Hurdles and highlights in the development of a novel robotic platform for endoscopic surgery

Jennie Y.Y. Wong,1 Khek-Yu Ho1,2,*

Abstract

Natural orifice transluminal endoscopic surgery (NOTES) is viewed by many as one of the most disruptive shifts in surgical practices in recent years. NOTES changes the approach to surgery in such a fundamental way that it poses an enormous challenge to current endoscopic technologies that were not designed to support NOTES. Implementation of NOTES necessitates transformative innovations with capabilities far beyond what incremental technology changes can provide. To address this unmet demand, innovators around the world have been working on new designs for instruments, each with its unique features and ability to mitigate specific technical challenges encountered in performance of NOTES. However, to date, most new inventions are still modeled on conventional endoscopy platforms. The MASTER-SPACE stands out as being the only approach that uses robotics to radically change the way endoscopic interventions are conducted. With robotics enhancement, MASTER-SPACE addresses some of the most critical technical issues hindering further development of NOTES. Here we describe the basis for the innovation of MASTER-SPACE, progress since design conception, and provide some insights on its further development, the success of which, we think, could be key to accelerating the advancement of NOTES.

Keywords: Endoscopic technology, Natural orifice transluminal endoscopic surgery, Robotics-enhanced endoscopic surgery

Introduction

Natural orifice transluminal endoscopic surgery (NOTES) represents a paradigm shift in surgical approach whereby surgical targets in the peritoneal cavity are accessed via natural body orifices and surgical procedures are conducted entirely through the endoscope. The approach eliminates the need to make external incisions on the body and thus promises no somatic pain and better cosmetic results. However, NOTES is technically more complex and more difficult to perform than laparoscopic surgery. This is primarily because surgical tools must be navigated through tortuous access routes and surgical instruments must be manipulated within a very limited operational field. Besides, the current lack of purpose-designed surgical tools is impeding adoption of this novel surgical approach. New, more dexterous endosurgical platforms, better endosurgical tools, and auxiliary devices designed to specifically support NOTES are just beginning to emerge, with most still under initial evaluation for efficacy and safety in NOTES applications. Among the emerging systems, notable ones include: (1) the Master and Slave Translumenal Endoscopic Robot (MASTER) developed by the National University of Singapore and Nanyang Technological University (Singapore)1–3; (2) the Anubis-scope developed by Karl Storz (Germany)4; (3) the Incisionless Operating Platform developed by USGI Medical (USA)5; (4) the EndoSAMURAI developed by Olympus (Japan)6; (5) the Direct Drive Endoscopic System developed by Boston Scientific (USA)7; (6) the i-slime in vivo robotic system developed under sponsorship by the Wellcome Trust (UK)8; and (7) the R scope developed by Olympus (Japan).9 In the following sections, we review the development of MASTER, which stands out from the rest because it is a standalone robotics-enhanced and haptics-enabled platform. We also provide insights into its further development.

Why the need for robotic technology?

The inherent lack of dexterity in current endoscopy systems remains the biggest challenge to adoption of NOTES; issues that need to be overcome include inefficient transmission of force through the flexible endoscope, inability to perform off-axis manipulation of surgical targets, and inadequate visualization of the surgical field. There are many ways to address technical deficiencies, including complete system innovations and stepwise technical modifications. To date, technical advances in endoscopy have been incremental, and medical device companies have largely focused on commoditization of tailored endoscopic accessories to sustain market share rather than making breakthrough innovations.

1 Department of Medicine, Yong Loo Lin School of Medicine, National University of Singapore, Singapore
2 Department of Gastroenterology and Hepatology, National University Hospital, National University Health System, Singapore
3 Received 25 July 2013; Revised 11 September 2013; Accepted 12 September 2013
4 Corresponding author. Department of Medicine, National University Health System, NUHS Tower Block, Level 10, 1E Kent Ridge Road, Singapore 119228.
E-mail address: khek_yu_ho@nuhs.edu.sg (K.-Y. Ho).
in endoscopic systems. While incremental changes enhance the functions of an existing system and often make applications easier, lead to more productive use, and even yield better clinical outcomes, such small advances do not lead to transformational changes in endoscopic practices. For NOTES implementation in clinical practice, the new endosurgical system must support multi-axis performance of tasks such that fundamental motions are independent of the endoscope’s motion. It should provide maximum instrumental dexterity for stable yet unrestricted articulation of effectors to facilitate precise surgical maneuvers, especially crucial actions such as tissue grasping, retraction, traction, and counter-traction, and effective triangulation of surgical instruments. Moreover, the system should allow effective transmission of force from the operator’s hands down the shaft of the endoscope to the surgical target, as well as provide good visualization of the surgical field. All these goals can only be realized through incorporation of robotic technology in the endosurgical platform.

Development of a robotics-enhanced endosurgical system

In 2004, inspired by the adeptness of crab chelipeds, a team of innovators in Singapore began to design a new robotics-enhanced endosurgical system for performance of intricate endoscopic procedures.10 Some 7 years later, the resulting invention, aptly named Master and Slave Transluminal Endoscopic Robot (MASTER), was used in a first-in-man multicenter clinical trial. Endoscopic submucosal dissection of gastric cancer was successfully performed on five patients at the Asia Institute of Gastroenterology (Hyderabad, India) and the Prince of Wales Hospital (Hong Kong, China).11 Details of this human trial and results of earlier animal survival studies have been reported in several peer-reviewed journals.11–14 Early MASTER development and specifications for the initial prototypes have been described.11,15 In brief, MASTER is a robotics-enhanced endosurgical system designed with an intelligent central controller (master) and a human–machine interface whereby the operator can remotely control the actions of the end surgical effectors (slaves) (Fig. 1). Robotic technology maximizes the degrees of freedom for articulation of any instruments deployed. It facilitates free spatial orientation and off-axis bimanual coordination of surgical instruments to allow easy retraction, approximation, and dissection of the target tissue. MASTER is intuitively operated, highly dexterous, and comes with haptic feedback capability that provides users with ease of use and a sense of touch when manipulating tissues.

Filling the remaining technology gaps

While MASTER has effectively mitigated most of the major technical challenges faced by endoscopists using conventional techniques, the endosurgical platform is incomplete without suitable auxiliary devices. The need for deliberate viscerotomy in NOTES is not in line with conventional tenets of safe surgery because safe closure of the visceral perforation remains difficult with currently available endoscopic tools. Simple endoscopic clips, T-tags, T-bars, T-fasteners, Padlock-G clips, the over-the-scope clip system, and septal occluders have been tested for this application, but have limitations.15–20 Although suturing devices such as endoscopic staplers (Ethicon Endo-Surgery), the g-Cath/g-ProxStisue approximation device (USGI Medical, USA), the flexible Endostitch (Covidien, USA), the OverStitch (Apollo Endosurgery, USA), the Plicator (NDO Surgical, USA), and the Eagle Claw VII (Apollo Endosurgery) may yield a better result, the efficacy and safety of these devices in NOTES has yet to be fully established.21–24 Besides difficult viscerotomy closure, creation of a pneumoperitoneum for adequate exposure and visualization of the surgical field during NOTES is an issue. Currently, endoscopic performance of intraluminal procedures relies on on-demand manual insufflation by an endoscopist. Air or CO2 is supplied through the endoscope with no pressure monitoring. This practice can produce wide fluctuations in endoluminal pressure, but is justified because the gastrointestinal tract allows migration of excessive gas into the upstream/downstream bowel. However, in NOTES, this can cause fluctuations in intraperitoneal pressure, and excessive insufflation can result in serious abdominal compartment syndrome and adverse hemodynamic effects, so conventional on-demand insufflation is unsuitable.26

The MASTER-SPACE solution

To overcome the above issue, the MASTER development team is now working with a Japanese industry–academia consortium, endeavor for Next-Generation Interventional Endoscopy (ENGINE), to incorporate a novel, flexible, automatic, CO2 insufflation platform called SPACE (Steady Pressure Automatically Controlled Endoscopy). SPACE comprises a commercially available standard endoscopic overtube and a newly developed detachable leak-proof device with an anti-reflux valve and a Luer lock connection. SPACE is designed to provide highly reproducible and automatically redistending endoscopic exposure in the gastrointestinal tract during endoscopic surgery.26,27 Use of SPACE removes the need for concurrent control of manual insufflation during endoscopic procedures so that the endoscopic surgeon can focus attention on performing the surgery. When ready, the combined MASTER-SPACE technology is expected to support a range of endoscopic surgical interventions, including NOTES.

Catering to new developments in NOTES

According to a recent review by Chiu et al.,28 recent developments in NOTES in Asia have mostly focused on extension of the concept of NOTES. These experimental NOTES-related procedures include: (1) endoscopic full-thickness resection (EFTR); (2) per oral endoscopic myotomy (POEM); and (3) submucosal endoscopic tumorectomy (SET). However, it was noted that most pilot human EFTR trials were carried out with laparoscopic assistance because of the lack of dedicated tools with sufficient dexterity to support the complex procedures. In POEM and SET, submucosal tunneling is used to perform myotomy and resect gastrointestinal submucosal tumors, respectively. It is believed that submucosal tunneling yields safer access to the peritoneal cavity and closure of

Fig. 1. MASTER with dexterous slave manipulators deployed at the distal end of the endoscope.
the gastrointestinal defect. However, with current endoscopic platforms, complications associated with such procedures may remain a problem, as reported by Ren et al.29 We expect that the use of MASTER-SPACE could mitigate some of the technical constraints. There is plan to develop a series of MASTER-adaptable dedicated tools to support tasks such as creation of a submucosal access route, endoscopic tunneling, and effective closure of the resultant defect in the gastrointestinal wall.

Next: a complete toolbox for NOTES

Experience from trials using earlier MASTER prototypes has provided new insights into further development of the system to better support the performance of NOTES. Apart from incorporating an automatic CO₂ insufflation system as described above, the MASTER development team is working on adaptation of some of the most desirable auxiliary devices for the most popular endolumenal and transluminal procedures, such as endoscopic submucosal dissection of gastrointestinal cancer, thickness-gaick resection, and total mesorectal excision of rectal cancer, among others.

Conclusion

The robotics-enhanced MASTER is one of the most promising endosurgical systems currently being developed for NOTES. Further development of MASTER-SPACE, together with a full range of easily deployable surgical end-effectors, is ongoing. When the completed system is ready, we expect that it will make performance of NOTES and related procedures easier and safer. The success of this innovative endosurgical system could be key to accelerating the advancement of NOTES towards better patient care.

Conflicts of interest

Khek-Yu Ho co-invented the MASTER. Jennie Wong declares no conflict of interest.

References