Advanced endoscopic imaging: European Society of Gastrointestinal Endoscopy (ESGE) Technology Review

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Bibliography
DOI http://dx.doi.org/10.1055/s-0042-118087
Published online: 6.10.2016
Endoscopy 2016; 48: 1029–1045
© Georg Thieme Verlag KG
Stuttgart · New York
ISSN 0013-726X

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Background and aim: This technical review is an official statement of the European Society of Gastrointestinal Endoscopy (ESGE). It addresses the utilization of advanced endoscopic imaging in gastrointestinal (GI) endoscopy.

Methods: This technical review is based on a systematic literature search to evaluate the evidence supporting the use of advanced endoscopic imaging throughout the GI tract. Technologies considered include narrowed-spectrum endoscopy (narrow band imaging [NBI]; flexible spectral imaging color enhancement [FICE]; i-Scan digital contrast [I-SCAN]), autofluorescence imaging (AFI), and confocal laser endomicroscopy (CLE). The Grading of Recommendations Assessment, Development and Evaluation (GRADE) system was adopted to define the strength of recommendation and the quality of evidence.

Main recommendations:
1. We suggest advanced endoscopic imaging technologies improve mucosal visualization and enhance fine structural and microvascular detail. Expert endoscopic diagnosis may be improved by advanced imaging, but as yet in community-based practice no technology has been shown consistently to be diagnostically superior to current practice with high definition white light. (Low quality evidence.) **2.** We recommend the use of validated classification systems to support the use of optical diagnosis with advanced endoscopic imaging in the upper and lower GI tracts (strong recommendation, moderate quality evidence). **3.** We suggest that training improves performance in the use of advanced endoscopic imaging techniques and that it is a prerequisite for use in clinical practice. A learning curve exists and training alone does not guarantee sustained high performances in clinical practice. (Weak recommendation, low quality evidence.)

Conclusion: Advanced endoscopic imaging can improve mucosal visualization and endoscopic diagnosis; however it requires training and the use of validated classification systems.

Abbreviations

AFI	autofluorescence imaging
BING	Barrett's International NBI Group
CAD	computer-aided diagnosis
CCD	charge-coupled device
CE	contrast enhancement
CLE	confocal laser endomicroscopy
ESGE	European Society of Gastrointestinal Endoscopy
FICE	flexible spectral imaging color enhancement (also termed Fujinon Intelligent Chromo Endoscopy)
GI	gastrointestinal
GRADE	Grading of Recommendations Assessment, Development and Evaluation
ICE	I-SCAN classification for endoscopic diagnosis
IBD	inflammatory bowel disease
iCLE	integrated confocal laser endomicroscopy
IPCL	intrapapillary capillary loop
I-SCAN	i-Scan digital contrast
JNET	Japanese NBI Expert Team
NADPH	nicotinamide adenine dinucleotide phosphate
NBI	narrow band imaging
NICE	NBI International Colorectal Endoscopic
pCLE	probe-based confocal laser endomicroscopy
SE	surface enhancement
SIM	specialized intestinal metaplasia
TE	tone enhancement
WASP	Workgroup serrAted polypS and Polyposis
WLE	white-light endoscopy

1. Introduction

Since the introduction of flexible gastrointestinal (GI) endoscopy in the 1960 s there has been a relentless advance in endoscopic imaging technology to assist clinicians to make better decisions. Initially this focused on the replacement of fiberoptics by a charge-coupled device (CCD) to acquire images and then on images of higher resolution. In the 1970 s, the use of dye-spray to stain the mucosa was introduced in Japan to aid diagnosis and was called "chromoendoscopy" [1]; however this has not been widely accepted by Western endoscopists, despite diagnostic advantages, as it is time-consuming and has a significant learning curve [2]. In the last 10 years a series of "push-button" technologies (e.g. narrowed-spectrum endoscopy and autofluorescence imaging [AFI]) have allowed advanced endoscopic imaging to be available more simply; concurrently confocal laser endomicroscopy (CLE) has allowed endoscopists to obtain "in vivo histology" [3]. Nevertheless, to be effective all the available imaging technologies require basic endoscopic elements such as high quality bowel preparation and dexterous operators, with appropriate training.

A previous ESGE Guideline has recently focused on the diagnostic performance of these technologies in the colon [4]. The current complementary technological review working group systematically reviewed the literature on these technologies throughout the GI tract and used the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system to define the strength of any recommendation and the quality of evidence [5], with multiple review rounds. This review aims to set out how the technologies work, how to implement them, and where they are best used in the GI tract; if they offer no or limited benefit this is also stated. Because of the scope of the review only key references on clinical utility are presented.

2. Mechanisms and equipment of commercially available technologies (Table 1)

1. We suggest that advanced endoscopic imaging technologies improve mucosal visualization and enhance fine structural and microvascular detail. Expert endoscopic diagnosis may be improved by advanced imaging, but as yet in community-based practice no technology has been shown consistently to be diagnostically superior to current practice with high definition white light. (Low quality evidence.).

2.1 Narrowed-spectrum technologies

Narrowed-spectrum endoscopy is so called because this group of image enhancement techniques relies on using only a narrowed part of the available spectral bandwidth, mainly corresponding to "blue light." This is accomplished through optical or digital filtering and has also been termed "virtual chromoendoscopy." All major manufacturers now offer this functionality built into endoscopic systems as standard. High definition is a prerequisite to optimal usage of these technologies.

2.1.1 Narrow band imaging

Narrow band imaging (NBI) (Olympus Medical Systems, Tokyo, Japan) was the first of the commercially available narrowed-spectrum technologies. NBI functions by filtering the illumination light. The red component of the standard red, green, and blue (RGB) filters is discarded and the spectral bandwidth of the blue and green light filters, centered on 415 and 540 nm, respectively, is reduced from 50 – 70 nm to 20 – 30 nm. The incoming signals from the charge-coupled device (CCD) are combined by the video processor to produce a false-color image. Hemoglobin presents an absorption peak at 415 nm and therefore it strongly absorbs the "blue" light; furthermore these shorter wavelengths penetrate the mucosa less deeply than red light which presents a wavelength of 650 nm [6]. This results in an increased contrast

Table 1 Advanced endoscopic imaging: equipment and manufacturers.

Technique	Company	Name	Geographic distribution	Components
Narrow band imaging (NBI)	Olympus	Lucera Spectrum/ Lucera Elite	Japan, UK	Video System Center (CV-260SL; Spectrum) (CV-290; Elite)
		Exera II/ Exera III	Rest of the world	Video system center, CV 180 (Exera II); CV190 (Exera III)
Flexible spectral imaging color enhancement (FICE) (also Fujinon Intelligent Chromo Endoscopy)	Fujifilm	EPX-4400 system	Worldwide	XL-4400 light source; VP-4400 HD processor
i-Scan digital contrast (I-SCAN)	Pentax	EPK-i	Worldwide	Combined processor and light source in: EPK-i7000 HD processor (high end, fully adjustable interface) EPK-i5000 HD processor (I-SCAN presets, not custom-adjustable)
Blue laser imaging (BLI)	Fujifilm	Lasereo	Japan, China, South America, Asian-Pacific	Processor VP-4450HD, Laser Light Source LL-4450 and L590 series endoscopes
Autofluorescence imaging (AFI)	Olympus	Lucera Spectrum	Japan, UK	Video System Center (CV-260SL), CFH260 colonoscope AZL
Confocal laser endoscopy (CLE)	Pentax		Worldwide	Pentax ISC-1000 endomicroscopy system; EC3870K endoscope
	Mauna Kea	Cellvizio	Worldwide	Cellvizio 100 series system; GastroFlex and ColoFlex UHD probes

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for superficial microvessels which appear brown/black and in greater clarity of mucosal surface structures [7].
In Japan and in the United Kingdom, NBI systems with a monochrome CCD (Lucera, "200" series) are predominantly used; in the rest of the world NBI systems with a color CCD (Exera, "100" series) are used (**Table 1**).

2.1.2 Flexible spectral imaging color enhancement

Flexible spectral imaging color enhancement (FICE) (Fujinon Intelligent Chromo Endoscopy; Fujifilm, Tokyo, Japan) is a post-processor technology for vascular and surface tissue image enhancement [8]. Unlike NBI, which utilizes physical optical light filters, FICE selects particular wavelengths from digitized data. The color intensity spectrum for each pixel of the white-light image is analyzed in a "spectral estimation" circuit in the video processor. Images can then be reconstructed, pixel by pixel, using only a single selected wavelength. Three such single-wavelength images are selected and assigned to the red, green, and blue monitor inputs to display a composite color-enhanced image in real time. This can be used like NBI to remove data from the red part of the waveband and to narrow the green and blue spectra. However, the system is flexible. It has 10 preset digital filter settings with the ability to program more (**Table 2**) [9].

2.1.3 i-Scan digital contrast (I-SCAN)

I-SCAN (Pentax, Tokyo, Japan) is another post-processing digital contrast technology that consists of three enhancement features: surface enhancement (SE), which sharpens the image; contrast enhancement (CE) where darker (depressed) areas look more blue; and tone enhancement (TE), a form of digital narrowed-spectrum imaging. TE has some similarities to FICE, in that the white-light image is split into its red, green, and blue components. Each component can then be independently modified, this being followed by recombination of the three components to construct a new digital image. Originally, four different types of TE modification, to enhance different mucosal structures, were available: TE-v for vascular pattern assessment, which is no longer used; TE-c for the intestine; TE-e for the esophagus; and TE-g for the stomach [10].
Three standardized I-SCAN settings are now readily available in the factory settings of the processor, including I-SCAN 1 (SE) recommended for detection, I-SCAN 2 (combination of SE and TE-c) recommended for lesion characterization, and I-SCAN 3 (combination of SE, TE-c, and CE) recommended for lesion demarcation, with I-SCAN 2 being probably the most widely used.

2.2 Autofluorescence imaging

Some natural tissue molecules, such as collagen, flavins, and nicotinamide adenine dinucleotide phosphate (NADPH), are fluorophores, that is, they emit fluorescence after excitation with short-wavelength light. Autofluorescence imaging (AFI; Olympus) is based on real-time detection of such fluorescence. The AFI signal is altered by changes in mucosal thickness, in mucosal blood flow, and in the endogenous tissue fluorophores. Thick tissue with increased blood flow such as that of adenomas attenuates both the excitation and autofluorescence signals [11].
Differences in fluorescence emission between neoplastic and non-neoplastic tissues are detected by an additional CCD image sensor equipped with a filter that cuts out the blue excitation light. The video processor combines the autofluorescence signal with some mucosal reflectance of the green light used for illumination, to produce a false-color image where tissues are visualized in real time as purple, violet, or green color. A dysplastic lesion would then be highlighted as a purple lesion in a green background corresponding to normal mucosa.
The image resolution in AFI is even lower than with standard definition endoscopy, and frame averaging is used to boost the quality of the autofluorescence image. Rapid movement of the endoscope tip leads to degradation of the images as the frame averaging cannot keep pace.

2.3 Confocal laser endomicroscopy (CLE)

Confocal laser endomicroscopy (CLE) was developed for cellular and subcellular imaging up to 250 micrometers below the mucosal surface [12]. A low-power laser is focused to a single point in a microscopic field of view and the same lens is used as both condenser and objective, folding the optical path so the point of illumination coincides with the point of interest within the specimen. Light emanating from that point is focused to the detector through a pinhole so that light emanating from outside the illuminated spot is blocked. As illumination and detection systems are at the same focal plane, they are termed "confocal" [13]. Successive points in a region are scanned to build up a digitized raster image. The image created is an optical section representing one focal plane within the examined specimen [13]. The image appears in gray tones.
Currently, two CLE-based systems are used in routine clinical practice and research [14, 15]. In integrated CLE (iCLE) (Pentax, Tokyo, Japan), a confocal scanner has been integrated into the distal tip of a flexible endoscope. This system is no longer commercially available but a hand-held system (FIVE1; Optiscan, Melbourne, Australia) is available for research applications. A probe-based system (pCLE) (Cellvizio Endomicroscopy System; Mauna Kea Technologies, Paris, France) is commercially available and consists of a flexible miniprobe which may be introduced through the working channel of a standard endoscope [15–17].
A direct comparison of technical aspects of the two systems is shown in **Table 3** [18]. iCLE allows higher resolution, wider field of view and deeper imaging depth, at the expense of frame rate compared to pCLE, and provides variable imaging depth.

Table 2 Preset wavelengths and gain for flexible spectral imaging color enhancement (FICE; also Fujinon Intelligent Chromo Endoscopy). By kind permission of Fujifilm Europe GmbH.

	Preset Wavelength in nm (Gain)									
	0	1	2	3	4	5	6	7	8	9
Red	525 (3)	550 (2)	550 (2)	525 (4)	520 (2)	560 (4)	580 (2)	540 (1)	540 (2)	550 (2)
Green	495 (4)	500 (4)	500 (2)	495 (3)	500 (2)	500 (5)	520 (2)	490 (5)	505 (4)	500 (2)
Blue	495 (3)	470 (4)	470 (3)	495 (1)	405 (3)	475 (3)	460 (3)	420 (5)	420 (5)	400 (3)

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Table 3 Technical aspects of confocal laser endomicroscopy (CLE) systems [18].[*]

	Endoscope-based	Probe-based
Outer diameter, mm	12.8 (scope)	1.0; 2.7; 2.6[†]
Length, cm	120; 180	300; 400[†]
Field of view, μm^2	475 × 475	240; 320; 600[†]
Resolution, μm	0.7	1.0; 3.5[†]
Magnification	× 1000	× 1000
Imaging plane depth, μm	0 – 250 (dynamic)	40 – 70; 55 – 65; 70 – 130 (fixed)[†]

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[†] Dependent on various probes.

Unlike narrowed-spectrum technologies or AFI, CLE requires contrast agents. The most commonly used dyes are fluorescein administered intravenously and acriflavine and cresyl violet which are applied topically [17, 19, 20].

2.4 Other technologies

The usefulness of most narrowed-spectrum technologies can be limited by a dark field of view. Blue laser imaging (BLI) (Lasereo; Fujifilm, Kanagwa, Japan), may overcome this limitation by combining two laser light sources of wavelengths 410 nm and 450 nm. The 450-nm laser strikes a phosphor, inducing fluorescent light that is equivalent to a xenon light source. The other laser provides enhanced mucosal surface information by applying a limited wavelength spectrum of 410-nm blue light, similarly to other narrowed-spectrum technologies. In a tandem endoscopy study in 39 patients in which the visibility provided by BLI and NBI was compared, the mean observable distance was significantly higher for BLI compared with NBI [21]. Promising early data are also available for characterization of small (< 10 mm) colonic polyps and for assessing invasiveness of colonic lesions, but large multicenter experience and validation is awaited [22, 23]. This technology is not available in Europe, but a similar technology using light-emitting diodes instead of lasers may soon become commercially available.

The Storz professional image enhancement system (SPIES; Karl Storz, Tuttlingen, Germany) is another post-processing digital contrast technology that has some similarities to I-SCAN and FICE. No published data are available for the GI tract.

Given the lack of available clinical data, BLI and SPIES will not be considered further in this review.

3 Optical diagnosis classification systems

2. We recommend the use of validated classification systems to support the use of optical diagnosis with advanced endoscopic imaging in the upper and lower GI tracts (strong recommendation, moderate quality evidence).

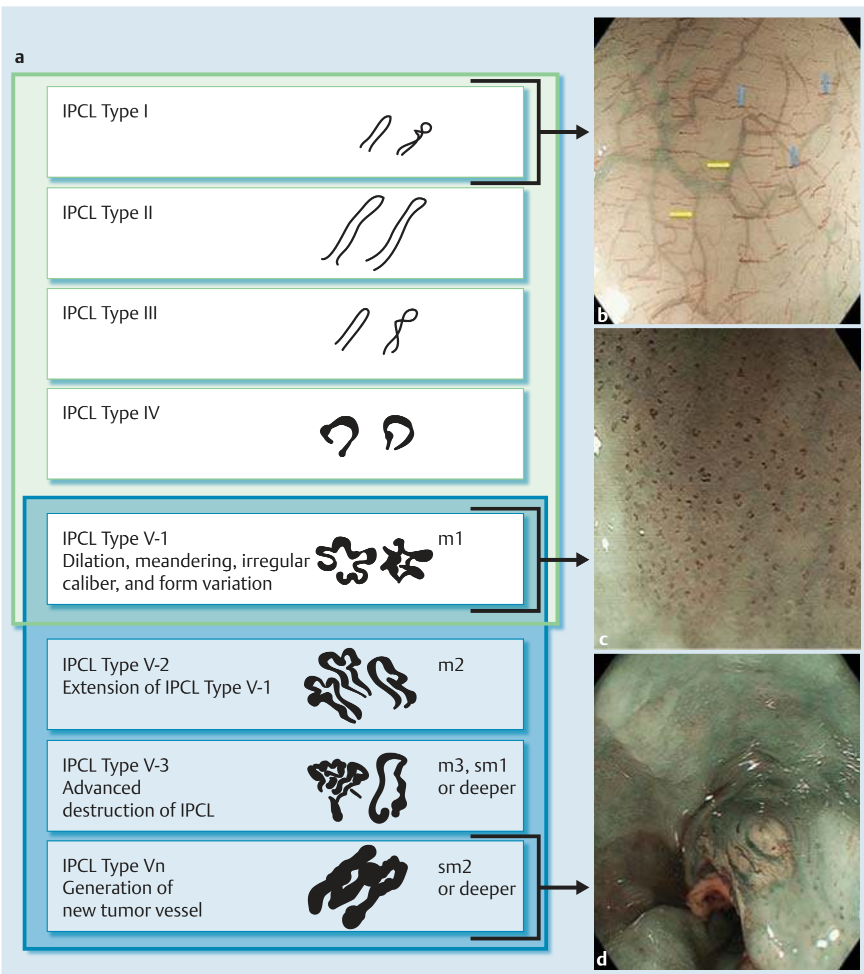

Fig. 1 Intrapapillary capillary loop (IPCL) pattern and four characteristic changes in squamous cell carcinoma of the esophagus: dilatation, tortuous (meandering) course, change in caliber, and variety of shapes. **a** Classification. Type I, normal pattern; type II, IPCLs have one or two out of the four changes, and elongation and/or dilatation is commonly seen; type III, IPCLs have minimal changes, type IV, IPCLs have three out of four characteristic changes; type V, IPCLs have all four characteristic changes indicating carcinoma in situ. (From Sato et al. [25].) **b – d** Microvascular caliber. **b** Normal IPCLs under magnifying endoscopy (× 80), seen as small-caliber loop-shaped brown vessels (blue arrows). The green vessel network located behind the IPCLs is of branching vessels (yellow arrows). **c** IPCL vessels of type V-1 under magnification endoscopy with narrow band imaging (NBI); these showed dilatation and irregularity in form. This pattern usually corresponded to an m1 lesion, i. e., limited to the mucosa. **d** IPCLs of type Vn ("new tumor vessels"), with NBI and magnification. Note the appearance of large transversely oriented green vessels This pattern corresponded to sm (invading the submucosa) massive cancer (T1b). (From Santi et al. [26].) Areas of squamous neoplasia of types IV and V1 – V2, and in selected cases type V3, can be treated by endoscopic mucosal resection/endoscopic submucosal dissection (EMR/ESD); however type Vn requires comprehensive treatment through surgery.

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3.1 Narrowed-spectrum endoscopy and optical diagnosis

3.1.1 Upper GI tract

Squamous cell carcinoma. Squamous cell dysplasia or carcinoma appears as dark brown patches on the esophageal mucosa. The intrapapillary capillary loop (IPCL) classification, also called the Inoue classification has been developed to enable endoscopic assessment of the likely depth of invasion using NBI and magnification [24–26]. Increasing dilatation and tortuosity of the IPCLs is associated with higher grade of dysplasia (**Fig. 1**).

Barrett's esophagus. NBI has been applied in Barrett's esophagus to enhance the targeting of both intestinal metaplasia and dysplasia. For NBI in conjunction with magnification, three main classification systems have been proposed, from Kansas, Amsterdam, and Nottingham (**Table 4**) [27–29]. These suggest that irregular mucosal pattern and vessels are predictive of dysplasia, and the "ridged/villous" pattern is predictive of specialized intestinal metaplasia (SIM). In one study that compared all three systems, accuracy for nondysplastic SIM ranged between 57% and 63% and for dysplasia the accuracy was 75% [30]. Interobserver agreement was fair (Nottingham classification) to moderate (Kansas and Amsterdam classifications).
More recently a simpler classification system to discriminate neoplastic from non-neoplastic Barrett's esophagus using NBI has been developed and validated. The Barrett's International NBI Group (BING) used near-focus technology, but not formal magnification endoscopy, with encouraging results (**Table 4**, **Fig. 2**) [31].

Gastric intestinal metaplasia and dysplasia. For gastric lesions examined with NBI some features are similar to those seen in Barrett's esophagus, with regular mucosal and vascular patterns favoring the absence of dysplasia, and ridged or villous patterns being found in areas that are suggestive of intestinal metaplasia. The "light blue crest" sign, not seen in Barrett's esophagus, is relatively specific for gastric intestinal metaplasia but its absence does not exclude intestinal metaplasia (**Fig. 3**, **Video 1**) [32]. Variable vascular density may indicate the presence of *Helicobacter pylori* infection. A proposed combined classification system is shown in **Table 5** [33].

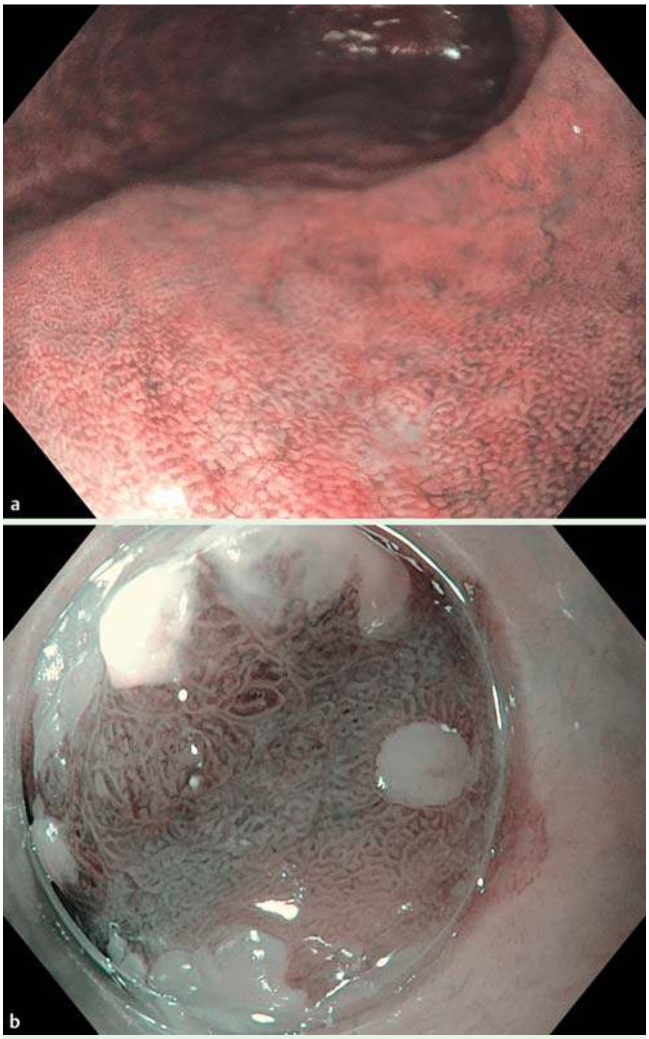

Fig. 2 Barrett's International Narrow band imaging Group (BING) classification for Barrett's esophagus seen with narrow band imaging (NBI) and near focus. **a** Barrett's esophagus showing nondysplastic ridged/villous pattern. **b** Barrett's esophagus with high grade dysplasia showing irregular mucosal and vascular pattern. Note use of cap to improve stability. (Images courtesy of Dr. Sreekar Venneleganti and Dr. Prateek Sharma, Kansas, USA.)

Table 4 Classification systems for Barrett's esophagus with magnification-narrow band imaging (NBI) [30].

	Kansas [27]	Amsterdam [28]	Nottingham [29]	Barrett's International NBI Group (BING) [31]
Normal	Mucosal pattern: circular Vascular pattern: normal	Mucosal pattern: regular Vascular pattern: regular Abnormal blood vessels: absent	Type A: round/oval pits with regular microvasculature	Mucosal pattern: circular, ridged/villous, or tubular Vascular pattern: blood vessels situated regularly along or between mucosal ridges and/or those showing normal, long, branching patterns
Intestinal metaplasia	Mucosal pattern: ridged/villous Vascular pattern: normal	Mucosal pattern: regular Vascular pattern: regular (villous/gyrus) Abnormal blood vessels: absent	Type B: villous/ridge/linear pits with regular microvasculature Type C: absent pits with regular microvasculature	
Dysplasia	Mucosal pattern: irregular distorted Vascular pattern: abnormal	Mucosal pattern: irregular Vascular pattern: irregular Abnormal blood vessels: present	Type D: distorted pits with irregular microvasculature	Mucosal pattern: absent or irregular patterns Vascular pattern: focally or diffusely distributed vessels not following normal architecture of the mucosa

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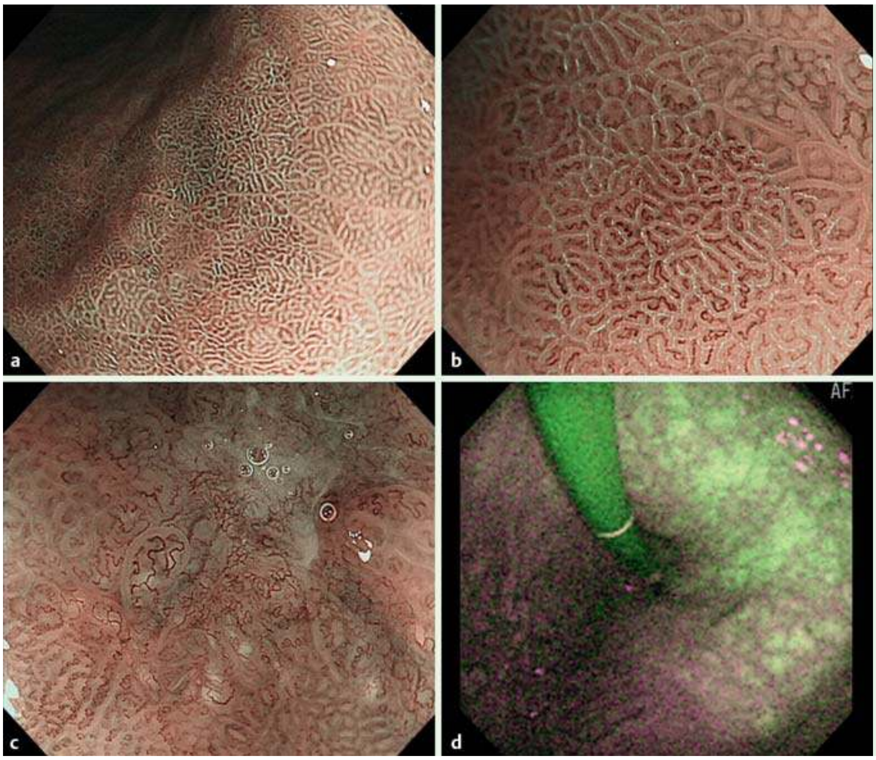

Fig. 3 Gastric intestinal metaplasia and dysplasia seen with advanced endoscopic imaging. **a** Gastric metaplasia seen with narrow band imaging (NBI) wide-field view. **b** Gastric metaplasia magnified view with NBI showing light blue crest sign. **c** Small depressed early gastric cancer showing irregular microvessel pattern within a demarcation line. **d** Gastric body thinning with atrophy (green) and normal mucosa (purple) seen with autofluorescence imaging (AFI). (Images courtesy of Dr. Noriya Uedo, Osaka, Japan).

Table 5 Proposed classification of gastric lesions with narrow band imaging (NBI). Regular mucosal and vascular patterns favor the absence of dysplasia, ridge or tubulovillous being found in areas with intestinal metaplasia. The light blue crest should be considered specific for intestinal metaplasia but its absence does not exclude intestinal metaplasia. A variable vascular density may favor the presence of *Helicobacter pylori* (*H. pylori*) infection (Hp +). (Pimentel-Nunes et al. [33]).

	Proposed classification				
	A	**B**		**Hp +**	**C**
Mucosal pattern	Regular circular	Regular ridge/ tubulovillous	Light blue crest	Regular	Irregular/absent White opaque substance
Vascular pattern	Regular Thin/peripheral (gastric body) or thick/central (gastric antrum) vessels	Regular		Regular with variable vascular density	Irregular
Expected outcome	Normal	Intestinal metaplasia		*H. pylori* infection	Dysplasia

3.1.2 Lower GI tract

Machida et al. [7] described NBI visualization of the microvessel network as a way of differentiating between neoplastic and non-neoplastic lesions; Hirata et al. [34] were the first to describe vessel thickness as seen with NBI as a way of assessing the histological grade and depth of invasion of colorectal tumors. NBI measurements of the microvascular density (meshed capillary vessels, vascular pattern intensity, or brown hue) present an accuracy for colonic polyp characterization similar to that of magnified chromoendoscopic assessment based on Kudo's pit pattern classification [35 – 37]. However, both the lesion color and vessel thickness are subjective estimates. This has led to the consensus-based development of the NBI International Colorectal Endoscopic (NICE) classification system, based on color, vessels, and surface pattern criteria, for the endoscopic diagnosis of small colonic polyps [38] (**Table 6**, **Video 2**). A key advantage of this classification is that it can be applied using colonoscopes with or without optical (zoom) magnification. This classification system has been validated [39]. During colonoscopy real-time diagnoses were made with high confidence for 75 % of consecutive small polyps, with 89 % accuracy, 98 % sensitivity, and 95 % negative predictive value. A subsequent development of the NICE classification is the Japanese NBI Expert Team (JNET) classification [40]. This requires magnification and subdivides adenomatous lesions (NICE type 2) into type 2A, namely low grade adenomas, and type 2B, high grade adenomas including shallow submucosally invasive cancer. The World Endoscopy Organization has included the JNET classification in the next version of its "minimal standard terminology" (MST; version 4.0), used in endoscopic reporting systems; however the JNET classification has not had widespread international validation and the increased complexity and need for magnification may restrict adoption by community-based endoscopists.

Sessile serrated polyps, recently recognized as precursor lesions of colorectal cancer [41], are not incorporated in the NICE classification. The "Workgroup serrAted polypS and Polyposis" (WASP) classification combines the NICE classification and four sessile serrated lesion-like features, namely, cloud-like surface, indistinct

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Table 6 Narrow band imaging International Colorectal Endoscopic (NICE) classification for colorectal polyps [38].[1]

	Type 1	Type 2	Type 3
Color	Same or lighter than background	Browner relative to background (verify that color arises from vessels)	Brown to dark brown relative to background, sometimes patchy whiter areas
Vessels	None or isolated lacy vessels coursing across the lesion	Brown vessels surrounding white structures	Has area(s) with markedly distorted or missing vessels
Surface pattern	Dark or white spots of uniform size, or homogeneous absence of pattern	Oval, tubular, or branched white structures surrounded by brown vessels	Areas with distortion or absence of pattern
Most likely pathology	Hyperplastic	Adenoma	Deep submucosally invasive cancer

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border, irregular shape, and dark spots inside the crypts (▶ **Fig. 4** and ▶ **Fig. 5**). The presence of at least two features is considered sufficient to diagnose a sessile serrated lesion. During the validation phase, optical diagnosis made with high confidence showed a pooled accuracy of 84 % and pooled negative predictive value of 91 % for diminutive neoplastic lesions [42].

I-SCAN classification systems for polyps have also been developed using pit patterns and microvessel features (▶ **Fig. 6**). Bouwens et al. [43] developed a simple system, termed the "i-scan classification for endoscopic diagnosis" (ICE), and based on the Kudo and NICE classifications, in which color, epithelial surface pattern, and vascular pattern were independently rated. A total of 11 nonexpert endoscopists were trained on I-SCAN optical diagnosis using a didactic training session and a training module. Afterwards they evaluated still images of 50 polyps, and the mean sensitivity, specificity, and accuracy for the diagnosis of adenomas were 79 %, 86 %, and 81 %, respectively. Of the diagnoses, 81 % were made with high confidence and these were associated with a significantly higher diagnostic accuracy compared with the remaining diagnoses.

For FICE (▶ **Fig. 7**), the classification by Teixeira et al. was described in 2009 and was based on magnified microvessel patterns:

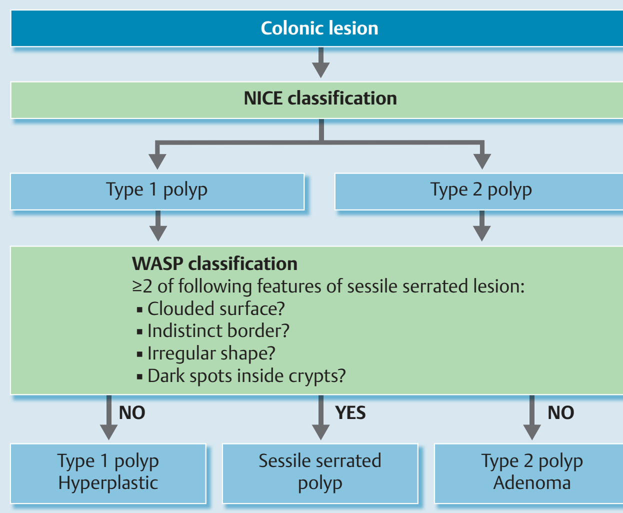
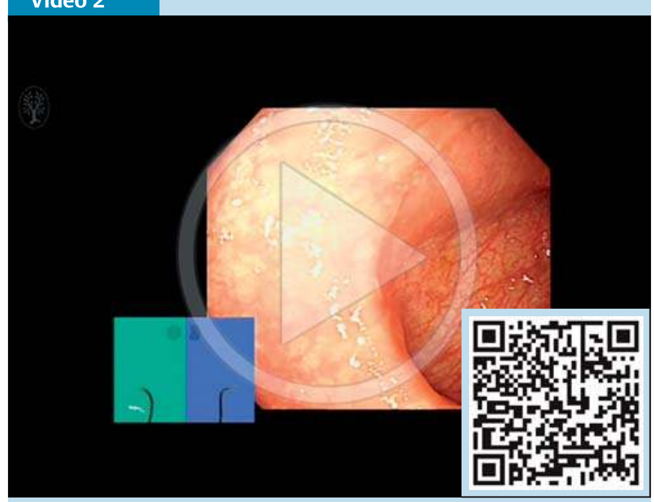


Fig. 4 Workgroup serrAted polypS and Polyposis (WASP) classification for optical diagnosis of hyperplastic polyps, sessile serrated lesions and adenomas, based on the Narrow band imaging International Colorectal Endoscopic (NICE) classification and four sessile serrated lesion-like features.

Video 1

Atrophic gastric body seen with white light with possible depressed, reddened area. Switch to narrow band imaging (NBI) reveals multiple pale areas suspicious for intestinal metaplasia. Subsequent magnification shows the "light blue crest" sign, confirming intestinal metaplasia. Nearby, the depressed area is shown to contain an area of irregular microvessels surrounded by a demarcation line, highly suspicious for early gastric cancer. (Video courtesy of Dr. Noriya Uedo, Osaka, Japan). Online content including video sequences viewable at: http://dx.doi.org/10.1055/s-0042-118087

Video 2



Narrow band imaging International Colorectal Endoscopic (NICE) classification (▶ **Table 6**). Assessment of a small colonic polyp using narrow band imaging (NBI) and near focus. The polyp is seen to have a dark color compared to the background mucosa, and white tubular structures surrounded by brown vessels; therefore it is a type 2 polyp – adenoma. Note lack of Workgroup serrAted polypS and Polyposis (WASP) classification features (see ▶ **Fig. 4**). Online content including video sequences viewable at: http://dx.doi.org/10.1055/s-0042-118087

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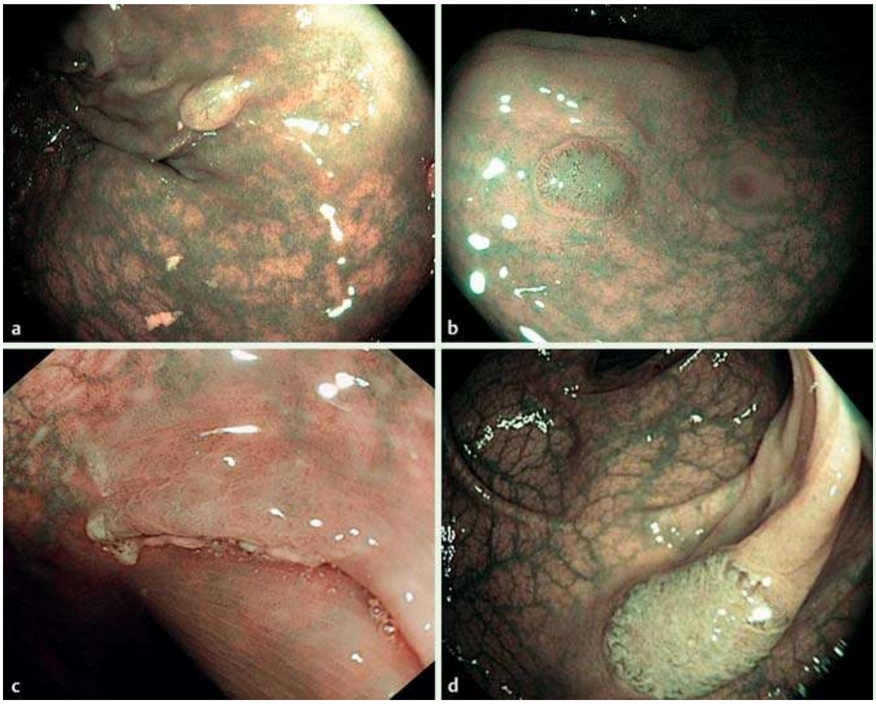

Fig. 5 Narrow band imaging International Colorectal Endoscopic (NICE) and Workgroup serrAted polypS and Polyposis (WASP) classification using NBI. **a** Type 1, hyperplastic polyp. **b** Type 2, adenomatous polyp. **c** Sessile serrated polyp, type 1 with NICE classification, then WASP classification showing clouded surface and indistinct border confirms sessile serrated polyp. **d** Type 3, carcinoma [38].

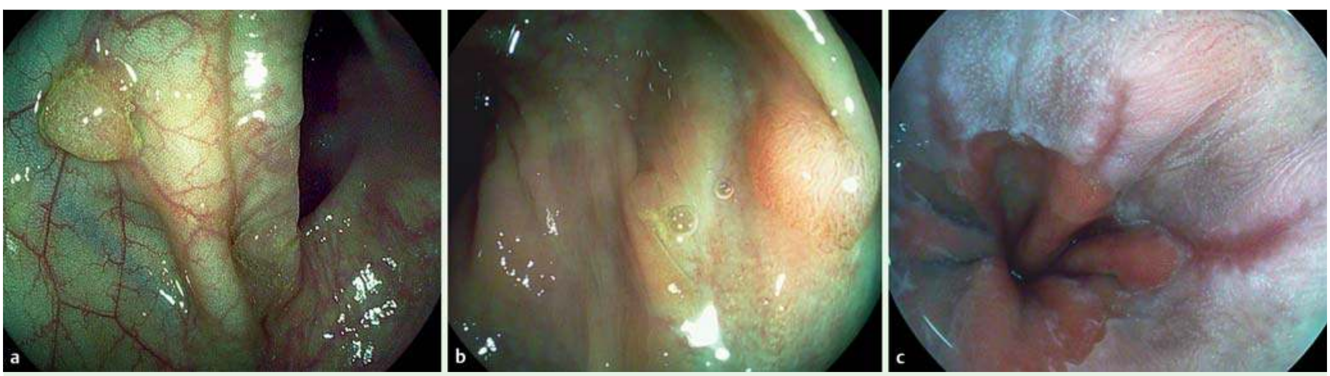

Fig. 6 I-Scan digital contrast (I-SCAN) images. **a, b** Colonic polyps seen with surface and tone enhancement: **a** hyperplastic; **b** adenomatous. **c** Minimal change erosive esophagitis.

types I and II show few, short, straight, and sparsely distributed vessels; and types III to V have numerous, elongated, and tortuous capillaries that are irregularly distributed. This classification provides good diagnostic accuracy for colonic polyps [44]. The assessment of observations made by two endoscopists using this classification suggests that agreement is very good (interobserver agreement 0.80; intraobserver agreement 0.73 and 0.88) [45].

Notably, a study that applied the NICE classification (which was developed for NBI) to videos of polyps recorded using FICE in order to differentiate adenomas from hyperplastic polyps showed an accuracy of only 77 %, with only modest interobserver and intraobserver agreement (0.51 and 0.40, respectively). This suggests that classification systems may not be not interchangeable between advanced imaging modalities [46].

3.2 Autofluorescence imaging and optical diagnosis

For optical diagnosis in the colon, an algorithm has been developed [47]: if the lesion of interest is colored purple this would indicate neoplastic tissue (**Fig. 8**); if it is green, this indicates non-neoplastic tissue; and if it is violet (in-between), NBI should be used for further discrimination.

In Barrett's esophagus, accuracy for diagnosing dysplasia using AFI was 69 % – 76 %, and this was further improved if high resolution white-light endoscopy (WLE) images were also available; interobserver agreement was fair to moderate [48].

3.3 Confocal laser endomicroscopy and optical diagnosis

The Mainz classification (**Table 7**, **Fig. 9**) was the first formal classification system for iCLE for colonic polyps that differentiated normal, regenerative, and dysplastic epithelium [12]. This has demonstrated high levels of accuracy, and interobserver as well as intraobserver agreements appeared to be substantial in one study that included three observers (0.68 – 0.84) [49].

The Miami classification was proposed in 2009 for pCLE covering both the upper and lower GI tracts, with dysplasia being associated with a dark, irregular, thickened epithelium [50]. In a pilot study in Barrett's esophagus, accuracy and interobserver agreement were high, and similar results were reported for in a pilot study for colonic polyps; however numbers of patients in both studies were very small [51, 52].

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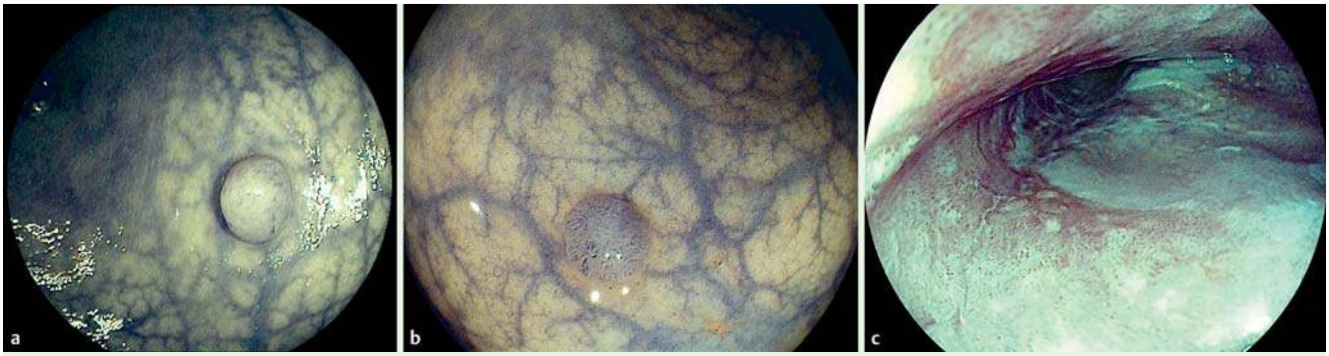

Fig. 7 Flexible spectral imaging color enhancement (FICE; also Fujinon Intelligent Chromo Endoscopy). **a, b** Colonic polyps seen with FICE setting 4 (preset wavelengths: red, 520 nm, gain 2; green 500 nm, gain 2; blue, 405 nm, gain 3): **a** hyperplastic; **b** adenomatous. **c** Squamous esophageal neoplasia; note abnormal intrapapillary capillary loops (IPCLs). (Image courtesy of Dr. Kesavan Kandiah, Portsmouth, United Kingdom.)

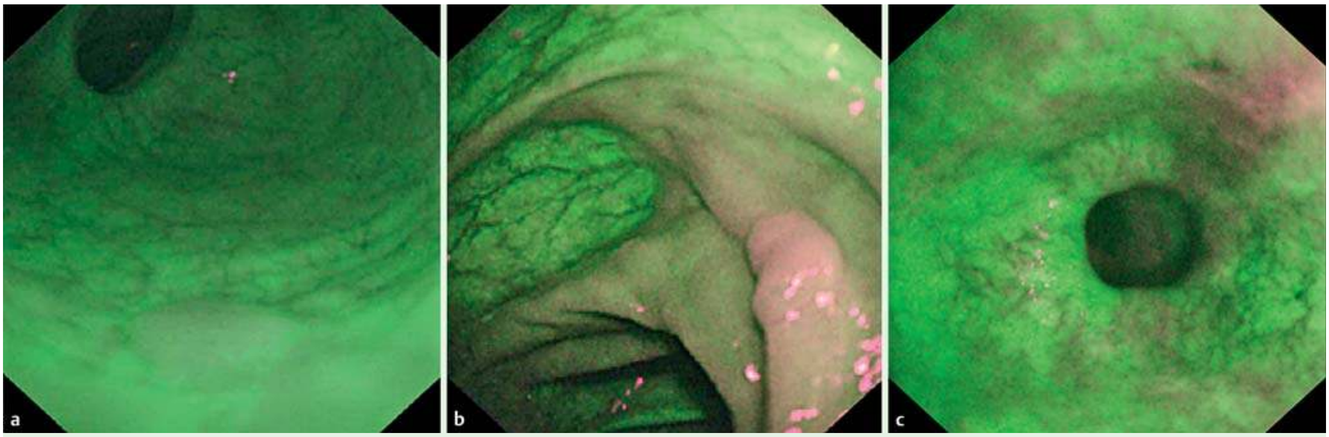

Fig. 8 Neoplasia seen with autofluorescence imaging (AFI) appears purple, non-neoplastic mucosa appears green: **a** hyperplastic colonic polyp; **b** adenomatous colonic polyp; **c** early neoplasia in Barrett's esophagus. (Fig. 8a. Adapted by permission from Macmillan Publishers Ltd, American Journal of Gastroenterology, from reference [47]., copyright 2013. http://www.nature.com/ajg/journal/v104/n6/full/ajg2009161a.html. Fig. 8c reprinted from Gastroenterology, 146, Boerwinkel DF, Swager A, Curvers WL, Bergman JJ. The clinical consequences of advanced imaging techniques in Barrett's esophagus, pages 622 – 629, copyright 2014 with permission from Elsevier.)

4. Training to achieve competence

3. We suggest that training improves performance in the use of advanced endoscopic imaging techniques and that it is a prerequisite for use in clinical practice. A learning curve exists and training alone does not guarantee sustained high performances in clinical practice. (Weak recommendation, low quality evidence.)

4.1 Upper GI tract: training

4.1.2 NBI

For NBI with magnification, a 2-hour training session in the IPCL classification improved diagnostic accuracy for both beginners and less experienced endoscopists, with the latter reaching the performance of highly experienced endoscopists. Training also improved interobserver agreement [53].

Baldaque-Silva et al. [54] were the first authors to report on the use of a structured learning program, using videos with continuous histological feedback, for the endoscopic classification of Barrett's esophagus using high magnification NBI and the Amsterdam criteria [28]; there was no improvement in diagnostic accuracy or interobserver agreement and these were suboptimal throughout the study.

In the stomach, Dias-Silva et al. [55] assessed the learning curve when using NBI without magnification to diagnose precancerous lesions. After an initial training module, feedback was given a week after answers were submitted, via a web-based learning system, for 20 tests each comprising 10 NBI videos. For all endoscopists global accuracy increased throughout the learning program, from 60 % for the first quartile to 70 % for the last one, as did specificity.

4.1.3 CLE

For CLE also, a learning curve was found for the diagnosis of esophageal squamous cell carcinoma [56], and for intestinal metaplasia in the stomach [57].

4.2 Lower GI tract: training

4.2.1 NBI

A number of training modules have been developed to improve accuracy of optical diagnosis using NBI. Initial training in NBI, using still images and either expert classroom training session or a validated PowerPoint presentation, was found to improve both the accuracy and interobserver agreement of optical diagnosis among endoscopists of various levels of experience [58, 59]. Studies using still images and NBI with magnification had similarly shown improvement in diagnostic accuracy following training [60, 61].

However still images are a poor representation of routine clinical practice, where multiple views of the polyp are obtained from

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Fig. 9 Colon and esophagus seen with confocal laser endomicroscopy (CLE). **a** Normal colonic mucosa; **b** hyperplastic colonic polyp; **c** colonic adenoma; **d** colorectal carcinoma; (for specific features see Mainz classification, **Table 7**). **e, f** Barrett's esophagus: **e** surface view with visible goblet cells; **f** deeper layers showing lamina propria (bright) and epithelial cells (dark bands)

Table 7 Mainz classification for the assessment of colonic lesions using confocal laser endoscopy (CLE) [12].[1]

Grade	Vessel architecture	Crypt architecture
Normal	Hexagonal, honeycomb appearance	Regular luminal openings, homogeneous layer of epithelial cells
Regeneration	Hexagonal, honeycomb appearance with no or mild increase in the number of capillaries	Star-shaped luminal crypt openings or focal aggregation of regular-shaped crypts with a regular or reduced amount of goblet cells
Neoplasia	Dilated and distorted vessels; irregular architecture with little or no orientation to adjunct tissue	Ridged-lined irregular epithelial layer with loss of crypts and goblet cells; irregular cell architecture with little or no mucin

[1] Reprinted from reference [12], Copyright 2004, with permission from Elsevier.

different angles. In a study using short video clips of polyps, non-academic gastroenterologists and community-based gastroenterologists improved their diagnostic accuracy following a 20-minute teaching module, although neither group reached the diagnostic accuracy of experts (81 % vs. 93 % for experts, $P < 0.05$) [62]. One study looked at retention of performance after trainees underwent a 20-minute training module followed by active feedback on 80 video clips. After 12 weeks, overall diagnostic accuracy had not significantly changed, suggesting some durability of initial training [63].

4.2.2 Other advanced imaging modalities

Similar improvements in diagnostic performance have been reported with either classroom lecture or online training for I-SCAN [43]. Neumann et al. [64] showed in a study of the learning curve of I-SCAN that the overall diagnostic accuracy improved from 74 % for the first quartile of polyp images to 94 % for the last one.

For CLE also a learning curve was reported with accuracy improving after training, from 63 % for the first quartile of polyp images to 86 % for the last quartile [65].

5. Decision support tools and computer-aided diagnosis

Several groups of authors have developed computer-aided diagnosis (CAD) systems to help with colorectal polyp characterization. Tischendorf et al. [66] reported a first prospective clinical study where a computer-based system used vascular features as observed with NBI and involved image preprocessing, vessel segmentation, feature extraction, and classification. The diagnostic performance of such algorithms has been improved so that they now match human performance (**Table 8**; [66–71]). Similar software has been developed for CLE with performance equivalent to that of human experts [67].

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Table 8 Diagnostic performance of computer algorithms for colonic polyp diagnosis.

First author, year, reference	Method	n	Size	Sensitivity, %	Specificity, %	Accuracy, %
Varnavas 2009 [71]	NBI magnification	62	–	82	79	81
Tischendorf 2010 [66]	NBI magnification	209	–	94	61	86
Hafner 2012 [69]	Chromoendoscopy magnification	716	–	77	89	86
Takemura 2012 [70]	NBI magnification	371	–	98	98	98
Gross 2012 [68]	NBI magnification	434	≤ 10 mm	95	90	93
Andre 2012 [67]	pCLE	135	1 – 60 mm	93	83	90

NBI, narrow band imaging; pCLE, probe-based confocal laser endomicroscopy

The big disadvantage of the current pilot computer algorithms is that they require manual segmentation of lesions before the algorithm can attempt a classification. In other words, the boundary of the lesion in the image must first be delineated by a human operator. Emerging work attempts to improve that aspect of CAD [72].

How such systems will be deployed in clinical practice remains unclear, with a number of possible paradigms. The most likely scenario is that these systems will be used as a "second reader" to support the endoscopist's diagnosis, with the endoscopist making the final decision or only making a definite high confidence assessment when endoscopist and CAD system agree. The "stand alone" use of such systems to completely replace clinical judgment for decision making would require a much higher diagnostic performance and additional safeguards. Nevertheless availability of CAD combined with advanced endoscopic imaging is likely to emerge in clinical practice in the next few years.

6. Techniques and utility of advanced endoscopic imaging in clinical practice (Table 9)

6.1 Esophagus

Heterotopic gastric mucosa. In an observational cohort study the routine use of NBI was shown to improve detection of inlet patches threefold compared to white-light endoscopy (WLE) (3 % vs. 1 %, $P = 0.005$) [73].

Squamous Neoplasia. In a randomized study NBI was shown to double the detection rate of squamous cell carcinoma and of high grade dysplasia in the esophagus [74]. NBI with magnification is also helpful to determine the likely invasiveness of lesions, using the IPCL (Inoue) classification [24]. FICE (Fig. 7 c) was similar to Lugol chromoendoscopy for detecting early squamous cell carcinoma (93 % vs 89 %, $P > 0.05$) [75]. AFI had a higher sensitivity than WLE in detecting superficial lesions (79 % vs. 51 %) [76]; however, its ease of detection for squamous cell carcinoma was lower than that of Lugol chromoendoscopy or NBI in a small study based on still images [77]. iCLE showed good diagnostic performance in a study of 43 lesions in 21 patients with early squamous cell carcinoma, with a sensitivity of 100 % and a specificity of 87 % [78]. pCLE also showed good accuracy in a small study of 21 Lugol-voiding (not stained by iodine) lesions, with a negative predictive value that was similar to that of near-focus NBI (92 % vs. 89 %) [79].

Neoplasia in Barrett's esophagus. NBI was shown to present reasonable accuracy (75 %) for the diagnosis of neoplasia in Barrett's esophagus, independently of the classification system used (Kansas, Nottingham, or Amsterdam) [30]. The more recent BING classification system for NBI allowed an accuracy of 85 %, which increased to 92 % with high confidence predictions (Fig. 2) [31].

I-SCAN has been shown in a small study to perform as well as acetic acid for targeting SIM, compared to random biopsy sampling (66 % vs. 21 % for I-SCAN-targeted vs. random biopsies, respectively) [80]. For the detection of neoplasia in Barrett's esophagus, FICE allowed a per-lesion sensitivity of 87 %, equivalent to that reported with acetic acid, in a study that involved 57 patients [81]. In a study that combined 5 study databases including 211 patients, AFI (Fig. 8) yielded an incremental neoplastic diagnosis of 13 % compared to WLE or random biopsies [82]. In a meta-analysis of iCLE and pCLE (Fig. 9) that included 7 studies with 473 patients, pooled per-patient sensitivity and specificity were 89 % and 83 %, respectively [83].

Gastroesophageal reflux disease (GERD). At NBI, patients with GERD showed increased number, and dilatation, and tortuosity of IPCLs, and greater presence of microerosions compared to controls ($P < 0.001$) [84]. Interobserver and intraobserver reproducibility also was improved with NBI, because of better depiction of small erosive foci [85]. I-SCAN showed significantly improved diagnosis of reflux esophagitis (Fig.6c) compared to WLE (30 % vs. 22 %, respectively), as well as improved detection of minimal reflux changes (12 % vs. 6 %, respectively) [86] For detecting GERD in 82 patients, AFI showed higher sensitivity and accuracy compared to WLE (77 % and 67 % vs. 21 % and 52 %, respectively), but lower specificity (53 % vs. 97 %) [87].

Eosinophilic esophagitis. The recognition of eosinophilic esophagitis was not improved with NBI [88] but specific changes have been described with CLE in a case report [89].

6.2 Stomach

Intestinal metaplasia. For NBI, a meta-analysis of 4 studies reported sensitivity and specificity for intestinal metaplasia of 86 % and 77 %, respectively [90]. The "light blue crest sign" seen with magnification-NBI (Fig. 3, Video 1) had sensitivity and specificity of 89 % and 93 %, respectively [32].

The yield of FICE endoscopy was assessed by comparing random and selective biopsy samples in 126 consecutive patients. For diagnosis of high risk intestinal metaplasia, sensitivity, specificity, and accuracy were 71 %, 87 %, and 86 % respectively [91].

AFI followed by NBI (Fig. 3, Video 1) detected more patients with intestinal metaplasia than did WLE (26/38 vs.

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Table 9 Utility of advanced endoscopic imaging techniques throughout the gastrointestinal tract. Clinical utility which represents both evidence and likely clinical impact: + +, very useful; +, useful; +/–, indeterminate; –, no additional benefit. References cited in the left-hand column indicate major reviews of the literature or meta-analysis; otherwise key references shown.

	NBI	I-SCAN	FICE	AFI	CLE
Esophagus					
Inlet patch	+ [73]	NA	NA	NA	NA
Squamous cell carcinoma (SCC) esophagus	+ + [24, 74]	NA	+ [75]	+/– [76, 77]	+ + [78, 89]
Barrett's esophagus	+ [30]	+/– [80]	+ [81]	+/– [82]	+ [83]
Gastroesophageal reflux disease	+ [84, 75]	+ [86]	NA	+/– [87]	NA
Eosinophilic esophagitis	– [88]	NA	NA	NA	+/– [89]
Stomach					
Intestinal metaplasia	+ + [32, 90]	NA	+ [91]	+ [92]	+[93, 94]
Early gastric cancer (diagnosis)	+ [33, 90]	+/– [95]	+/– [96]	– [97]	+[98]
Helicobacter pylori	+/– [33]	+/– [99]	NA	NA	+[100, 101]
Duodenum					
Celiac disease [102]	+	+/– [104]	+	NA	+ +[103]
Familial adenomatous polyposis (FAP)/Polyposis	– [105]	NA	NA	NA	NA
Ampulla dysplasia	+ [106]	NA	NA	NA	– [107]
Small intestine					
Angiodysplasia	NA	NA	+/– [108, 109]	NA	NA
Colorectum					
Polyp assessment "optical biopsy" [110]	+ +	+ +	+ +	+/–	+ +
Sporadic polyp detection [112]	–	+/–	–	+/–	NA
Colitis surveillance (detection)	– [113]	NA	NA	+/– [115]	NA
Microscopic colitis	NA	NA	NA	NA	+[117, 118]
IBD mucosal healing	+/– [119]	+/– [120]	NA	NA	+[121, 122]

NBI, narrow band imaging; I-SCAN, i-Scan digital contrast; FICE, flexible spectral imaging color enhancement; AFI, autofluorescence imaging; CLE, confocal laser endoscopy; NA, no data available.

13/38, $P=0.011$), in a prospective, randomized crossover trial that included 65 patients [92].

CLE consistently outperformed WLE in the detection of intestinal metaplasia and its diagnostic performance is similar to that of magnification-NBI [93]. However in a parallel group randomized controlled trial of CLE vs. WLE in 168 patients for the diagnosis of intestinal metaplasia, the difference in rates was not significant on a per-patient basis (45 % and 31 %, respectively, $P=0.074$) [94].

Gastric dysplasia. For the diagnosis of dysplasia in the stomach with NBI (**Fig. 3**, **Video 1**), a meta-analysis of 4 studies reported sensitivity and specificity of 90 % and 83 %, respectively [90].

In another study, magnified I-SCAN was shown to have sensitivity and specificity for high grade dysplasia (HGD) and cancer versus all other diagnoses (including intestinal metaplasia and low grade dysplasia) of 100 % and 77 %, respectively [95]. Magnified FICE also yielded an increased agreement between endoscopic and pathological diagnosis compared with WLE [96].

AFI alone did not improve diagnosis of superficial gastric neoplasia on a per-lesion basis compared to WLE, with sensitivity of 68 % vs.77 %, and specificity of 24 % vs. 84 %, respectively [97].

In a large study that included 1786 patients, iCLE was significantly more accurate than WLE for the diagnosis of high grade dysplasia and early gastric cancer (99 % vs. 94 %, respectively) [98].

***Helicobacter pylori (H. pylori)* diagnosis.** Variable vascular density in the gastric mucosa seen with NBI was moderately associated with *H. pylori* infection with an overall accuracy of 70 %. In a pilot study, I-SCAN with magnification outperformed magnifying WLE for the prediction of *H. pylori* infection with accuracy of 94 % versus 85 % ($P=0.046$) [99]. A case report described how iCLE in the stomach allowed direct in vivo visualization of *H. pylori* [100]. A further blinded, prospective study involving 83 patients where iCLE was used for *H. pylori* diagnosis demonstrated an accuracy of 93 % [101].

6.3 Duodenum

Villous atrophy. For detecting villous atrophy associated with celiac disease, FICE (accuracy 100 %) and NBI (sensitivity 93 %, specificity 98 %) both seem helpful [102]. CLE also showed excellent diagnostic performance compared to histopathology in a study of 31 patients with a receiver operating characteristic area under the curve of 0.946 [103]. I-SCAN was shown to allow excellent accuracy for the diagnosis of total villous atrophy (100 %) but performed less well in assessing partial villous atrophy or normal villi (90 % each) [104].

Familial adenomatous polyposis. In 33 patients with familial adenomatous polyposis, NBI did not lead to a clinically relevant upgrade in the Spigelman classification of duodenal polyposis and it did not improve the detection of gastric polyps in comparison with WLE. However more duodenal adenomas were detected with NBI in 16 examinations [105].

Ampullary dysplasia. When the duodenal ampulla was assessed for dysplasia, the observation with NBI of pinecone- or leaf-shaped villi or irregular/nonstructured villi accurately predicted dysplastic changes in a small study (14 patients) [106]. A pilot study (12 lesions) to evaluate the utility of pCLE for ampullary lesion assessment showed poor interobserver agreement [107].

6.4 Small intestine

Vascular lesions found at capsule endoscopy. In a study of 152 vascular lesions detected by capsule endoscopy in the small intestine, FICE enhancement was considered to improve color contrast and

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allowed a higher sensitivity than WLE (100% vs. 83%, respectively) [108]. However in a study of 60 patients there was no difference in detection of vascular lesions assessed as pathological at capsule endoscopy using FICE compared to WLE, with more non-pathological lesions detected by FICE (39 vs. 8, $P<0.001$) [109].

6.5 Colon

Polyp characterization and detection. A meta-analysis that summarized a total of 91 studies looking at the ability to characterize polyps as adenomatous or hyperplastic, using NBI, FICE, I-SCAN, AFI, or CLE (▶ **Fig. 4**, ▶ **Fig. 5**, ▶ **Fig. 6**, ▶ **Fig. 7**, ▶ **Fig. 8**, ▶ **Fig. 9**, ▶ **Video 2**), concluded that all techniques except AFI (sensitivity 87%, specificity 66%) could be used by appropriately trained endoscopists to make an optical diagnosis [110]. The ESGE Guideline on advanced imaging in the colorectum supports the clinical use of NBI, FICE, and I-SCAN for optical diagnosis of diminutive (≤5 mm) polyps by experts [4]. The American Society for Gastrointestinal Endoscopy offers similar support but for NBI only [111].

For the detection of sporadic polyps in average-risk individuals a summary of 6 meta-analyses (range 5–14 studies, 1199–5074 patients) that considered NBI, FICE, I-SCAN, and AFI, did not show a significant benefit for adenoma or polyp detection for any modality [112]. The ESGE Guideline on advanced imaging in the colorectum did not support the clinical use of NBI, FICE, or I-SCAN to enhance polyp detection [4].

Inflammatory bowel disease (IBD). For colonoscopic surveillance of longstanding IBD to detect dysplasia, chromoendoscopy is now the recommended standard of care in international guidelines [4, 113, 114]. NBI was not shown to be significantly superior to chromoendoscopy in a meta-analysis conducted for an international consensus statement on surveillance and management of dysplasia in IBD which favored chromoendoscopy (incremental yield, 6%; 95% confidence interval –1 to 14%) [113]. A single-center back-to-back study comparing AFI and WLE in 50 patients showed a lower miss rate with AFI (0/10 vs. 3/6, $P=0.036$) [115]. No head-to-head comparison with chromoendoscopy is available. The ESGE Guideline did not support narrowed-spectrum endoscopy or AFI as an alternative to chromoendoscopy in colitis surveillance [4].

Microscopic colitis, both collagenous and lymphocytic, has been shown to be detectable with iCLE, in case reports and small case series [116–118]. Whether this translates into true clinical utility remains to be defined.

Mucosal healing in IBD is now recognized as an important outcome and apparently normal "healed" mucosa can be subclassified using advanced endoscopic imaging techniques, recognized in recent guidelines from the European Crohn's and Colitis Organisation (ECCO) [114]. NBI has allowed detection of increased angiogenesis in IBD mucosa that looked normal using WLE [119]. Retrospective assessment of I-SCAN images in 78 consecutive patients with ulcerative colitis showed subtle vascular and mucosal abnormalities in patients with Mayo endoscopy subscore of 0 or 1 at WLE, and these abnormalities closely related to histological outcomes [120]. Local barrier dysfunction of normal mucosa (cell shedding, fluorescein leakage), demonstrated by CLE, predicted relapse in IBD at 12 months [121]. Healed mucosa in ulcerative colitis showed impaired crypt regeneration, persistent inflammation, and abnormalities in angioarchitecture and increased vascular permeability under CLE examination [122].

7. Conclusion and future research questions (Box 1)

Advanced endoscopic imaging has become a routine part of the practice of most endoscopists; however to realize the benefits from these technologies we need robust evidence as to their effectiveness. The second challenge is then translating this into real world changes that benefit patients. Although in the last decade considerable advances have been made in demonstrating effectiveness [4], especially in academic centers, the quality and quantity of data to allow widespread adoption in community-based practice is either lacking or has been disappointing. The use of narrowed-spectrum endoscopy for optical diagnosis of diminutive colonic polyps is a case in point, where early expectations of high diagnostic accuracy with a short learning curve have been tempered by experiences in community-based studies where diagnostic performance has not met criteria for safe introduction to community-based practice [58, 59, 110, 123]. However recent data suggest that by changing the way we introduce new advanced imaging techniques, with periodic training, audits, and feedback, we may be able to convert promising early results into safe, widespread community implementation [124, 125]. These concepts need to be included into training programs for endoscopists.

We therefore need to plan studies on new techniques that move rapidly beyond single-center, single-operator studies towards the larger, more controlled studies, in large numbers of patients that we see in other medical specialties, notably oncology and cardiology. The development of validated criteria or scales for diagnosis by advanced endoscopic imaging, and of defined training programs to help endoscopists surmount the learning curves for use of these technologies, linked to outcomes, will be a key area of research for the endoscopic community [126].

Box 1

Questions for implementation of advanced endoscopic imaging techniques

1. What systems are needed to safely introduce advanced endoscopic imaging techniques into community-based practice?
2. How do we assess initial and continued competency in advanced endoscopic imaging techniques?
3. How do we develop and validate new scoring or classification systems, and what biostatistical performance measures should we use?
4. If histopathology should be replaced by advanced endoscopic imaging techniques, how would we ensure high quality image storage for auditing to verify optical diagnosis?
5. How do we secure medicolegal protection for endoscopists who use advanced endoscopic imaging techniques for optical diagnosis?
6. How do we involve patients in or obtain their consent for the use of advanced endoscopic imaging, especially where advanced techniques will replace the current standard, e.g. histopathology?
7. How can computer-aided diagnosis (CAD) assist in training for optical diagnosis and assist in accurate optical diagnosis and therapeutic decision making?

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ESGE technology reviews represent a consensus of best practice based on the available evidence at the time of preparation. They are not rules and should not be construed as establishing a legal standard of care or as encouraging, advocating, requiring, or discouraging any particular treatment.

Competing interests: P. Bhandari's department receives research grants from Aquilant Endoscopy (30 June 2015 to 30 June 2017) and Pentax Medical (30 June 2015 to 1 June 2017), and continuing meeting sponsorship from Olympus (from 1 January 2008). R. Bisschops has been on advisory boards for, provided consultancy for, and received speaker's fees from Pentax (2008 to 2016) and Fujifilm (2013 to 2016), and has provided support for hands-on training for Olympus (2011 to 2015); his department has received research support from Pentax (2008 to 2016) and Fujifilm (2013 to 2016); he receives an editorial fee from Thieme Verlag. J. East's department receives research funding from Olympus; he is a member of the British Society of Gastroenterology (BSG) Endoscopy Committee, and advises the UK National Institute for Health and Care Excellence (NICE). C. Hassan has provided consultancy for Olympus and for Fujinon; his department has received equipment on loan from Olympus and Fujinon. P. Roelandt's department has received research support from Pentax (2008 to 2016) and Fujifilm (2013 to 2016). A. Wilson provides video reading services to Cosmo Pharmaceuticals (2014 to present). E. Dekker, J.-M. Dumonceau, G. Horgan, R. Kiesslich, G. Longcroft-Wheaton, and J. L. Vleugels have no competing interests.

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