



REVIEW

The endoscopy evolution: 'the superscope era'

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ABSTRACT

Developments to the design of the flexible endoscope are transforming the field of gastroenterology. There is a drive to improve colonic adenoma detection rates leading to advancements in the design of the colonoscope. Novel endoscopes now allow increased visualisation of colonic mucosa, including behind colonic folds, and aim to reduce pain associated with the procedure. In addition, a shift in surgical paradigm towards minimally invasive endoluminal surgery has meant innovations in flexible platforms are being sought. There are a number of limitations of the basic endoscope. These include a lack of stability and triangulation of instruments. Modifications to the flexible endoscope design form the basis of a number of newly developed and research platforms, some of which are discussed in this review.

INTRODUCTION

The flexible endoscope plays a pivotal role in myriad aspects of endoluminal and transluminal surgery. Colonoscopy remains the gold-standard method of examining the colonic mucosa, yet the flexible endoscope has changed little since its inception in the 1960s.

The risk of colorectal cancer is reduced with adenoma polypectomy¹; however, only around 85% of the colonic mucosa is visualised.² The procedure also fails in approximately 4–20% of cases though this has improved with endoscopy training and quality improvement programmes.³

There are several predictors of difficult or incomplete colonoscopy. The most common include poor bowel preparation, diverticular disease, female gender, older patients, prior surgery, low body mass index and operator experience.

The advent of minimally invasive surgery has pushed endoluminal surgery (ELS) to the forefront of gastroenterology. The development of natural orifice

endoscopic transluminal surgery (NOTES) has also resulted in modifications of the conventional flexible device.

In a bid to improve colonoscopy, ELS and NOTES, a number of new age endoscopes are emerging. This review discusses a number of 'superscopes' designed to improve the quality of colonoscopy and overcome the challenges of ELS and transluminal surgery.

IMPROVING COLONIC MUCOSA VISUALISATION

One of the leading challenges of colonoscopy is to improve the amount of colonic mucosa seen, particularly at flexures and behind colonic folds, in order to improve adenoma detection. Miss rates of colonic polyps have been shown to be ~28%,⁴ though this can be improved with the use of wide-angle colonoscopes.² Cap-assisted colonoscopy and retroflexing the colonoscope in the right colon have been used to improve visualisation; however, they have not been widely taken up due to safety concerns.⁵ To overcome these visual challenges, a number of endoscopes have been developed.

THIRD EYE RETROSCOPE (AVANTIS MEDICAL)

This catheter-mounted video chip has been used to improve diagnostic yield of colonoscopy, particularly in hard-to-reach areas.

The device passes through the working channel of a standard colonoscope. As it emerges from the endoscope, the pre-shaped catheter automatically turns 180° into the 'J-position' to face the distal end of the endoscope and locks into place (figure 1). This allows the colonoscopist simultaneous forward and retroflexed views of the colon on withdrawal of the endoscope.



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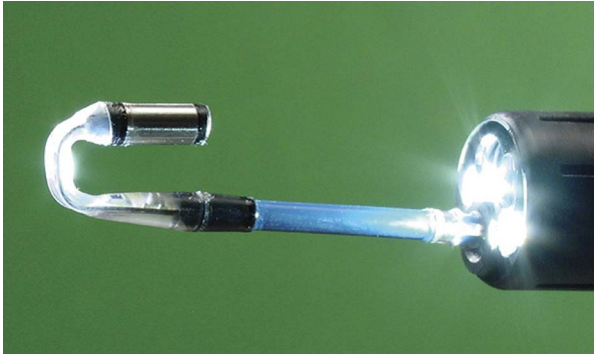


Figure 1 Third Eye Retroscope.

It has shown to significantly improve polyp detection rates in both animal model and human studies.⁶ The Third Eye Retroscope Randomised Clinical Evaluation (TERRACE) study also showed a significantly improved adenoma detection rate in diagnostic and surveillance colonoscopy.⁷

PEERSCOPE SYSTEM (PEERMEDICAL LTD)

This consists of a main control unit and PeerScope CS colonoscope with a wide-angle lens, allowing a high-resolution field of view of up to 330°. The PeerScope model H is an advance on the legally marketed model B with improvements in video resolution and software. Bench-top and usability tests show this model is safe and effective and human trials are promising.⁸

THERAPEUTIC ENDOSCOPES

Endoscopic mucosal resection is widely performed; emerging techniques such as endoscopic submucosal dissection (ESD) and per-oral endoscopic myotomy are also gaining popularity.

There are a number of challenges posed by the flexible endoscope for ELS and NOTES. These include a lack of stability, triangulation of instruments for adequate tissue manipulation and inadequate force transmission to perform accurate microsurgery. This in turn has prompted a wave of new endoscopes to be developed (figure 2).

ENDOSAMURAI (OLYMPUS)

This device is an advance on the conventional endoscope for ELS and NOTES. It comprises a conventional endoscopic unit, an overtube and two flexible arms. The overtube stabilises the device once locked into place.

The two arms are in parallel during insertion of the endoscope and can be opened out and controlled with laparoscopic-like handles. The manipulator arms have working channels through which flexible instruments can be deployed and an additional channel through the working shaft.

This device has been used to perform a number of procedures in animal studies including intra-abdominal exploration and transgastric small bowel resection.⁹ It has been shown to be an improvement with respect to stability, tissue manipulation and triangulation of instruments compared with a dual-channel endoscope (DCE).¹⁰

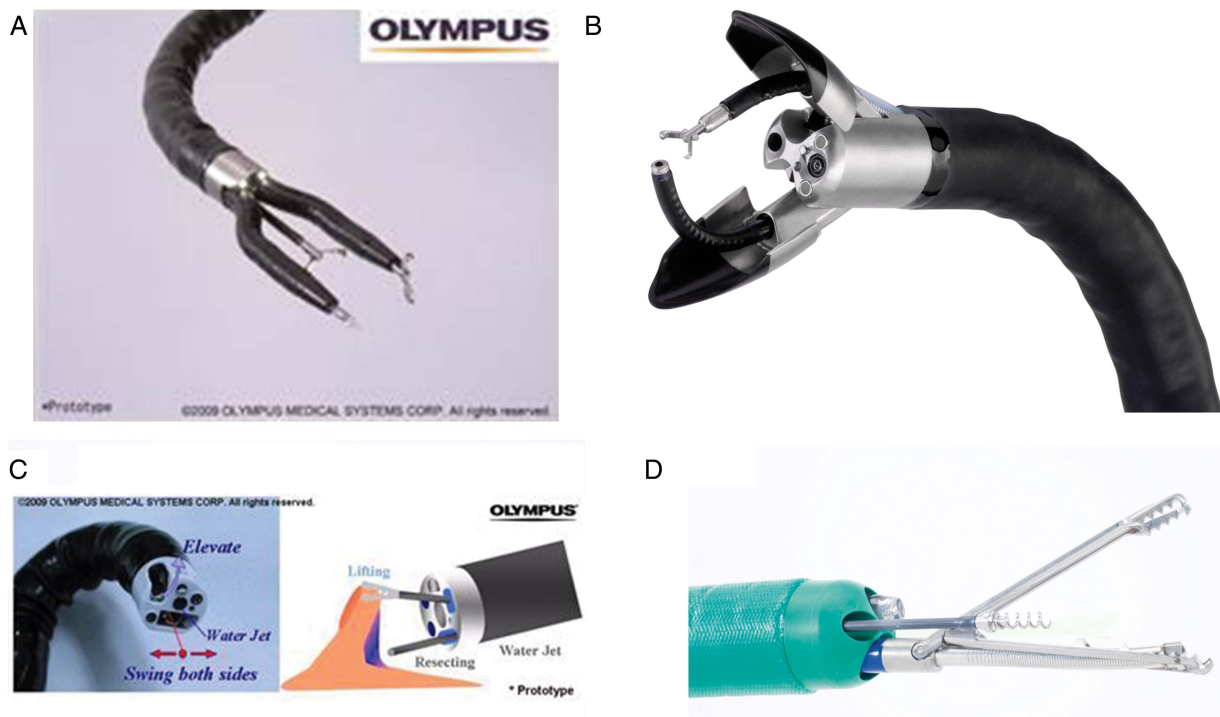


Figure 2 Multitasking platforms: (A) EndoSamurai; (B) ANUBISCOPE; (C) R-scope; (D) TransPort.

ANUBISCOPE (STORZ)

This novel platform for ELS and transluminal surgery is a four-way articulating endoscopic shaft 16 mm in diameter and 110 cm long with a 16 mm vertebrae flexible section. The 18 mm distal tip of the device is tulip-shaped and acts as a trocar during insertion, preventing injury to surrounding structures. When at the site of interest, the wings comprising the tulip-shaped distal tip open out, allowing two opposing flexible arms to emerge from working channels located within the wings.

Interchangeable tools can be deployed down the working channels of the arm and a central working channel in the shaft device enables triangulation of up to three instruments. The wings limit the use of the device in confined workspaces. Despite this, it has been used to perform oesophageal myotomy and transluminal procedures such as transgastric cholecystectomy¹¹ and sigmoidectomy.¹²

R-SCOPE (OLYMPUS)

This flexible endoscope was initially designed to overcome challenges posed by the DCE such as stability and triangulation of instruments for ESD.¹³

The device is 13.5 mm in diameter with two articulated 2.8 mm working channels with vertical and horizontal lifting gates. The channels are arranged at right angles of each other enabling simultaneous separate movements of the instruments in perpendicular planes. This allows off-axis movements, thereby improving tissue handling and raising the potential for its use in transluminal settings.

It has been shown to be superior to the DCE in gastric ESD in certain gastric locations,¹⁴ reducing gastric ESD procedure time and improving tissue manipulation.¹⁵ It has also been successfully used to perform transgastric cholecystectomy¹⁶ and full-thickness colonic and gastric resections.

INCISIONLESS OPERATING PLATFORM (USGI MEDICAL)

This multilumen platform was designed to overcome a number of challenges posed by NOTES. It consists of the TransPort device (a flexible over-sheath 18 mm in diameter and 110 cm long) and tissue approximation, suturing and manipulation tools. It has a four-way flexible tip and conventional endoscopic controls. A flexible endoscope such as an Olympus N-scope can be inserted into the 6 mm working channel giving the device an adjustable visual horizon. There are four working channels, a 7 mm for irrigation, 6 mm for optics and two 4 mm channels for interchangeable instruments capable of delivering electrocautery.

The ShapeLock over-sheath promises to offer improved stability of the platform after stiffening once in position. Titanium rings connected by wires make

up the sheath and tighten when locking into place to improve lifting and torsion abilities.

The IOP has been used to perform a number of extraluminal procedures such as fundoplication and gastric restriction surgery, in addition to hybrid laparoscopic/NOTES procedures such as transgastric cholecystectomy and appendectomy.¹⁷ More recently, it has been shown to be a safe and effective platform for the Primary Obesity Surgery Endoluminal (POSE) procedure.¹⁸

DIRECT DRIVE ENDOSCOPIC SYSTEM (BOSTON SCIENTIFIC)

The direct drive endoscopic system (DDES) is a flexible controllable sheath with three working channels. A <6 mm fibre optic endoscope is housed in one channel and two 4 mm articulating flexible instruments controlled by two ergonomic handles can be used for tissue manipulation. There are only a limited number of instruments available and difficulties with the instrument orientation interfering with the optical axis.

The platform is fixed to the procedural table using a rail system, although repeated calibrations cause disturbance during the procedure. The sheath adds stability to the device for more complex procedures though at only 55 cm long this limits completion colonoscopy.

It has been used with success in animal studies and has been shown to be superior to other platforms reducing procedural time and improving bi-manual coordination in bench-top experiments.¹⁰

NEOGUIDE (INTUITIVE SURGICAL)

This innovative device is a computer-assisted colonoscope comprising 16 articulated segments. Position sensors located at the distal tip and externally at the base of device provide real-time three-dimensional mapping of the leading tip of the endoscope. Articulation of the shaft is based on the tip sensor during insertion, enabling automatic shape control of the shaft to decrease looping and patient discomfort during the procedure. The platform allows the colonoscopist to have accurate images of the tip position, endoscope shaft configuration and luminal views.¹⁹

It has been shown to reduce looping and lateral force transmission compared with a conventional colonoscope, and feasibility studies have shown successful caecal intubation in 10 patients.²⁰ Further human studies are warranted in order to improve the platform and to establish its potential for NOTES.

PAIN

Experienced colonoscopists may fail to reach the caecum in up to 10% of cases.²¹ This is multifactorial and may in turn lead to a loss to follow-up or reluctance to have further procedures.

ScopeGuide can aid navigation of the endoscope and increased sedation may ease discomfort. Radiological procedures such as virtual colonoscopy, MRI and contrast studies can be used, although these are merely diagnostic studies. While paediatric colonoscopes, variable stiffness endoscopes, gastroscopes and push enteroscopes can be used, we discuss below a number of alternative endoscopes in development (figure 3).

BALLOON ENDOSCOPE

The double balloon enteroscope used to examine the small bowel is 200 cm long with a 145 cm overtube providing stiffness. It can be used to complete colonoscopy in around 95% of patients who have had a previously failed colonoscopy.²²

Soft balloons on the distal tip of the endoscope and overtube can be inflated and deflated sequentially using foot pedals to advance the device. The balloons provide traction and enable progressive movements of the endoscope and overtube to achieve effective and safe procedure completion.

CATHCAM

This is a novel thin, flexible guide wire-directed colonoscope, developed to reduce pain during colonoscopy. The device aims to overcome challenges posed by the standard colonoscope during insertion of the endoscope around tight or difficult flexures to minimise pain associated with looping.

It is a disposable 11 mm diameter multilumen catheter through which a 0.6 mm guide wire can be inserted into the device and used as a guide during insertion.

This has been shown to be useful in patients with previous failed procedures with a caecal intubation rate of over 90%²³ and with modification could be used for difficult or failed cases.

AER-O-SCOPE (GI VIEW)

This self-propelling, self-navigating disposable colonoscope promises to reduce pain experienced during colonoscopy.

It consists of a 19 mm silicone rectal inducer and balloon to anchor the device and seal the anus. An imaging capsule with a camera and light emitting diodes (LEDs) allowing high-resolution images is mounted onto a scanning balloon and inserted through the hollow rectal introducer. It is connected to a supply cable to provide light, suction, air and water.²⁴

A PC-based workstation is used to control the device that snaps into place on the unit and can be pulled to the patient's side by a flexible arm.

Pressure sensors located inside, in front of and behind the balloons enable computer algorithm-generated pressure gradients across the balloon to be created, resulting in movement of the device. The

balloons have a preset maximum diameter and are designed to mould to the colonic wall shape and ensure a maximum colonic pressure of 80 mBar is not exceeded.

Following ex vivo studies, the device has shown promise in a feasibility study with the device being used to intubate the caecum in 10 out of 12 patients.²⁵ Further larger scale clinical studies are now warranted.

INVENDOSCOPE (INVENDO MEDICAL)

This is a novel single-use motorised device with an endoscopic sheath, high-resolution camera, 3.2 mm working channel and electrohydraulic deflectable tip able to move 180° in any direction.

The device can be moved forwards and backwards by pressing the respective keys on the hand-held device that activates a motorised eight-wheel driving unit. An inverted sleeve allows the device tip to shrink or elongate with minimal forces applied to the colon. The driving unit wheels grip the inner surface of the inverted sleeve enabling it to move.

There are two prototypes with working lengths between 170 and 200 cm. The device has been trialled in vivo, and a proof-of-concept study was performed in 34 volunteers with a 72% caecal intubation rate and an absence of pain in 82% of cases.²⁶

Technical defects with the propulsion mechanism and optics resulted in premature termination of the procedure in a few cases, and these will need rectification prior to further clinical human testing.

ENDOTICS COLONOSCOPY SYSTEM (ERA ENDOSCOPY S.R.L)

The Endotics System is a novel robotic self-propelling device. It is a disposable flexible probe with a steerable tip 7.5 mm in diameter (E-worm), able to adapt its shape to configure the colon. The head of the E-worm contains a light source, camera, water and air channels. A workstation enables the operator to steer the E-worm 180° in every direction using a hand-held device.

The device moves in a unique manner comparable to a worm using proximal and distal clampers sited within the E-worm. Using vacuum and mechanical grasping, the proximal clasper adheres to the colonic mucosa, the central probe body is manually elongated and the distal clasper automatically adheres to the mucosa. The proximal clasper is released and the central body of the probe contracts. The proximal clasper adheres to the mucosa followed by the distal clasper being released for the cycle to repeat itself.

In vitro experiments and a prospective, open-label clinical trial showed forces exerted by the E-worm were 90% lower and the procedure more tolerable than conventional colonoscopy with improved diagnostic accuracy.²⁷

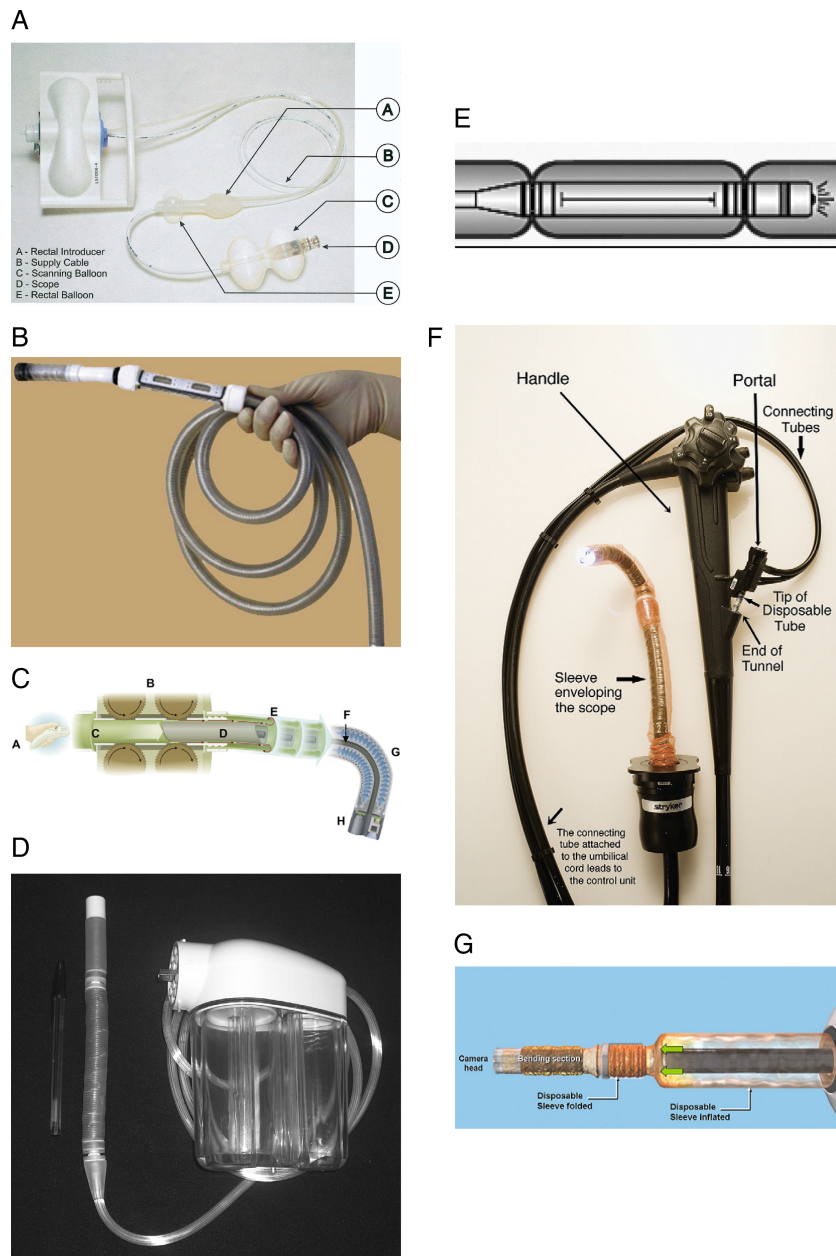


Figure 3 (A) Aer-O-Scope; (B) Invendoscope SC40; (C) Invendoscope SC40 components and the propulsion mechanism. A is the hand-held device that performs all the endoscopic and software functions. B is the driving unit with eight wheels that moves the endoscope in and out of the colon. C is the inverted sleeve, enabling the endoscope to grow or shrink at the tip. D is the inner endoscope sheath. E is the inner layer of the inverted sleeve, when driven forward, unfolds here and becomes part of the outer layer, which then stays in position. There is hence no relative movement, and minimal forces are exerted on the colonic wall. F is the working channel. G is electrohydraulic deflection of the endoscope tip, which can move 180° in any direction. H is the high-resolution camera with three light-emitting diodes. (D) Endotics single-use probe (E-worm). (E) Method of locomotion: (i) adhesion of proximal clasper; (ii) elongation and adhesion of distal clasper; (iii) release of proximal clasper and E-worm shortening. (F) ColonoSight. (G) ColonoSight. The force generated by insufflating the sleeve propels the tip of the colonoscope forward in the direction of the green arrows.

SIGHTLINE COLONOSIGHT (STRYKER GI)

This system consists of EndoSight, a colonoscope with integrated LED located at the distal tip. It is covered by a compressed disposable multilumen sheath (ColonoSleeve) acting as a proactive barrier eliminating the need for disinfection.

The device is powered by an electro-pneumatic unit that generates a pulling forward force at the distal tip,

thereby reducing the ‘pushing’ force required to insert the device. This mechanism delivers 0.5 kg of effective force at the distal tip.²⁸

A multicentre trial showed a 90% caecal intubation rate in a mean time of 11.2 ± 6.5 min²⁹ Biopsies were taken in some of the procedures and no complications noted after a fortnight,^{28 29} showing promising potential of this device over standard colonoscopy.

Table 1 New age endoscopes

Device	Disposable	LED/FO	Robotic	Movement mechanism	Instrument channel?
Third Eye Retroscope	N	FO	N	M	Y
PeerScope	N	FO	N	M	Y
NeoGuide	N	FO	Y	M	Y
DDES	N	FO	N	M	Y
EndoSamurai	N	FO	N	M	Y
ANUBISCOPE	N	FO	N	M	Y
IOP	N	FO	N	M	Y
R scope	N	FO	N	M	Y
CathCam	Y	LED	N	M	N
Aer-O-Scope	Y	LED	N?	S (gas)	N
DBE	N	FO	N	M	Y
Invendoscope (SC20)	Y	LED	N	S	Y
Endotics	Y (probe)	LED	Y	S	N
ColonoSight	Y (sheath)	LED	N	P	Y

DBE, double balloon enteroscopy; DDES, Direct Drive Endoscopic System; FO, fibre optic; IOP, incisionless operating platform; LED, light-emitting diode; M, manual; N, no; P, pneumatic; S, self-propelling; Y, yes.

CONCLUSION

There are a number of exciting developments to the conventional flexible endoscope (table 1). Endoscopes improving colonic visualisation and reducing patient discomfort may help improve adenoma detection rates and encourage colonoscopy uptake, a critical step in the detection and prevention of colorectal cancer.

Adaptations of the endoscope for ELS and NOTES are particularly noteworthy given the ongoing development of NOTES and increased uptake of ELS worldwide. Improvements to the stability of devices, triangulation of instruments to improve tissue handling and visceral closure techniques are paramount.

Increasingly there are a number of snake robotic devices such as the MASTER robot in development to further improve dissection accuracy, tissue manipulation and platform stability in confined workspaces for minimally invasive surgery. These are largely in the research and development stage, although some platforms have been successfully used to perform ESD.³⁰

As the role of gastroenterologists changes to perform increasingly minimally invasive ELS, so too must the flexible endoscope adapt. Modifications to keep in line with these advances in the field of gastroenterology are leading to ‘super’ and ‘smarter’ endoscopes.

Could this signal a rebirth of the endoscope in an increasingly invasive era of medical gastroenterology?

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