ABSTRACT

Robotic gastrectomy for gastric cancer relies on innovative technology to provide advanced surgical care for gastric cancer patients. The da Vinci® Surgical system equips surgeons with articulated instruments with tremor elimination and 3-dimensional magnified visualization with which to achieve short-term surgical outcomes for robotic gastrectomy that appear to be comparable to or slightly better than those of laparoscopic gastrectomy. However, limitations of higher costs and longer operation times have yet to be resolved. While the long-term oncologic outcomes of robotic gastrectomy remain inconclusive, they are expected to be similar to those for other approaches. Meanwhile, researchers have continued to explore the real advantages and the applicability of the robotic system for more technically challenging procedures for gastric cancer treatment. To address unsolved issues, well-designed randomized clinical trials and further development of surgical robotic systems are required. In this review, we summarize the current state of robotic gastrectomy for gastric cancer and future perspectives.

Keywords: Stomach neoplasms; Gastrectomy; Robotic surgical procedure

INTRODUCTION

Now 25 years after the first laparoscopic gastrectomy with lymph node dissection was reported [1], laparoscopic surgery for gastrectomy has become an alternative treatment for early gastric cancer [2]. Meanwhile, the recently published Korean Laparoendoscopic Gastrointestinal Surgery Study Group (KLASS)-02 trial demonstrated that laparoscopic distal gastrectomy with D2 lymph node dissection is also beneficial in terms of short-term outcomes for advanced gastric cancer [3], and ongoing randomized clinical trials designed to assess the long-term oncologic outcomes of laparoscopic gastrectomy are anticipated to expand the indications of minimally invasive surgery for gastric cancer.

Since the first report of robotic surgery with the da Vinci® Surgical system [4], there have been 5270 systems installed worldwide, as of June 30, 2019 [5]. An increasing number of studies on robotic gastrectomy and related procedures has also been performed and reported after the first report of robotic gastrectomy in 2003 [6]. To help overcome the limitations of conventional minimally invasive surgery, the da Vinci® Surgical system provides...
surgeons with tremor-filtered, articulated wrist movement with 7 degrees of freedom and with 3-dimensional visualization within the robotic console for performing technically-demanding, minimally invasive surgeries comfortably and accurately. However, robotic gastrectomy has not yet been shown to be cost effective or to offer oncologic safety over laparoscopic or open gastrectomy. In this review, we summarize current evidence and discuss future perspectives of robotic gastrectomy for gastric cancer.

METHODS

We searched and reviewed articles evaluating robotic gastrectomy in comparison to laparoscopic gastrectomy in terms of short- and long-term oncologic outcomes. All of the reviewed articles were written in English and published between December 2003 and September 2019. Articles with data or subgroup analyses duplicated from previously reviewed data were excluded.

SURGICAL PROCEDURE

In the literature, the da Vinci Si® and Xi® systems have primarily been used for robotic gastrectomy, following the standard surgical procedure for conventional laparoscopic gastrectomy. Song et al. [7] described the first 100 consecutive cases of both robotic distal and total gastrectomy for gastric cancer in detail. Therein, 5-ports were used to employ wristed instruments, such as Cardiere and Maryland forceps, and ultrasonic shears for all procedures (Fig. 1). Kim et al. [8] from the same study group reported on a video-guided surgical procedure for radical gastrectomy with D2 lymph node dissection. The authors attempted to standardize the utility of robotic surgical instruments and the surgical procedure for radical gastrectomy. Although the more recent da Vinci Xi® system provides surgeons with several additional technologies, including a unique overhead architecture, rotating boom-mounted arms that are...
slimmer than the previous ones, extended instrument reach, and guided targeting, researchers have failed to show any exclusive differences in surgical outcomes after gastrectomy, compared to those after gastrectomy with the Si system [9]. So far, no reports have been published on the usage of the latest da Vinci SP® system for gastric cancer surgery.

Building on these initial experiences, a few expert surgeons have sought to implement new procedures for gastric cancer, for example, reduced-port robotic surgery. Lee et al. [10] described the initial 20 cases of reduced-port robotic distal gastrectomy with a Single-Site® port and 2 curved instruments, finding it to be both feasible and safe (Fig. 2). In their reduced-port procedure, a 12-mm assistant port can be omitted, with access for an assistant granted via the Single-Site® port; thus, the procedure can be performed with just 2 incisions (Single-Site® and one other port). Seo and his colleagues [11] reported another reduced-port totally robotic distal gastrectomy procedure with an overturned Single-Site® port and 2 additional ports (Fig. 3). In this procedure, only one curved instrument and 2 rigid robotic instruments were utilized. This technique was also found to provide sound operative outcomes and to facilitate the performance of technically-demanding intracorporeal anastomosis [12].

**SHORT-TERM SURGICAL OUTCOMES**

**Operation time**

Reports have consistently indicated that operation times for robotic gastrectomy are longer than those for laparoscopic gastrectomy. The operation times of robotic gastrectomy range from 202 to 439 minutes in the literature [13-34], while those for laparoscopic gastrectomy range from 140 to 361 minutes. The longer operation times for robotic gastrectomy are largely in part due to docking times: after insertion of abdominal ports, the robotic surgical cart is delivered to the patient the robotic arms were aligned. Then, the robotic arms are docked to the abdominal ports, and the surgical instruments are inserted. During surgery,
the surgical instruments are often interchanged, and it takes a few seconds for the console to recognize them. Newer robotic operating systems are expected to show reduced preparation times, including docking time, making the time truly spent on the procedures in robotic gastrectomy comparable or shorter than those for laparoscopic surgery (Table 1).

**Learning curve**

Robotic gastrectomy shows a shorter learning curve than laparoscopic surgery of about 20 cases [35-37]. As robotic surgical systems do not show the same limitations of conventional surgery, it can be easily adopted by experienced surgeons who already have extensive experience in laparoscopic surgery. However, the learning curve for novice surgeons or surgeons who only have experience in open gastrectomy is not well-known. Well-designed prospective studies might be needed to better document learning curves for robotic gastrectomy.

**Blood loss and retrieved lymph nodes**

Generally, robotic gastrectomy has been performed with relatively less blood loss than laparoscopic gastrectomy. According to the literature, blood loss ranges from 26 to 134.5 mL during robotic gastrectomy and from 33 to 152.8 mL during laparoscopic gastrectomy [13-20, 22, 27-29, 32-34]. However, 4 studies showed inconsistent results thereon [13-16], which might be attributable to the usage of different energy devices during lymph node dissection. One study from Japan used Maryland bipolar forceps for lymph node dissection during robotic gastrectomy, but ultrasonic shears during laparoscopic surgery [13]. Another 2 studies reported no significant difference between robotic and laparoscopic groups [14,15]. The remaining study only reported overall P-values for comparisons of robotic, laparoscopic, and open gastrectomy without post hoc analysis [16].

Regarding retrieved lymph nodes, robotic gastrectomy has been found to retrieve a greater number of lymph nodes, ranging from 25 to 44 lymph nodes, than laparoscopic gastrectomy, ranging from 22 to 40 lymph nodes [13-20, 22-34]. Nevertheless, the number
of retrieved lymph nodes can be affected by the extent of lymph node dissection, which varies among studies, and by surgical extent, pathologic examination, and patient factors. Thus, through this review, we could not conclude that robotic gastrectomy is superior to laparoscopic gastrectomy in terms of radicality presented as the number of retrieved lymph nodes. Nonetheless, some experienced surgeons expect that robotic gastrectomy may prove beneficial to performing difficult surgical procedures, such as supra-pancreatic and splenic hilar lymph node dissection, which targets lymph nodes around small, deep-seated, complicated vessels [38]. In a comparative study of splenic hilar lymph node dissection performed in robotic vs. laparoscopic gastrectomy, a robotic procedure yielded a larger number of retrieved lymph nodes in the splenic hilar and supra-pancreatic area.

Table 1. Short-term surgical outcomes of robotic versus laparoscopic gastrectomy for gastric cancer

| Author              | Year | Country | Type of approach (No. of patients) | Type of surgery (TG/STG) | D2 LND | Operation time (min) | Blood loss (mL) | Retrieved LN | Hospital stay | Morbidity (%) | Mortality (%) |
|---------------------|------|---------|-----------------------------------|--------------------------|--------|----------------------|----------------|--------------|---------------|---------------|---------------|
| Pugliese et al. [19]| 2010 | Italy   | Robot (16)                        | Laparoscopy (48)         | 0/16   | 0.18                 | 344            | 90           | 25            | 10            | 6             |
| Kim et al. [20]     | 2010 | Korea   | Robot (16)                        | Laparoscopy (11)         | 0/11   | 3/8                  | 203.9          | 44.7         | 37.4          | 6.5           | 9             |
| Yoon et al. [21]    | 2012 | Korea   | Robot (16)                        | Laparoscopy (65)         | 0/16   | 2/14                 | 259.2          | 30.3         | 41.1          | 8.8           | 16.7          |
| Kang et al. [22]    | 2012 | Korea   | Robot (100)                       | Laparoscopy (282)        | 16/84  | 32/68                | 202            | 93.2         | -             | 9.8           | 14            |
| Kim et al. [23]     | 2012 | Korea   | Robot (346)                       | Laparoscopy (861)        | 109/37 | -                    | 226            | 40.2         | 7.5           | 9.6           | 0.4           |
| Park et al. [24]    | 2012 | Korea   | Robot (30)                        | Laparoscopy (120)        | 0/30   | -                    | 218            | 60           | 35            | 7             | 17            |
| Hyun et al. [15]    | 2013 | Korea   | Robot (38)                        | Laparoscopy (83)         | 9/29   | 24/14                | 234.4          | 131.3        | 32.8          | 10.5          | 47.3          |
| Huang et al. [25]   | 2014 | Taiwan  | Robot (72)                        | Laparoscopy (73)         | 8/64   | 5/67                 | 357.9          | 79.6         | 30.6          | 11            | 12.5          |
| Junfeng et al. [26] | 2014 | China   | Robot (120)                       | Laparoscopy (394)        | 26/32/2(PG) | 118/361/15(PG) | 221.3          | 137.6        | 32.7          | 7.9           | 4.3           |
| Noshiro et al. [27] | 2014 | Japan   | Robot (21)                        | Laparoscopy (160)        | 0/160  | 79/61                | 439            | 96           | 44            | 8             | 9.5           |
| Han et al. [28]     | 2015 | Korea   | Robot (68)                        | Laparoscopy (68)         | 68(PGG) | -                    | 258.3          | -            | 33.4          | -             | 19.1          |
| Seo et al. [29]     | 2015 | Korea   | Robot (40)                        | Laparoscopy (40)         | 0/40   | 22/18                | 243            | 76           | 40.4          | 6.7           | 27.5          |
| Yoon et al. [30]    | 2015 | Korea   | Robot (16)                        | Laparoscopy (20)         | 0/20   | 11/9                 | 271.9          | -            | 44.3          | 11.4          | 12.5          |
| Kim et al. [18]     | 2016 | Korea   | Robot (223)                       | Laparoscopy (211)        | 42/160/1(PG)/20(PGG) | 30/167/1(PG)/2(PGG) | 226            | 50           | 33            | 6             | 30            |
| Kim et al. [31]     | 2016 | Korea   | Robot (87)                        | Laparoscopy (288)        | 0/87   | 8/79                 | 248.4          | -            | 37.1          | 6.7           | 5.7           |
| Nakauchi et al. [13]| 2016 | Japan   | Robot (84)                        | Laparoscopy (437)        | 27/57  | 35/49                | 378            | 44           | 40            | 14            | 2.4           |
| Cianchi et al. [17] | 2016 | Italy   | Robot (30)                        | Laparoscopy (41)         | 0/30   | 5/28                 | 312.6          | 99.5         | 39.1          | 9.5           | 13.2          |
| Parisi et al. [16]  | 2017 | International | Robot (151) | Laparoscopy (131) | 40/111 | 8/143                | 365.4          | 117.9        | 27.8          | 8.9           | 17.9          |
| Lu et al. [32]      | 2018 | China   | Robot (101)                       | Laparoscopy (101)        | 66/35  | 1/100                | 226.6          | 26           | 38            | 11.9          | 3             |
| Liu et al. [33]     | 2018 | China   | Robot (100)                       | Laparoscopy (303)        | 40/58  | 3/47                 | 240            | 100          | 40.9          | 11            | 5             |
| Gao et al. [14]     | 2019 | China   | Robot (163)                       | Laparoscopy (163)        | 60/72/30(PG) | 60/103 | 232.2          | 109.5         | 29.3          | 7.6           | 1.8           |
| Ye et al. [34]      | 2019 | China   | Robot (99)                        | Laparoscopy (106)        | 99/0   | 0/99                 | 203.9          | 134.5        | 25.8          | 8             | 7.5           |

TG/STG, total gastrectomy/subtotal gastrectomy; LND, lymph node dissection; LN, lymph node; PG, proximal gastrectomy; PPG, pylorus preserving gastrectomy.
Less blood loss and a larger number of retrieved lymph nodes suggest that robotic gastrectomy may be technically easier and oncologically safer than conventional laparoscopic gastrectomy. However, the true role of robotic surgery for gastric cancer still remains an unexplored area, and whether the advantages above transfer to improved long-term oncologic outcomes should be addressed in future studies. The potential benefits of robotic gastrectomy should be investigated in various conditions under well-designed clinical trials in order to justify wider application of robotic gastrectomy.

**Morbidity**

Due to considerable heterogeneity in the designs of studies published in the literature, it is difficult to conclude the impact of robotic gastrectomy on surgery-related morbidity and mortality. Generally, robotic gastrectomy has been reported to show a morbidity rate similar to that for laparoscopic gastrectomy (0% to 47.3%, robotic, vs. 1.3% to 38.5%, laparoscopic) [13-34]. Nevertheless, a single-center study in Japan reported that robotic gastrectomy was a protective factor in terms of postoperative complications [39]. Although most studies have reported no mortality cases with robotic or laparoscopic gastrectomy, mortality rates of 3.3% for robotic gastrectomy and 4.9% for laparoscopic gastrectomy were reported by an Italian group comparing robotic with laparoscopic gastrectomy for D2 lymph node dissection [17]. Based on the results of these studies, we suggest that robotic gastrectomy does not show results superior to laparoscopic gastrectomy in terms of morbidity and mortality.

**Cost**

Robotic gastrectomy, until now, has only been conducted with the da Vinci® system, and issues related to cost are a problem. Two studies have documented comparative results of the cost between robotic and laparoscopic gastrectomy: one multicenter prospective study in Korea indicated that the difference in cost was about 4,500 USD [18]; the difference in the other retrospective study in China was 5,300 USD [14]. Investigations into the impact of robotic gastrectomy on the costs associated with post-discharge events, encompassing complication-related readmission and quicker return to work after recovery, may support the cost effectiveness of robotic gastrectomy.

**LONG-TERM OUTCOMES**

Evidence of the oncologic safety of robotic gastrectomy for gastric cancer is limited, and only retrospective data have been published for long-term oncologic outcomes after robotic gastrectomy (Table 2). Among available results, 3-year overall survivals were reported to range from 76.1% to 86% for robotic gastrectomy and from 79.8% to 88.8% for laparoscopic

| Author          | Year | Country | Type of approach/ No. of patients | Stage (I/II/III) | 3YDFS | 3YOS | 5YDFS | 5YOS |
|-----------------|------|---------|----------------------------------|-----------------|-------|------|-------|------|
| Pugliese et al. [19] | 2010 | Italy   | Robot (16) / Laparoscopy (48)    | - / -           | 78    | -    | -     | -    |
| Nakauchi et al. [13] | 2016 | Japan   | Robot (84) / Laparoscopy (437)   | 49/19/16 / 280/80/71 | 86.9  | 86.9 | -     | -    |
| Obama et al. [40] | 2017 | Korea   | Robot (311) / Laparoscopy (311)  | 252/29/30 / 267/25/19 | -    | 90.7 | 93.2  | -    |
| Gao et al. [14]  | 2019 | China   | Robot (163) / Laparoscopy (163)  | 0/57/106 / 0/63/100 | 73    | 76.1 | -     | -    |

YDFS, year disease free survival; YOS, year overall survival.

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gastrectomy. In one study, 5-year overall survival rates were 93.2% for robotic gastrectomy and 94.2% for laparoscopic gastrectomy [13,14,19,40]. Making any conclusions on these data is difficult due to the various pathologic stages included in these studies. While we presume that the oncologic outcomes of robotic gastrectomy will not prove inferior to laparoscopic gastrectomy, more long-term results are required, particularly those for the oncological safety of robotic gastrectomy and those associated with the benefits of superior lymph node dissection.

FUTURE PERSPECTIVES

Recent studies have sought to document additional benefits for robotic gastrectomy in cases in which laparoscopic gastrectomy can be challenging, for instance, advanced gastric cancer, upper third or esophagogastric junction cancer, obese patients, and remnant stomach cancer. Reduced-port gastrectomy is an example thereof and has been implemented by experienced surgeons seeking to overcome the technical limitations of reduced-port laparoscopic gastrectomy [41-44].

Initial experiences with reduced-port robotic gastrectomy have been described [10,11]. Therein, the Single-Site® system was used to relocate multiple instruments, including the camera, into a 2.5-cm periumbilical incision. In these initial reports, intra-corporeal gastroduodenostomy was able to be readily performed with acceptable short-term surgical outcomes [11,12]. Showing a better postoperative clinical course, reduced-port gastrectomy using a robotic surgical system is expected to improve upon reduced-port laparoscopic gastrectomy.

Fluorescent image-guided robotic surgery with indocyanine green has been introduced for cancer surgery and has been used to visualize lymphatics in the surgical field. Recently, image-guided robotic gastrectomy was reported [45]. In this study, the surgeons were able to retrieve more lymph nodes by using fluorescent lymphography than by not, and the noncompliance rate of D2 lymph node dissection was low. More meticulous lymph node dissection with robotic fluorescent lymphography may improve long-term oncologic survival. Although lymphography is also available and is being used in laparoscopic surgery, surgeons can change images readily via the robotic console during a robotic procedure, and the finer movements of the robotic instruments can enhance lymph node dissection.

CONCLUSION

Robotic gastrectomy for gastric cancer shows similar surgical outcomes to laparoscopic gastrectomy. Higher cost and longer operation times have yet to be resolved. More competition and cheaper robotic surgical systems may help to achieve advanced surgical care at a justifiable cost for more patients.

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