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EDITORIAL

Current status of robot-assisted gastric surgery

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Abstract

In an effort to minimize the limitations of laparoscopy, a robotic surgery system was introduced, but its role for gastric cancer is still unclear. The objective of this article is to assess the current status of robotic surgery for gastric cancer and to predict future prospects. Although the current study was limited by its small number of patients and retrospective nature, robot-assisted gastrectomy with lymphadenectomy for the treatment of gastric cancer is a feasible and safe procedure for experienced laparoscopic surgeons. Most studies have reported satisfactory results for postoperative short-term coutcomes, such as: postoperative oral feeding, gas out, hospital stay and complications, compared with laparoscopic surgery; the difference is a longer operation time. However, robotic surgery showed a shallow learning curve compared with the familarity of conventional open surgery; after the accumulation of several cases, robotic surgery could be expected to result in a similar operation time. Robotic-assisted gastrectomy can expand the indications of minimally invasive surgery to include advanced gastric cancer by improving the ability to perform lymphadenectomy. Moreover, "total" robotic gastrectomy can be facilitated using a robot-sewing technique and gastric submucosal tumors near the gastroesophageal junction or pylorus can be resected safely by this novel technique. In conclusion, robot-assisted gastrectomy may offer a good alternative to conventional open or laparoscopic surgery for gastric cancer, provided that long-term oncologic outcomes can be confirmed.

Key words: Robot surgery; Stomach; Minimally invasive surgery

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INTRODUCTION

Since its introduction in the 1980s, laparoscopic surgery has become widely accepted and used as a minimally invasive approach for a number of procedures[1] because it offers a number of patient benefits compared to open surgery such as milder morbidity, earlier time to walking, flatus, and oral intake, and quicker recovery with a shorter hospital stay[2-5]. In the field of gastric cancer, laparoscopic gastrectomy has been rapidly adopted, especially in Korea and Japan[6-11]. Although patients benefit from laparoscopic surgery, its ergonomic discomfort and counterintuitive instruments hinder the application of laparoscopic surgery for more advanced procedures; this procedure is also more stressful for surgeons than open surgery.

In an effort to minimize the difficulty of laparoscopy, a robotic surgery system was introduced[12,13]. The da Vinci Surgical System (Intuitive Surgical Inc., Sunnyvale, CA, USA) aimed to relieve the shortcomings of laparoscopic surgery by maximizing the comfort of the surgeon, while providing instruments that enable technically demanding operations, three-dimensional views, and improved dexterity with an internal articulated EndoWrist that allows seven degrees of freedom[14-17].

To date, the most successful application of robotic surgery is robot-assisted radical prostatectomy. Robot-assisted radical prostatectomy was rapidly adopted worldwide[18]. In 2008 in the United States, nearly 80% of radical prostatectomies were performed with robot assistance. More importantly, multiple robot-assisted radical prostatectomy series are now mature enough to demonstrate the safety, efficiency and reproducibility of the procedure, as well as oncologic and functional outcomes comparable to its open counterpart. Robot-assisted surgery is also used in many fields of advanced surgical procedures, such as those for cardiac, gynecologic and pediatric disease. Particularly in cases of complex procedures like mitral valve surgery or surgery in an area that is hard to approach *via* conventional laparoscopy, a surgical robot is expected to expand the range of minimally invasive surgery (MIS)[19-25].

In the field of general surgery, application of the da Vinci in various gastrointestinal cancers is one of the most important concerns. The purpose of this article is to review the current status of robotic surgery for gastric cancer and submucosal tumors representing gastrointestinal stromal tumor (GIST) and to foresee future prospects.

REPORTS OF APPLICATION IN CLINICAL PRACTICE

Robotic surgery using the da Vinci is a minimally invasive cutting edge surgical technique for treatment of gastric cancer. However, while robot-assisted gastrectomy in the setting of gastric cancer has been reported, only a few reports have examined the technical feasibility. Table 1 summarizes chronologically how robotic surgery has been applied for gastric tumors.

The first robot-assisted gastrectomy was reported by Hashizume *et al*[26]. in 2003. Since then, a few small series have been reported that show relatively good short-term results comparable to those obtained with laparoscopic or conventional open surgery[27-37]. In 2009, Song *et al*[32] presented their initial 100 cases of robot-assisted gastrectomy with lymph node dissection; it is the largest series for robotic surgery with gastric cancer in the literature. Then, Hur *et al*[33] reported total robotic gastrectomy using robot-sewn anastomosis and Ryu *et al*[36] reported a robot-assisted gastric wedge resection for gastric GIST. These reports appeared to verify the safety and feasibility of this new technology by providing examples of how the robotic surgical system can produce maximum benefits.

The first report on intermediate survival after robot-assisted gastrectomy was recently presented by Pugliese *et al*[34]. While the number of reports is limited, extra attention is being focused on this new technology and many surgeons are actively trying to perform it for gastric cancer, and the short-term and long-term results will be followed for many years to come.

COMPARISON WITH CONVENTIONAL SURGERY

Feasibility and safety

In general, a longer operation time as well as higher cost and loss of tactile sense are considered to be the disadvantages of robotic surgery in comparison to laparoscopic or open conventional surgery (Table 2). The prolonged operation time is due to the additional time that it takes to set up the robotic arms[16,38-40]. Song *et al*[32] reported that the docking time initially took about 15 minutes, but that time decreased gradually and reached a plateau after the initial 30 cases. This report on robot-assisted gastrectomy shows that the console time, without additional setting time, was shorter than the total operative time of the initial laparoscopic group and was even similar to the time it took for a recent laparoscopic gastrectomy.

Robotic assistance provides surgeons with the familiarity of conventional open surgery with its easier maneuverability, allowing MIS to be performed more easily[41]. Thus, in a report comparing the learning curve between conventional laparoscopy and robotic assistance in surgical tasks, laparoscopic surgery showed a steep learning curve, whereas robot-assisted surgery showed better results from the beginning of the initial case with a shallower learning curve, showing the easy adaptability of robot-assisted surgery[31,42-44]. Our unpublished report from a multicenter study also demonstrated that robot-assisted gastrectomy could be rapidly adapted after an initial of around 10 cases by three experienced laparoscopic surgeons.

In conclusion, a robotic surgical system in MIS is a tool that can be used by experienced laparoscopic surgeons to perform robot-assisted surgery, even for initial cases, with a certain level of skill. This report provides good evidence for experienced laparoscopic gastric surgeons who want to start robotic surgery. However, to

Table 1 Summary of reports on robotic surgery for gastric tumors

Ref.	Yr	Country	Study design	Patients	Surgery	Sample
Hashizume *et al*[26]	2003	Japan	Review		Robot	
Anderson *et al*[27]	2007	USA	Case series	Gastric adenocarcinoma only	Robot	7
Hyung *et al*[28]	2007	South Korea	Review, Nonrandomized comparative	Gastric adenocarcinoma only	Initial Robot	10
					Initial Lap.	10
					Recent Lap.	10
Patriti *et al*[29]	2008	Italy	Case series	Gastric adenocarcinoma only	Robot	13
Pugliese *et al*[30]	2009	Italy	Nonrandomized comparative	Gastric adenocarcinoma only	Robot	9
					Lap.	46
Song *et al*[31]	2009	South Korea	Nonrandomized comparative	Gastric adenocarcinoma only	Initial Robot	20
					Initial Lap.	20
					Recent Lap.	20
Song *et al*[32]	2009	South Korea	Case series	Gastric adenocarcinoma only	Robot	100
Hur *et al*[33]	2010	South Korea	Case series	Gastric adenocarcinoma only	Robot	7
Pugliese *et al*[34]	2010	Italy	Nonrandomized comparative	Gastric adenocarcinoma only	Robot	16
					Lap.	48
Kim *et al*[35]	2010	South Korea	Nonrandomized comparative	Gastric adenocarcinoma only	Robot	16
					Lap.	11
					Open	12
Ryu *et al*[36]	2010	South Korea	Case series	Gastric adenocarcinoma and	Robot	2
				Gastric SMT	Lap.	19
Buchs *et al*[37]	2010	Swizerland	Case series	Gastric SMT only	Robot	5

Lap.: Laparoscopy; SMT: Submucosal tumors.

Table 2 Patients' characteristics and operative outcomes

Ref.	Surgery	Sample	Sex (M:F)	Mean age (yr)	Mean BMI (kg/m^2)	Operation time (min)	Blood loss (mL)	Conversion (%)
Anderson *et al*[27]1	Robot	7	4:3	64 (53-80)	25.8 (19.3-29.3)	420 (390-480)	300 (100-900)	0
Hyung *et al*[28]	Initial Robot	10	6:4	54 (35-73)	23.4 (20.8-26.7)	253 (200-316)	-	0
	Initial Lap.	10	8:2	55	23.9 (16.9-29.6)	337 (285-450)	-	0
	Recent Lap.	10	7:3	56	23.1 (19.5-26.1)	164 (120-200)	-	0
Patriti *et al*[29]	Robot	13	1:1	68.4 ± 11.9	26.13 ± 4.73	286.0 ± 32.6	103.0 ± 87.5	-
Pugliese *et al*[30]	Robot	9	-	-	-	350 ± 71 (240-460)	92 ± 58 (50-200)	-
	Lap.	46	-	-	-	236 ± 20 (145-360)	156 ± 57 (45-250)	-
Song *et al*[31]	Initial Robot	20	8:12	51.6 ± 12.5	23.4 ± 2.1	230.0 ± 34.9[a]	94.8 ± 121.5	0
	Initial Lap.	20	14:6	62.5 ± 12.9	23.6 ± 3.6	289.5 ± 59.3	-	0
	Recent Lap.	20	13:7	55.0 ± 5.8	22.4 ± 2.1	134.0 ± 40.0	39.5 ± 27.7	0
Song *et al*[32]	Robot	100	54:46	55.4 ± 13.0 (25-89)	23.3 ± 2.74 (17.0-30.1)	231.3 ± 43.2 (155-330)	128.2 ± 217.5 (12-1400)	0
Hur *et al*[33]	Robot	7	4:3	62 (35-72)	-	205 (190-240)	-	-
Pugliese *et al*[34]	Robot	16	-	-	-	344 ± 62 (240-460)	90 ± 48 (50-200)	12
	Lap.	48	-	-	-	235 ± 23 (145-360)	148 ± 53 (45-250)	6
Kim *et al*[35]	Robot	16	10:6	53.8 ± 15.6	21.3 ± 3.4[a]	259.2 ± 38.9[a]	30.3 ± 15.1[a]	-
	Lap.	11	10:1	57.9 ± 13.1	25.3 ± 2.5	203.9 ± 36.4	44.7 ± 37.1	-
	Open	12	9:3	56.0 ± 12.4	25.2 ± 1.9	126.7 ± 24.1	78.8 ± 74.1	-

[1]Values in parentheses are interquartile range. [a]$P < 0.05$. Lap.: Laparoscopy; BMI: Body mass index.

compare the adaptability of robot-assisted surgery to that of laparoscopic surgery, the results of surgeries performed by a surgeon who had no experience in either field should be compared.

Short-term outcomes

Most studies have reported similar results for postoperative short-term outcomes after robot-assisted gastrectomy compared with laparoscopic surgery (Table 3). Pugliese *et al*[30,34] showed no differences in time to start mobilization (1.2 d *vs* 1.2 d, $P > 0.05$), time to resume diet (4.5 d *vs* 5 d, $P > 0.05$) and postoperative hospital stay (10 d *vs* 10 d, $P > 0.05$) between the two groups. In contrast, Kim *et al*[35], in their comparative study of 16 robotic, 11 laparoscopic, and 12 open gastrectomies, reported a significantly shorter postoperative hospital stay (5.1 d *vs* 6.5 d *vs* 6.7 d, $P < 0.0001$).

Multiple series have reported various ranges in morbidity (5%-46.2%) after robot-assisted gastrectomy, which was not inferior to that of conventional surgery and most cases were wound complications that were minimal without evisceration. Two cases of postoperative mortality were reported but none of these complications were related to the robotic procedure.

Table 3 Postoperative courses

Ref.	Surgery	Sample	Oral feeding (d)	First flatus time (d)	Postoperative hospital stay (d)	Total complication (%)
Anderson *et al*[27]1	Robot	7	4 (2-8)	-	4 (3-9)	14.3
Hyung *et al*[28]	Initial Robot	10	4	2.9	6.0 (5-10)	-
	Initial Lap.	10	4.8	3.1	6.9 (5-8)	-
	Recent Lap.	10	4.3	3.3	6 (5-8)	-
Patriti *et al*[29]	Robot	13	-	-	11.2 ± 4.3	46.2
Pugliese *et al*[30]	Robot	9	5 ± 1.1	-	11 ± 1 (10-13)	-
	Lap.	46	5 ± 0.8	-	10 ± 2.5 (7-24)	-
Song *et al*[31]	Initial Robot	20	4 ± 0	3 ± 0.40	5.7 ± 1.0	5
	Initial Lap.	20	4.95 ± 1.47	3 ± 0.40	7.7 ± 3.5	5
	Recent Lap.	20	4.1 ± 0.45	3.25 ± 0.58	6.2 ± 3.1	10
Song *et al*[32]	Robot	100	4.2 ± 1.2 (3-15)	2.9 ± 0.5 (1-4)	7.8 ± 17.1 (5-175)	14
Pugliese *et al*[34]	Robot	16	4.8 ± 1.3	-	10 ± 3 (10-13)	12
	Lap.	48	5 ± 0.8	-	10 ± 2.6 (7-24)	14.5
Kim *et al*[35]	Robot	16	-	3.2 ± 1.1	5.1 ± 0.3a	-
	Lap.	11	-	3.6 ± 0.9	6.5 ± 0.8	-
	Open	12	-	3.4 ± 0.9	6.7 ± 1.4	-

1Values in parentheses are interquartile range. a$P < 0.05$. Lap.: Laparoscopy.

ROUTINE D2 LYMPHADENECTOMY AND EXPANSION OF INDICATION IN MIS FOR GASTRIC CANCER

Standard curative surgical treatment for gastric cancer involves radical gastrectomy with lymphadenectomy, nodal clearance is regarded as an especially important factor influencing long-term survival. According to stage-oriented treatment indications by The Japanese Gastric Cancer Association (JGCA), the indication for laparoscopic gastric surgery is limited to the clinical study for Stage Ⅰ A and Stage Ⅰ B because there are some limitations to laparoscopic lymphadenectomy compared to conventional open surgery[45,46].

Laparoscopic dissection of the lymph nodes around the superior mesenteric vein (LN 14v), celiac axis (LN 9), and splenic artery (LN 11) is the most frequent source of intraoperative bleeding because of the anatomic complexity of the vascular structures, the limited range of instrument movement, and even for experienced laparoscopic surgeons, unintentional tremor and poor vision[7,43,47,48]. For this reason, laparoscopic gastrectomy was first recommended for only early gastric cancer (EGC) that did not require extensive lymph node dissection because a D1+β dissection with removal of 1 and 3-9 stations according to JGCA is adequate[5,6,11,45,49].

However, some authors assert that D2 dissection should be performed routinely, even in cases diagnosed as EGC from preoperative workup[34,50,51]. Although preoperative staging has become more accurate with the help of recent advances in diagnostic tools, such as endoscopic ultrasonogram, invasiveness through the gastric wall is sometimes underestimated during the preoperative workup[50,52,53]. Pugliese *et al*[34] reported in their study that preoperative underestimation occurred in 25% of patients diagnosed with mucosal EGC; on histologic examination, 7.5% had advanced gastric cancer (AGC) and 17.5% had submucosal EGC. Therefore, they contend that, until the accuracy of preoperative staging is 100%, routine performance of all gastric cancer surgery with standard D2 dissection remains justified.

Robotics can improve a surgeon's dexterity and may be especially helpful during maneuvers in restricted fields such as in an extended lymphadenectomy[54-57]. Kim *et al*[35], in their comparative study of robotic, laparoscopic, and open gastrectomy, noted no significant differences between the three groups in terms of the number of retrieved lymph nodes (Table 4); this is probably because experienced laparoscopic surgeons can also perform sufficient lymphadenectomy during laparoscopic surgery, similar to open surgery. However, even in this case, the estimated blood loss in the robot-assisted gastrectomy group was significantly less than in other groups. In our unpublished study, we found no significant difference between the number of retrieved lymph nodes in the initial 50 cases of robot-assisted gastrectomy and 85 cases of laparoscopic gastrectomy after the initial learning curve, during the same period, performed by a single surgeon (34.9 *vs* 34.1, $P = 0.733$). But, this result is only based on the initial experience; after the accumulation of several cases, robotic surgery is expected to outperform conventional laparoscopic surgery for successful lymph node dissection.

Robot-assisted gastrectomy with lymphadenectomy for treatment of gastric cancer is safe and can result in good oncologic outcomes, comparable to the results obtained with open surgery, while maintaining the advantages of laparoscopic surgery. Also, robotic surgery is an easy way to expand the indications of MIS to include AGC.

RESPECT OF ONCOLOGIC PRINCIPLES

It is still too early to know for certain the long-term oncologic results of robot-assisted gastrectomy as a

Table 4 Pathologic outcomes

Ref.	Patients	Surgery	Sample	LN dissection (D1 + α or β/D2)	LN harvested (number)	Stage (Ⅰa/Ⅰb/Ⅱ)
Anderson *et al*[27]1	Gastric adenocarcinoma only	Robot	7	-	24 (17-30)	2/2/2
Hyung *et al*[28]	Gastric adenocarcinoma only	Initial Robot	10	-	34 (16-50)	-
		Initial Lap.	10	-	29.2 (12-54)	-
		Recent Lap.	10	-	37.8 (26-51)	-
Patriti *et al*[29]	Gastric adenocarcinoma only	Robot	13	-	28.1 ± 8.3	3/3/6
Pugliese *et al*[30]	Gastric adenocarcinoma only	Robot	9	-	27.5 ± 5 (18-40)	-
		Lap.	46	-	31.5 ± 9.5 (20-45)	-
Song *et al*[31]	Gastric adenocarcinoma only	Initial Robot	20	16/4	35.3 ± 10.5	19/1/10
		Initial Lap.	20	10/10	31.5 ± 17.1	14/4/2
		Recent Lap.	20	12/8	42.7 ± 14.9	19/0/1
Song *et al*[32]	Gastric adenocarcinoma only	Robot	100	58/42	36.7 ± 13.3 (11-83)	74/16/4
Hur *et al*[33]	Gastric adenocarcinoma only	Robot	7	-	-	-
Pugliese *et al*[34]	Gastric adenocarcinoma only	Robot	16	-	25 ± 4.5 (18-40)	-
		Lap.	48	-	31 ± 8 (20-45)	-
Kim *et al*[35]	Gastric adenocarcinoma only	Robot	16	2/14	41.1 ± 10.9	-
		Lap.	11	3/8	37.4 ± 10.0	-
		Open	12	0/12	43.3 ± 10.4	-

[1]Values in parentheses are interquartile range. [a]P < 0.05. Lap.: Laparoscopy; LN: Lymph node.

treatment for gastric cancer. To date, there is only one published article reporting intermediate survival (Pugliese *et al*[34]). In that study, 16 patients including EGC and AGC who underwent the robot-assisted gastrectomy, had a mean follow-up of 28 mo (range = 2-44 years). The 3-year overall survival rate was 78% as compared to 85% in the laparoscopic group, but the differences in survival between the two groups were not statistically significant based on the log rank test. Further, there were many limitations in this study, such as non-homogeneous population, small number of series and short follow-up period. It would be more appropriate to wait for long-term oncologic outcomes from large randomized studies.

CHALLENGES IN THE ADVANCED FIELD

Most studies have reported that anastomosis after robot-assisted gastrectomy was performed by extracorporeal hand-sewing sutures or intracorporeal stapler[29,31,32]. The mean body mass index of patients is not high for patients in Eastern countries, because of this extracorporeal anastomosis with a small mini-laparotomy of 4 to 5 cm in length is possible. For the removal of the resected specimen, an incision of at least 3.5 cm is needed, even for Eastern patients. In these cases, extracorporeal anastomosis may be acceptable, considering the technical difficulties and longer operation time required for intracorporeal anastomosis[32,58].

On the other hand, Hur *et al*[33] presented results of a pilot study in which anastomosis after gastrectomy was successfully achieved by a robot-sewing technique and they showed the possibility of "total" robotic surgery for the treatment of gastric cancer, not just "robot-assisted surgery," or "robot-assisted laparoscopic surgery". According to their results, not only anastomosis, such as gastroduodenostomy or gastrojejunostomy, was possible, but also esophagojejunostomy, which should be performed in the deep and narrow space of the abdominal cavity, was feasible, such as urethral anastomosis in radical prostatectomy or valve replacement in cardiac surgery, owing to three-dimensional visualization, wristed instruments with seven degrees of surgical freedom, and tremor filtration[14,17,19-21,59].

This technique seems to maximize the advantage for patients with a high BMI, because the length of mini-laparotomy for extracorporeal anastomosis is not "mini" for obese patients[60-65]. This potential benefit of robotic surgery maintains the merits of laparoscopic surgery compared to open surgery, in terms of postoperative pain and cosmesis[48,49,66]. A recent trend in MIS has been an attempt to reduce the length of skin incision, such as NOTES and single incisional laparoscopic surgery, which is also applicable to robotic surgery.

The advantage of advanced movement using robotic arms in inaccessible areas is also an applicable operative procedure for gastric submucosal tumors (SMTs) including GIST located in difficult positions, especially near the gastroesophageal junction or pylorus, preserving gastric capacity[36,37]. If the issues of high cost and long-term oncologic outcomes are resolved, robot-assisted surgery can be an option for management of patients with gastric SMTs.

UNRESOLVED ISSUES

Current evidence suggests that the safety and feasibility of robot-assisted gastric surgery has been established. There are still some unresolved issues related to this new technology[28]. First, the appropriateness of surgery in the oncologic perspective should be secured. It is imperative to determine the long-term oncologic outcomes in order to know the exact role of robot-assisted surgery in gastric cancer, especially for application in AGC. Cost-effectiveness is also an important matter. Second, there is the issue of standardization in the training of surgeons with different laparoscopic experience[16,27,40]. The prior results of robot-assisted gastrectomy are derived from studies of experienced laparoscopic surgeons with a certain level of skill. Therefore, a discussion of how to train surgeons without prior laparoscopic experience is needed. Third, appropriated robotic instruments are necessary. The absence of basic devices, such as a suction-irrigator or endostapler, in robotic surgery demands extra ports and the help of an assistant. Through the development of these instruments, the benefits of robotic surgery can be maximized and combined with other fields, such as single incisional laparoscopic surgery, where the use of a robotic system is possible.

CONCLUSION

Although the current study was limited by its small number of patients and retrospective nature, we found that robot-assisted gastrectomy with lymphadenectomy for the treatment of gastric cancer is technically feasible and safe for experienced laparoscopic surgeons and can produce satisfying postoperative outcomes. Since the oncologic and survival outcomes are the mandatory conclusions in surgical oncology, at least one prospective study comparing open, laparoscopic and robotic gastrectomy and lymphadenectomy is required. Until that time, robot-assisted gastrectomy might be applied very carefully and only in selected patients with Stage Ⅰa and Ⅰb gastric cancer.

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