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Review Article

The development of robotic flexible endoscopic platforms

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A B S T R A C T

Many different types of endoscopy robot have been developed or are under development. Some of these innovative biotechnologies are dedicated to complex endoscopic procedures such as endoscopic submucosal dissection whereas others are purely diagnostic. In endoscopy robotics, there are still several problems that need a solution. These problems basically concern robotic locomotion and instrument control, as well as clinical application. Flexible robotic endoscopic platforms are divided into four categories as follows: robot-assisted flexible endoscopy for maneuvering, robotic flexible endoscopy with therapeutic functions, active flexible colonoscopy, and active capsule endoscope. A thorough literature analysis was performed to assess the current status of robotic flexible endoscopic platforms designed for advanced endoluminal procedures.

Keywords: Endoscopes; Endoscopic submucosal dissection; Robotics; Robotic surgical procedures

Introduction

Since various flexible endoscopes were applied in the field of gastrointestinal tract, they have taken a key role in the diagnosis and treatment of gastrointestinal tract diseases. However, flexible endoscopic platforms have several limitations or problems to use, in terms of a limitation of instrumental freedom and a limited widespread implementation of endoscopic submucosal dissection (ESD). These problems basically are related to difficulty in manipulating flexible endoscopes. A lot of times and efforts are required to be skillful in handling a flexible endoscope. Therefore, many different types of flexible robotic endoscopic systems have been developed. Some of these robotic flexible endoscopic platforms are dedicated to complex endoscopic procedures such as ESD, whereas others are purely diagnostic. In addition, augmented reality, advances in actuation and reduction of hysteresis, optical analysis, and wireless movement transmission are also under investigation.

Here, I will overview current status of development of robotic flexible endoscopic platforms.

Types of Flexible Robotic Endoscopy

Flexible robotic endoscopic platforms are divided into four categories as follows: robot-assisted flexible endoscopy for maneuvering, robotic flexible endoscopy with therapeutic functions, active flexible colonoscopy, and active capsule endoscope. In this review, the first two platforms will be discussed.

Robot-assisted flexible endoscopy for maneuvering: electromechanical control of a conventional endoscope

The EndoDrive®

The EndoDrive® (ECE Medical Products, Erlangen, Germany) developed in Germany was the first commercially available system to electro-mechanically support the shaft insertion of flexible endoscopes (Fig. 1).[1] It makes the shaft of flexible endoscopes be positioned and driven with a foot pedal, thereby both hands are left free for maneuvering endoscopic instruments. However, rotation of endoscopic shaft is done manually.

The Invendoscope™

The Invendoscope™ (Invendo Medical, Kissing, Germany) was developed as a single-use, hand-held, motor-controlled colonoscope. The endoscope with a diameter of 10 mm contains an inverted sleeve and a driving unit with 8 wheels. The endoscope is driven by a hand-held joystick and the tip of endoscope could be flexed by 180 degrees. During insertion, the driving wheels hold the inner side of the inverted sleeve and move the endoscope forward or backward. In a study about the efficacy of Invendo-

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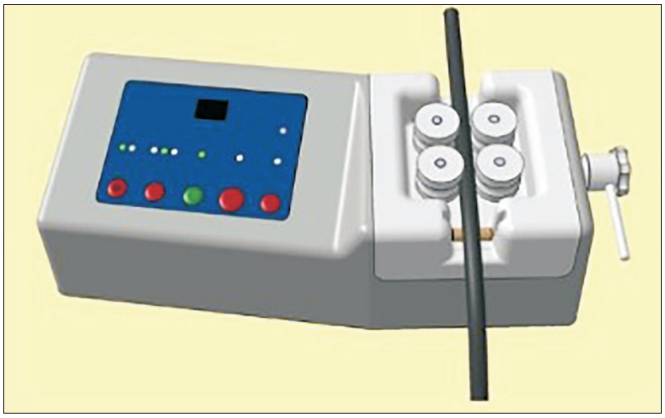

Fig. 1. The EndoDrive® system (ECE Medical Products, Erlangen, Germany). Image from the pamphlet of ECE Medical Products.

scope™ on 34 patients, the rate of cecum intubation was 82%. In a later clinical trial with the Invendo SC20 (Invendo Medical) on 61 patients, the rate of cecum intubation was 98.4% within 15 minutes.[2] In addition, in the other trial with 23 patients, polypectomies were successfully performed through a 3.1 mm channel inside Invendoscope™.[3] Although Invendoscope™ was known to ease endoscopic manipulation, the time to cecal intubation is significantly long and therapeutic performance for large polyp and other types of neoplasms was not fully evaluated. Therefore, further studies are mandatory to compare between Invendoscope™ and conventional colonoscopy.

Colonoscopy with robotic steering and automated lumen centralization (RS-ALC, Enschede, Netherlands)

This is a robotic platform equipped with an ALC to help the endoscopist in manipulating the tip of endoscope. A remote drive unit allows docking of the angulation wheels of a conventional endoscope. Open loop control is achieved by handling a joystick with operator visual feedback. It was known that novices were more positive than experts about the new platform and mean cecal intubation time of novice with RS-ALC was 781 seconds.[4]

The master-slave endoscopic operation robot

The master-slave endoscopic operation robot (EOR; Kyushu Institute of Technology, Kitakyushu, Japan) was developed as a master-slave robotic system mounted on a conventional endoscope. It allows steering, advancing, rotating, and stabilizing of a standard colonoscope by 2 joysticks. In the latest version, haptic feedback was added and an endoscope can be controlled by one hand.[5–7] However, its effectiveness was not evaluated in a clinical trial.

A master-slave robot with force feedback for colonoscopy

This platform was developed as a master-slave robot with force feedback for colonoscopy in South Korea. The master robot consists of 2 parts; a tilting device used for controlling the angulation of tip (master) and an insertion/rotation device (slave). The slave robot grips a conventional colonoscope. The robot enables endoscopist insert colonoscope up to 1.5 m, rotate by 360 degrees, and make a ±180 degrees tilt angle. In a study with a colon model, this robot system was evaluated with 4 experienced endoscopists and novices, showing the insertion time of 17.4 ± 2.1 minutes and 39.0 ± 5.3 minutes in experienced endoscopists and novices, respectively.[8]

A robotic system for holding a gastroscope, using a gastroscope intervention mechanism with pneumatic-driven clamping function

This system developed by Li et al[9] is a robotic system for holding a gastroscope, using a gastroscope intervention mechanism (GIM) with pneumatic-driven clamping function. The GIM can give uniform pneumatic pressure around the gastroscope compared to the EndoDrive® and the EOR which use rigid roller pairs to hold and drive the flexible endoscope. Therefore, this system can protect the flexible endoscope from damage by being over-clamped. However, in a study with animal model, the insertion speed by using the GIM was significantly slower than manual insertion (269 vs 118 sec). This system was not also evaluated in a clinical trial.

Robot-assisted flexible endoscopy for maneuvering: systems with autonomous locomotion

The Aer-O-Scope™ (GI View Ltd., Ramat Gan, Israel)

This system which is pneumatically actuated and disposable colonoscope, was developed by a company in Israel. Its active locomotion is carried out by 2 balloons and pneumatic pressure. The first balloon is mobile, while the second balloon is fixed to the overtube. The colonic section between two balloons is sealed by inflating the 2 balloons. As carbon dioxide (CO_2) is insufflated between the balloons, the pneumatic force pushes the mobile balloon forward. Once the mobile balloon reaches the cecum, the CO_2 between the balloons is aspirated. Then, CO_2 is insufflated between the cecum and the mobile balloon and the pneumatic force pushes the mobile balloon backward. The omni-directional complementary metal-oxide semiconductor camera is located in front of the mobile balloon and manipulated to inspect the colon. During endoscopic procedure, the operating pressure is kept below 5,400 Pa to protect the intestine.[10] In a study with this system, the rate of cecum intubation was 98.2% and the rate of polyp detection was 87.5% compared with conventional colonoscopy.[11]

The NeoGuide™ Endoscopy System

The NeoGuide™ Endoscopy System (NES; NeoGuide Systems Inc., Los Gatos, CA, USA) was developed for diagnosis and treatment in the colon. It has two sensors; a sensor at its tip to measure the tip steering and an external position sensor to measure the insertion depth. This system has multiple segments controlled by electromechanical force. During insertion, the segments follow the movement of the tip, thus adjusting to the shape of the colon thereby the patient's discomfort could be reduced, even if the NES is pushed from the back side. In a clinical trial with 11 patients, the rate of cecal intubation by this system was 90.9% (10 of 11 patients).[12]

Endotics (Era Endoscopy Srl, Peccioli, Italy)

The locomotion of this system is achieved by an inch-worm mechanism. The device has proximal and distal clamps that attach to the colon allowing sequential anchoring and locomotion. This system is disposable and composed of four departments; a steerable tip with a camera and a light-emitting diode light, flexible body and a special tank with electro-pneumatic connector. And, there is an insufflation and suction channel inside of the system. This platform is connected to a plug-in external workstation through a 7.5-mm sized cable and has a operative channel of 3 mm diameter for biopsies and polypectomies. Patient's discomfort was reported to be significantly lowered with this platform. However, in subsequent studies, the rate of cecal intubation was considerably low compared to that with conventional colonoscopy, and the rates of polyp detection and the procedure time of Endotics system were inferior to those of conventional colonoscopy.[13] Because Endotics was conformite Europeenne (CE)-marked only and enable endoscopists to perform comfortable colonoscopy without sedation, it has been clinically applied.

Robotic flexible endoscopy with therapeutic functions

The Endoluminal Assistant for Surgical Endoscopy

The Endoluminal Assistant for Surgical Endoscopy (EASE; KARL STORZ/IRCAD, Strasbourg, France) is a robotic flexible endoscopic platform composed of a master and a slave unit. It is an upgraded version of STRAS (KARL STORZ/IRCAD), previously described in a single-arm animal study for a colorectal ESD.[14,15] On a slave unit, there are instrument and endoscope modules for robotic actuation and insertion of instruments. The detachable endoscope is 53.5 cm length and has a shaft diameter of 16 mm, two 4.3-mm lateral working channels for flexible instruments, and a third 3.2 mm central working channel for conventional endoscopic instruments. The master unit was ergonomically designed and allowed a single operator to control both the endoscope and the instruments. The whole system has 10 degrees of freedom and the operator can have the endoscopic view on a frontal screen and a graphical user interface on a lateral screen mapping the position of the endoscope and instruments. With this platform, surgical triangulation can be easily made to cut submucosal layer. In a study with *in vivo* animal model for colorectal ESD, the performance of ESD with the EASE platform was favorable than that with conventional endoscope in terms of dissection speed and complication rate.[16]

K-FLEX

The K-FLEX (EasyEndo Surgical, Daejeon, Korea) has been developed for solo-endoscopic procedures. By attaching a motor pack to a conventional endoscope, this platform allows easy and intuitive endoscopy without assistants. Portable endoscopic tool handler (PETH) has been developed for more advanced procedures with additional surgical arms attached to the conventional endoscope. Several preliminary *ex vivo* experiments have shown the improved performance of conventional endoscope and the feasibility of PETH. And, K-FLEX enables surgeons to perform expertise robotic surgery by adding small robot arms to the inside of flexible endoscope. These robot arms can exert a great deal of force to lift organs and tissues with a constraint joint mechanism.

MASTER

This system was developed to perform ESD.[17] The effectiveness of MASTER (EndoMASTER Pte, Singapore) in the performance of ESD has been proven in various animal studies.[18–21] And, the median dissection time was 16 minutes (3–50 min) in a small study with 5 patients. Because of several encountered problems in previous trials, such as the lack of ability for instrumental exchange, large external actuator, and bulky control units, the second phase of development is ongoing.

Endomina™ (Endo Tools Therapeutics, Gosselies, Belgium)

It is a triangulation platform which can be mounted on a conventional flexible endoscope and obtained CE mark certification. It has two instrument channels with 3 degrees of freedom, which can guide two standard flexible instruments up to 3.0 mm in diameter. The system is electromechanically actuated by traction cables and the control interface has two joysticks.[22] Clinical human trials are ongoing.

Conclusion

From a position of endoscopists and endoscopic surgeons, current trend for the development of robotic flexible endoscopic platforms is great to be welcomed. In near future, some types of platforms would be definitely implemented in a real clinical field. However, at the same time, a higher cost for clinical application of robotic system would be a great huddle. The development of robotic flexible endoscopic systems is more difficult than that of robotic laparoscopic platform, because the transmission of power to the end effector can be weak and not enough to perform therapeutic procedures. I hope that more advanced and clinically applicable robotic flexible endoscopic platform could be introduced and tested more freely in a clinical trial.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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