Indications for surgery

Laparoscopic gastric surgery is gaining popularity in Japan as well as worldwide, although laparoscopic surgeries are still less than 30% of the total. A laparoscopic wedge resection [3], laparoscopic intragastric resection [4], and laparoscopy-assisted distal gastrectomy [5] were devised and developed in Japan. The Japanese Gastric Cancer Association (JGCA) issued the first version of gastric cancer treatment guidelines in March 2001 [6]. This article aims to outline the treatment guidelines for doctors' reference outside Japan.

These guidelines provide standardized indications for the optimal treatment modalities according to the clinical stage of each patient (Table 1), but do not deal with the technical aspects of treatment. The survival time is the primary endpoint of treatment results, although relief of symptoms, tremor shrinkage, and quality of life are also considered as secondary endpoints. Recommendations for daily practice are listed in the guidelines, and some promising but not yet confirmed treatment modalities such laparoscopic procedures are also recommended for clinical investigation. According to these stage-oriented treatment indications, the indication for laparoscopic gastric surgery is Stage IA and Stage IB (see Table 1). That is

Table 1
Stage-oriented treatment indications

	N0	N1	N2	N3
T1 (M)	**IA** EMR (diff.; < 2.0 cm, UL [-]) MGA	**IB** MGB (< 2.0 cm) Standard (>2.1 cm) LADG	**II** Standard	**IV** Extended Palliative Chemotherapy Radiotherapy Terminal care
T-1 (SM)	**IA** MGA (diff. < 1.5 cm) MGB Local res, LADG			
T2	**IB** Standard LADG	**II** Standard	**IIIA** Standard	
T3	**II** Standard	**IIIA** Standard	**IIIB** Standard Extended (+D3)	
T4	**IIIA** Extended	**IIIB** Extended	**IV**	
H1, P1 CY1, M1 Recurrence	**IV**			

Abbreviations: CY1, cancer cells on peritoneal cytology; EMR, endoscopic mucosal resection; H1, liver metastasis; M, mucosa; M1, distant metastases other than the peritoneal, liver, or cytological metastases; MGA, modified gastrectomy A; MGB, modified gastrectomy B; LADG, Laparoscopy-assisted distal gastrectomy; P1, perotoneal metastasis.

T1 or T2, and N0 or N1, and M0 according to the Japanese classification of gastric carcinoma [7].

Available treatment modalities for gastric cancer

The following treatment modalities are presently available for gastric cancer: endoscopic mucosal resection (EMR); laparoscopic gastrectomy; modified gastrectomy A (MGA) and B (MGB); standard gastrectomy; extended gastrectomy; chemotherapy; radiotherapy; and multimodality therapy, including neoadjuvant and adjuvant chemotherapy, immunochemotherapy, hyperthermochemotherapy, also a treatment for terminal patients. A standard gastrectomy is a procedure consisting of a resection of more than two thirds of the stomach. It includes a proximal, distal, or total gastrectomy associated with a D2 dissection according to the size and location of the tumor. A modified gastrectomy is a resection of less than two thirds of the stomach. The difference between MGA and MGB is the extent of lymph-node dissection. MGA is associated with a lymph-node dissection of D1 + No. 7 and No. 8a only when a cancer lesion is located in the lower part of the stomach, whereas MGB is associated with a lymph node dissection of D1 + No. 7, 8a, and 9. An extended gastrectomy is associated with either a combined resection of other organs, or a D3 dissection in addition to a standard gastrectomy.

Stage-oriented treatment indications

The following guidelines show the treatment indications according to the clinical stages (see Table 1).

Stage IA (T1 N0)

EMR or a modified gastrectomy is indicated at this stage. EMR is indicated in patients with small mucosal cancer and no lymph node metastasis. It is reported that intestinal type mucosal cancer measuring less than 2 cm in diameter has no lymph node metastasis. An en-bloc resection is preferable because of a risk of residual cancer left behind after EMR. The upper limit of an en-bloc resection is for lesions measuring 2 cm in diameter.

Mucosal cancer that does not meet the above-mentioned conditions is treated by a modified gastrectomy A. A modified gastrectomy A is also indicated for differentiated submucosal cancer lesions measuring less than 1.5 cm in diameter. Submucosal cancer that does not meet this condition should be treated by a modified gastrectomy B.

Stage IB (T1N1, T2N0)

Either a modified gastrectomy B or standard gastrectomy is indicated for Stage IB cancer, according to the T and N categories. If a T1N1 tumor measures less than 2.0 cm in diameter, then a modified gastrectomy B is indicated, whereas a T1N1 tumor larger than 2.0 cm or T2N0 tumor is treated by a standard gastrectomy.

Stage II (T1N2, T2N1, T3N0)

A standard gastrectomy is indicated for Stage II cancer regardless of the T and N categories.

Anatomical indications

A laparoscopic wedge resection (Fig. 1) is indicated for small early cancer (T1N0, Stage IA) that is not associated with lymph node metastasis and is located in the anterior wall of the gastric body (Fig. 2). The greater curve or the posterior wall of the gastric body is technically operable, but requires special techniques. The lesser curve, the cardiac area, and the pyloric area, which are difficult to approach and to obtain a sufficient cancer free margin in, are not indicated for a laparoscopic wedge resection, but are indicated for a laparoscopic intragastric resection.

A laparoscopic intragastric resection (Fig. 3) is indicated for small early cancer (T1N0, Stage IA) that is located in the cardiac area, posterior area, pyloric area, or lesser curve of the stomach.

A laparoscopy-assisted distal gastrectomy (LADG) is indicated for Stage IA and Stage IB cancer. If surgeons have sufficient technical skill to perform a D2 dissection, they might be able to perform a laparoscopic standard gastrectomy regardless of the anatomy, size of the tumor, histological type, or depth of wall invasion. Surgeons should keep in mind, however, that such laparoscopic procedures remain controversial and have not yet been generally accepted. Informed consent should be obtained from all patients and prospective clinical trials still need to be performed before these surgical procedures can gain general acceptance.

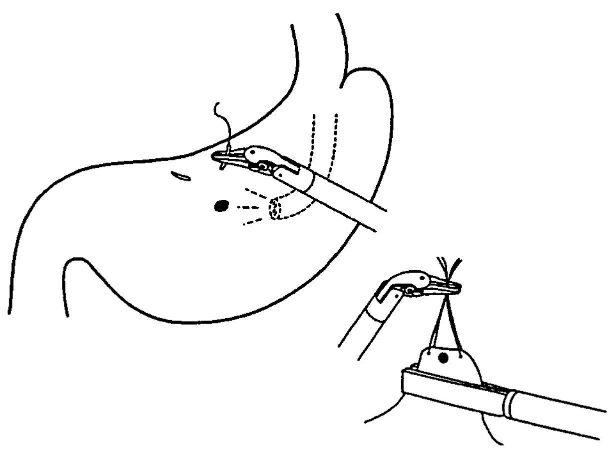


Fig. 1. Schematic drawing of a laparoscopic wedge resection: Under direct vision via an endoscope in the stomach, a few stitches through the whole layer of the stomach are placed as a marker to obtain a definite cancer free margin (*left*). While holding the sutures with the tip of the forceps, the lesion is cut with an endoscopic stapler (*right*).

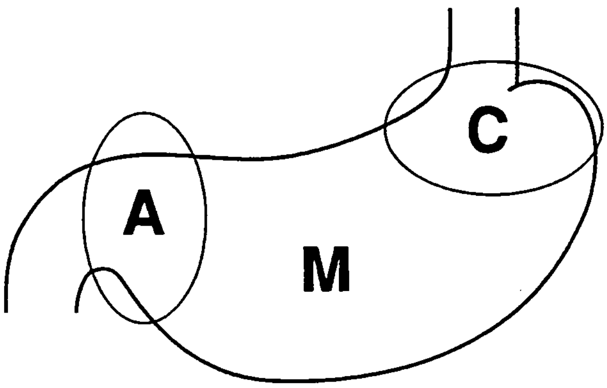


Fig. 2. Indications according to the site of the lesion: The early gastric cancer lesion located within the mucosal layer is indicated to undergo either an endoscopic mucosal resection (EMR) or a laparoscopic resection. The cardiac area (*C*) and antral area (*A*) where an endoscopic or laparoscopic wedge resection is difficult are good indications for a laparoscopic intra-gastric resection, while the anterior wall of the gastric body (*M*) is an indications for a laparoscopic wedge resection.

Necessity of the robotic surgical system for endoscopic gastric surgery

The development of endoscopic or minimally invasive surgical techniques has reduced both patient morbidity and mortality. Performing surgery through small incisions or ports reduces the infection rates, the amount of required pain medication, and the recovery time. In addition, the quality of life in patients with early gastric cancer is reported to be significantly better after laparoscopic procedures than after open surgery [8].

The principal disadvantage of conventional endoscopic technique is that it is difficult to precisely control the conventional endoscopic instruments, due to limitations in the movement of the instruments, the visualization of

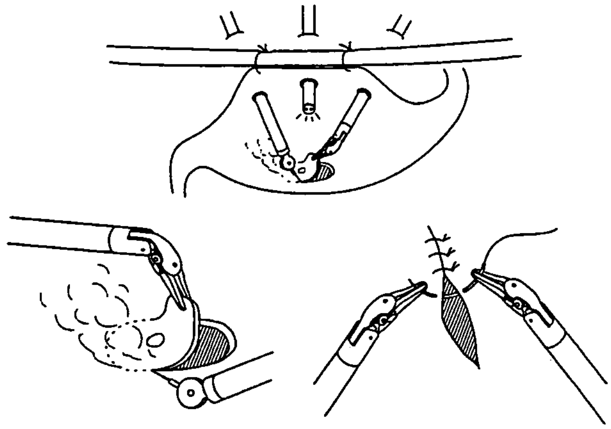


Fig. 3. A schematic drawing of an intragastric resection: The early gastric lesion that is located within the mucosal layer at the cardia, antrum, or posterior area of the stomach is easily resected in this manner (*upper*). A sufficient area with cancer and a cancer free margin is removed (*left*) and the remnant mucosa is approximated and sutured if necessary (*right*).

the operative field, and the haptic input. For complex minimally invasive procedures to become more widely adopted by surgeons, significant improvements must therefore be made in the operating environment.

The da Vinci Intuitive Surgical Endoscopic Instrument Control System facilitates the process of performing endoscopic surgery. The system provides: 1) an intuitive translation of the instrument handle to the tip movement, thus eliminating the mirror image effect; 2) scaling; 3) tremor filtering; 4) coaxial alignment of the eyes, hands, and tool tip image; and 5) an internal articulated endoscopic wrist, providing an additional three degrees of freedom. This computer-enhanced surgical system thus allows surgeons to overcome various difficulties during endoscopic surgery.

Preparation of the robotic system

The position of the patients is the same as that in conventional endoscopic surgery. After the induction of unconsciousness by anesthesiologists, the robotic system is set-up by the mechanical engineers and nurses. The three robotic arms on the surgical cart are wrapped with transparent, clean sheets. The surgical cart and the robotic arms are positioned on the same side of the lesion in each case. The whole computer system is set up and the camera-vision system is prepared.

The operating room setup is shown in Fig. 4. The surgeon's console, surgical cart, and vision cart are set up. The operator, assistants, and nurses are positioned on the same side and the surgical cart and vision cart are positioned on the opposite side so that the operator can see the same two-dimensional TV monitor as the other staff members, and thereby improve the degree of cooperation with the assistants. A telementoring system established with a use of 3 Integrated Services Digital Network (ISDN) is also useful for communicating with other doctors outside the operating room as well as for education and training.

The EndoWrist instruments used in robot-assisted gastric surgery are the small and large forceps-type (Cadiere's forceps) EndoWrist, needle holder-type EndoWrist, scissors-type EndoWrist, spatula-type and hook-type electrocoagulator (monopolar) EndoWrist, bipolar-type electrocoagulator EndoWrist, ultrasonically activated dissecting coagulator, 3-0 vicryl atraumatic needle, 2-0 silk of 8 cm to 10 cm in length, 30-mm and 60-mm endoscopic staplers, an endoscopic retractor, a large bag for retrieval, and conventional endoscopic instruments for the assistants.

Intraoperative management of the patients

The patient is operated on in the supine position. A 20° head-up tilt is applied. A nasogastric tube and urinary catheter are inserted. Antibiotic prophylaxis is given as a single dose intravenously at the time of induction.

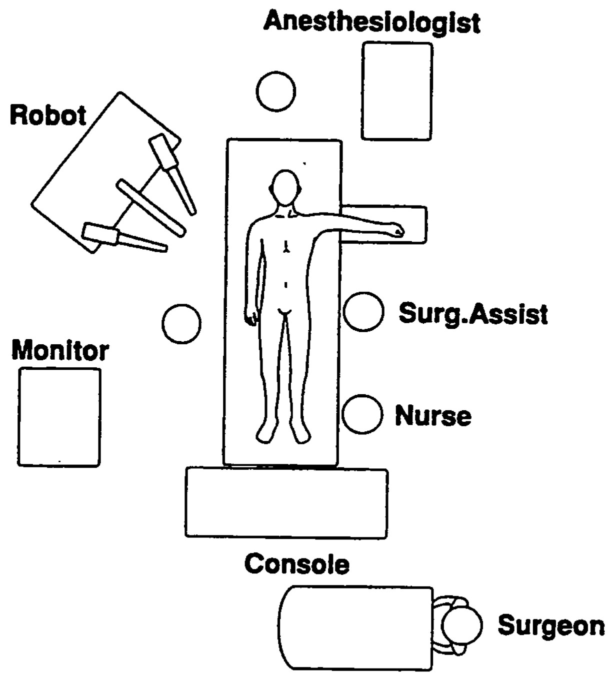


Fig. 4. Operating room: The surgical cart with active robotic arms and camera holder is placed on the right side of the patient. The console in front of which the operator sits and operates is put at the foot of the patient. It is important that the operator and the surgical assistant can see the same monitor from the same direction to share the same optical information.

General anesthesia is administered with endotracheal intubation. Endotidal CO2 is monitored.

After pneumoperitoneum has been made under a minimal open laparotomy, three 10-mm to 12-mm ports are inserted for the camera and operation arms by the surgical assistants. The distance between the two ports for the operation arms is more than 14 cm (Fig. 5). The camera port is inserted at the site closer to the lesion that is to be removed than in conventional endoscopic surgery. One or two additional ports measuring 10 mm to 12 mm in diameter are also inserted when necessary on a case-by-case basis. This provides maximal flexibility in the insertion of endoscopic staplers, which require at least a 12-mm port size through the assistant port site. Fig. 5 shows the position of the laparoscopic ports. A laparoscopic local resection can be performed with only the two robotic arms, without any assistant ports.

Surgical technique assisted with the robotic surgical system

Wedge resection

The anterior wall of the gastric body is one of the most frequently indicated sites when the early small cancer is localized (see Fig. 2). The port

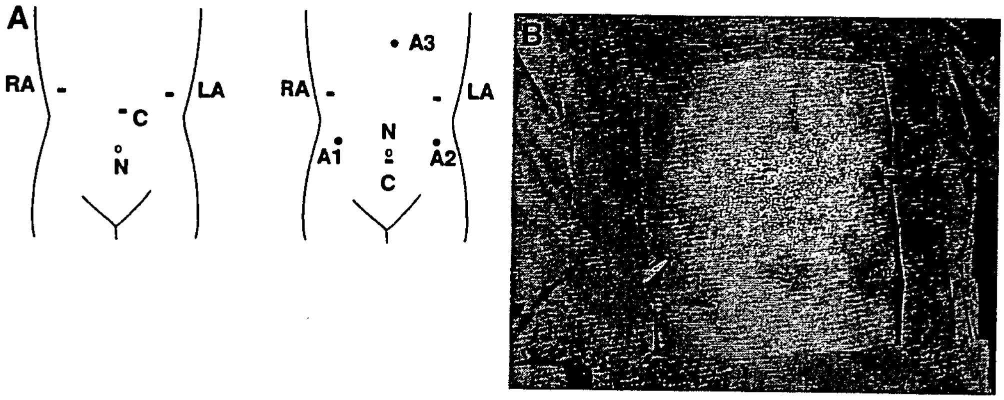


Fig. 5. Skin incision (*A*): The left side shows the position of the skin incision for a wedge resection or intragastric resection, while the right side shows the position for a laparoscopic distal gastrectomy (*B*). C, camera; RA, right robotic arm; LA, left robotic arm; A1, A2, A3, assistant trocars; N, navel.

sites are shown in Fig. 5. Only three ports are needed for this procedure: one is for a camera port and the other two are for operation arm ports. The camera port is inserted at the site closer to the lesion. Under a direct vision with an intragastric gastroscopy the cancer lesion is oriented to the configuration of the stomach and identified on the surface. When the resection line is across the greater curve, the mobilization and dissection of the greater curve should be performed. The individual branches of the epiploic vessels supplying the greater curve are dissected out, clipped, and transected close to the edge of the stomach.

A T-fastener is inserted into the stomach or a few stitches are put in the whole layer of the gastric wall to obtain a sufficient cancer-free margin with a distance of more than 1 cm (see Fig. 1). While lifting the strings up with both robotic hands of EndoWrist forceps, an endoscopic stapler is applied by an assistant to transect the gastric lesion. The specimen is inserted into a bag and then is taken out of the abdominal cavity through a port site.

The merit of using the robotic system in this laparoscopic wedge resection is that it is easily performed by placing a few stitches through the whole layer of the stomach as a landmark of the transection line, because of the articulations attached with the EndoWrist of the needle holder. Otherwise it is difficult to catch the whole layer with one forceps and not let the stomach wall slip between the mucosal layer and the seromuscular layer, and to put a precise puncture into the gastric wall with a needle and not leave any remnant cancer cells.

Intragastric resection

The cardiac area, posterior area, pyloric area, and lesser curve sites for a laparoscopic intragastric resection are indicated when small early cancer is localized and when it is hard to operate on the cancer lesion using an intraluminal fiberscopic approach. The position of the port sites of three robotic arms is the same as those in a laparoscopic wedge resection (see Fig. 5). The anterior wall of the stomach is first fixed to the abdominal wall with a few stitches between the whole layer of the stomach and the abdominal wall. Three trocars are inserted into the stomach, as shown in Fig. 3; one is for a camera port and the other two are for the operation arm ports.

First, the cutting line with a cancer-free margin of more than 1 cm in distance is marked with an electrocoagulator-type EndoWrist. While lifting the mucosal layer up with a forceps-type EndoWrist, the cancer lesion is cut off from the gastric wall with a hook-type electrocoagulator EndoWrist.

The merits of using the robotic system in this laparoscopic intragastric resection is that the resection can be easily done in any area except the anterior wall of the stomach, and it is also easy to approximate the cut stumps with a suture using a needle holder-type EndoWrist (see Fig. 3). Regardless of the direction, both cutting and suturing are easily performed with this system, and the movements are very precise, thanks to the articulations of the EndoWrist and the three-dimensional vision system.

Distal gastrectomy

A distal gastrectomy is one of the standard gastrectomies. A standard gastrectomy includes a resection of more than two thirds of the distal stomach associated with a lymph node dissection of D2. A modified gastrectomy A and B are defined as a procedure in which less than two thirds of the stomach is associated with a lymph node dissection of No. 7 or No. 8a plus D1 dissection (D1 + alpha), or with a lymph node dissection of No. 7, 8a, and 9 plus a D1 dissection (D1 + beta), respectively. The total procedure of distal gastrectomy can now be performed with the da Vinci system in the same fashion as during open surgery.

According to the Guidelines of the Japanese Gastric Cancer Association, a laparoscopy-assisted distal gastrectomy is indicated for Stage IA and Stage IB cancer. As a result, a modified gastrectomy and standard gastrectomy may be possible laparoscopic procedures for gastric cancer as well as a laparoscopic wedge resection or laparoscopic intragastric resection. Less invasive, simpler, and easier procedures are recommended in the beginning. In addition, all patients should be well informed regarding robot-assisted gastric surgery. Small early gastric cancer is a good indication for these procedures.

The patient is placed in a supine position and a 20° head-up tilt is applied. The skin incisions are made as shown in Fig. 5. Three assistant ports are necessary to maintain the operative field and to support the surgeon. The size of the port should be at least 12 mm for maximal flexibility when inserting the endoscopic staplers.

A diagnostic laparoscopy is performed to orientate the configuration of the stomach and identify the cancer on the surface. Gastroscopy is useful for identifying the location of the cancer site on the surface. The greater curve of the stomach is picked up with the assistant EndoBabcock forceps, stretched out, and lifted anteriorly. The greater omentum is dissected from the transverse colon with an ultrasonically activated coagulator on a case-by-case basis. The individual branches of the epiploic vessels supplying the greater curve are dissected out, clipped, and transected close to the edge of the stomach. The dissection is performed about two-thirds up the greater curve proximally and down to the pylorus distally. The proximal part of the right gastroepiploic artery is doubly ligated with 2-0 silk using a forceps-type EndoWrist and cut at the same time a lymph node dissection is performed.

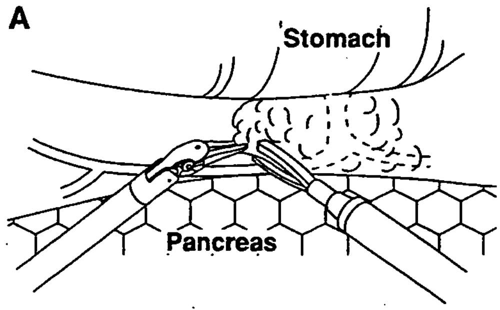
The posterior wall of the first portion of the duodenum should be adequately dissected to provide enough space for a safe transection with an endoscopic stapler. The small vessels on the inferior and posterior surface, and the superior angle of the first portion of the duodenum should be carefully dissected with a hook-type electrocoagulator EndoWrist. The right gastric artery is dissected out, clipped or ligated, and transected.

To transect the duodenum safely, the endoscopic stapler (30 mm or 60 mm) inserted through a left lower assistant port is positioned transversely across the duodenum so that both blades of the stapler protrude beyond the superior border, while both forceps of the robotic arms are used to pull the distal stomach and the duodenum against the hilt of the stapler jaws.

After transecting the duodenum, the distal stomach is mobilized from the median to the left upper quadrant space to obtain a clear operative view. The lesser omentum is dissected through the least vascular areas close to the liver and the regional lymph node dissection is performed along the hepatic artery and the left gastric artery with a hook-type electrocoagulator EndoWrist (Fig. 6) or ultrasonically activated dissecting coagulator-type EndoWrist. The left gastric artery and vein are doubly ligated with a 2-0 silk by using the forceps-type EndoWrist (Figs. 7, 8).

The distal stomach is transected at the middle of the gastric body, with the endoscopic stapler (60-mm) through the left lower assistant port. The transection line should leave about one third of the stomach. Both the superior and inferior angles of the duodenum and the stomach are approximated and anchored with a suture, and both stumps of the stomach and the duodenum are clamped with a conventional endoscopic long forceps inserted through right and left lower assistant ports. To complete anastomosis of the remnant stomach with the duodenum, whole-layer suturing and seromuscular suturing are performed completely in the abdominal cavity with a 3-0 vicryl atraumatic needle, using the needle holder-type EndoWrist in a manual fashion (Figs. 9, 10).

The surgical specimen is put into a plastic bag and then is taken out of the abdominal cavity through the left lower assistant port site with a 3 cm extension (Figs. 11, 12). A completely total endoscopic distal gastrectomy with reconstruction using the Bilroth I method is then completed using the da Vinci system.



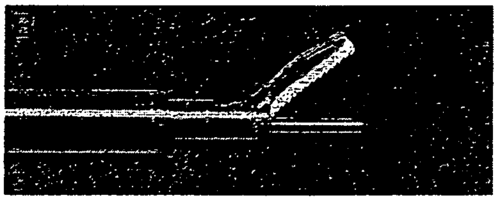


Fig. 6. Lymph node dissection. (*A*) A lymph-node dissection is easily performed under a magnified, clear vision. An ultrasonically activated coagulating dissector (*B*) is a very useful tool for both dissecting the gastrointestinal tract and for performing lymph-node dissection.

These procedures of intestinal anastomosis as well as lymph node dissection can be easily performed using the robotic system. All procedures can be done as well in the abdominal cavity as those in open surgery. It is not necessary to take the cancer-diseased stomach out of the abdominal cavity until all procedures have been completed. The complicated procedures such as anastomosis, ligature, and lymph node dissection can be done safely even in the deep and narrow spaces of the abdominal cavity.

Techniques of hemostasis in robotic surgery

Intraoperative bleeding is the major complication in endoscopic surgery that leads to a conversion to conventional open surgery. The technique of hemostasis is a very important aspect of laparoscopic surgery. The articulation of the EndoWrist makes it possible for us to freely ligate and suture in the narrow abdominal cavity with few limitations in the movement

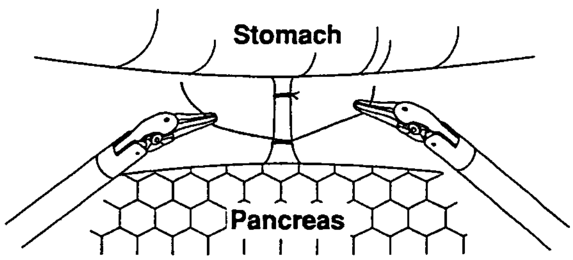


Fig. 7. Vascular ligation. The important vessels are sufficiently exposed and doubly ligatured in a manual fashion even if they are located in the deep, or narrow area of the abdominal cavity.

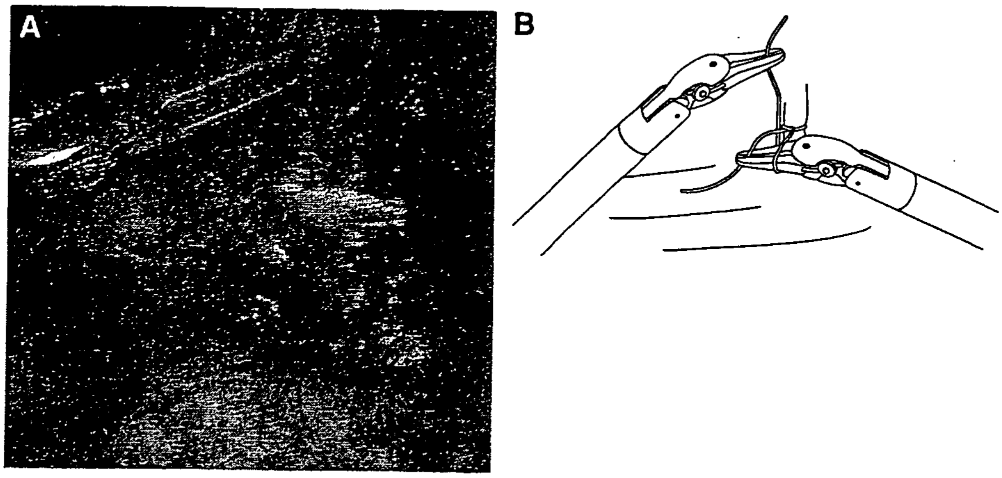


Fig. 8. The ligation of the left gastric artery is shown (*A, B*).

of the instruments, thus resulting in a good hemostasis. New instruments such as the bipolar electrocoagulator and ultrasonically activated dissecting coagulator (see Fig. 6B), which are commercially available for robotic surgery, are very useful for performing gastrointestinal (GI) tract surgery. Almost all dissections of the omentum and the mesenterium along the GI tract are easily done and safely performed with these new instruments.

The support of assistants is still necessary to complete robotic surgery at present. While the bleeding vessel is caught with the forceps-type EndoWrist of the robotic arm by the surgeon, an assistant can insert an endoclip, string for ligatures, or an electrocoagulator through the assistant port to help the surgeon perform hemostasis. The surgeon can more clearly and definitely identify and easily catch the bleeding vessels using this robotic system than in conventional endoscopic surgery without such a robotic system. This is mainly due to the fact that the robotic system provides a three-dimensional view and has few limitations in the movement of the instruments.

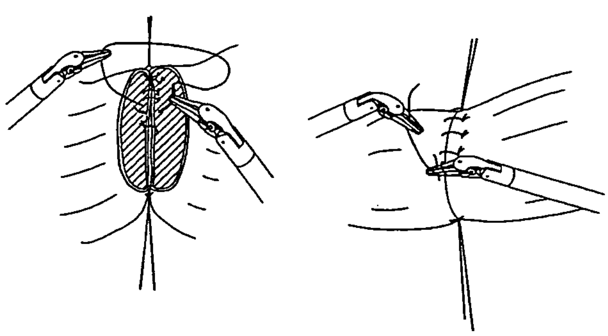


Fig. 9. Suturing. Distal gastrectomy with a reconstruction by Billroth I method. Suturing in all directions (*left*) is performed as easily as in open surgery. Whole layer suturing or seromuscular layer suturing is smoothly done in a manual fashion. The ligature technique is also performed as easily as in open surgery (*right*).

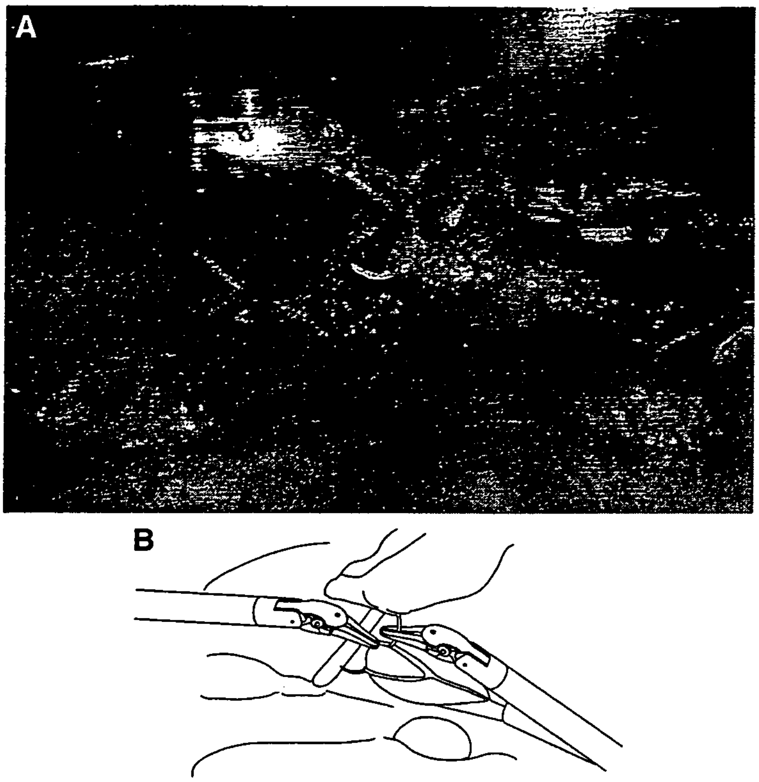


Fig. 10. Suturing of the whole layer of the remnant stomach with the duodenum (*A*, *B*).

Pitfalls in robotic surgery

Breakdown of the system

The one troublesome aspect regarding the da Vinci system is the breakdown of the wire for the EndoWrist, even though the company guarantees the instrument to be usable for at least 10 patients. A mechanical breakdown of the devices or computer system power outages tend to be the major problems in robotic surgery. Surgeons should always be ready to

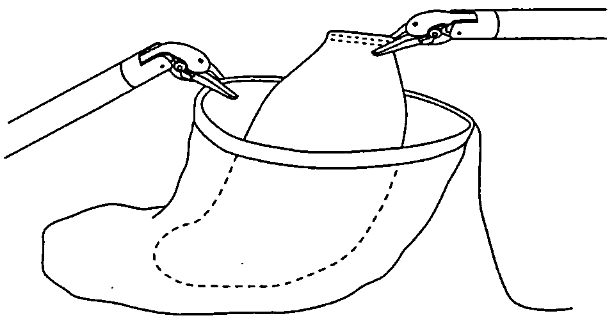


Fig. 11. The resected specimen (two thirds of the distal stomach) is inserted into a large sac with a long string.

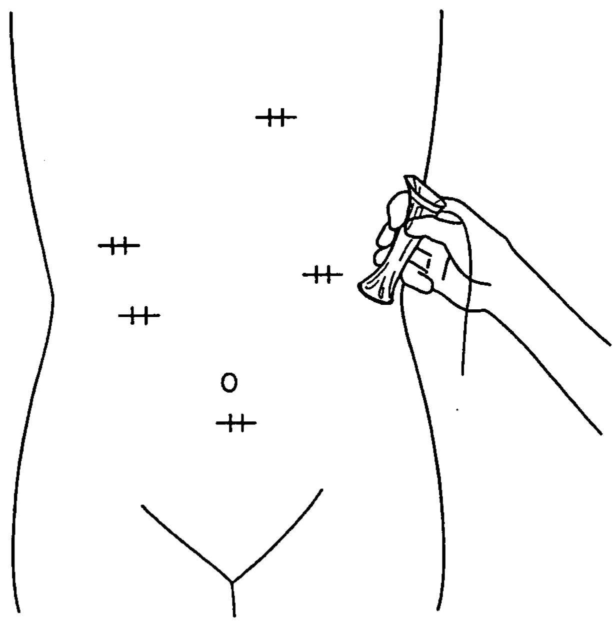


Fig. 12. Retrieval of the specimen. The large sac with the specimen is taken out of the abdominal cavity through a slightly extended skin incision at the left lower lateral abdomen.

change over to conventional open or endoscopic surgery when necessary, and all patients should be aware of this possibility when giving their informed consent. It is very important for us to know what security system is used in case of problems. A special engineer who is familiar with the system should always be on standby.

Loss of sensation

It is difficult for the operator to get a sufficient feel for the extent of tightening up the ligatures. Therefore, ligatures can easily break due to a loss of tension feedback. We accidentally caught the GI tract in one case at the highest power level and thereby caused a slight degree of tissue damage. It is much easier using the da Vinci system for us to catch the strings and to precisely place the needle than in conventional endoscopic surgery; a high degree of experience and good eye coordination is required for the operator to determine how tight to tie a ligature.

Difficult communication

Communication among the operators and the assisting staff members remains the major problem in telemanipulation surgery in comparison to conventional endoscopic surgery. Because the robotic system still needs assistants, including surgical assistants, engineers, scrub nurses, and anesthegiologists, a communication system that is fully supported by both software and hardware should be clearly established among them.

New strategy for future robotic surgery

Training

New robotic surgery needs a special team consisting of doctors, nurses, engineers, and anesthesiologist. The team should undergo sufficient training on how to use the robotic system, operation system, and safety system. New training systems for the surgical procedures should also be established to allow surgeons to master the practical procedures with a computer simulation system. In the near future there may be some doctors who will have no experience in open surgery because minimally invasive surgery may become more popular and replace open surgery all over the world.

Practical use

The present robotic system is huge in size and conventional operation rooms have no space to keep such a giant machine. The robotic system is now being continually modified to decrease its size. It is not always necessary to use the robotic system for all endoscopic procedures, but it is more practical to use this robotic system only where the system is required to overcome technical difficulties in conventional endoscopic surgery. The merits of using this robotic system are that this system allows us to perform more precise and safer operative techniques in a minimally invasive way. Numerous new operative procedures are awaited to enable us to overcome some of the difficulties in conventional surgery.

New technology

The present robotic system does not yet have a navigation system like that available in car navigation systems. To develop and make robotic surgery safer and more popular, it is mandatory to develop a navigation system and also make the system smaller. The future navigation system would show the vascular structures of the organs or tumor location overlaying on the actual vision. Augmented reality or virtual reality techniques will make it possible to prepare or plan the operative procedures, to provide real-time biological information on the patient, or to make a prognosis of the operative results on a computer screen before or during the actual surgery.

Summary

In conclusion, robot-assisted gastric surgery is now considered to be feasible in patients with Stage IA (T1N0) and Stage IB (T1N1, T2N0) early gastric cancer. The optimal treatment modalities have yet to be identified, however, and therefore clinical trials are called for. The authors believe that this new technology will markedly increase the survival rate of such patients all over the world in the near future, while also helping to significantly decrease the complication rates and hospital stay of the patients, which will thus result in a major beneficial socioeconomic impact.

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3. 医療ロボットの臨床応用

3.1 腹部手術への応用

はじめに

21世紀の医療は，患者さんに優しい医療を目指すよくいわれます。特に，外科治療は患者に負担の少ない低侵襲治療へと大きく変わろうとしています[1]。低侵襲治療は，できるだけ小さな傷口で従来と同等ないしはそれ以上の治療効果を発揮して病気を治し，術後の痛みを少なくして，早期に回復させ，早期社会復帰を図ろうとするものです。従来の治療に比べ，患者のQuality of Life（QOL，生活の質）を重視した治療法といえます。

「患者さんに優しい医療」とは，1）患者さんに精神的，肉体的な苦痛を与えない，2）生活の質（QOL）を悪くしない，3）安全でかつ確実な治療である事と考えています。これを実現するには，まず「医療の質」を向上させる必要があります。

低侵襲治療法には，遺伝子治療，細胞療法，再生医療，内視鏡的治療法など様々な分野が含まれます。手術支援ロボットは，これらの内，内視鏡的治療法のひとつに位置づけられるもので，コンピュータを用いて，人の力だけではできない，より精密な操作や，アクセス困難な場所でのアプローチを可能とします。結果として，より効果的で，安全な治療の達成を支援します[2-4]。本稿では，腹部外科領域で用いられている最新の手術支援ロボットの動向について紹介します。

3.1.1 内視鏡下外科手術の限界

一般外科領域において，1990年代より全世界で爆発的に普及した内視鏡下外科手術は，患者にとって負担が少なく，かつ早期回復が見込め，入院期間も短く，医療経済的にもコスト削減に貢献できることから，現在では，一般外科手術の約30％以上が内視鏡的に治療される時代となりました。胆嚢摘出術では実に95％以上が内視鏡的に行われています。この他に，呼吸器外科，乳腺内分泌外科，整形外科，産婦人科，小児外科領域など外科領域全体の総症例数は年間約6万件に上ります（図1）。

しかし，内視鏡下外科手術は，二酸化炭素で気腹した狭いスペースの中で，内視鏡に映し出された限られた視野を二次元画像で観察しながら，自由度の少ない鉗子を用いて操作しなければなりません。開腹術のように術者の思い通りに手術を行うことは極めて困難といえます。従って，充分な開腹術での経験がなく，入念な術前計画を立てず，内視鏡下外科手術の訓練も受けずに手術を執刀する場合には，手術ミスや，術中合併症を起こす危険性があります。

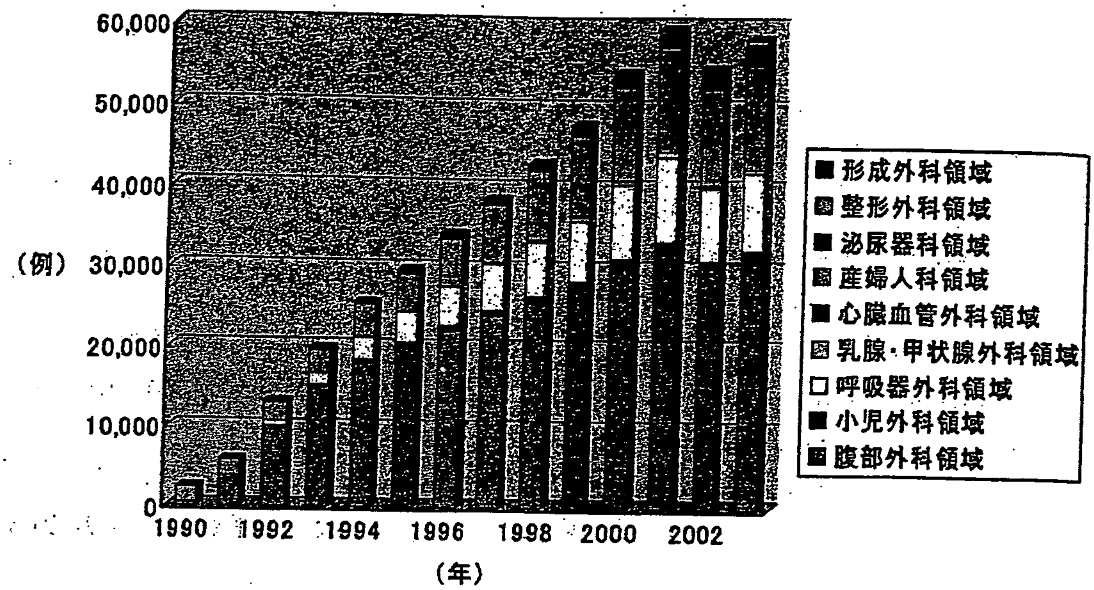

図1　領域別の内視鏡外科手術総症例数の推移

3.1.2　技術的困難の克服

内視鏡下外科手術の現状の問題点を打破するためには,

(1) 鉗子の自由度をあげる

(2) 内視鏡の視野を広げ解像度をあげる

(3) 力覚や触覚情報を提供する

などが考えられますが，これは，従来の外科手術の教育訓練を受けた外科医の観点からみた意見です。

今後，未来型医療を実現するためには,

(1) 従来，外科医の手ではできなかったことを可能とする (super-hand)

(2) 従来，外科医の目では見えなかったものを可視化する (super-vision)

(3) リアルタイムな生体情報をオンデマンドに提供する

(4) 治療計画のためのシミュレーションなどヴァーチャルリアリティを実現する

などの新しい技術革新が必要と考えます。外科の基本手技である把持，剥離，結紮，切離，切除などの操作を解析し，外科治療の最終目的を新たな観点から見直し，手術器具や手術手技を創意工夫する必要があります。

3.1.3 手術支援ロボット

内視鏡下外科手術の技術的問題点の解決策の一つが，この手術支援ロボットです。患者と外科医の間に高機能を備えたコンピュータ支援のインターフェースが介在し，従来の手法よりも，より安全で確実な手術手技が可能となります。現在，世界中で臨床応用されている手術支援ロボットとしては，ゼウスやダビンチなどがあります。

3.1.3.1 ナビオット

ナビオット（図2）は，純日本製の腹腔鏡把持支援ロボットで，日本学術振興会未来開拓学術研究推進事業で開発した技術を用いて製作されました。平成14年に，厚生労働省より医療用具としての認可を受けた，日本初の手術支援ロボットです。東京大学の土肥・佐久間・小林氏らによる開発と，九州大学による臨床試験，日立製作所による製品化までの間には，何度もやり直しを繰り返しながら実現した産学連携の賜です。グッドデザイン賞に輝き，現在，腹部外科や胸部外科のみならず，産婦人科や泌尿器科などにおいてもひろく使用されています。

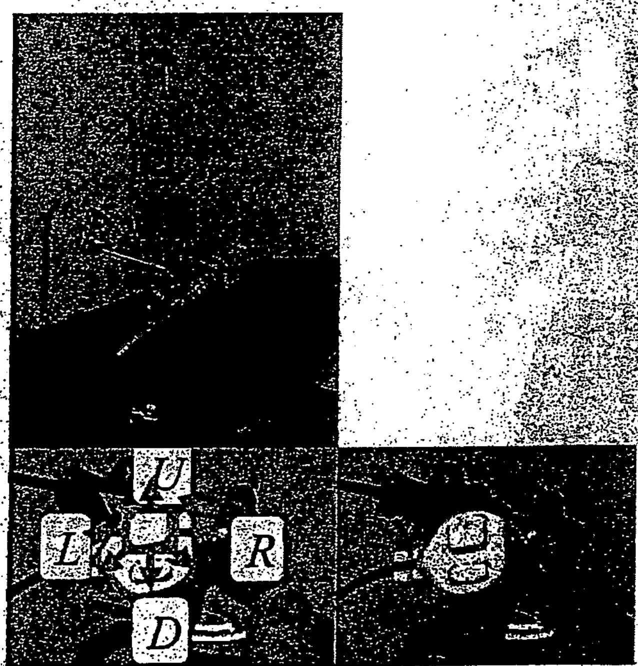

図2　Naviot：腹腔鏡把持支援ロボット（上図）で，鉗子に設置されたボタン式インターフェースを用いて内視鏡を8方向に自在に動かしたり，拡大や縮小も可能。

ボタン式のインターフェースが鉗子に取り付けられ，外科医が自らの指先で操作して自分が欲する視野を自らの手で即座に出すことが可能です。ズーム機能が付いているため，カメラ先端が臓器に接したり，返り血で見えなくなったりすることがありません。内視鏡を持つ医師は必要でなく，外科医一人での手術（ソロサージャリー）が可能となりました。

3.1.3.2　ゼウス

ゼウス（図3）は，米国Computer Motion社が開発したマスタースレーブ型の手術支援ロボットで，スレーブマニピュレータは，内視鏡把持ロボットと2本の鉗子把持ロボットの計3本からなり，各アームを手術台横のレールに設置して，遠隔から操作します。術者は，偏光メガネをかけると，テレビモニターの画面を3次元で見ることができます。

鉗子は，直径5mmで，先端に関節を有します。全体として6自由度で，トレーニングを受けることで，比較的自在に縫合結紮を行うことが可能です。

図3　Zeus：術者は偏光メガネをかけ，手術台に設置されたスレーブマニピュレータを操作しているところ

わが国では，大阪大学，東北大学，九州大学の他，いくつかの民間病院に導入されています。Computer Motion社が，Intuitive Surgical社に買収され新たにゼウスを販売しなくなったことから，今後の普及が危ぶまれますが，将来ダビンチと合体し，マイクロサージャリーに特化した手術支援ロボットが誕生するのではないかと期待されます。

3.1.3.3 ダビンチ

ダビンチ（図4）は，ゼウスと同様，米国Intuitive Surgical社が開発したマスタースレーブ型手術支援ロボットです。世界中ですでに約300台が稼動しており，全症例数は30,000例を越えます。この内，約200台以上が米国で，次にヨーロッパが多く，アジアでは各国に1-2台程度の普及にとどまっています。このような欧米での活発な活動を背景に，平成16年10月には国際ロボット手術学会（The 1st International Meeting for Minimally Invasive Robotics Association）が開催されました。

術者は，手洗いをする必要はなく，コンソール（操作卓）の前に座ってこれを覗くと患者の体内を立体的に見ることができます。鉗子は7自由度を有するため，開腹術と同様な感覚で，運動制限を感ずることなく，自在に操作を行うことができます。

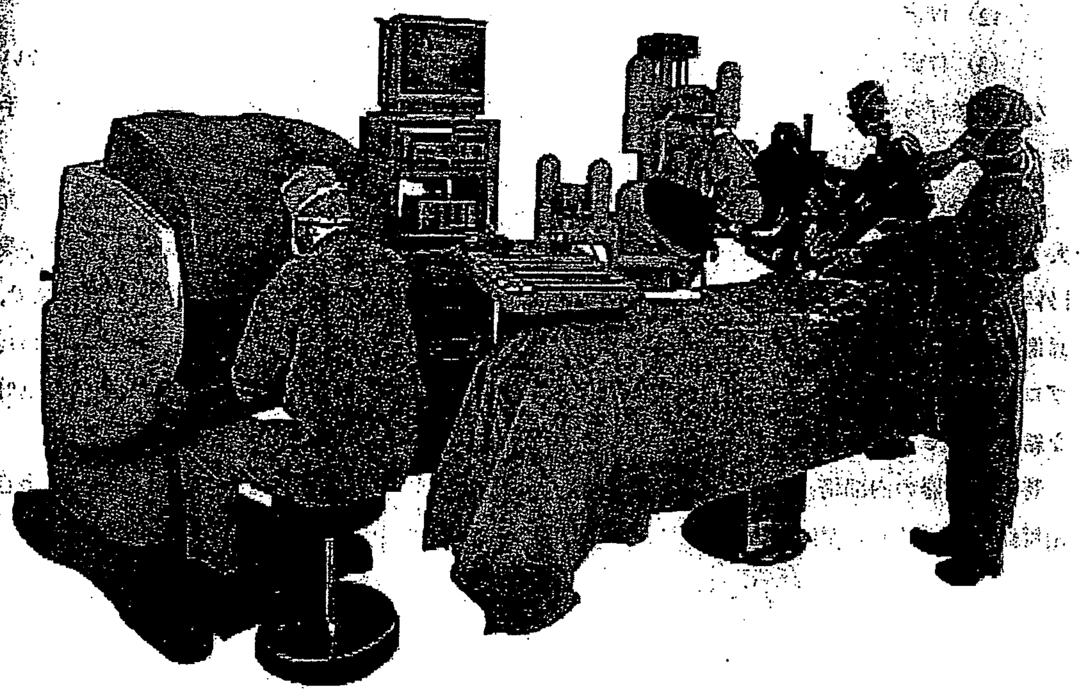

図4　da Vinci：術者がコンソール（左）の前で操作をし，surgical curt（右）のスレーブマニピュレータを動かして手術を行っているところ