Comprehensive Atlas of High-Resolution Endoscopy and Narrowband Imaging
This book is dedicated to JJC and EJC for their lifelong inspiration. AEL-CFI-S!

JC
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Since the introduction of the flexible endoscope, physicians have been able to explore the images of the gastrointestinal tract in health and in disease and use this information to make diagnoses and direct therapies. As technology has advanced, endoscopists have steadily been able to reach more locations and visualize the mucosa with increasing clarity.

Over the past decade, the growing use and capabilities of competing noninvasive imaging technologies have cast some doubt as to the future utility of performing endoscopy for purely diagnostic purposes. To survive as more than a purely therapeutic modality, endoscopy had to evolve not only to provide better-quality images than available by other new technologies, but also to reveal more useful diagnostic information than previously possible with standard optical imaging. By providing immediate intelligence about the lesions detected and their extent at the same time as interventions are carried out, advanced imaging technology might also confer greater efficiency and effectiveness to minimally invasive endoscopic therapy.

Numerous advances have been introduced during the past decade that allow the gastrointestinal endoscopist to see more and to better define abnormalities of the gastrointestinal mucosal lining. Specifically, the development of high-resolution endoscopy (HRE) and optical contrast technology such as narrowband imaging (NBI) has breathed critically needed new attention into the endoscopic examination of the gastrointestinal tract. To paraphrase Mark Twain, reports of the demise of diagnostic endoscopy have been greatly exaggerated.

In 2007, the first edition of this atlas introduced academic and practicing endoscopists around the world to the new look of high-resolution imaging and NBI. For many of the potential applications, data supporting its value was limited. The general purpose of the book was to allow readers to understand the technology, to recognize the defining features of key pathologies, and to interpret the images they encountered in their clinical practices.

The limitations to the initial adoption of the technology were access to the new equipment, knowledge about how to properly use it, and motivation that using it made a significant difference. Over the past 10 years, much has transpired to eliminate these barriers. Since the release of the first edition of the atlas, investigators have generated a much clearer understanding of what applications of HRE and NBI lead to specific patient benefits. In the key areas of Barrett’s esophagus and colon polyps, wider acceptance of the value of targeted biopsy and the potential benefits of optical polyp diagnosis has resulted. As more and more practicing endoscopists have access to high-resolution scopes, and as motivation grows to take advantage of the technology, the need for guidance is perhaps even greater than it was in 2007 to provide the resources needed to use it to maximum advantage. In this context, the current atlas has been produced to support the efforts of clinicians to learn to use and adopt this technology in their practices.

The chapters of this volume explore in detail the critical literature in HRE and NBI since 2007 and will allow readers to apply this evidence to guide when to use advanced imaging in their practice. For readers from North American and European countries using the EXERA system scopes, the improvements in lighting and magnification conferred by the H190 EXERA III instruments and processors have resulted in much sharper and brighter images in which the signature features of important pathologic findings are easier to discern and to illustrate.

The desire to provide a thorough guide to accelerate the learning curve for individuals wishing to adopt this new imaging capability remains the primary motivating force behind this book. Emphasis is naturally placed on those conditions for which NBI is considered particularly useful, such as detecting dysplasia in Barrett’s esophagus and squamous mucosa, and distinguishing between adenomatous and hyperplastic colon polyps. However, since HRE and NBI generate such dramatic new images throughout the gastrointestinal tract, we aim to provide a comprehensive look at the bowel using this lens. It is intended that the images selected will generate the excitement that resulted at each of the earlier major steps forward in endoscopic imaging technology.

This book begins with a series of introductory chapters to review the theoretical framework for HRE and NBI, the historical development of this technology, the way it actually works, and the essential practical information needed to start using these endoscopes. The subsequent sections include chapters examining the clinical applications of HRE and NBI along with supportive data, organized by organ system. Finally, the atlas contains color plates of images in high-resolution white and narrowband light, in low and high magnification, along
with some pathology confirmation, to illustrate normal and abnormal pathology throughout the gastrointestinal tract.

In this second edition, all chapters have been reviewed and revised wherever new evidence was available to assess applications and benefits. In addition, three new chapters have been included on the topics of colon polyp optical diagnosis for resect and discard strategies, the use of HRE and NBI in the bile duct and pancreatic duct, and the use of NBI to enhance therapeutic endoscopy in real time. Over 500 new images have been added to the atlas section, primarily new H190 EXERA III images. One feature is the inclusion of many more examples of some of the key pathologic findings than appeared in the first edition, in order to provide readers with the best resources to learn the characteristic findings.

Instead of the CD-ROM provided in 2007, this book comes with access to a special accompanying website that will contain searchable access to all atlas images, and over 80 video clips, to provide a more complete sense of how HRE NBI works and looks in real time. This is fitting as this imaging modality is geared to enhance endoscopic decision-making during the procedure, to facilitate therapeutic maneuvers, and to make tissue sampling more precise and of higher diagnostic yield.

The reader will note that this atlas contains many images from both Japan, using the LUCERA system, and from throughout Europe and North America, using the EXERA system. The reader should note that all images appearing in the atlas section of this volume from Japanese contributors are taken from LUCERA series endoscopes; all other images taken using EXERA series instruments will be designated in the captions as coming from the EXERA III H190 or the older H180 series instruments. Contributing centers are credited for all photos, and differences between the two systems are explained in the introductory chapters.

Many of the contributing authors to this volume are pioneers in developing this technology and in discovering the clinical implications of the patterns that are revealed. I am indebted to their efforts to collaborate on this project and help generate this atlas to rapidly disseminate their expertise and demonstrate the way endoscopy will look in the years to come.

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I wish to thank the many colleagues throughout the world who have submitted text, images, and video clips to this volume. Their enthusiasm and excitement for this field are reflected in their commitment to teaching and in the high quality of their contributions.

The detailed explanations and images of NBI in the laryngopharynx (Dr. M. Muto), esophagus (Dr. H. Inoue), stomach (Dr. K. Yao and Dr. M. Kaise), and colon (Dr. Y. Sano and Dr. T. Matsumoto) are abstracted from a book published in Japan, entitled *Atlas of New Endoscopic Imaging Technologies – Unique Diagnostic Imaging Using NBI, AFI and IRI*, Nihon Medical Center, Inc. 2006 (edited by Hisao Tajiri). I am indebted to this publisher for the use of this material.

Special thanks are due to Dr. Brian West for his assistance in reviewing the pathology images and captions included in this volume.

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About the Companion Website

Don’t forget to visit the companion website for this book:

www.wiley.com/go/cohen/NBI

There you will find valuable material designed to enhance the book, including:

- Videos illustrating key procedures
- Images from the print book available in digital format

Scan this QR code to visit the companion website:
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PART 1

The Basics of NBI
Narrowband imaging: historical background and basis for its development

Shigeaki Yoshida

In Japan, where the incidence of gastric cancer is very much higher than in the rest of the world, greater attention has been paid to early diagnosis since the beginning of the 1950s when the “gastrocamera” was first introduced. In those days, the finding of early gastric cancer (EGC) was not frequent and most of these lesions were identified from the differential diagnosis of deeply ulcerated (type III) or polypoid (type I) lesions, which can be easily detected. In the 1970s, early diagnosis progressed and it became possible to detect those cancers showing the appearance of ulcer scar (type IIc) and plateau-like elevation (type IIa). Furthermore, at the beginning of the 1980s, early diagnosis of gastritis-like malignancy (type IIb-like) became more readily possible following the results of retrospective studies of rapidly growing advanced cancer [1]. With this increased appreciation of the appearance of early superficial lesions, the widespread use of biopsy and with careful scrutiny of the mucosa using dye-spraying techniques, EGCs appearing as just faint mucosal irregularities or discoloration came to be the most frequent EGC being diagnosed by the late 1980s [2].

Such results were also applied to esophageal and colorectal malignancies, and there has been a general acceptance in Japan that early malignancies in the alimentary tract may not appear polypoid or ulcerative. The desire to better recognize such malignancies, which may be difficult to distinguish from nonspecific inflammation or trauma, had prompted us to envision new endoscopic technology capable of revealing cancer-specific images of the surface structure of the mucosa. It is within this context that the field of narrowband imaging (NBI) was developed as a promising way to facilitate the endoscopic diagnosis of early neoplastic and pre-cancerous lesions in the alimentary tract.

NBI is an optical image enhancement technology that visualizes vessels on the surface of the mucosa and patterns on the surface of mucosa by employing the characteristics of the visible light spectrum. The development of NBI goes back to the study of spectroscopy more than 20 years ago. The Japanese government implemented the Second Term Comprehensive 10-Year Strategy for Cancer Control in 1994. Together with Professor N. Oyama of the Tokyo Institute of Technology and Olympus Medical Systems Corp., we received funding from the project and started the study in which we intended to digitalize the color and structure of mucosa in order to establish a more objective/quantitative pathologic diagnosis and hence better diagnostic yield. At that time, multiple facilities and industries had conducted studies to achieve optical biopsy using the characteristics of the visible light spectrum. We aimed to achieve differentiation of normal and abnormal mucosa using a custom-made spectrophotometer developed by Olympus Medical Systems Corp.

Using the method described in Figure 1.1, we obtained and analyzed more than 2000 samples from esophagus, stomach, and colon. However, we faced multiple challenges to establish a stable diagnostic standard. The spectrum showed different patterns in normal and abnormal tissues but the spectral pattern differed from patient to patient, so that it was quite difficult to achieve stable classification between normal and abnormal. Furthermore, spectral data were not stable under the measuring conditions employed.

However, throughout the study we noticed a specific spectral pattern when selecting certain narrowband wavelengths (Figure 1.2). To highlight the specific pattern, we shifted our study from qualitative analysis using spectroscopy to qualitative imaging that enhanced details of the mucosal surface. As a result, when employing a
narrowband filter, we found excellent light enhancement deep in the mucosa at red light wavelengths, shallow mucosal surface features at blue light wavelengths, and levels in between at green light wavelengths [3]. Based on the findings, we continued the study with the research and development group at Olympus and finally found that narrowband blue light wavelengths matched the light absorption characteristics of blood hemoglobin and enhanced details of the mucosal surface.

In December 1999, we obtained the world’s first clinical images using NBI in our facility (Figures 1.3–1.6). The original technology only generated black and white monochrome images with limited information for diagnosis, making it impractical for clinical applications. The challenge was shortly solved by the introduction of newer improved filters and the development of a prototype incorporating a circuit board exclusively for NBI color display.

Since these first clinical NBI pictures were achieved, we have actively expanded the study in cooperation with multiple research facilities. As a result of this collaborative investigation, the application of NBI diagnosis has expanded rapidly [4,5]. Starting with the diagnosis of colonic tumor and squamous cell carcinoma of esophagus, the applications of NBI were established in other fields such as superficial carcinoma in pharynx, Barrett’s esophagus and adenocarcinoma, stomach cancer, and inflammatory bowel disease. Multiple studies have been published in these areas; the results have been published in academic society proceedings, research committee reports and clinical papers in peer-reviewed journals. Much of this data is discussed in detail in subsequent chapters of this book.

In December 2005, the NBI system became commercially available from Olympus, and the technology and diagnosis expanded further, not only in Japan but also worldwide.

In summary, endoscopic diagnosis has been rapidly progressing. Beyond technical advances such as chromoendoscopy and improvements in image quality, endoscopic diagnosis has now advanced to the area of pathology. This is possible because the imaging technology now allows assessment of the three-dimensional architecture of tissue by fine examination of the mucosal surface with magnifying endoscopy. In the coming years, special light observation such as NBI may be able to provide even more information about a targeted lesion, in order to clarify the indication of new cancer therapies.

Such endoscopic diagnosis through special light observation holds great promise. None of these advances could have been achieved without the great contribution of Professor H. Niwa, Board Chairman of the Japan Gastroenterological Endoscopic Society, and his colleagues who have devoted themselves to the development of multiple modalities of optical diagnosis, such as ultraviolet gastrocamera, infrared and autofluorescence imaging, since the project was first initiated while working together at Tokyo University. We must recognize the history of endoscopic diagnosis and the contribution and diligence of these individuals in bringing the field to where it is today. I hope that special light diagnosis through NBI will become an increasingly reliable tool with more clinical evidence to support its applications. As this occurs, the technology should make important contributions to improve and facilitate diagnosis in clinical practice.

Video clips to accompany this book can be found in the online material at www.wiley.com/go/cohen/NBI

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Chapter 1  Narrowband imaging: historical background and basis for its development

Figure 1.1  Spectral reflectance analysis. Spectral data were sampled at intervals of 2 nm ranging from 400 to 800 nm. In each examination, we measured spectral reflectance in both normal and neoplastic areas. (Copyright S. Yoshida.)

Figure 1.2  Spectral sensitivity functions for discrimination of cancerous regions. (Copyright S. Yoshida.)

Figure 1.3  Normal gastric mucosa: mucosal crypt pattern of the stomach can be observed without dye spraying by blue-filtering of NBI. (Copyright S. Yoshida.)
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**Figure 1.5** Flat adenoma of sigmoid colon: crypt pattern of the depressed area can be observed without dye spraying by blue-filtering of NBI. (Copyright S. Yoshida.)

**Figure 1.6** Esophageal cancer (type 0–Iic): the margin of the lesion is clearly detected by blue-filtering of NBI. (Copyright S. Yoshida.)
An introduction to high-resolution endoscopy and narrowband imaging

Kazuhiro Gono

Introduction

The development of narrowband imaging (NBI) started in May 1999. To confirm the idea of NBI, a study using a multi-spectrum camera capable of producing spectroscopic images and high-power light source was conducted, with this author volunteering as a test subject. The study revealed that the use of 415-nm narrowband light can improve the contrast of capillary images, which are difficult to observe under conventional white light. The first image of living tissue ever produced on NBI is shown in Figure 2.1. The development of an NBI endoscopy system proceeded in cooperation with Dr Sano of the National Cancer Center Hospital East. On December 14, 1999, based on a study using the NBI prototype, we confirmed that the technology was promising for endoscopies of colon, stomach, and esophagus. Since that time, we have developed products in cooperation with not only Japanese endoscopists, but also endoscopists from around the world in an effort to expand the capacity of the prototype. EXERA II, the next generation system equipped with both high-definition TV (HDTV) and NBI, was introduced in December 2005.

At present, Olympus has two types of video endoscopy systems in use worldwide. The difference between these two systems is based on how a color image is produced. One is based on a color charge-coupled device (CCD) chip which has several tiny color filters in each pixel. This system is the 100 series and is branded as EVIS EXERA II. The second system is based on a black and white CCD, in which color separation is achieved through the use of an RGB color filter wheel within the light source unit. This system is the 200 series and is branded as EVIS LUCERA SPECTRUM. Both systems possess NBI technology. Research and development for NBI was first attempted with the EVIS LUCERA SPECTRUM system, the system predominant in Japan, the UK, and Asian countries. Once success was achieved with that system, research and development was focused on the use of NBI with the color CCD system or EVIS EXERA II. Both systems possess the same optical filter in the light source, which enables the illumination of two narrowbands within the visible spectrum of light for NBI. As such, both systems are “optically” identical. However, since both technologies are fundamentally different, there are actually some minor differences in image reproduction. For NBI, both systems are the same, as they both provide improved image contrast when viewing microvessel patterns within the superficial mucosa. If images from both systems are compared simultaneously without magnification, some observers may notice slight differences. However, these differences are quite minor and have not been shown to be clinically significant.

Apart from these optical features, the two systems do differ in the method of magnification incorporated into the endoscopes and the resulting ability to magnify the images observed. In the EXERA II system, the endoscope currently has digital zoom at 1.2× and 1.5× magnification. The HDTV format also possesses “physical zoom” properties that allow the scope tip to be advanced up to 2 mm from the mucosal surface without losing resolution. This combined feature results in a capacity for at least a 50-fold magnification. In contrast, the LUCERA system utilizes an optical zoom system, similar to that used in previous non-high-resolution zoom magnification endoscopes, that allows for magnification of the image up to 80 times. However, these numbers for mucosal magnification have somewhat limited reliability, as there are a number of variables that may affect the actual magnification of tissue that is observed, such as the size of the monitor that is used.

HDTV is a video format that provides clear and high-resolution images while NBI offers high-contrast images of blood vessels. In theory, combining these technologies will give the best performance in close observation of
the mucosa. Knowledge of the design concept underlying the functions of EXERA II, its technical limitations and how to read NBI images should be helpful in learning the practical use of HDTV and NBI.

There are many “high definition” TV formats. At the time of product development, 1080i and 720p were the most popular, as they still are today. Olympus had to consider which format would provide the highest level of resolution for motion and still imaging, as well as maintain its popularity within the market so that current and future peripheral devices such as monitors, printers and digital recorders would remain compatible. As the result, 1080i was selected and has proven to be the most popular high-definition broadcast format to this day.

Unlike conventional image processing, NBI is a technology in which an image is emphasized by light. Designing such light requires an in-depth understanding of the optical characteristics of living tissue. As an introduction, this chapter first discusses the characteristics of light, including wavelength and color, as well as the interaction between living tissue and light, such as absorption and scattering. Next, it describes the value offered by HDTV and NBI in terms of image quality and the method for designing chromatic images on NBI. Finally, the chapter explains how typical endoscopic findings such as fine mucosal pattern and blood vessel images look on NBI and why they look that way, using illustrations.

**Light and bio-optics**

**Light and wavelength**

Light is an electromagnetic radiation having the characteristics of both wave and particle. When light is considered as a wave, the distance from peak to peak in each wave is called “wavelength” (Figure 2.2). Visible wavelength ranges from 400 to 700 nm. A different wavelength is perceived as a different color. Although colors look different depending on the psychological state of each individual, 400 nm, on average, is perceived as blue, 550 nm as green, and 600 nm as red. Generally, saturation decreases when light contains more wavelengths. In other words, blue light of narrow bandwidth looks more vivid compared with that of broad bandwidth. Light of broad bandwidth within the range 400–700 nm looks white.

**Color, absorption, and reflection**

When white light illuminates the surface of an apple, the pigment in apple skin absorbs light at wavelengths of 400–550 nm. The absorbed light is converted to heat. In other words, energy in the blue–green range of the white light is converted to heat. Unabsorbed light at 550–700 nm is reflected. The reflected light reaches our eyes and the apple is perceived to be red. How would an apple look if cyan-colored light, instead of white, illuminated it? Cyan-colored light mainly consists of blue and green light, and because such light is absorbed by pigment and almost no light is reflected, the apple looks black. That is to say, white light is needed to perceive the natural color of an object. Contrarily, the light does not need to be white if it is not intended to reproduce the appearance of an object in natural color. NBI is based on this idea and has been developed for the purpose of highlighting blood vessels, not reproducing natural colors. Therefore, light other than white is used for NBI.

**Light scattering**

In relation to light propagation in an optically turbid medium such as diluted milk, light scattering needs to be taken into consideration in addition to reflection and transmission. Milk contains a number of fat globules of various sizes (1–100 μm). When light strikes such small particles, it diffuses three-dimensionally. This is called light scattering. When there are a multitude of particles, multiple scattering occurs as scattered light is scattered again by striking another particle. Light propagates diffusively due to this light scattering even when a flux of light such as a laser beam is injected into milk.

**Absorption and scattering in tissue**

A schematic diagram of the interaction between light and living tissue is shown in Figure 2.3. When light enters biological tissue, some reflects from the surface and some diffuses within the body. Multiple scattering occurs among light and small particles such as cell nuclei, cell organelles and nucleoli in the tissue. As a result, light propagates diffusively through the tissue. The propagation of light is determined by its wavelength. Red light, having a long wavelength, diffuses widely and deeply, while blue light, having a short wavelength, diffuses over a smaller range. This is shown in Figure 2.4.

Part of the scattered light is absorbed by blood. To be accurate, hemoglobin absorbs blue and green light. Hemoglobin is a type of chromophore. Components in the gastrointestinal mucosa apart from hemoglobin, such as cell nuclei and fiber tissue, do not have colors. Therefore, the color of the gastrointestinal mucosa is mainly determined by hemoglobin.

The interaction between light and living tissue is characterized by hemoglobin, which strongly absorbs blue and green light, and multiple scattering in biological tissue.

**Resolution and contrast**

Resolution and contrast are terminologies to describe image quality. Figure 2.5 shows the relationship between
resolution and contrast. A good-quality image cannot be provided when resolution is high but contrast is poor. Image quality is best when the level of both resolution and contrast is high.

Resolution is a term that describes the capacity to present minute patterns. The capacity of an optical device to reveal fineness of detail is defined by using a resolution chart (Figure 2.5). Resolution is determined by the pixel numbers of the CCD, signal processing, and lens characteristics. The resolution of an endoscope capable of producing HDTV standard images is significantly greater than that attained by conventional endoscopes.

Contrast is defined as the ratio of density or brightness between a pattern and its background. The word describes clarity – how vividly the subject stands out against the background or vice versa. As shown in Figure 2.5, a pattern cannot be seen clearly when it is low in contrast though high in resolution. NBI is a technology capable of improving the contrast of blood vessels selectively. Resolution is enhanced by HDTV while NBI improves contrast. As a result, the combination of HDTV and NBI can offer a high-quality image of blood vessels, analogous to the illustration at upper right in Figure 2.5.

Basic principles and system design

Basic principles

Figure 2.6 is a schematic diagram of NBI. Two blood vessels running in living tissue are named BV(A) and BV(B), respectively. Broadband light composed of wavelengths of λ1, λ2 and λ3 is injected into BV(A) and narrowband light composed of wavelength λ2 is injected into BV(B). The degree of absorption into blood is λ2 >> λ1, λ3. λ1 and λ3 diffuse more widely and deeply within the tissue compared with λ2. When λ2 strikes the blood vessel, most of its energy is absorbed by blood. On the other hand, when λ1 and λ3 light rays strike the blood vessel, some of the energy transmits to the blood vessel and scatters deeply and widely. As a result, some of the scattered light rays of λ1 and λ3 re-transmit to the blood vessel or bypass the blood vessel and exit from the mucosal surface. When the vessel is illuminated with light that is rarely absorbed by blood and which scatters widely and deeply like λ1 and λ3, a blurry image is produced, labeled VI(A) in Figure 2.6. This is analogous to the conventional light source of endoscopes. On the other hand, when λ2 strikes the peripheral mucosa, the light is observed at the mucosal surface as scattered light without bypassing the blood vessel. As a result, the contrast of the blood vessel is improved and the vessel shows black due to its strong absorbing capacity and in brighter colors for other parts, labeled VI(B) in Figure 2.6. Figure 2.7(a) is an image of the blood vessel pattern of the underside of the human tongue mucosa illuminated by conventional broadband blue light. Figure 2.7(b) is an image produced by narrowband blue light. By changing the illumination to narrowband, we can see that the contrast of the capillary patterns of Figure 2.7(a) is improved in Figure 2.7(b). NBI is a technology for observing biological tissue with narrowband light, created by extracting from conventional broadband light wavelengths that are strongly absorbed by blood and which do not diffuse widely and deeply.

System design

Figure 2.8 shows blood vessel images of the underside of the human tongue mucosa produced by narrowband light of 415, 500, 540, and 600 nm. A very fine pattern of blood vessels is reproduced by the 415-nm wavelength, while a thicker pattern is indicated by light of longer wavelength. Blood vessels in the tongue mucosa are believed to become finer at the superficial layer of the mucosa, as shown in the lower part of Figure 2.8. The relationship between the blood vessels and the narrowband images is provided in the figure. It is therefore most appropriate, by the principle of NBI, to select 415 nm for observing capillaries on the surface and 540 nm for thicker vessels. On the other hand, blood vessels in the deeper part are reproduced in the 600-nm image. However, considering the fact that early cancer develops in the superficial layer and changes the blood vessel structure there, using 600-nm images in NBI can only make a small contribution to medical applications. Therefore, the NBI system uses two narrowband illuminations of 415 and 540 nm. Figure 2.9 shows the configuration of the NBI system in the EVIS EXERA II system. A xenon lamp is installed in front of an optical filter for NBI. It is a double-band filter (415 and 540 nm) as described previously. When observing with NBI, the filter is placed in the light path. Under normal observation, the filter is removed from the optical axis. Under NBI observation, the light from the xenon lamp splits into two bands (415 and 540 nm) and the split light illuminates the mucosa.

As shown in Figure 2.9, two narrowband images of 415 and 540 nm are reproduced when the NBI filter is placed. However, in order to create color images, we need three images to be outputted to the R, G and B channels of the monitor. There are variations concerning which bandwidth goes to which channel, but in order to achieve high visibility of blood vessels, first, the capillary patterns on the superficial layer of the mucosa need to be reproduced as a black and white pattern and, second, the relatively thick vessels in the
deeper part of the mucosa need to be highlighted with a color different from that of the capillary pattern. Therefore, colors are allocated according to human visual perception.

The human observer finds it easier to perceive very fine patterns when they are brightly lit (Figure 2.10, Pattern A) rather than when they are colored (Figure 2.10, Pattern B). Thicker vessels can be perceived easily with a color pattern (Figure 2.10, Pattern C). Considering such characteristics, 415 nm is allocated to B and G channels so that the blood vessels on the surface are reproduced in a brownish pattern much like the black and white pattern, and 540 nm is allocated to R channel so that the vessels in the deeper parts are indicated in a cyan color pattern (Figure 2.11).

**Blood vessels and bleeding**
When observing the mucosal surface closely with an HDTV scope, capillaries in the superficial layer of the mucosa are seen as a brownish pattern on NBI (lower part of Figure 2.12a). When a blood vessel is thin and the CCD is unable to produce its image clearly, it is reproduced as a blurry brownish spot. Relatively thick blood vessels located in the deeper part of the mucosa are reproduced in cyan hue.

On the other hand, bleeding is shown in a black tar-like color, because light rays of 415 and 540 nm are absorbed by blood on the mucosal surface and not reflected.

In many tumors, blood vessel density on the superficial layer of the mucosa becomes high. In cases of esophageal squamous cell carcinoma, for example, expansion, growth and meandering of intrapapillary capillary loops are findings characteristic of the disease. These are perceived as brownish areas when observed by NBI from middle to long distance (upper part of Figure 2.12a).

**Fine mucosal pattern**
Figure 2.12(b) shows a cross-sectional diagram of the colonic mucosa. Microvessels running in the tissue between the crypt foci are reproduced in brownish hue since they are the same as capillaries on the mucosal surface, shown in Figure 2.12(a). On the other hand, no materials around the crypt foci absorb light except cells surrounding the gland. Therefore, a significant amount of light is reflected and the crypt foci present as a white pattern. As a result, the fine mucosal pattern of the large bowel is reproduced as a brown–white pattern. Gastric mucosa and Barrett’s mucosa, both having a similar gland structure, are also presented in the same way. NBI is expected to produce an effect similar to chromoendoscopy. NBI can highlight the fine mucosal pattern as long as mucus is transparent, which does not exert influence over observation. On the other hand, when capillaries are not developed in the tissue between the crypt foci, as seen in hyperplastic polyps, the fine mucosal pattern is not highlighted on NBI.

**Squamo-columnar junction**
Stratified squamous epithelium of the normal esophageal mucosa has few blood vessels and reflects light strongly when seen optically. Therefore, it presents as a bluish-white image on NBI. On the other hand, because the surface of the gastric mucosa has a number of blood vessels, whole mucosa is observed in brownish hue. Therefore, the esophageal mucosa and gastric mucosa at the squamo-columnar junction are reproduced in a strong contrast of white and brown (Figure 2.12c). The extent of Barrett’s mucosa, like the normal squamo-columnar junction, can be detected easily by the contrast with normal esophageal mucosa. Detecting normal esophageal epithelium surrounded by Barrett’s mucosa would be especially easy compared with normal observation.

**Residue and bile**
Residue and bile in the large bowel are reproduced in yellow hue under white light. The yellow pattern is presented in red (as if bleeding) on NBI. Residue and bile strongly absorb the 415-nm light while reflecting 540-nm light strongly. Since NBI produces 540-nm images on R channel and 415-nm images on B and G channels of the output monitor, images on B and G channels become darker while those on R get brighter. Therefore, residue and bile are highlighted in blood red.

**Second-generation NBI on EVIS EXERA III**
Since the first-generation NBI was introduced onto the market as an advanced imaging technology, branded EVIS EXERA II, Olympus R&D has been committed to improving the performance of NBI. The first-generation NBI has limitations with regard to brightness: in gastric observation, the distal end of the endoscope needs to be carefully advanced towards the mucosa to obtain sufficient brightness in NBI mode. This insufficient brightness adversely affects the operability of the endoscope. To overcome this limitation, we have made various modifications to increase the brightness of NBI. We have developed a high-intensity discharge lamp, intensified the brightness of the lens in the light source, improved the sensitivity of the image sensor, and worked on the image processing in the processor to reduce noise. As a result of these modifications at various parts of the system, from the tip of the endoscope to light source and signal processor, the second-generation NBI has been able to deliver more than one-and-a-half times as much brightness as the first-generation NBI and to achieve
twice the viewable distance in the lumen. The difference in brightness of test models between first-generation and second-generation NBI is shown in Figure 2.13.

In addition, the dual focus function has been incorporated in some models of the 190 scope developed for EVIS EXERA III. In the conventional magnification endoscope (GIF-Q160Z), the user needs to advance the distal end of the endoscope close to the mucosa while controlling the zoom lever on the control section. The dual focus function has enabled the user to switch the zoom mode between wide observation and macroscopic observation with only the touch of a button. This function, combined with the increased focus distance, has facilitated magnified observation. The dual focus function exhibits its benefits when used in combination with the brighter second-generation NBI.

**Figure 2.1** The 415-nm narrowband image of human tongue mucosa. The 415-nm narrowband image reflects the fine capillary pattern on the mucosa, which is hard to visualize under conventional white light. (Copyright K. Gono.)

**Figure 2.2** Wavelength and related color. Wavelength is defined as the distance from peak to peak in each wave. Longer wavelengths have a reddish appearance while shorter wavelengths have a bluish appearance. (Copyright K. Gono.)

**Figure 2.3** Interaction between light and biological tissue. (Copyright K. Gono.)
**Figure 2.4** Diffusive light propagation in a turbid medium. Red light diffuses widely and deeply in the turbid medium, while blue light does not propagate diffusively. (Copyright K. Gono.)

**Figure 2.5** Contrast vs. resolution. Resolution here means the resolution of the CCD used for imaging resolution chart. (Copyright K. Gono.)

**Figure 2.6** Contrast of blood vessel. (Copyright K. Gono.)
Figure 2.7 Blood vessels of human tongue: (a) image under conventional broadband blue light; (b) image under narrowband blue light. (Copyright K. Gono.)

Figure 2.8 Endoscopic images of human hypoglottis mucous membrane. (Copyright K. Gono.)
Figure 2.9 Structure of NBI system. (Copyright K. Gono.)

Figure 2.10 Human visual perception of black and white pattern and color pattern. (Copyright K. Gono.)

Figure 2.11 Appearances of endoscopic findings on NBI endoscopy EXCERA III. Fine superficial capillaries appear brown whereas the deeper vessels appear cyan in color. (Image courtesy of Jonathan Cohen, NYU Langone Medical Center.)