Communication from the ASGE Technology Committee

TECHNOLOGY STATUS EVALUATION REPORT

High-resolution and high-magnification endoscopes

The American Society for Gastrointestinal Endoscopy (ASGE) Technology Committee provides reviews of existing, new, or emerging endoscopic technologies that have an impact on the practice of GI endoscopy. Evidence-based methodology is used, with a MEDLINE literature search to identify pertinent clinical studies on the topic and a MAUDE (Food and Drug Administration Center for Devices and Radiological Health) database search to identify the reported complications of a given technology. Both are supplemented by accessing the ''related articles'' feature of PubMed and by scrutinizing pertinent references cited by the identified studies. Controlled clinical trials are emphasized, but, in many cases, data from randomized controlled trials are lacking. In such cases, large case series, preliminary clinical studies, and expert opinions are used. Technical data are gathered from traditional and Web-based publications, proprietary publications, and informal communications with pertinent vendors.

Technology Status Evaluation Reports are drafted by 1 or 2 members of the ASGE Technology Committee, reviewed and edited by the committee as a whole, and approved by the governing board of the ASGE. When financial guidance is indicated, the most recent coding data and list prices at the time of publication are provided. For this review, the MEDLINE database was searched through April 2008 for articles related to endoscopy by using the keywords high resolution, high definition, high magnification, and magnifying endoscopy.

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BACKGROUND

Video endoscopy is used to visually detect GI mucosal pathology. It permits the endoscopist to identify abnormal tissue and may enable differentiation between various degrees of dysplasia and even malignancy. This distinction often has diagnostic and therapeutic implications for clinical care. The quality of endoscopic visualization involves both resolution and magnification. Video resolution is defined as the ability to optically distinguish 2 closely approximated objects or points and is a function of pixel density (the number of pixels wide times the number of pixels or lines of height). High-resolution imaging improves the ability to discriminate detail, whereas magnification enlarges the image. This report reviews advances in white-light high-resolution and high-magnification endoscopic imaging systems.

TECHNOLOGY UNDER REVIEW

The video capabilities of color images of standard definition (SD) endoscopes are based on traditional television (TV) broadcast formats (NTSC in the United States, Canada, and Japan or PAL formats in Europe and the rest of the world).[1,2] The SD signals offer images in a 4:3 (width:-height) aspect ratio, with image resolutions of 640 to 700 pixels width by 480 to 525 pixels or ''lines'' height (approximately 367,000 pixels).[2] Standard displays, such at cathode-ray TVs, are 640 pixels wide × 480 lines in height (standard video graphics array) (approximately 300,000 pixels.).[2] SD endoscopes are equipped with charge coupled device (CCD) chips that produce an image signal of 100,000 to 400,000 pixels, which are displayed in the SD format. Advances in CCD technology have resulted in smaller chips with an increased number of pixels and increased resolution. The chips used in current so-called high-resolution or high-definition (HD) endoscopes produce signal images with resolutions that range from 850,000 pixels to more than 1 million pixels (Table 1).

The general consensus definition of a HD image or display, and the definition of high resolution for the purposes of this review, is one with more than 650 to 720 lines of resolution (height).[3] Images may be progressive or interlaced. With progressive (''p'') images, lines are scanned consecutively and the image is painted 60 times per second, whereas with interlaced (''i'') images, every other line is scanned and the image is painted in 2 passes at 30 times per second each. This difference between the 2 halves shows up as ''interlaced artifacts'' that become more pronounced with fast-moving objects. Because progressive scanning provides twice the temporal resolution (60 frames/s) as that of interlaced scanning (30 frames/s),

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TABLE 1. High-resolution and high-magnification endoscopes available in the United States

	Olympus America, Inc (Center Valley, Pa)				Pentax Medical Co (Montvale, NJ)			
	Colonoscope		Gastroscope		Colonoscope			
Model no.	CF H180A L/I	CF Q160ZL	GIF type H180	GIF Q160Z	EC-3890Li	ED-3872LZK	EC-3430LZ	EC-3830LZ
Working length (mm)	L = 1680, I = 1330	1680	1030	1030	1700	1700	170	170
Insertion tube OD (mm)	12.8	12.8	9.8	10.8	13.2	13.2	11.7	12.8
Channel diameter (mm)	3.7	3.7	2.8	2.8	3.8	3.8	2.8	3.8
Angle view (degrees)	170		140		140	140	120	120
Additional CE	NBI	NBI	NBI	NBI	i-Scan			
Angulation (degrees)								
Up/down	180/180		210/90		180/180	180/180	180/180	180/180
Right/left	160/160		100/100		160/160	160/160	160/160	160/160
Magnification	D, ×1.5	D, ×1.5; O, ×150†	D, ×1.5	D, ×1.5 + O, ×115†	D, ×2	O, ×80	O, ×105	O, ×105
Zoom controller				MAJ-570*				
HD format (pixels)	1280 × 1024	640 × 480	1280 × 1024	640 × 480	1280 × 1024	640 × 480	640 × 480	640 × 480
Price ($)	36,000	31,500	31,000	27,000	36,950	26,775	26,250	26,250
Processor (price [$])	Evis Exera II (22,000)				EPK-i (36,750)			
Light source (price [$])	Evis Exera II (12,500.00)							

Various medical grade HD monitors are available, which vary in price based on size.
L, Long version; *I*, intermediate length version; *CE*, contrast enhancement; *OD*, outer diameter; *FICE*, Fuji image contrast enhancement; *D*, digital; *O*, optical.
*Additional charges apply.
†On a 20-inch monitor.
‡On a 19-inch monitor.

progressive scanning is thought to be better for video display of fast-moving objects.

HD video imaging can be displayed in either TV or computer monitor formats. Broadcast HD TV (HDTV) is available in 3 standard formats, 720p, 1080i, and 1080p, all in a 16:9 aspect ratio. The 720p images are 1280 pixels wide × 720 lines (approximately 921,000 pixels). The 1080 images are 1920 pixels wide × 1080 lines (2.07 million pixels). The 16:9 aspect ratio is not useful to display images from round endoscopic lenses. Historically, endoscopic images are typically displayed in a 4:3 aspect ratio to match the standard aspect ratios of SD TV and because this ratio provides the highest pixel density and resolution possible given the lens shape. Display in computer-monitor formats use progressive scanning and is not restricted by broadcast HD formats or aspect ratios. Monitors have traditionally been 4:3 aspect ratios but recently 5:4 ratios have become more popular. As HD signals were being developed, computer monitors were built with increasing resolutions, such as 1024 × 768 pixels (extended graphics array [XGA]), 1280 × 1024 pixels (super XGA), and as high as 5120 × 4096 (Hex super XGA [HSXGA]).[2] Current high-resolution endoscopic CCD chips display images in either 4:3 or 5:4 aspect ratios.

It is important to recognize that, to provide a true HD image, each component of the system (eg, the endoscope CCD chip, the processor, the monitor, and transmission cables) must be HD compatible, and, ideally, they would match formats such that image signals will be displayed in ''native resolution'' or without digital enhancement. HD processors and monitors can upconvert inputted image signals, such as from non-HD or lower-resolution endoscopes, through pixel interpolation that may compromise image resolution relative to a true HD image.

Three different high-resolution endoscope systems are currently available in the United States (Table 1). Olympus America (Center Valley, Pa) high-resolution endoscopes were designed based on commercial availability of TVs

TABLE 1 (*continued*)

Pentax Medical Co (Montvale, NJ)	Fujinon Inc (Wayne, NJ)		
Gastroscope	Colonoscope	Gastroscope	
EG 2990i	EC-590 ZW/L	EG-590WR	EG-590ZW
1050	1690	1100	1100
10.2	12.8	10.8	10.8
2.8	3.8	2.8	2.8
140	140	140	140
i-Scan	FICE*	FICE*	FICE*
210/120	180/180	210/90	210/90
120/120	160/160	100/100	100/100
D, ×2	O + D, ×135‡	D, ×2	O + D, ×135‡
1280 × 1024	1280 × 960/1080i	1280 × 960/1080i	1280 × 960/1080i
31,500	31,995	28,430	28,430
	VP-4400 (35,140)		
	EPX-4400/EPX-4400HD		

and recorders for output onto HDTVs. The output from the endoscope is enhanced to 1080i; however, the endoscopic image itself is displayed within a 1280 × 1024-pixel frame. The actual CCD chip specifications are proprietary. Pentax Medical Co (Montvale, NJ) and Fujinon Inc (Wayne, NJ) high-resolution endoscopes were designed for output onto computer monitors. The first Fujinon CCD chips were 1077 × 788 pixels (approximately 850,000 pixels) and their output was equivalent to XGA monitors (1024 × 728 pixels),[2] but current endoscopes have an output of 1280 × 960 pixels. The actual resolution of the CCD chip is proprietary. The newest processors will enhance the image to 1080i. The Pentax CCD chip is 1280 × 1024 pixels (approximately 1.25 million pixels) and displays at native resolution.

HD CCD chips have lower light sensitivities because of the smaller size of their pixels. Hence, for optimal illumination, the standard light source for HD endoscopy is a 300-W xenon lamp. The digital output from the processors to either HDTV or computer monitors usually requires HD-serial digital interface or digital video interface cables, respectively, to provide the adequate bandwidth needed for the HD digital signal. Optical fibers can also be used. Because the digital signals do not travel long distances well, a distribution amplifier or matrix router may be needed to provide adequate transmission. HD signals may be better sent over long distances with analog components (red, green, blue cables), although the signal quality may be compromised because of their limited bandwidth. The ultimate choice in cables may be dictated by the preexisting setup of cables in an endoscopy suite. In reality, there may be a mix of component formats and, as a consequence, HD-compatible processors and monitors have built-in flexibility. For example, HD processors can output their images in SD formats to non-HD peripherals, including endoscopic report generators, printers, or monitors.

At baseline, standard-resolution and high-resolution endoscopes magnify the endoscopic images 30 to 35 times. High-magnification endoscopes are defined by the

TABLE 2. High-resolution and high-magnification endoscopes not available in the United States

	Olympus Medical Systems Corp (Tokyo, Japan)							
	Colonoscope					Gastroscope		
Model no.	CF-H260AZL/I	CF-Q240ZL/I	PCF-Q240ZI	CF-2TQ240ZI	CF-FH260AZL/I	GIF-H260Z	GIF-Q240Z	GIF-FQ260Z
Working length (mm)	L = 1680 I = 1330	L = 1680 I = 1330	1330	1330	L = 1680 I = 1330	1030	1030	1030
Insertion tube OD (mm)	12.9	12.9	11.5	13.7	13.2	10.5	9.8	10.5
Channel diameter (mm)	3.2	3.2	3.2	3.2/3.2	3.2	2.8	2.8	2.8
Zoom magnification	×70*	×100†	×80†	×80†	×85‡	×85‡	×80†	×85‡
Zoom controller	MAJ-570§	MAJ-570§			MAJ-570§			
HD format (pixels)‖	HD	SD	SD	SD	HD	HD	SD	SD
Processor/light source	CV-260SL/260	CV-260SL/260	CV-260SL/260	CV-260SL/260	CV-260SL/260	CV-260SL/260	CV-260SL/260	CV-260SL/260

L, Long version; *I,* intermediate length version; *OD,* outer diameter; *D,* digital; *O,* optical; *HD,* high definition.
*On an 18-inch monitor.
†On a 14-inch monitor.
‡On a 19-inch monitor.
§Additional charges apply.
‖For SD, NTSC (United States, Japan) 640 × 480 pixels; PAL (Europe) 720 × 486 pixels.

capacity to perform optical zoom by using a movable lens in the tip of the endoscope. A translucent cap on the tip of the endoscope may be used to stabilize the focal length between the lens and the target tissue to improve image quality.[4] Optical zoom obtains a closer image of the target while maintaining image display resolution. This is distinguished from electronic magnification, which simply moves the image closer on the display and results in a decreased number of pixels that compose the area of the display, with no improvement in resolution. With the proper processor, conventional endoscopes permit an electronic magnification of ×1.5 to ×2. Although standard endoscopes magnify images 30 to 35 times, zoom endoscopes can optically magnify images up to 150 times, depending on the size of the monitor (Tables 1 and 2). All 3 companies have zoom endoscopes available in the United States, with combined optical and digital zoom (Table 1). Other Olympus zoom endoscopes reported in the literature are not commercially available in the United States (Table 2).

EFFICACY AND COMPARATIVE STUDIES

Most studies combine high-resolution magnification endoscopy, along with chromoendoscopy or with equipment-based mucosal-imaging enhancements, such as Narrow-Band Imaging (NBI) (Olympus Medical Systems Corp, Tokyo, Japan) or Multiband Imaging (Fujinon Corp, Saitama, Japan), which are technologies reviewed in separate reports.[5,6] Acetic acid has also been used to help enhance mucosal changes. It, therefore, is difficult to establish the independent effect of these improved imaging systems.

Esophagus

There have been multiple attempts with magnification endoscopy and mucosal enhancement to identify mucosal patterns that accurately predict the presence of Barrett's esophagus, with or without dysplasia. An initial study with indigo carmine with magnification endoscopy noted a correlation of slightly raised mucosa with a villiform pattern.[7] Another study used methylene blue and magnification endoscopy to describe a villous and tubular staining pattern associated with Barrett's esophagus as opposed to small round and straight pits, which were associated with gastric epithelium.[8] Similarly, a separate report described 4 different mucosal surface patterns enhanced by SD magnification endoscopy and acetic acid (type 1, round; type II, reticular; type III, villous without pits; and type IV, ridged). Type III and type IV were associated

TABLE 2 (*continued*)

Pentax Co (Tokyo, Japan)					Fujinon Co (Saitama City, Japan)				
Colonoscope				Gastroscope	Colonoscope				
EC-3890Li	ED=3872LZK	EC-3430LZ	EC-3830LZ	EG 2990i	EC-590WM2	EC-590WM	EC-590WI	EC-590WL	EC-590ZW/M
1700	1700	170	170	1050	1330	1330	1520	1690	12.8
13.2	13.2	11.7	12.8	10.2	12.0	12.8	12.8	12.8	3.8
3.8	3.8	2.8	3.8	2.8	3.8	3.8	3.8	3.8	Yes
×140	×140	×120	×120	×140	×2	×2	×2	×2	×135
					D	D	D	D	O + D
1280 × 1024	SD	SD	SD	1280 × 1024	HD/HDTxV 960p/1080i	HD/HDTV 960p/1080i	HD/HDTV 960p/1080i	HD/HDTV 960p/1080i	HD/HDTV 960p/1080i
EPK-i	EPK-i	EPK-i	EPK-i	EPK-i	EPX-4400/ EPX-4400HD	EPX-4400/ EPX-4400HD	EPX-4400/ EPX-4400HD	EPX-4400/ EPX-4400HD	EPX-4400/ EPX-4400HD

with Barrett's epithelium.[9] By using indigo carmine staining and magnification endoscopy, another report described 3 distinct patterns: ridged and/or villous, circular, and irregular and/or distorted.[10] Barrett's epithelium was most commonly identified in the ridged-villous pattern, where, as high-grade dysplasia, was found entirely within in mucosa with the irregular-distorted pattern.[10] A study with magnification endoscopy and acetic acid identified 3 mucosal patterns (type 1, normal; type 2, slit reticular; and type 3, gyrus-villous), with Barrett's epithelium correlating with type 3.[11] However, all of these existing classifications are more complicated relative to their clinical value and require a learning curve for the endoscopist.[12,13] Another significant limitation of these 3 classification systems is their interobserver and intraobserver variability.[14,15] Three recent studies that used narrow-band imaging (NBI) and SD magnification endoscopy reported success in identifying intestinal metaplasia based on different types of capillary and fine mucosal patterns.[16-18] To date, there is no standard classification of mucosal image patterns.

A randomized trial with crossover of acetic-acid–guided biopsies by using SD magnification endoscopy and random 4-quadrant biopsies with SD conventional endoscopy showed that diagnostic yield to detect Barrett's esophagus increased 1.4-fold to 1.6-fold when using magnifying endoscopy and acetic-acid enhancement.[19] However, magnification endoscopy has not uniformly been shown to be better than conventional endoscopy at detecting intestinal metaplasia.[20]

Two studies also suggest that high-resolution imaging may be enough to detect Barrett's esophagus.[21,22] With regard to detecting nondysplastic Barrett's esophagus, 1 study that compared high-resolution (upconverted from SD), high-magnification endoscopic images (reviewed by experts and nonexperts), with and without NBI, chromoendoscopy, and acetic acid, showed no improvement in detecting intestinal metaplasia, thereby calling into question the added benefits of these imaging enhancement techniques.[21] It may be that NBI is most useful to reduce false-positivity rate relative to using high-resolution image interpretation alone.[23]

The role of high-resolution or magnification endoscopy for the identification of dysplasia and adenocarcinoma[10,22] or early squamous cell carcinomas[24,25] in the esophagus remains to be clarified. A prospective, randomized, crossover study that compared high-resolution endoscopy with either indigo carmine or NBI showed that the mucosal enhancement techniques did not increase detection of high-grade dysplasia or early cancer when compared with high-resolution imaging alone.[22]

Stomach

The use of chromoendoscopy or NBI with magnification endoscopy has primarily been used for the evaluation of early gastric cancers before EMR, but surrounding gastritis can compromise specificity.[26-29] Early adenocarcinomas were noted to have irregular, tortuous capillaries when compared with adenomatous, hyperplastic, or normal mucosa. There were differences noted between elevated-type and depressed-type lesions, but this has yet to be prospectively validated.[26] The importance of detecting early lesions and establishing depth of invasion based on mucosal patterns would help stratify between surgical or endoscopic therapies (including EMR or submucosal dissection).[28,30] Mucosal pit patterns may also be useful to identify *Helicobacter pylori*–induced gastritis,[27,31,32] intestinal metaplasia,[33,34] and gastric atrophy[31,34] with good interobserver and intraobserver agreement.[33,34] These data are primarily from Asian or Portuguese studies, and the generalizability to lower prevalence regions is unclear.

Small intestine

There is limited analysis of magnification endoscopy in small-bowel disease, although there were promising reports of targeting biopsies in celiac sprue or malabsorption.[35-38] One study, of 34 patients with either celiac or tropical sprue, found that SD magnification chromoendoscopy identified villous atrophy better than did standard endoscopy and, therefore, helped target biopsies.[35] A study of 191 patients showed that high-resolution magnification endoscopy had a 95% sensitivity, 99% specificity, 95% positive predictive value, and 99% negative predictive value to detect the presence of any villous abnormality.[36]

Colon

High-resolution and high-magnification endoscopy have been examined as a tool to enhance detection of colonic neoplasia, including flat or depressed lesions. Chromoendoscopy has been used as an adjunct in this effort. Kudo et al[39,40] proposed 5 major pit patterns to differentiate among non-neoplastic, neoplastic, and malignant polyps. This classification system yielded a high level of interobserver and intraobserver agreement.[41,42]

There are large cases series that report the utility of using magnification colonoscopy and pit-pattern analysis to differentiate neoplastic and non-neoplastic lesions,[43-45] including flat or depressed lesions.[46-48] Three studies found that SD magnification chromocolonoscopy is more accurate than nonmagnification chromocolonoscopy in differentiating adenomas from hyperplastic polyps. One prospective trial randomized 660 patients to either magnification chromoendoscopy with indigo carmine or conventional chromocolonoscopy.[47] The aim was to detect neoplasia by using the Kudo pit-pattern system. The accuracy of magnification colonoscopy in distinguishing neoplastic from non-neoplastic lesions <10 mm in size (92% [372/405]) was significantly higher than for nonmagnifying colonoscopy (68% [278/407]).[47] The higher accuracy of magnification chromocolonoscopy over conventional chromocolonoscopy was validated in another recent study of 500 patients.[49] Another study compared the diagnostic accuracy of differentiating neoplastic from non-neoplastic lesions by conventional colonoscopy, chromoendoscopy with indigo carmine, and SD magnification chromoendoscopy. All lesions were sequentially evaluated by all 3 methods.[50] Magnification chromocolonoscopy was found to have a significantly higher accuracy (95.6%) compared with either chromoendoscopy (89.4%) ($P = .015$) or conventional colonoscopy without indigo carmine (84%) ($P = .0001$).

Recent studies demonstrated the utility of NBI with magnification colonoscopy in the detection of adenomatous lesions. Prospective studies demonstrated that high-magnification NBI was more accurate than conventional colonoscopy[51] and was equivalent to magnification chromoendoscopy in differentiating between neoplastic and non-neoplastic colonic lesions,[51,52] although the Kudo system may need to be modified for NBI.[53] Without magnification, high-resolution colonoscopy with NBI did not result in better detection of adenomas relative to high-resolution without NBI, although this finding may be primarily related to an endoscopist with a high-baseline adenoma detection rate.[54]

It may be that the mucosal magnification, in combination with tissue staining, is more important than high-resolution imaging. In a randomized trial, high-resolution (850,000 pixels) chromocolonoscopy (with indigo carmine) was compared with conventional colonoscopy in the detection of adenomas in high-risk patients.[55] The number of lesions detected was the same between the high-resolution colonoscope without tissue staining and the standard colonoscope. More hyperplastic polyps and flat adenomas were detected by using tissue staining and high-resolution colonoscopes than when using standard colonoscopes alone, but the total number of adenomas (the primary end point) was the same between the 2 groups. The investigators concluded that high-resolution chromoendoscopy was not required for routine care.

Magnification chromoendoscopy has been reported to be useful in predicting histology and invasive depth of cancer,[56-59] although the sensitivity may be low,[45] and it is less accurate in staging than US.[60] Magnification colonoscopy with NBI has also shown promise in predicting histology and depth of invasion.[61] Ultimately, magnification colonoscopy with tissue stains or NBI may help direct endoscopic therapy, eg, EMR,[59,61,62] and assess the completeness of the resection.[63]

Magnification endoscopy has also been studied in ulcerative colitis, again, typically with chromoendoscopy. A randomized controlled trial demonstrated that SD magnification endoscopy with methylene blue was better than magnification endoscopy alone at identifying intraepithelial

neoplasia.[64] Prospective trials with targeted chromoscopy (indigo carmine) confirmed these findings[65] and demonstrated improved detection of intraepithelial neoplasia compared with random quadratic biopsies.[66] Magnification high-resolution endoscopy with NBI may also be useful to detect dysplasia in ulcerative colitis.[67] However, 1 study noted that active mucosal inflammation may interfere with the accuracy of magnification chromoendoscopy in the detection of neoplasia.[12] In small studies, magnification chromoendoscopy was also used to assess disease severity[68-70] and may even predict relapse,[69] but these findings require confirmation.

SAFETY

There has been no report of adverse events from the high-resolution or high-magnification features of endoscopes.

FINANCIAL CONSIDERATIONS

The costs of equipment available in the United States are included in Table 1. The financial burden of converting to HD imaging systems requires updating the entire endoscopy unit, including monitors, processors, and endoscopes, and if desired, peripherals, eg, recorders or printers. There are currently no Current Procedural Terminology codes (American Medical Association, Chicago, Ill) for high-resolution or magnification endoscopy. There have been no formal cost-effective analysis of using high-resolution magnification chromoendoscopy. The impact on endoscopy-unit efficiency has not been examined but, given the increased time required to perform inspection under magnification, efficiency will be compromised.

AREAS FOR FUTURE RESEARCH

The most pressing need is for standardization of GI mucosal abnormalities found on high-resolution and magnification endoscopy. The new standards need to be simple enough for clinical use and reliable interobserver interpretation. The ultimate clinical value for high-resolution and high-magnification endoscopy to provide improved detection of neoplasia and, therefore, improved clinical outcomes (eg, early detection of cancer and improved survival rates) has not yet been demonstrated.[71] Further studies that examine the independent value of these endoscopic modalities relative to mucosal enhancement techniques are needed, with particular emphasis on the capacity to reliably predict histology.

SUMMARY

High-resolution and high-magnification endoscopy, with or without mucosal enhancement techniques, enable detailed visualization of GI mucosa. These new endoscopic systems have the goal of helping to target biopsies or endoscopic resection, but standardization of abnormal mucosal patterns in the GI tract must be established. Further studies are needed to validate their utility in the form of improved clinical outcomes, and the independent value of high-resolution and high magnification features relative to mucosal enhancement techniques needs to be defined.

Abbreviations: ASGE, American Society for Gastrointestinal Endoscopy; CCD, charge coupled device; HD, high definition; HDTV, high-definition television; i image, interlaced image; NBI, narrow-band imaging; p image, progressive image; SD, standard definition; TV, television; XGA, extended graphics array.

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