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The Developments and Achievements of Endoscopic Surgery, Robotic Surgery and Function-preserving Surgery

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The breakthrough in laparoscopic surgery has been the development of a charge-coupled device camera system and Mouret performing cholecystectomy in 1987. The short-term benefits of laparoscopic surgery are widely accepted and the long-term benefit of less incidence of bowel obstruction can be expected. The important developments have been the articulating instrumentation via new laparoscopic access ports. Since 2007, single-incision laparoscopic surgery has spread all over the world. Not only single-scar but also no-scar operation is a current topic. In 2004, Kalloo reported the flexible transgastric peritoneoscopy as a novel approach to therapeutic interventions. In 2007, Marescaux reported transvaginal cholecystectomy in a patient. The breakthrough in robotic surgery was the development of the da Vinci Surgical System. It was introduced to Keio University Hospital in March 2000. Precision in the surgery will reach a higher level with the use of robotics. In collaboration with the faculty of technology and science, Keio University, the combined master–slave manipulator has been developed. The haptic forceps, which measure the elasticity of organs, have also been developed. The first possible sites of lymphatic metastasis are known as sentinel nodes. Otani reported vagus-sparing segmental gastrectomy under sentinel node navigation. This kind of function-preserving surgery will be performed frequently if the results of the multicenter prospective trial of the dual tracer method are favorable. Indocyanine green fluorescence-guided method using the HyperEye charge-coupled device camera system can be a highly sensitive method without using the radioactive colloid. 'Minimally invasive, function-preserving and precise surgery under sentinel node navigation in community hospital' may be a goal for us.

Key words: quality of life – endoscopic surgery – laparoscopic surgery – laparoscopy-assisted distal gastrectomy (LADG) – gastrointestinal mesenchymal tumors (GIMT) – gastrointestinal stromal tumors (GIST) – single-incision laparoscopic surgery (SILS) – natural orifice transluminal endoscopic surgery (NOTES) – robotic surgery – pylorus-preserving gastrectomy (PPG) – sentinel node navigation surgery – indocyanine green (ICG) – fluorescence

INTRODUCTION

'Great surgeon, great incision', there are some of the most important words we were taught in the first several years of our surgical training. The words told us the importance of securing the comfortable circumstance including adequate operation field in order to perform a quality operation. On the other hand, the words sound paradoxical on the assumption that surgeons have a conscience about incising the human body. Since patients complain of long-term pain of the operation scar, it is obvious that a smaller incision means a better sense of satisfaction of patients. Patients do compare the sizes of their operation scars. These are probably the simple reasons why endoscopic surgery has become major part of surgery. With the accumulation of experience in endoscopic surgery, surgeons are realizing that endoscopy enables us to perform precise surgery. Robotic surgery is

the tool for seeking a more precise and accurate operation.

Function-preserving surgery is the earnest approach to obtain a 'better life' of patients. The words 'quality of life' comprehends patients' sense of values. Coming back alive from the struggle against cancer itself enhances the patients' sense of satisfaction. It is not easy to compare the quality of life after the operation. However, scientists can have an insight into function after the operation and it is important to seek the 'better life' of patients. This is probably the reason why function-preserving surgery is still developing.

In this article, the authors intend to overview the developments and achievements of endoscopic surgery, robotic surgery and function-preserving surgery.

ENDOSCOPIC SURGERY

In 1881, Yukichi Fukuzawa, founder of Keio University (Tokyo, Japan), published an article entitled 'Progress in Medicine'. 'In future, technology of the endoscopy will be developed. Dorsal surface of the uterus, rectum, urinary bladder and stomach will be observed by inserting slender equipment. Medicine will be developed by surgery'. He predicted future achievements of the endoscopic surgery. Kelling (1) reported the laparoscopic observation in 1901. Then, the trocar with a non-return valve was developed by Jacobaeus in 1910 followed by Hopkins' report of laparoscopy with the Rod Lens System in 1954 (2). Gynecologic surgery was performed using abdominal insufflators and endo-loop by Semm (3). In 1985, Muhe performed laparoscopic cholecystectomy in Germany. The breakthrough in laparoscopic surgery was the development of laparoscopy with a charge-coupled device camera system and Mouret (4) performing cholecystectomy in 1987. Laparoscopic cholecystectomy quickly spread all over the world.

ENDOSCOPIC GASTRIC SURGERY

The first endoscopic surgery for gastric cancer was distal gastrectomy (laparoscopy-assisted distal gastrectomy; LADG) performed by Kitano et al. (5) (Japan) in 1991, 1 year after Yamakawa performed the first case of laparoscopic cholecystectomy in Japan. However, the number of institutions that perform LADG did not increase before the development of the ultrasonic scalpel. Surgeons tried to resect the stomach without an ultrasonic scalpel in the early 1990s. Using the lifting bar inserted beside the lesion, laparoscopic wedge resection of the stomach was performed by Ohgami et al. (6) (Ohgami's method, lesion-lifting method). The authors postulated (7) in 1997 that laparoscopic wedge resection of the stomach can be considered a first-line treatment for gastrointestinal mesenchymal tumors including gastrointestinal stromal tumors (GIST) (7). However, it was reported (8) in 2005 as expert agreement (National Comprehensive Cancer Network; level 2A), that laparoscopic surgery should be avoided, owing to the higher risk of tumor rupture and subsequent peritoneal seeding. After that, data reported by Otani et al. (9) and four other articles (10–13) showed that laparoscopic gastric resection for GIST is a feasible option.

Technical and instrumental developments in laparoscopic surgery have increased the number of LADG in the 2000s. Two meta-analyses (14,15) published in 2010 showed that the short-term outcome of LADG for patients with early gastric cancer is superior to the open procedure. It is now widely accepted that LADG results in lesser blood loss, is less painful and is associated with a low risk of complications. Moreover, some single-center studies showed low incidence of adhesion-related bowel obstruction after laparoscopic surgery (16,17). The long-term benefit of less incidence of bowel obstruction can be expected and we need to wait for further investigations.

SINGLE-INCISION LAPAROSCOPIC SURGERY AND NATURAL ORIFICE TRANSLUMINAL ENDOSCOPIC SURGERY

In 1992, Pelosi and Pelosi (18) reported the single-puncture laparoscopic appendectomy. However, a breakthrough in single-incision laparoscopic surgery (SILS) was the development of the articulating or bent instrumentation via new laparoscopic access ports capable of allowing several instruments to be inserted through different cannules of a single port. Since 2007, SILS has quickly spread all over the world and many operations including repair of inguinal hernias (19), splenectomy (20), sleeve gastrectomy (21) and cholecystectomy (22) have been reported; there has also been an accumulation of experience in colonic and gastric surgeries. Not only a single-scar but also no-scar operation is a topic of interest with minimally invasive surgery. In 2004, Kalloo et al. (23) reported the flexible transgastric peritoneoscopy as a novel approach to diagnostic and therapeutic interventions in the peritoneal cavity. Natural orifice transluminal endoscopic surgery (NOTES) is the concept that the peritoneal cavity can be accessed through natural orifices. In 2005, the Natural Orifice Surgery Consortium for Assessment and Research (NOSCAR) was established as a working group of the American Society for Gastrointestinal Endoscopy (ASGE) and Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) to study and evaluate NOTES. Transgastric, transcolonic and transvaginal approaches were examined by animal studies (24–26). Then, in 2007, Marescaux et al. (27) reported a NOTES cholecystectomy in a patient. However, clinical experience remains limited as current technological capacity is not enough. We may need to wait for technical and instrumental developments in the near future.

ROBOTIC SURGERY

In the history of endoscopic surgery, instrumental developments have been breakthroughs in spreading new surgery. It is obvious that engineering enhance the development of the surgery. Medicine and engineering combined research has always been important topic for the last few decades. The voice-controlled camera holder, AESOP (Computer Motion Inc.) was the first robot marketed in 1994. Jacobs et al. (28) reported the clinical appreciation of the robot. Ohgami et al. (29) and Kitajima et al. (30) also introduced the AESOP robot; and 3-D endoscopy (Fig. 1A), head mount display (Fig. 1B) cooperative telesurgery system (Fig. 2) and virtual reality educational system were developed in collaboration with the faculty of technology and science, Keio University. The breakthrough in robotic surgery was the development of the da Vinci Surgical System (31) (Intuitive Surgery, Inc.) (Fig. 3), classified as a master–slave surgical system. It uses true 3-D visualization and EndoWrist®. It was approved by the FDA in July 2000 for general laparoscopic surgery, and in November 2002 for mitral valve repair surgery. It provides several advantages to conventional laparoscopy such as 3-D vision, motion scaling, intuitive movements, visual immersion and tremor filtration. In March 2000, the da Vinci System was introduced to Keio University Hospital (32); and cholecystectomy, Heller–Dor operations for achalasia and Nissen's fundoplication for reflux esophagitis were performed without any adverse event. However, the equipment of the da Vinci System is large and the operator needs to sit apart from the patient. In collaboration with the faculty of technology and science, Keio University, the combined master–slave manipulator, which can be used as forceps, has been developed (33). Since currently available master–slave manipulators cannot recognize the elasticity of organs or tissues, the haptic forceps using linear motors which measure the elasticity of organs have also been developed (Fig. 4). The use of the haptic forceps enables the measurement of disruption limit values of organs to be measured, and the device could be useful for setting safety limits when grasping organs during endoscopic surgery (34). Using the haptic forceps, 'telesensation' between Japan and Slovenia was demonstrated (Fig. 5).

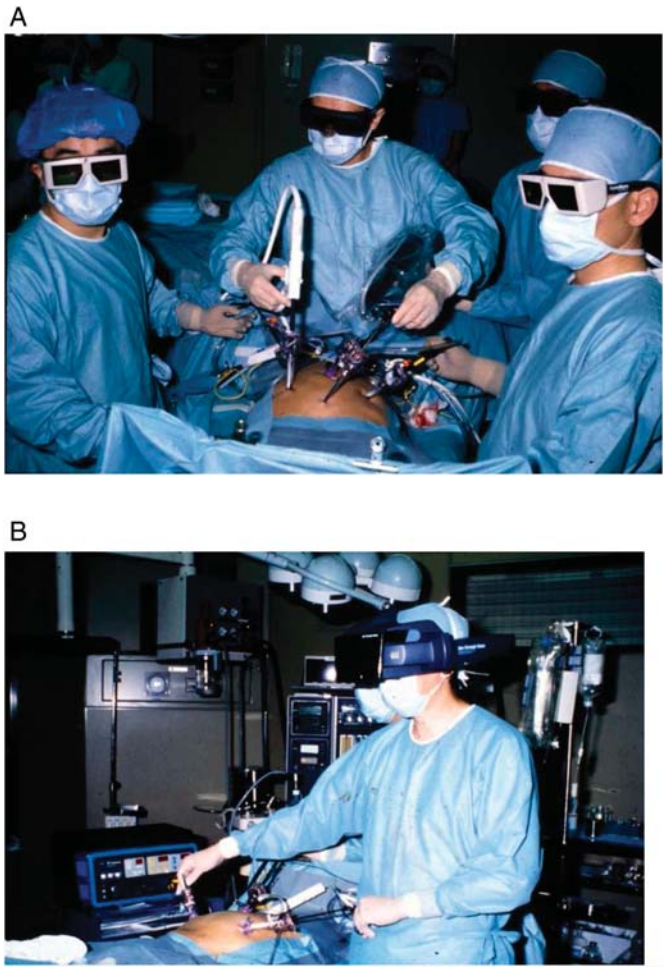

Figure 1. (A) Three-dimentional laparoscope. (B) Head mount display.

FUNCTION-PRESERVING SURGERY

'Function preserving' is a vague word. What surgeons preserve is organ, a part of organ and/or nerve. The aim of the preservation is sustainment of functions. For the most part, function-preserving surgery is a part of modified surgery aiming to preserve functions. Authors reported that Roux-en-Y reconstruction after distal gastrectomy, in comparison to Billroth-I anastomosis, preserve the function and form of the cardia (35). This can also be recognized as function-preserving surgery. The aim of surgery is important for this category. In gastroenterological surgery, there are many kinds of function-preserving surgery including larynx-preserving esophagectomy (36) for cervical esophageal cancer, vagal-sparing esophagectomy (37), vagus nerve-preserving gastrectomy (38), pylorus-preserving gastrectomy with or without preserving pyloric and hepatic branches of the vagal nerve (39), pylorus-preserving pancreaticoduodenectomy (40), duodenum-preserving pancreatic head resection (41), intersphincteric resection for low rectal tumors (42) and external sphincteric resection (43). In comparison with distal gastrectomy, pylorus-preserving gastrectomy was reported to have fewer subjective postprandial symptoms (44) and is associated with a low incidence of cholecystolithiasis and reflux esophagitis.

Most of the function-preserving surgery is modified surgery with smaller resection area. The application of the function-preserving surgery can be wider if intra-operative lymph node metastasis detection is highly sensitive. Sentinel node navigation surgery is a possible breakthrough in modified surgery including function-preserving surgery. The first possible sites of metastasis along the route of lymphatic drainage from the primary lesion are known as sentinel nodes. The dye-guided and radioisotope-guided methods are common methods for detecting sentinel nodes. In most

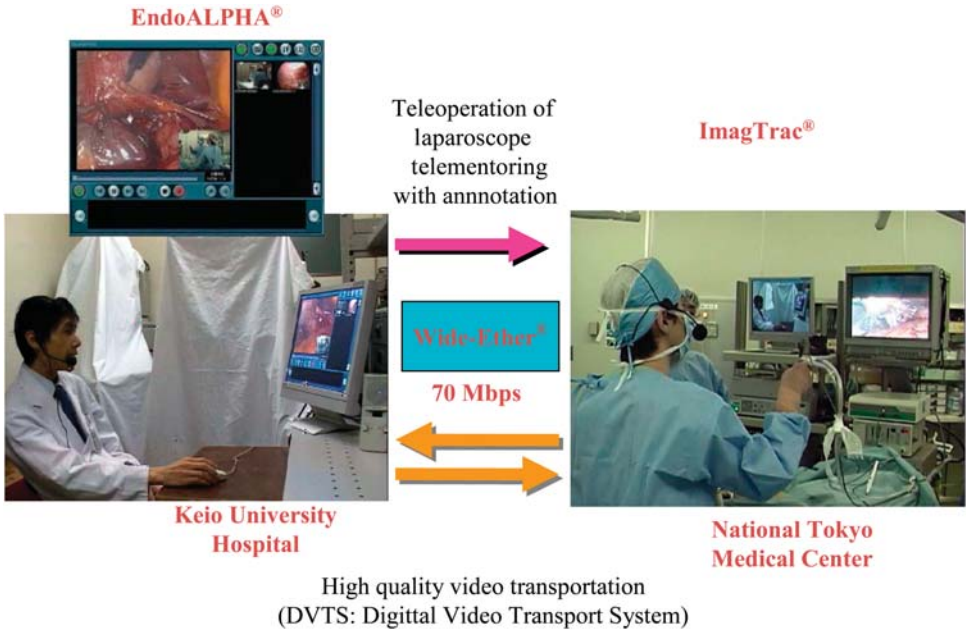

Figure 2. Cooperative telesurgery system.

Figure 3. da Vinci System.

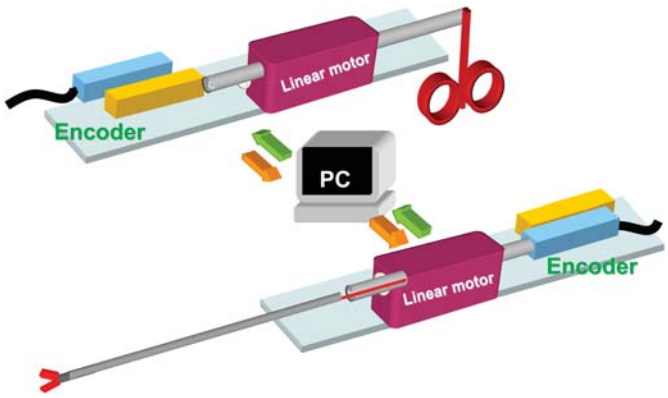

Figure 4. The haptic forceps consist of linear motors and encoders.

reports (45) on gastric cancer, detection rates of sentinel nodes were 91–100% regardless of the methods. The dye method is a simple method that can be conducted in a community hospital without special equipment. However, it is unsuitable for long-time observation, deep layer observation and back table observation. The sensitivity of the dye method tends to be low. The reported sensitivity of the radioisotope + dye method (dual tracer method) was 92–100%. A study group in the Japan Society of Sentinel Node Navigation Surgery is conducting a multicenter prospective trial of sentinel node mapping by a dual tracer method with blue dye and radioactive colloid and the results are expected to be shown in the near future. Otani et al. (46) reported vagus-sparing segmental gastrectomy under sentinel node

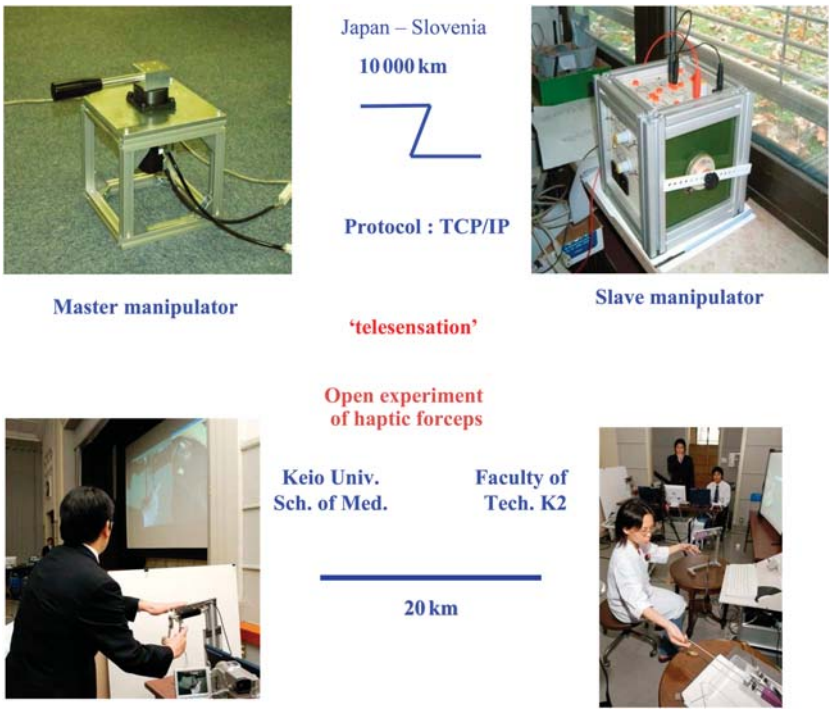

Figure 5. 'Telesensation' was demonstrated by bilateral teleoperation experiment over internet communication (Japan–Slovenia).

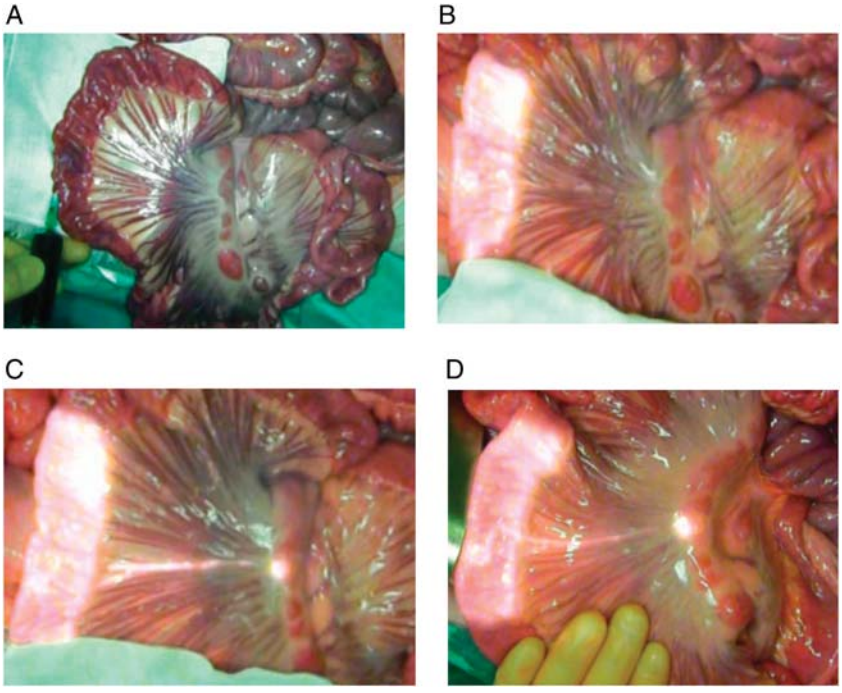

Figure 6. HyperEye charge-coupled device camera system is suitable for long-time observation. (A) Injection of indocyanine green. (B) Indocyanine green flowed into a lymphatic vessel. (C) A sentinel lymph node detected. (D) Two hours after the injection.

navigation. This kind of function-preserving surgery will be performed frequently if the results of the multicenter prospective trial are favorable.

Furthermore, we investigate the new method guided by indocyanine green fluorescence, which can be conducted in a community hospital without the approved area for injection of the radioactive colloid. In comparison with the ordinal dye-guided method, the indocyanine green fluorescence-guided method is more sensitive and allows visualization of the lymph nodes when indocyanine green is injected the day

before surgery (47). The available detection system for indocyanine green fluorescence is gray scale imaging and requires a dark room. The operation is interrupted during the observation of the fluorescence. Kochi University (Prof Sato and his group) developed a new device, HyperEye charge-coupled device camera system, for indocyanine green fluorescence (Fig. 6). This system can simultaneously detect color and near-infrared rays and can be used under bright light. The operation can be continued, simultaneously, under the guidance of indocyanine green fluorescence. This device was developed for intra-operative graft assessment in cardiovascular surgery (48). In cooperation with Kochi University, the authors made an appraisal of the effectiveness of the device to the sentinel node detection in digestive surgery. Experiment with swine showed that this system may be suitable for deep layer observation, long-time observation (Fig. 1) and back table observation. Indocyanine green fluorescence-guided sentinel node sampling can be performed under light. Further investigation is expected for clinical use.

CONCLUSIONS

Minimally invasive surgery is going to be minimal-scar surgery, even no-scar surgery. In addition, endoscopic surgery enables surgeons to perform precise surgery. Precision in surgery will reach a higher level with the use of robotics. It is likely that sentinel node navigation surgery will be a breakthrough in function-preserving surgery. A simple and sensitive sentinel node detection method that can be conducted in community hospital is required. 'Minimally invasive, function-preserving and precise surgery under sentinel node navigation in community hospital' may be a goal for us.

Conflict of interest statement

None declared.

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