoscopic procedures, compared to open surgery. In robotic gastrectomy, about half of all publications report less bleeding than that in laparoscopic surgery (7,17,20,23-28). Statistically, less bleeding may have no impact on the clinical course of the patients; however, it implies that robots offer more precise dissection of the lymph nodes following the surgical plane. Checking long-term survival in relation to whether the reduced bleeding associated with more precise dissection could affect cancer recurrence is warranted (41).

Fewer complications

Most publications comparing robotic over laparoscopic and laparoscopic over open surgery show similar complication rates. Only a few publications have reported fewer complications for laparoscopic surgery than for open surgery (31,32). Currently, only one publication has shown fewer complications for robot surgery in comparison to laparoscopic surgery (18). The authors of the report proposed that the increased dexterity and maneuverability offered by the robotic system facilitated less pancreatic fistula.

Shorter hospital stay

As seen in *Figure 2*, newer technology seems to provide shorter hospital stay, which is likely associated with less trauma and faster recovery. Laparoscopy shortened hospital stays, compared to open surgery (31,33,36,38,39). While robotic surgery further decreased hospital stays over laparoscopy, although the clinical relevance thereof is uncertain (16, 18,22,25,27-29).

New approaches using the technological advantages of robotic surgical systems

Image-guided surgery

Using robotic systems, preoperative CT images can reportedly be used to guide anatomical dissection of lymph nodes during gastrectomy (42). This navigation surgery is based on the concept that although the stomach is flexible and vascular structures are subject to change, in accordance with the position of the patient during an operation, the length of the vessel is fixed. After reconstruction of preoperative CT images for surgery, they can be used to aid in dissection. Not only CT images, but also real-time endoscopic images can be visualized in the console view (43). This additional visual information allows for easier manipulation of targeted tissues and materials.

Also, robot surgical systems can be equipped with near-infrared detectors for visualization of fluorescent indocyanine green (ICG), allowing for more complete removal of lymph nodes. Contrary to a previous report on the use of ICG for sentinel lymph node mapping (44), a

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Surgical outcome following robot compared to laparoscopic gastrectomy (prospective and retrospective)

Year	Author	Setting	Journal	Country	Group (Robot/Lap)	Operation time (min)	Retrieved LN	Bleeding (mL)	Complications	Hospital stay	Cost	survival	Pain
2016	Kim **et al.** (15)	Prospective	Ann Surg	Korea	223/211							NA	NA
2015	Kim **et al.** (16)	Retrospective	Surg Endosc	Korea	87/288			NA			NA	NA	NA
2016	Shen **et al.** (17)	Retrospective	Surg Endosc	China	93/330						NA	NA	NA
2015	Suda **et al.** (18)	Retrospective	Surg Endosc	Japan	88/438				Major complications		NA	NA	NA
2015	Park **et al.** (19)	Retrospective	World J Surg	Korea	148/622		*Total gastrectomy, non-obese, N2				NA		NA
2015	Lee **et al.** (20)	Retrospective	Surg Endosc	Korea	133/267						NA		NA
2014	Son **et al.** (21)	Retrospective	Surg Endosc	Korea	51/58		*Splenic artery				NA	NA	NA
2014	Noshiro **et al.** (22)	Retrospective	Surg Endosc	Japan	21/160						NA		NA
2014	Junfeng **et al.** (23)	Retrospective	Surg Endosc	China	120/394							NA	NA
2014	Huang **et al.** (24)	Retrospective	PLoS One	Taiwan	72/72							NA	NA
2015	Han **et al.** (14)	Retrospective	Ann Surg Oncol	Korea	68/68			NA			NA	NA	NA
2013	Hyun **et al.** (13)	Retrospective	Ann Surg Oncol	Korea	38/83						NA	NA	NA
2012	Yoon **et al.** (12)	Retrospective	Surg Endosc	Korea	36/65			NA			NA	NA	NA
2012	Park **et al.** (11)	Prospective	Br J Surg	Korea	30/120							NA	
2012	Kang **et al.** (7)	Retrospective	J Gastric Cancer	Korea	100/282		NA		NA		NA	NA	NA
2012	Huang **et al.** (25)	Retrospective	J Gastrointest Surg	Taiwan	39/64/586						NA	NA	NA
2012	Eom **et al.** (10)	Retrospective	Eur J Surg Oncol	Korea	30/62							NA	NA
2011	Woo **et al.** (26)	Retrospective	Arch Surg	Korea	236/591						NA		NA
2011	Caruso **et al.** (27)	Retrospective	Int J Med Robot	Italy	29/120 (Open)						NA	NA	NA
2010	Pugliese **et al.** (9)	Retrospective	Surg Endosc	Italy	18/52						NA	NA	NA
2010	Kim **et al.** (28)	Retrospective	Surg Endosc	Korea	16/11/12						NA	NA	NA
2009	Song **et al.** (29)	Retrospective	Surg Endosc	Korea	20/20 L-early/20 L-late						NA	NA	NA

Surgical outcome following laparoscopy compared to open gastrectomy (prospective only)

Year	Author	Setting	Journal	Country	Group	Operation time (min)	Retrieved LN	Bleeding (mL)	Complications	Hospital stay	Cost	survival	Pain
2015	Misawa **et al.** (30)	Prospective	Gastric Cancer	Japan	73/72					NA	NA	NA	
2016	Kim **et al.** (31)	Prospective	Ann Surg	Korea	644/612						NA	NA	NA
2013	Kim **et al.** (32)	Prospective	Surg Endosc	Korea	82/82	NA	NA	NA		NA	NA		
2013	Takiguchi **et al.** (33)	Prospective	World J Surg	Japan	20/20				NA		NA		
2013	Sakuramoto **et al.** (34)	Prospective	Surg Endosc	Japan	31/32						NA	NA	
2010	Kim **et al.** (35)	Prospective	Ann Surg	Korea	161/179	NA	NA			NA	NA	NA	NA
2008	Kim **et al.** (36)	Prospective	Ann Surg	Korea	82/82						NA	NA	
2005	Lee **et al.** (37)	Prospective	Surg Endosc	Korea	30/25						NA	NA	
2005	Huscher **et al.** (38)	Prospective	Ann Surg	Italy	24/23						NA		NA
2005	Hayashi **et al.** (39)	Prospective	Surg Endosc	Japan	14/14						NA	NA	NA
2002	Kitano **et al.** (40)	Prospective	Surgery	Japan	14/14						NA	NA	

*Specified subgroup only. Other subgroup showed no statistical difference.

New approach is significantly unfavorable
New approach is unfavorable (not statistically tested)
New approach is significantly favorable
New approach is favorable (not statistically tested)
No significant difference

Figure 2 Comparison of newer approaches to their respective predecessor, robot to laparoscopy (7,9-29) and laparoscopy to open (30-40).

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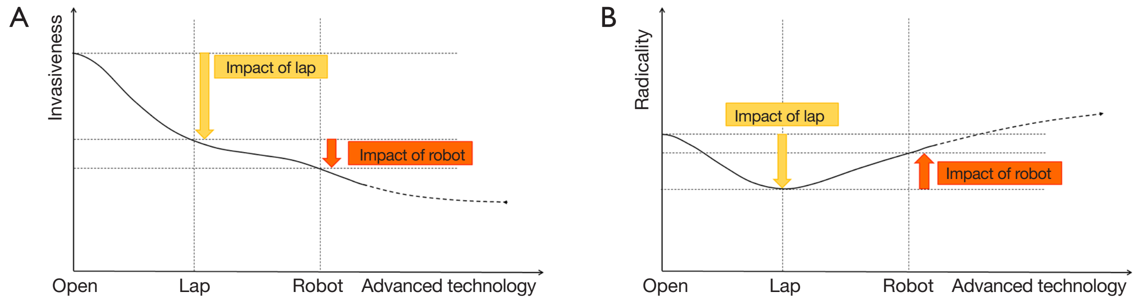

Figure 3 Clinical impact of laparoscopic and robotic surgery over open surgery.

new concept utilizing ICG for more radical surgery, with complete lymph node dissection, is currently undergoing validation (NCT01926743).

Mentoring system

Training young surgeons to use robotic systems is of great importance. The Tilepro® system can also be used to guide novice surgeons (NCT01319084). Using prepared video clips, novice surgeons can be reminded of critical points in the procedure before continuing on to the next step. Also, as previously reported, dual console systems can also be used to train young surgeons (45,46).

Reduced-port surgery

The Single-Site® system was initially developed for single-site cholecystectomy or hysterectomy (47,48). Currently, reduced-port robotic gastrectomy using the Single-Site port with an additional third robotic arm is currently under investigation (NCT02347956). Therewith, reduced-port surgery can be performed enjoying a similar degree of freedom as that for conventional robotic gastrectomy.

Conclusions

Currently, perioperative surgical outcomes comparable to those for laparoscopy are reported for robot gastrectomy, along with longer operation time and high cost. Nevertheless, robot surgery is still in its primitive stage, merely seeking to replicate surgical tasks performed by laparoscopic surgery. Thus, we offer two strategies for the continued development of robotic surgery: First would be to develop less invasive procedures (*Figure 3A*). Image-guided surgery and reduced-port gastrectomy can potentially lessen the invasiveness of gastrectomy. Second would be to expand robotic surgery to more radical procedures (*Figure 3B*). ICG-guided lymph node dissection and image-guided surgery could be of use therein.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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