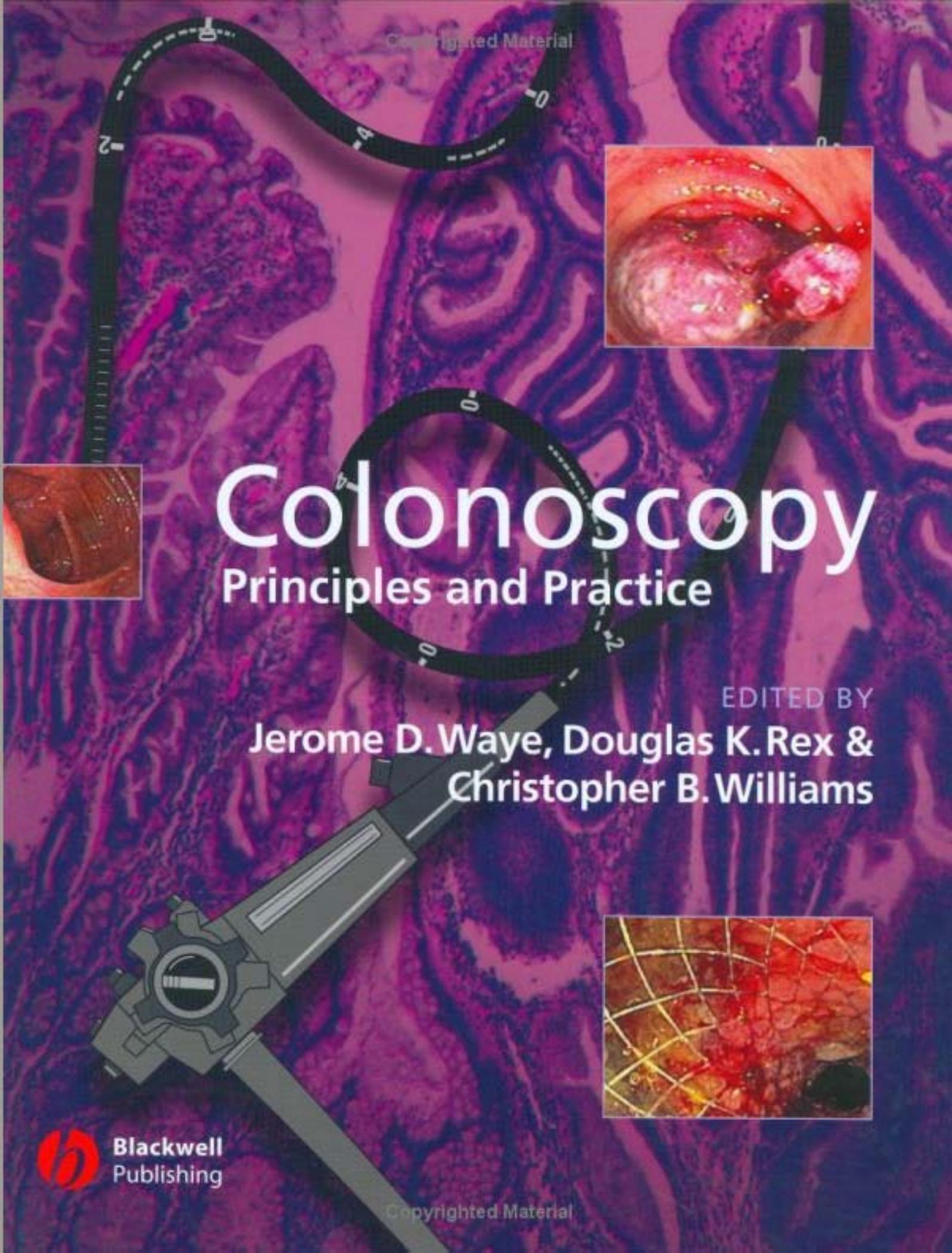


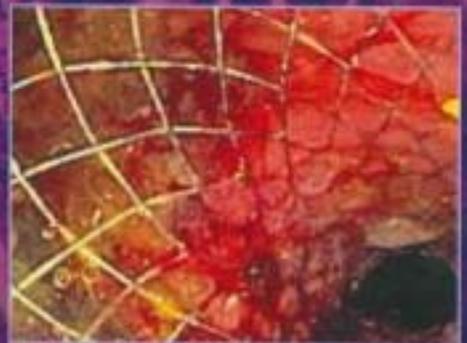
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Colonoscopy

Principles and Practice

EDITED BY
**Jerome D. Wayne, Douglas K. Rex &
Christopher B. Williams**



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Colonoscopy

Principles and Practice

Thanks to our wives—Meg Waye, Leslie Rex and Christina Williams—for their support in yet another time-consuming enterprise. Thanks also to those to whom we have taught colonoscopy and the many on whom we have performed colonoscopy. We have learned so much from you all, as we have from our friends the contributors to this book.

Colonoscopy

Principles and Practice

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Preface

Flexible endoscopy of the colon was introduced in 1963, six years after Basil Hirschowitz developed the fiberoptic gastroscope. Since the first attempts at intubating the entire colon, this procedure has now become a primary diagnostic and therapeutic tool for evaluation and treatment of colonic diseases. Using the ability to inspect, obtain tissue samples and remove colon polyps, colonoscopy has expanded our knowledge of the natural history of colonic neoplasia. Multiple large studies have shown that removal of benign adenomas will prevent colorectal cancer. Because of the increasing awareness of colorectal cancer being a common cause of death from cancer throughout the world, and the possibility to interrupt the adenoma to carcinoma sequence by polypectomy, the volume of colonoscopies around the world continues to be driven upward by widespread acknowledgement of the effectiveness of the procedure.

Colonoscopy is not merely a tool in the hands of a practitioner, but it is a discipline with an infrastructure built upon many areas of medicine, including internal medicine, the general practice of medicine, and gastroenterology in particular, as well as surgery, pathology, radiology, pediatrics, and molecular biology. The expanding horizon of colonoscopy was the stimulus for us to organize a new comprehensive textbook on this field. The chapters in this volume address every aspect of colonoscopy, and its interface with all of the other sections of medicine.

The editors of this book learned and indeed developed many techniques of colonoscopy when imaging was limited to the barium enema and there was no capability to visualize the intraluminal topography in the intact patient. This book represents the “state of the art” in colonoscopy. However, colonoscopy is a procedure in evolution and investigators around the world are

actively pursuing improvements. Colonoscopy is a relatively new discipline, and although tremendous strides have been made since its introduction, there are many unanswered questions such as how can we improve training in colonoscopy? Can bowel cleansing be made less toxic and less miserable? Can colonoscopy be made painless? Can we improve the detection of neoplasia? Can we make colonoscopy faster? Can we eliminate complications from both diagnostic and therapeutic procedures? The answers to these questions will determine the future of colonoscopy and its ultimate impact on colorectal disease. We look forward to the continuing pursuit of answers to all questions concerning colonoscopy, and urge future generations of colonoscopists to continue the quest for knowledge and add more information to each of the chapters in this book.

For many colonoscopists and certainly for ourselves, colonoscopy is not considered as part of a job, but rather as a passion. Every colonoscopy presents an opportunity to improve a patient outcome, to learn, often to reassure, to identify new questions and problems both clinical and scientific, and to enjoy the application of skills both manual and cognitive in nature. Thus, to edit a volume on colonoscopy has been for us a particular pleasure. We extend our most sincere thanks to the authors who contributed to this volume. The list of authors includes the world’s most foremost practitioners from every aspect of medicine. Their expertise, diligence, and friendship are deeply appreciated. On behalf of all the authors, we thank the many, many thousands of patients who have trusted us and been our teachers.

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Chapter 1

History of Endoscopy in the Rectum and Colon

H. Niwa, Y. Sakai & C.B. Williams

Introduction—from rigid endoscopes to colonofiberscopes

Before endoscopes for colon examination achieved the remarkable technological progress that we see today, there was a long period when rigid proctosigmoidoscopes were used for examination of the distal half of the sigmoid colon and rectum.

Intracolonic photography of colonic mucosa, using a modification of the gastrocamera described as “sigmoidocamera” or “colonocamera,” was briefly used in Japan. Diagnosis was by examining pictures of the colonic mucosa obtained with the colonocamera.

Compared to today’s latest technically advanced colonofiberscopes and colonovideoscopes, the rigid hollow tube sigmoidoscopes were primitive and gave a limited view, but nonetheless had significant clinical value, as disease of the large bowel is most commonly found in the distal half of the sigmoid colon and rectum. Experimentation on these predecessors provided the foundations for endoscopic diagnosis made possible by use of current colonofiberscopes and videoscopes.

Any history of colonoscopy must take such devices into account, so this chapter therefore covers the topic of these early inventions.

Rigid endoscopes

Primitive specula

It was in the time of Hippocrates that people first attempted to observe inside the human body. An instrument called a speculum was used to examine the rectum and vagina, and with it cautery treatment of hemorrhoids was carried out. Primitive instruments that have similar structure and function to today’s anoscopes and coloscopes were discovered in the ruins of Pompeii, buried under volcanic ash after the eruption of a volcano in the 1st century AD (Fig. 1.1). Because the light source for a speculum was sunlight, observation was limited to areas at the openings of the body. After these primitive instruments, no significant progress was made until the 19th century.

Reverie of endoscopy

A Japanese writer predicted today’s endoscopes as early as 200 years ago, not inventing an actual endoscope, but imagining a kind of telescope closely resembling early rigid endoscopes. In the book called *Chikusai-Rou-Takara-no-Yamabukiuro*, published in 1794 in Japan by the author Zenkou Tsukiji, is a picture (Fig. 1.2) in which Dr Chikusai, the main character of this story, tries to look inside the human body through the navel with his special telescope. He examines the organs in the chest through the mouth, the organs in the epigastrium through the navel, and the organs in the hypogastrium through the anus, both to make a diagnosis and decide what treatment is appropriate. He enjoys a reputation as a discerning doctor and makes a lot of money.

Of course, this is not what really happened, but just an imaginary story. To mention the background which enabled the author to think of the story, mass importation of eyeglasses from Holland and China started in the mid 1600s; toward the end of 17th century production of eyeglasses started in Japan and in 1793, the year before publication of the book, a 3-m-long astronomical telescope had been produced in Japan.

Early endoscopes

Although the first telescopes were developed in Europe in the early 17th century, it was Philipp Bozzini who first actually tried to observe inside the human body, through a rigid tube without optics. He developed an apparatus called the light conductor (Lichtleiter) in 1805, which he used in his attempt to observe rectum, larynx, urethra, and upper esophagus [1]. Bozzini’s father was originally from Italy, but fled from his country after a duel. Bozzini was born in Mainz, Germany in 1773 and started to study medicine in this city, moving to Frankfurt in 1803. He was a man of a wide range of cultural accomplishments including medicine, mathematics, engineering, and the fine arts [1].

The main body of the light conductor was a rectangular box like a lantern (Fig. 1.3), used as the light source unit [1–3]. A replica of the light conductor is displayed in the Museum of Medical History in the Institute of



Fig. 1.1 (a) Roman speculum from the ruins of Pompeii in 79 AD and (b) anorectal dilator supplied with early Olympus colonoscopes in 1970 AD.



Fig. 1.2 Observing the inside of a patient's abdomen—a Japanese fantasy (1794 AD).

Medical History, the University of Vienna. It had round openings on the front and back walls of the light source box. The box was partitioned lengthwise into two areas, in one of which a candle was placed as the light source, with a concave mirror behind it. The position of the candle flame was kept unchanged with a spring. Observation through the unlit partition was from the back window of the light source unit, a speculum having been attached to the front opening. Several different specula were prepared for observation of different organs. For

inspection of larynx, pharynx, and esophagus, a special speculum was developed on the tip of which a concave mirror and a flat mirror were attached. The concave mirror was used for light transmission and the flat mirror for viewing the target area [4].

Using this device, Bozzini conducted experiments on corpses and patients. On December 9 in 1806, a public demonstration on corpses using his light conductor was held during a meeting of the Imperial Josephs Surgical Academy in Vienna. The details of this experiment are stored in archives in Vienna and later recorded in the paper by Lesky describing observation of the rectum, vagina, and uterine cervix of the corpse. In a second gathering of the Academy in 1807, using an improved version, observation was carried out of the rectum and the vagina, as well as an approach from a wound in the abdomen of the corpse. The first attempt to apply the device to a living patient was made in the same gathering.

The building of Josephs Surgical Academy, where the public experiments were held by Bozzini, is now the Institute of Medical History, the University of Vienna. The Museum of Medical History and the Museum of the Endoscope are in this building as well.

Based on the achievement of these experiments, Bozzini published a book on his light conductor in 1807. However, the Faculty of Medicine of the University of

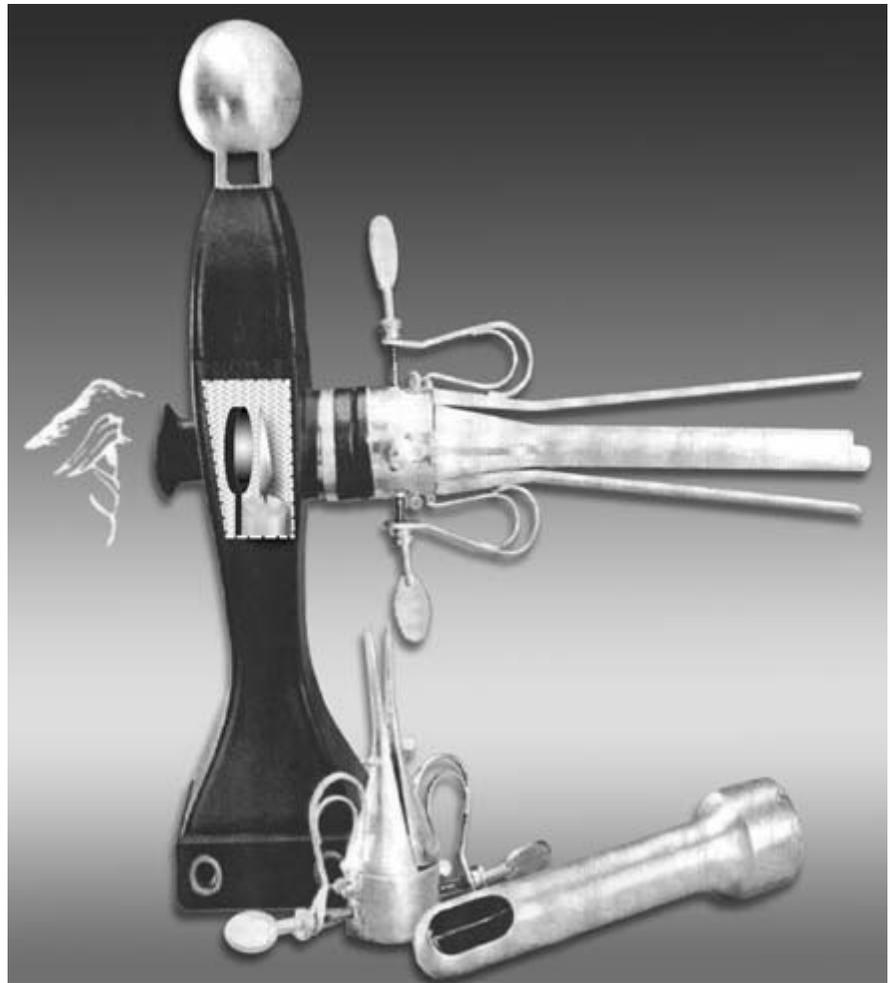


Fig. 1.3 Bozzini's "Lichtleiter" or light conductor (1706)—the dotted cutaway diagram shows the position inside it of the spring-mounted candle with a light shield behind it.

Vienna would not permit further study using the device. The authorities regarded it as nothing but a plaything, of no medical value but a "laterna magica in corpore humano." Use of the light conductor was forbidden, partly due to conflicts between the Surgical Academy and the University, but also due to the reluctance of the authorities to adopt anything new.

In 1826, Segales of France reported on a new method for examining inside the human bladder using a funnel-shaped metal tube, with a concave mirror and candle light as the light source. Fischer of America developed another cystoscope in 1827, while Avery of England developed an instrument designed for observation of urethra, bladder, vocal chords, and esophagus. Light for Avery's device was by reflecting candle light using a concave mirror. These achievements of our predecessors in development of cystoscopes and urethroscopes provided the foundation for development of gastrointestinal endoscopes, especially the open tube rigid proctosigmoidoscope.

In 1853, Désormeaux (1815–81) of France developed the first endoscope of practical value and called this

instrument an "endoscope" for the first time in history. Désormeaux utilized his instrument (Fig. 1.4) for diagnosis and treatment of urological diseases. The unit comprised a body tube and a light source unit. The light source was a gazogene lamp lit by firing a mixture of alcohol and turpentine. Inside the body tube, at its junction with the light source, was a mirror with a small hole in the center, which reflected the light provided by the source through the body tube and into the insertion part connected to end of the body tube. The diameter of the insertion part for urethra and bladder observation was about 6–8 mm. Observation was carried out from the small hole on the top end of the body tube. The body tube was freely rotatable around the axis of the connecting part, so that the light source unit would always stay vertical even though the main tube was moved. Désormeaux published a book in 1865 to summarize his achievements in observing urethra and bladder with the endoscope. In this book, he mentions that he succeeded in observing inside the rectum as well, although without details, and predicts that it should prove possible to observe inside the stomach.

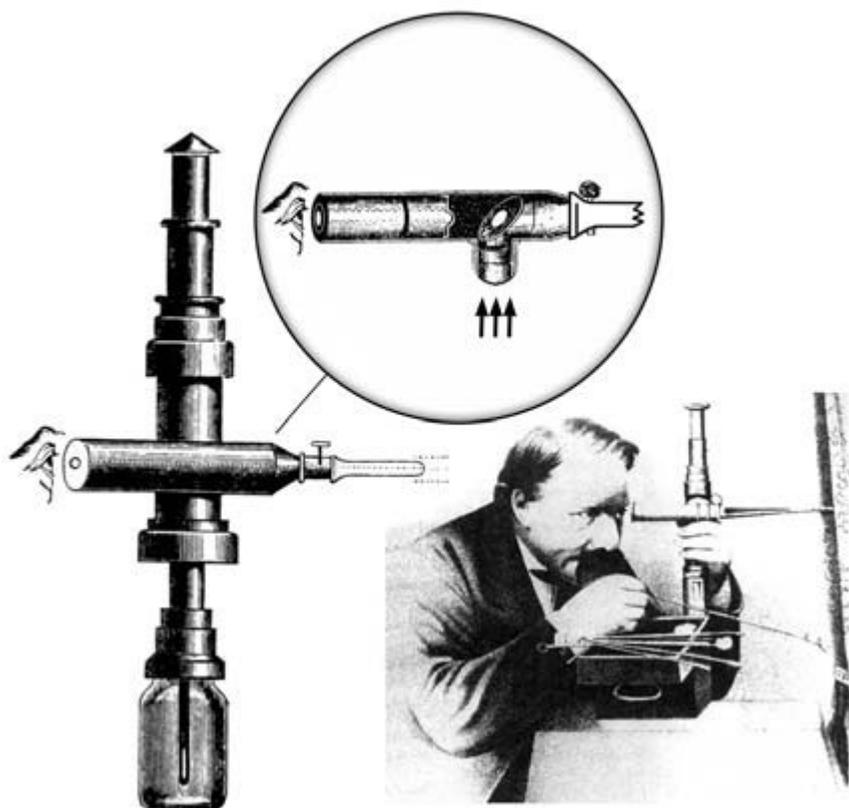


Fig. 1.4 Désormeaux's "endoscope" (1853)—with (inset) cross-section cutaway diagram showing the lensless view through a perforated mirror reflecting light from the source.

Désormeaux's endoscope was essentially a mere hollow rigid tube and did not have a lens in its optical system. It was Kussmaul who further developed Désormeaux's method and succeeded in making the first gastroscope in 1868. Kussmaul first tried observing the rectum and then the esophagus with Désormeaux's endoscope [5], succeeding in observing cancer of the upper esophagus. He then developed a new device with a longer insertion tube, as it was impossible to observe further than the upper esophagus with Désormeaux's endoscope.

It is said that Kussmaul got the idea of inserting a straight tube inside the stomach when he saw the performance of a sword-swallower. Happening to see the performer insert a straight rigid metal bar from his mouth into the esophagus, Kussmaul's assistant asked the performer to come to the university to carry out an experiment.

The gastroscope that Kussmaul made was a brass hollow tube of 47 cm in length and 1.3 cm in diameter, with two types of cross-sectional shapes, round and oval. No lens was used in the optical system. Although he succeeded in inserting the tube up to the stomach, the candle light source of Désormeaux's device was totally inadequate to supply enough light to illuminate all the way from mouth to stomach and this method had to be abandoned.

Leiter's rectoscope

Before the invention of the electric incandescent light bulb, it was known that bright light could be obtained by passing direct current electricity through a platinum wire, using a water-cooling system. This water-cooled electrical lighting system was applied to observation of the larynx in 1860s and subsequently to other endoscopes (Fig. 1.5). Nitze and Leiter made a cystoscope in 1879, and an esophagoscope and a gastroscope later on. Leiter, a Viennese optical instrument maker, developed a rectoscope with a similar light source, which appears in his catalogue, although it is not known whether it was actually used.

Modern proctosigmoidoscopes

With the introduction of Edison's electric incandescent bulb, the size of bulbs reduced. In 1886 Nitze and Leiter succeeded in developing a cystoscope with a miniature electric incandescent bulb at the tip, which became the basis for development of gastrointestinal endoscopes.

Nevertheless, this technology was not used for early proctosigmoidoscopes. In 1895 Kelly in the USA produced the first proctoscope of practical value [6]. It had a metal hollow tube, produced in various lengths, widening to the handle end except for one type which

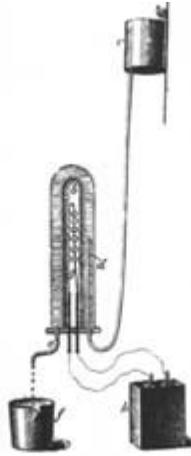


Fig. 1.5 "Stomatoscope" (1867, Breslau, Germany)—designed for oral illumination but also used up the rectum. Note the water-cooled electric lighting system.

had the same diameter through its length. There was an obturator for insertion and illumination was by a concave reflector, as used by otorhinolaryngologists. The rectum was well seen, but there was difficulty observing the proximal sigmoid colon with longer versions because of poor illumination.

In 1899, Pennington in the USA [7] sealed the eyepiece of the tube with a glass window and supplied air from a rubber ball to expand the sigmoid colon. He also inserted a small light bulb at the distal end for better illumination. In the same year, Laws used a thin metal rod with a miniature light bulb installed at the tip, inserted through the proctosigmoidoscope.

In 1903 Strauss in Germany followed the Laws' approach, developing a proctosigmoidoscope that distended the sigmoid colon with a rubber hand pump and safety bellows. This became the basis of commercially available Strauss-type proctosigmoidoscopes, which were very widely used until the arrival of fiber-sigmoidoscopes. Strauss proctosigmoidoscopes consisted of metal tubes 2 cm in diameter and of various lengths, inserted into the rectum or distal colon with an obturator in position. For observation the obturator was removed and a thin metal tube with a miniature light bulb inserted to the tip (Fig. 1.6). A magnifying apparatus was available that could provide six times magnified images, showing that there has been interest in magnification endoscopy for a long time. In 1910 Foges invented a proctoscope with a miniature light bulb installed at the eyepiece window. Another proctosigmoidoscope with a light source at the eyepiece end of the scope was developed by Yeomans in 1912 [8]. Illumination from an outside light source with a fiberoptic light guide is now widely used [9].

There are several lengths of rigid endoscopes for use in the rectum and sigmoid colon. Officially shorter

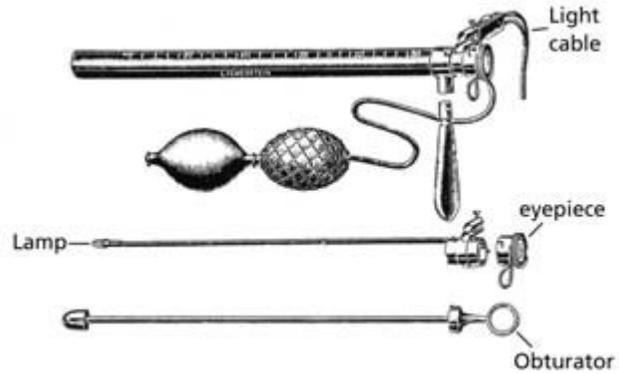


Fig. 1.6 Strauss type proctosigmoidoscope.

ones, for use in the rectum, are called rectoscopes or proctoscopes and longer ones, for use in the distal sigmoid colon, have been called sigmoidoscopes or proctosigmoidoscopes. However the terms rectoscope, proctoscope, sigmoidoscope, proctosigmoidoscope are effectively synonymous.

Sigmoidoscopy has been performed in various positions, in lithotomy, lateral decubitus or "chest-knee" position. It seems that Kelly was the first to carry out and emphasize the significance of chest-knee or "knee-elbow" position [6]. In this position air could flow into the sigmoid colon, with improved view.

Sigmoidoscope photography

Sigmoidoscopic photography was tried, for example using the Strauss sigmoidoscope with special apparatus for taking pictures. However it proved difficult to take good pictures through sigmoidoscopes until the early 1960s. Amongst other problems, the sensitivity of the reversal color film (Kodak) used for slides around 1960 was only ASA 10. Sufficient light was required, but this was difficult to achieve with the built-in sigmoidoscope bulbs available at this time. Therefore many solutions were tried, such as using multiple light bulbs or use of a high voltage light source. Picture-taking proctosigmoidoscopes were developed by Tohoku University in technical cooperation with a medical engineering company, Machida, and by Henning in Germany, using bulbs as the light source.

Apart from these types using light bulbs, Sakita, Niwa and their coworkers developed a different type of picture-taking sigmoidoscope in order to obtain better pictures in 1960. This used a Strauss type sigmoidoscope with tip light bulb for observation but a separate distal xenon lamp for photography. By integrating the xenon lamp and objective lens into the tip of this instrument, shutter speeds of 1/500–1/1000 were possible (Fig. 1.7). Figure 1.7(b) is a picture of a colonic polyp obtained with this instrument. Because the xenon lamp required high

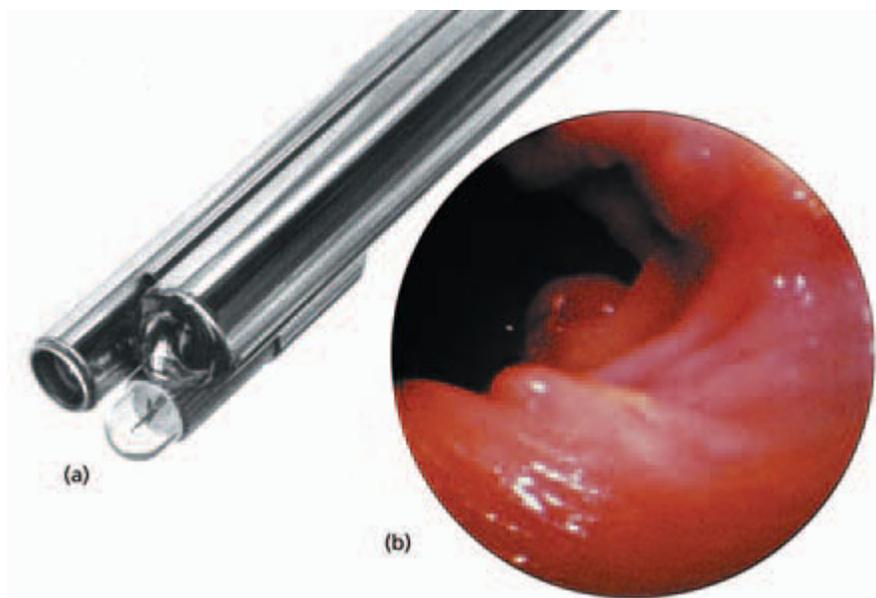


Fig. 1.7 (a) The tip of the optical tube for a picture-taking rigid sigmoidoscope, with (b) photograph of a colonic polyp.

voltage and other types of picture-taking sigmoidoscopes had poor illumination, these original picture-taking sigmoidoscopes gradually fell out of use. With the introduction of fiberoptic light guides sigmoidoscopic photography became more popular again, but colonofiberscopes and subsequently videoscopes have become the main means of taking pictures.

Special kinds of proctosigmoidoscope

Magnified three-dimensional proctosigmoidoscope

Special proctosigmoidoscopes allowing magnified three-dimensional observation of the rectal and colonic mucosa were used by Niwa in 1965 [10]. A special Kelly-type proctoscope (Fig. 1.8a) was coupled to a surgical stereomicroscope (Fig. 1.8b) on a stand (Fig. 1.8c). With this instrument, magnification of up to $\times 40$ was possible up to 15 cm from the anus, and up to $\times 64$ less than 10 cm from the anus. By this method, the surface of the normal rectal mucosa was observed to be transparent like gelatin, with thick blood vessels running horizontally underneath but also many thin vessels running vertically that could not be seen on conventional observation. With inflammation of the mucosa, the gelatinous transparency disappeared, with a red background and crypt openings showing up white. If toluidine blue was sprayed onto the surface of the mucosa, the pits became more obvious (Fig. 1.8c), which helped clarify the changes in the appearance of pit pattern in polyps or the mucosa of ulcerative colitis.

The method of dye spray in diagnosis has been used since the early days of otorhinolaryngology and gynecology. Besides Niwa's work using stereomicroscopy in gastroenterology, pontamine sky blue and toluidine

blue were used in 1961 for intraluminal microscopic observation of rectal mucosa by Yamagata and Miura [11], although the first referenced report of dye methodology in the field of gastroscopy was by Tsuda *et al.* in 1966 [12].

Intraluminal microscopy of rectal mucosa

Yamagata and Miura invented an intraluminal microscope for *in vivo* rectal mucosa. Observation using this apparatus was performed by first using a conventional sigmoidoscope, then inserting the intraluminal microscope through the sigmoidoscope in order to observe the pit openings of the rectal glands close up, the microscope tip being positioned immediately onto the target area. This device could provide between $\times 5$ and $\times 130$ magnified images of rectal mucosa surface by switching modes.

Development of intraluminal microscopy of the rectal mucosa (by Yamagata and Miura) or magnified three-dimensional observation of the rectal mucosa using stereomicroscopy (by Niwa) was in the days that the Japanese medical world was still under the influence of German medicine. German medical opinion was that inflammation of the colonic mucosa was accompanied by an intense inflammatory cell infiltration, which should not be described as ulcerative colitis but as "chronic idiopathic proctocolitis"; microscopy was expected to help diagnose and discriminate between the types of inflammation.

"High colonic" endoscopy

Another example of a special kind of sigmoidoscope, was one made by Regenbogen in Germany and pre-

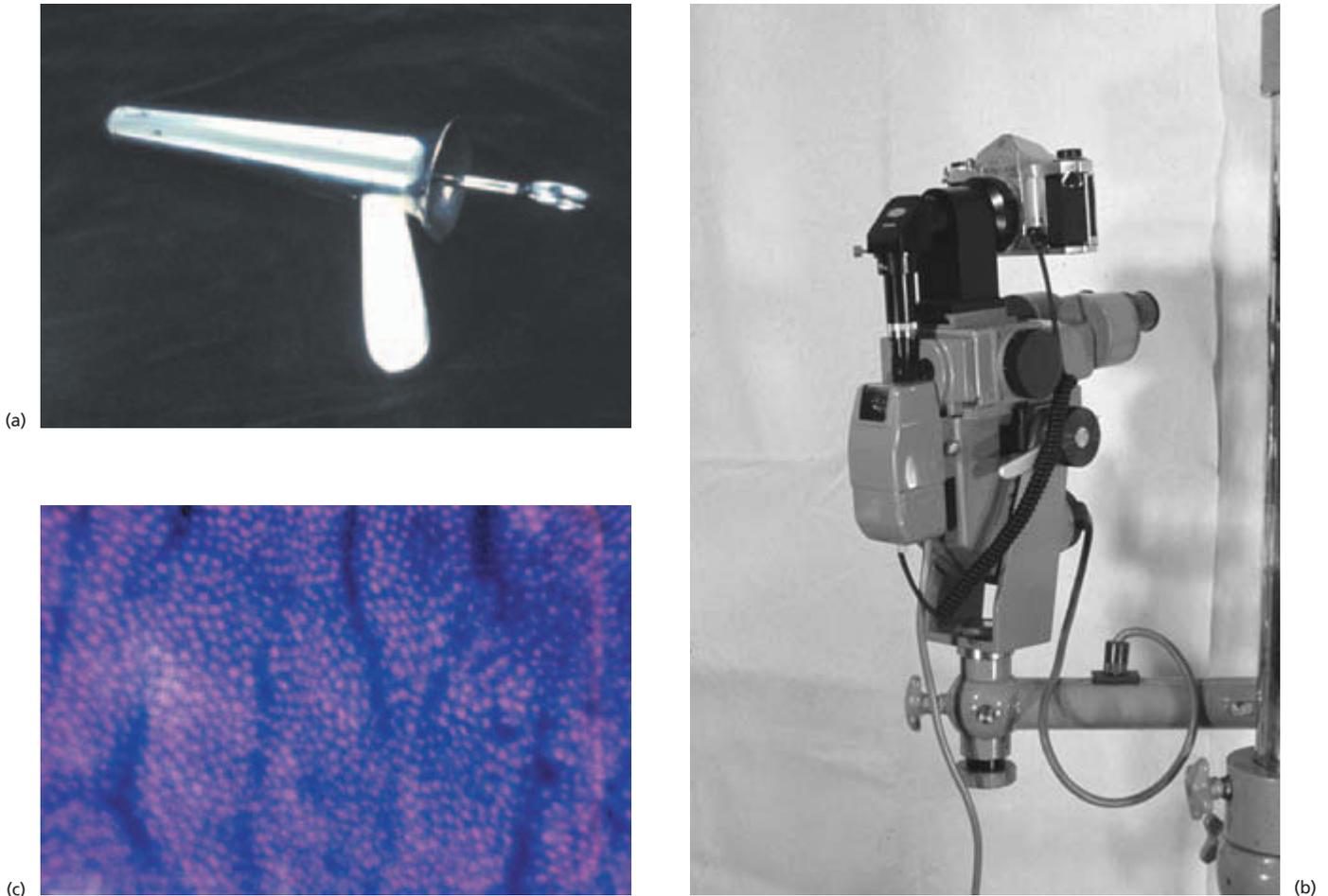


Fig. 1.8 Magnifying three-dimensional proctosigmoidoscope. (a) Scope body. (b) Surgical stereomicroscope. (c) Crypt openings of rectal mucosa with dye method.

sented at the First Congress of the International Society of Endoscopy in Tokyo in 1966. Using Regenbogen's sigmoidoscope it was possible to observe more proximal segments of the sigmoid colon (high colonic endoscopy) [13]. For this purpose, his sigmoidoscope had a rounded tip to help insertion round the sigmoid colon when there was acute bending or contraction. In order to assure insertion and observation of the proximal sigmoid further improvements were made (Fig. 1.9). Two slits in the body of the sigmoidoscope and a rubber covering allowed the atraumatic arms of an "extender" to open out of the slits. With the extender arms open at the tip end of the slit, the bowel fixed by the arms could be pulled back over the sigmoidoscope, rather as a glove is pulled over the fingers. The area observed depended on the anatomy of the bowel and the experience of the operator, but Regenbogen reported that he could observe at least 15 cm deeper than with an ordinary sigmoidoscope.

Some laughed at Regenbogen's report, questioning its benefits. However, since current colonoscopes are advanced into the proximal colon by straightening the bowel as much as possible, looking back at Regenbogen's report we can say that it actually anticipated some of the basis of current technique.

Sigmoidocamera and colonocamera

In 1929, Porges and Heilpern reported the "Gastrophotor" (Fig. 1.10), a pin-hole stereoscopic camera for use in the stomach and rectum. At the tip of Gastrophotor was an eight-pin-hole stereoscopic camera, allowing taking of pictures of a wide area of stomach or rectum. The Gastrophotor set, as supplied commercially, contained two instruments: one for the stomach (black shaft) and one for the rectum (red shaft). Using this apparatus, trials were made of taking pictures of the rectal mucosa, but there are no reports in the literature of its clinical use in the rectum.

The sigmoidocamera was first developed by Matsunaga and Tsushima in 1958, modifying the type II gastrocamera [14]. A conventional sigmoidoscope was first inserted into the sigmoid colon and the sigmoidocamera

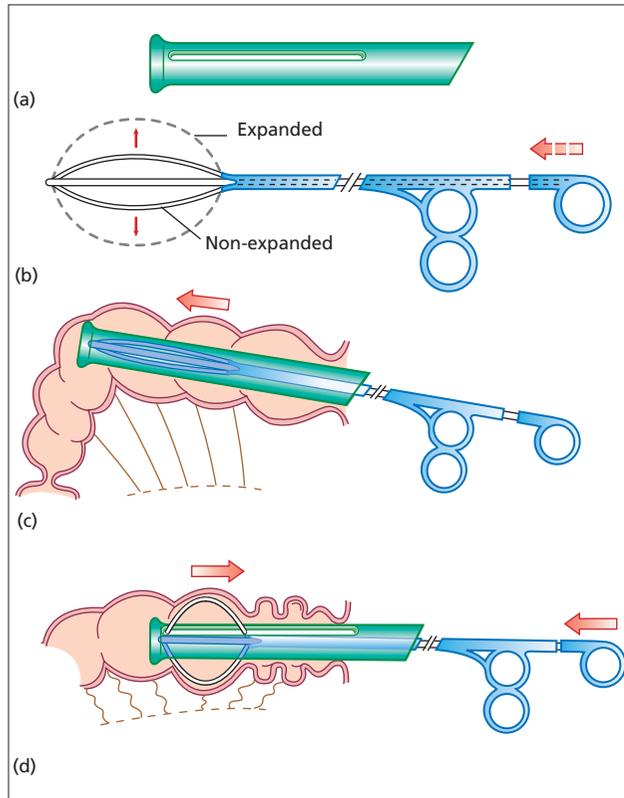


Fig. 1.9 Regenbogen's sigmoidoscope. (a) Slotted end of tube. (b) Wire 'extender' mechanism, closed and open. (c) Sigmoidoscope insertion stretches and angulates sigmoid colon. (d) Expanded 'extender' grips and straightens colon on withdrawal.



Fig. 1.10 Gastrophotor.

then inserted through the hollow body of the sigmoidoscope to take pictures. In other words, this instrument was developed as a way of photographing endoscopic findings of areas visible on sigmoidoscopy, which was otherwise impossible at that time.

In 1960, Niwa developed the prototype of a new colonocamera (Fig. 1.11) [15], a modification of the mass survey gastrocamera (later called the type V Gastrocamera) but with a much longer shaft. The visual angle of the lens was 80° and the film used was 5 mm in width. With this prototype, photography up to the left (splenic) flexure was successful, indicating for the first time that observation of the proximal colon was possible.

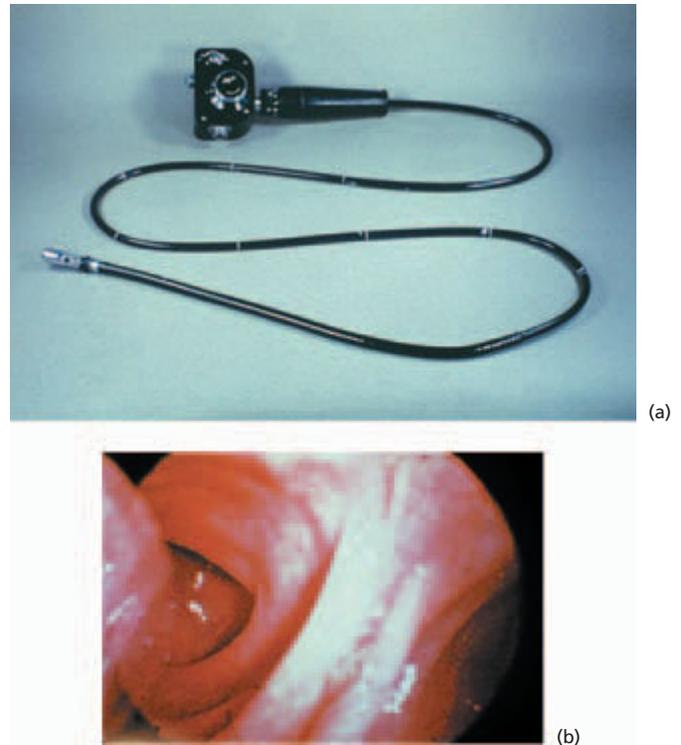


Fig. 1.11 (a) Colonocamera (Niwa, 1960) and (b) image of sigmoid colon.

Figure 1.11(b) shows an example of the pictures taken by this instrument.

Further improvements were made to this prototype colonocamera and its length extended (Colonocamera type III). The instrument was inserted into the proximal colon under fluoroscopic guidance. The mechanism of picture-taking was the same as with the gastrocamera; however, the colonocamera was not always able to take good pictures due to the narrow colonic lumen, its lateral-viewing optical system and the limited number of pictures it could take.

American fiberscope development

Whilst gastrocamera and colcamera development proceeded in Japan, Hopkins and Kapany in the UK in 1954 had demonstrated image transmission down a short fiberoptic bundle and speculated on its potential use for gastroscopy [16]. Hirschowitz and Curtiss at the University of Michigan developed a fiberoptic viewing bundle by 1957, used it to perform the first flexible gastroduodenoscopy [17], and then worked with American Cystoscope Makers Inc. (ACMI) to produce prototype endoscopes. By 1961 the ACMI "Hirschowitz fibergastroscope" was commercially available, creating excitement in Japan and around the world.

In 1961 Overholt, also at the University of Michigan, obtained US government funding to develop fiberscopes



Fig. 1.12 Prototype fiberoptic sigmoidoscope: Illinois Institute of Research (Overholt, 1963).



Fig. 1.13 The first fiberoptic sigmoidoscope—four-way angling: Eder Instrument Co. (Overholt, 1963).

for colonic use. By 1963 three different US manufacturers had prototype short colonoscopes and Overholt was able to perform the first flexible sigmoidoscopy with a crude four-way angling instrument (Figs 1.12 & 1.13). ACMI, a relatively small company, had been pre-occupied with gastroscope development and unwilling to accept governmental conditions for colonoscope



Fig. 1.15 Commercialized Hirschowitz fiberoptic gastroscope (American Cystoscope Makers Inc., ACMI, 1964), as also used in colon. Side-viewing, no angulation controls (focussing lever only), with transformer for distal tip light bulb.

development. ACMI did however supply both passive viewing bundles and prototype side-viewing fiberoptic gastroscopes which were used in 1966–8 by pioneer colon enthusiasts in the USA [18], the UK [19], and Italy. By 1967 Overholt could report 40 successful flexible sigmoidoscopies [20]. A fourth company, American Optical, was able to produce fiberoptic bundles [21] and sold some to Japan for use in prototype development.

ACMI, partly because of the small and very flexible fibers produced by their development of the Hirschowitz and Curtiss two-glass drawn-fiber method of production (Fig. 1.14), were able by 1971 onwards to produce highly robust colonoscopes (Fig. 1.15). These were capable of acute tip angulation without damage to the fibers, and had an innovative “flag-handle” method of controlling four-way angulation (Fig. 1.16), although

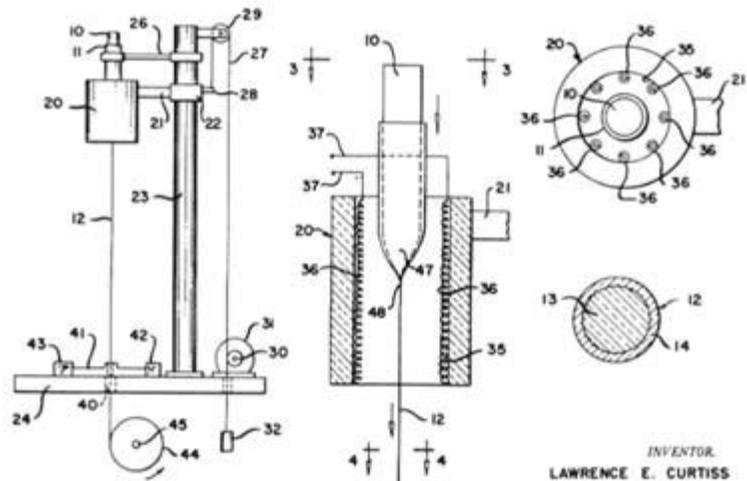


Fig. 1.14 The original patent diagram (Curtiss and Hirschowitz, filed 1957; registered 1971). This shows the technique for drawing a “two-glass” fiber through an electric furnace.



Fig. 1.16 ACMI F9A “flag-handle coloscope” (1974) with single-lever giving four-way angulation control.

with mechanical construction and torque-stability characteristics somewhat inferior to Japanese instruments of the same period.

The US endoscope companies were too small to sustain the costs of quality improvement in the long term and larger American corporations proved uninterested in the medical market, so by the late 1980s colonoscope production ceased. ACMI at least had the satisfaction, on behalf of Hirschowitz and Curtiss, of winning the battle to establish their patent rights on the critical underlying principles for fiberoptic manufacture.

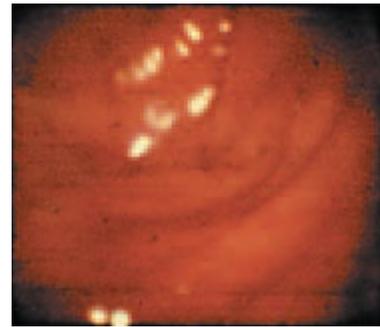
Japanese colonofiberscope development

With the spread of “gastrocamera with fiberscope” (GTF, an instrument combining gastrocamera and fiberscope produced in 1964), attempts were made to utilize it for colonic examination. However, insertion into the proximal half of the sigmoid colon proved extremely difficult because of the shaft characteristics of the scope and the field of view, which was very limited due to the side-viewing optical system. To adapt to the narrow and tortuous lumen of the colon, modifications were necessary to make the shaft of the colonofiberscope more flexible and to alter the direction of optical view.

A prototype forward-viewing colonofiberscope was first made for Niwa in 1965 [10] by Olympus (Fig. 1.17). The visual angle of the lens was 35° , there was no angulation mechanism, it used a fiberoptic light guide for illumination, and the shaft was 2 m in length. Partly because the shaft was too stiff, insertion into the descending colon was still very difficult. When inserting into the proximal sigmoid colon, the tip pressed into the colonic wall, so losing the view. Observation during withdrawal was also difficult because of poor illumination at a distance. This passive prototype instrument



(a)



(b)

Fig. 1.17 (a) Prototype forward-viewing colonofiberscope (Niwa, 1965). (b) Example through the forward-viewing colonofiberscope.

therefore proved impractical, although Niwa tried, without much success, to avoid impaction by attaching a centering balloon at the tip end.

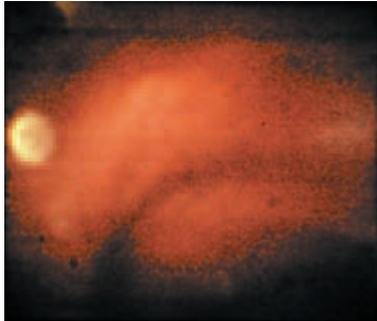
The next prototype was the forward-/side-viewing colonofiberscope shown in Figure 1.18, which could be used as either a forward- or side-viewing scope by changing the lens at the tip [22]. However the image was not good, either in forward view because of poor illumination, or side viewing, due to an inner reflection at the cover glass of the lens.

A “rotating prism” colonofiberscope was developed next [22,23] (Fig. 1.19). The prism could be rotated in either direction from the control body. The visual angle was 40° , it had four-way angulation of the bending section, and the shaft was 120 cm in length. Insertion into the descending colon remained very difficult with this model too, because of shaft stiffness and the long rigid metal tip. The image was also poor because of internal reflections from the illuminating light caused by rotation of the prism.

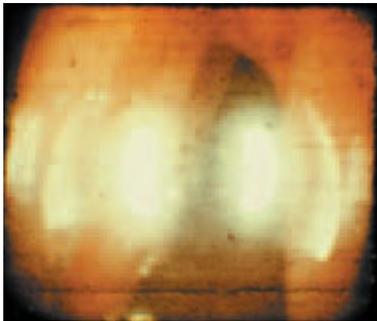
From the experiments carried out on these various prototypes, the conclusions were that the colonofiberscope should have a more flexible shaft and needed a forward-oblique-viewing lens. Oblique viewing was adopted to compensate for the narrow visual angle of the forward-viewing model, resulting from the limited



(a)



(b)



(c)

Fig. 1.18 (a) The prototype forward- plus side-viewing colonofiberscope (Niwa *et al.*, 1966) (detachable side-viewing lens is on right). (b) Image through forward-viewing lens. (c) Image obtained with side-viewing attachment, showing limited view and unacceptable reflections.

resolution of the fiber bundle at the time. As the result, a prototype short colonofiberscope was produced with only up/down angulation (Fig. 1.20) [24,25]. The same handle mechanism was used as in the esophagoscope,

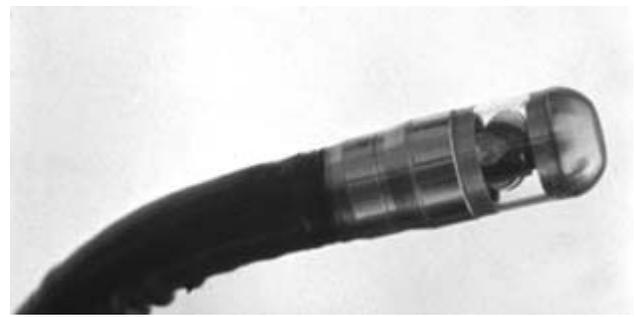


Fig. 1.19 "Rotating prism" colonofiberscope—side-viewing with 30° view (Niwa *et al.*, 1966).

already commercialized at the time. This colonofiberscope was deliberately made shorter than the earlier prototypes which had proved difficult to use in the sigmoid colon. The author realized that, rather than aiming at the proximal colon from the beginning, it was preferable to simplify design in order to observe the sigmoid colon effectively, the site of most disease. Examinations were much easier with this prototype and images were good, as shown in Figure 1.20(b).

The first practical colonofiberscope had been invented at this point. Later the length of the shaft was extended by 25 cm and the forward-oblique viewing was changed from downward to upward, to coincide with the direction of bending of the sigmoid colon. This colonofiberscope became the basis of the SB type short colonofiberscope manufactured by Olympus, shown in Figure 1.21.

In contrast to the small fibers produced by the two-glass method used by the American manufacturers the Japanese fiber bundle manufacture was, from an early stage, by the three-glass method [26]. This entailed orderly rows of coated glass rods being drawn out in a matrix of acid-leachable glass, which was finally dissolved away leaving the characteristic orderly rows of glass fibers at each end. Olympus bundles were therefore better looking than the ACMI bundles, but had thicker fibers which limited resolution and angle of view, and were more easily damaged (Fig. 1.20b), so angulation of early Olympus colonoscopes was limited to only around 90°.

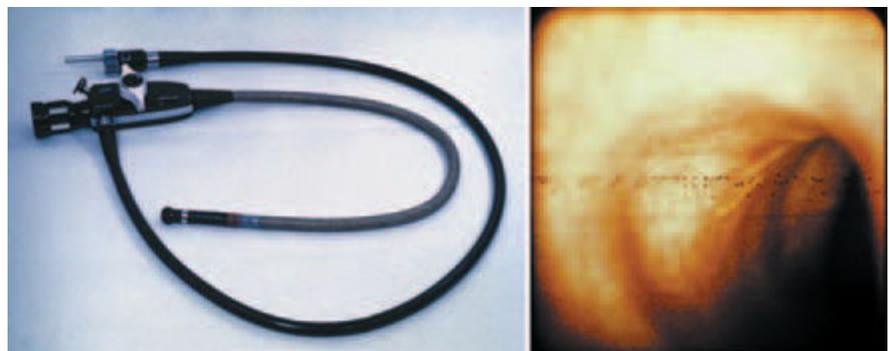


Fig. 1.20 (a) Prototype short colonofiberscope (Niwa, 1968). (b) Image through prototype short colonofiberscope—note typical broken glass fibers.



Fig. 1.21 Olympus colonofiberscopes (1970–1).

In contrast to Niwa, Matsunaga's group had aimed at reaching the right side of the colon from the beginning, using a prototype fiberoptic in 1968 which had a 120-cm long shaft and four-way angulation [27]. They extended its shaft length to 2 m in 1969, the basis of the Olympus LB type long colonofiberscope (Fig. 1.21). However insertion into the proximal colon was extremely difficult and their success rate for insertion into the ascending colon was reported to be 8% in 1970.

Yamagata and his coworkers developed yet another type of colonofiberscope in cooperation with Machida Seisakusho (medical & optical equipment manufacturer). At first they used a scope designed for duodenoscopy in the colon, but insertion proved difficult. They later developed a scope with an olive-shaped tip (Type IV) in 1966, other prototypes in 1968 and 1969, and finally achieved a practical fibercolonoscope with the development of Type VII in 1970. The shaft of this prototype was 190 cm long with four-way angulation. It was the basis for the excellent fibercolonoscope later manufactured by Machida (Fig. 1.22).

However, problems still remained after commercialization, including difficulty of insertion into the proximal colon and blind areas to observation. Therefore research into optics, flexibility and stiffness of the shaft and structure were carried out [18,28–30]. For example, Niwa *et al.* made a prototype 30° forward-oblique-viewing colonofiberscope in 1974, which had greater flexibility of the first 20 cm of the shaft compared to the stiffer shaft overall [28]. With such developments, colonofiberscopes became much easier to use.

Further improvements continued subsequently, especially in fiber bundle technology, so current Olympus



Fig. 1.22 Machida fibercolonoscope control body (1970)—note right- and left-hand controls, giving four-way tip angulation.

colonofiberscopes have 140° angle of view, up/down distal angulation of 180°, and left/right angulation of 160°. The outer diameter of the standard distal end is 13.8 mm. There are three different body lengths available with the same optical specification. There are also two channel types for therapy and thinner diameter models. Other manufacturers (Fujinon, Pentax) have similar products in their endoscopy range.

Other attempts at insertion to the proximal colon

During the course of colonoscopy development various attempts were made to facilitate insertion into the

proximal colon. In the early days Kanazawa inserted a polyethylene tube under fluoroscopic control from the sigmoid colon to descending colon beforehand. Through this tube, a colonocamera or gastrofiberscope could be inserted to the descending colon with improved success. Fox, in the UK, devised a similar method for suction biopsy through a flexible polyvinyl tube inserted under fluoroscopy, and then utilized this method to insert a passive bundle (ACMI) or fibergastroscope into the proximal colon [31].

There were many other attempts to facilitate insertion. These included supplementary instruments such as a guiding split-sigmoidoscope, which was withdrawn and dismantled after inserting the fiberoscope through it [32], a stiffening wire method [33], intestinal string pull-up methods [34–36], intestinal string guidance method [37], and a sliding tube method [38].

The stiffening wire method was a way of maintaining the straightened shape of the sigmoid colon, initially by inserting a steel wire through the biopsy channel to enhance the stiffness of the body [33] (see later). For the intestinal pull-up methods (end-to-end method), an intestinal tube was swallowed by the patient the day before examination. In the “pulley” approach a loop was then made in the tube when it emerged from the anus, threaded through with another string connected to the tip of the colonofiberscope. The looped tube was pulled back from the mouth into the proximal colon and used as a pulley through which the anal pull-string could be used to tug the endoscope into the proximal colon [36]. In the “string guidance” method, the tube coming out from the anus was inserted through the biopsy channel as a guide to help insertion proximally.

The “splinting tube” or “sliding tube” method (see later) was used to maintain straightening of the colonoscope [38]. It was necessary to apply the sliding tube over the colonofiberscope before the procedure and use of fluoroscopy was desirable for safety. Improvements were made on sliding tubes (demountable assembly or split-type) so that they could be put together when necessary [39].

Early researchers went through considerable difficulties, since colonoscopy requires much greater skill compared to that of upper digestive endoscopy. Even if a colonofiberscope was successfully inserted, it took great effort to make full use of it and achieve good routine results.

Other countries involvement in fibercolonoscopy

Only limited manufacture of short colonoscopes occurred in other countries, and used Japanese fiber bundles. In Germany the Storz and Wolff endoscope companies achieved small-scale production, whilst in Russia and China larger-scale manufacture was licensed.

Researchers around the rest of the world, however, did pioneer in developing and establishing many aspects of the technique of colonoscopy. In the USA, Waye [40] and Shinya [41] played the leading role. Deyhle in Germany [33], Rossini in Italy, and Williams in England [42] all made great contributions. Colonoscopic snare polypectomy was pioneered by Deyhle and Shinya. Recently Williams participated in the development of the position-detecting device (Scope Guide/UPD, Olympus), which makes it possible to know the shape and position of an endoscope during the procedure without using fluoroscopy. Magnetic position-indicators installed inside the endoscope communicate to the main device which detects the magnetic fields and displays the configured images on the TV monitor [43].

The transition to electronic endoscopes

Fiberoptic endoscopes enabled examination of body cavities, but by only one person—the operator. “Lecture scopes” (teaching attachments) were developed to overcome this problem. A prism was attached to the scope eyepiece with a fiber bundle to send the same visual information to another eyepiece, allowing two people to observe the same image. However, the attachment resulted in insufficient brightness for the operator, caused difficulty in operating the hand-held control unit, and increased the risk of scope dislodgement during complex maneuvers. The second observer received an image transmitted via glass fiber over a distance of about 1 m, so lacked clarity and definition. The lecture scope thus permitted multiple observers to view the same endoscopic image, but was far from ideal.

To improve image quality, endoscopists began direct connection of video cameras to the scope eyepiece lens. Initially a three-tube camera was suspended from the ceiling and attached to an endoscope (Ikegami, Tokyo), but proved cumbersome and the scope was often dislodged on rotation. Nonetheless the images obtained were displayed on a large television monitor and easily recorded on videotape, adding to the interest of the procedure not only for the operator but also for the many observers. A commercially available TV camera was subsequently used (Keymed, London), connection between eyepiece and camera being by 30-cm straight tubes and prismatic joints. Maneuverability was improved, but the scope had to be disconnected for derotation and the TV trolley was too large and heavy to move around conveniently.

A single-tube camera was eventually developed (OTV-E, Olympus) that could be directly attached to the eyepiece, similarly to a lecture scope. It was rectangular (length 14 cm, weight 290 g plus cable) but caused strain on the examiner’s left hand, because of its attachment to the end of the control body and eyepiece. Compared

with the larger cameras, brightness was poorer but nonetheless it proved popular with endoscopists. Units continued to become smaller with the introduction of charge-coupled device (CCD) technology, decreasing to 7.5 cm in length and 150 g in weight (OTV-F3, Olympus). However the poor quality of the enlarged fiberoptic images displayed on the TV monitor encouraged development of electronic endoscopes.

Early electronic endoscopes

Progress in electronics led to the American development in 1969 of silicon CCDs containing picture elements (pixels) able to generate electric signals in response to light. Even though Japanese glass fibers were reduced down to 7 μm diameter, with reduced “packing fraction” between fibers and superior resolution, CCD images were able to be made several-fold higher in quality. Early CCDs were too large for small-diameter gastroscopes, so the first “videoendoscope” was a colonoscope produced in the USA by Welch-Allyn Company in 1983 [44]. Placement of the CCD directly behind the objective lens made the instrument tip more bulky and stiff. The bending section was less agile than that of a fiberoptic colonoscope, so more difficult to retrovert and sometimes restricting angulation and view. Videoendoscopes were initially received with surprise and skepticism by Japanese manufacturers, but market forces soon led to their adoption—videocolonoscopy sales rapidly overtaking those of fiberoptic instruments.

Because CCDs could transmit monochrome brightness of their individual elements but not color (the glass fiber was only for illumination), two methods were devised to display images in color, the “sequential system” and the “white light” or simultaneous system (see Chapter 22). With the sequential system, light emitted from the light source was converted into strobed colored light by means of rotating red (R), green (G), and blue (B) filters. The light-based information was recorded in separate R, G, and B image memory-stores in the processor, before being combined into a color screen image. The sequential method permitted use of a smaller CCD, i.e. a small number of image elements, but color blurring or break-up often occurred. By contrast, the simultaneous system used R, G and B filters superimposed in a mosaic pattern over the CCD pixels. Each pixel thus received color information, simultaneously sent to the processor and displayed on the monitor. Although this system had no color blurring, a larger CCD was necessary, and the greater ratio of G relative to R and B in the filter mosaic altered the color tone on the monitor, creating an unusual hue for endoscopists used to fiberoptic endoscopes. Gradually, with miniaturization, CCDs became smaller and the number of pixels increased, resulting in high-quality images.



Fig. 1.23 “Standard” and “slim” fibercolonoscope tip/bending sections.

Further developments in colonoscopy

Ultra-thin endoscopes

The need for ultra-thin endoscopes is less in the colon than in the upper gastrointestinal tract. However, whilst an external diameter of 10–13 mm permits good maneuverability, the instrumentation channel should have an internal diameter of at least 2.8 mm (larger if possible) to facilitate the passage of accessories. The diameter of the upper gastrointestinal tract is 10 mm or less in some patients. Ultra-thin fiberscopes were technically easy to manufacture and were commercially available from the earliest days of endoscopy—ACMI in the USA had a 2.5-mm passive “ureteroscopy” in 1967 (R Wappler, personal communication). However, since a thin diameter led to a scope that was too flexible, efforts were made to increase rigidity, even in thin scopes for adults. These stiffer scopes could not be used in children or in some adults with colonic strictures, pronounced tortuosity, or severe adhesions. Very flexible ultrathin scopes were therefore also developed and manufactured at the same time (CF-SV, Olympus, Fig. 1.23). To produce ultra-thin scopes, the length of the tip had to be shortened and the radius of curvature during maximal bending reduced. The technology involved was used to improve the performance of standard adult endoscopes, permitting acute angulation but also allowing accessories to pass.

Stiffening methodology

When shaft characteristics are too soft, looping of the scope occurs when there is resistance produced by the tip passing through acute flexures. Such bending most frequently occurs in the sigmoid colon and pressure was

applied to the abdominal wall to oppose it and/or stiffening devices used from the early days of the fiberoptic endoscope. From the spring steel stiffening wires used by some colonoscopists in the early 1970s there developed a stiffening wire and stiffening tube. The ACMI internal stiffening wire of 1974 consisted of a core tensioning wire surrounded by a 3.5-mm-diameter coil. Tensioning the core wire, the outer coil contracted and stiffened. The large diameter required to achieve effective stiffening restricted use to large-channel “therapeutic colonoscopes,” such as the ACMI F9A. Thinner wires for standard colonoscopes did not produce the desired stiffness.

Stiffening, “splinting” or “overtubes” were, for the same reasons, also in use from the start of colonoscopy. The commercialized, rather rigid, Olympus stiffening tube had to be put in place over the scope before insertion, and its length reduced the effective working length of scope. Prototype Gortex “split-overtubes” overcame this problem and were floppy enough to be inserted without using fluoroscopy. However with the development of “one-man” colonoscopy handling technique and better understanding of loop control, less flexible scopes became more popular and stiffening overtubes are currently rarely used.

Looping can sometimes not be avoided, even if a very stiff scope is used—and formation of a loop in a stiff scope generally causes the patient considerable discomfort. Scopes using the same principle as a stiffening wire were therefore developed, based on a 1975 prototype

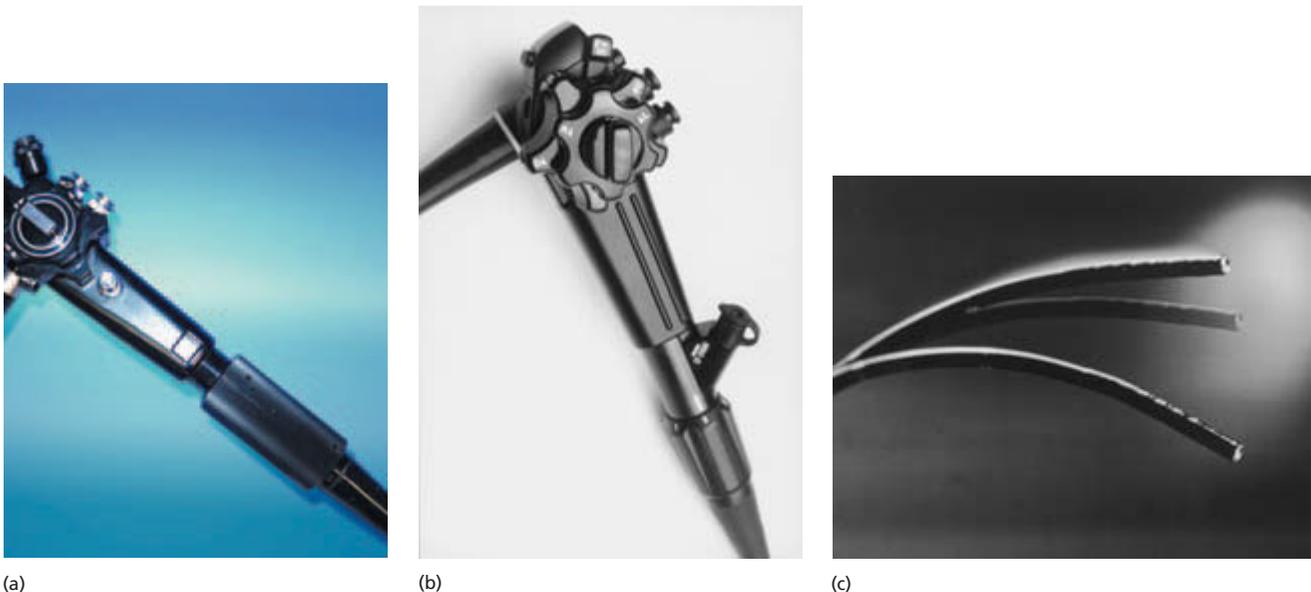
made for UK use (Fig. 1.24a) commercialized in 2000 (Olympus CF240AI/L, Fig. 1.24b). Stiffness is applied by twisting the tensioning-ring installed between the control body and shaft. The shaft characteristics are designed to be only slightly stiffer than a pediatric scope when set to “floppy,” but similar to a hard scope when set to “stiff” (Fig. 1.24c). An ultra-thin colonoscope incorporating the same mechanism was also produced. More improvements are needed because shaft looping remains a problem in colonoscopy.

Imaging endoscope configuration

It is important to know the configuration of the scope during colonoscopy without the use of fluoroscopy, particularly when difficulty and persistent or atypical looping occurs during the procedure, when the patient suddenly complains of pain, or to allow the endoscopist to confirm the site of lesions. To overcome such uncertainties two different UK groups produced prototype “3-D magnetic imaging” systems in 1993–4 (Williams 1993 [43], Bladen 1994 [45]), finally commercialized as the Olympus “Scope Guide” or “UPD” 3D imager in 2002. Small electromagnet coils are installed inside the scope at about 5-cm intervals from the tip (Fig. 1.25) and each coil is activated at a different frequency. A sensor dish detects the magnetic fields produced by each coil, and position-sensing information for all the coils is processed by a computer and displayed as a three-dimensional real-time screen image of endoscope shape. The strength of the magnetic fields is minimal by international specifications, so that the system is safe for continuous use.

Images showing the shape of the scope can be displayed from the direction desired by the operator,

Fig. 1.24 Shaft-mounted stiffening control of Olympus Innoflex “variable” colonoscopes: (a) 1975 prototype; (b) 2000 commercialized version; (c) effect on shaft stiffness demonstrated.



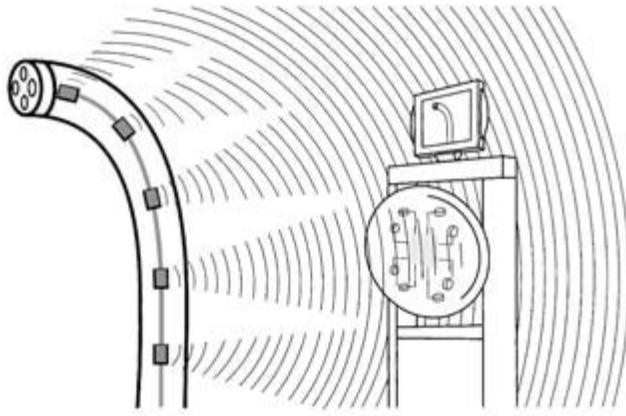


Fig. 1.25 Diagrammatic representation of three-dimensional imaging system (Scope Guide/UPD, Olympus), showing field(s) from within-scope electromagnets computed to produce an image of shaft configuration.



Fig. 1.26 Lateral view of alpha loop shown by “3D imager” (Scope Guide, Olympus).

independent of the patient’s body position. In addition, both frontal (AP) and lateral views can be displayed simultaneously split-screen. To facilitate 3-D image presentation, gray-scale shading is used, close-up regions of the scope being displayed bright and distant regions dark (Fig. 1.26).

In addition to the commercialized coil-fitted “imager colonoscopes” (CF240AI, Olympus), 2-mm-diameter “imager probes” containing the coils can be inserted into the biopsy channel of conventional scopes (Fig. 1.27), which interferes with suction. A hand-coil can be used during abdominal manipulation to ensure that the assistant’s hand pressure is correctly located over a loop.

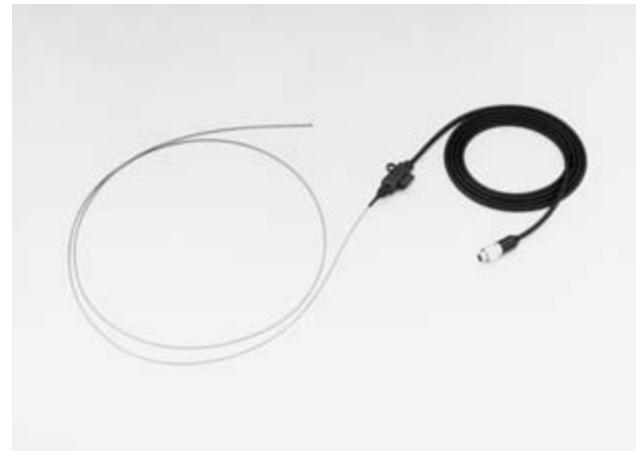


Fig. 1.27 “3D Imager” probe for insertion down instrumentation channel of any endoscope.

Magnification and dyeing

Prototype magnifying fiberoptic colonoscopes were developed which could magnify objects up to 170 times, resolving even the nuclei of superficial epithelial cells. At that time there was no clinical need for such a degree of magnification, since commercially available magnifying scopes were able to magnify objects up to 35 times (CF-HM Olympus), physically moving some of the objective lenses at the tip of the scope, giving a depth of focus of up to 2–3 mm. These principles were also applied to electronic scopes, using a piezoelectric method to zoom the objective lenses move smoothly and simply (Fig. 1.28). As CCDs became even smaller and resolution increased, minute changes visible only on magnification could be displayed in full detail on a high-resolution television monitor. Compared with the upper gastrointestinal tract, the colon is less susceptible to pulsation,

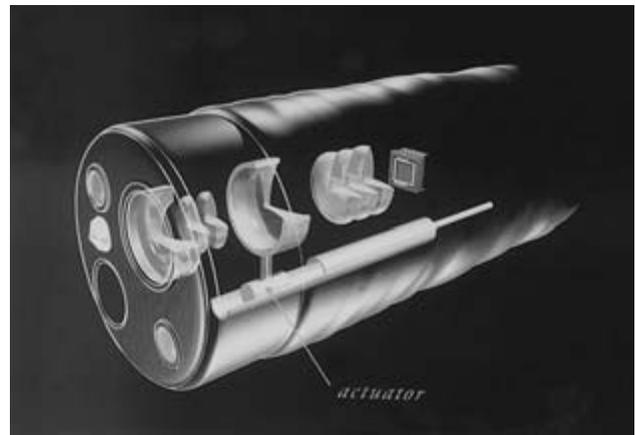


Fig. 1.28 Zoom lens mechanism of magnifying scopes—piezoelectric actuator adjusts position of the moveable lens.

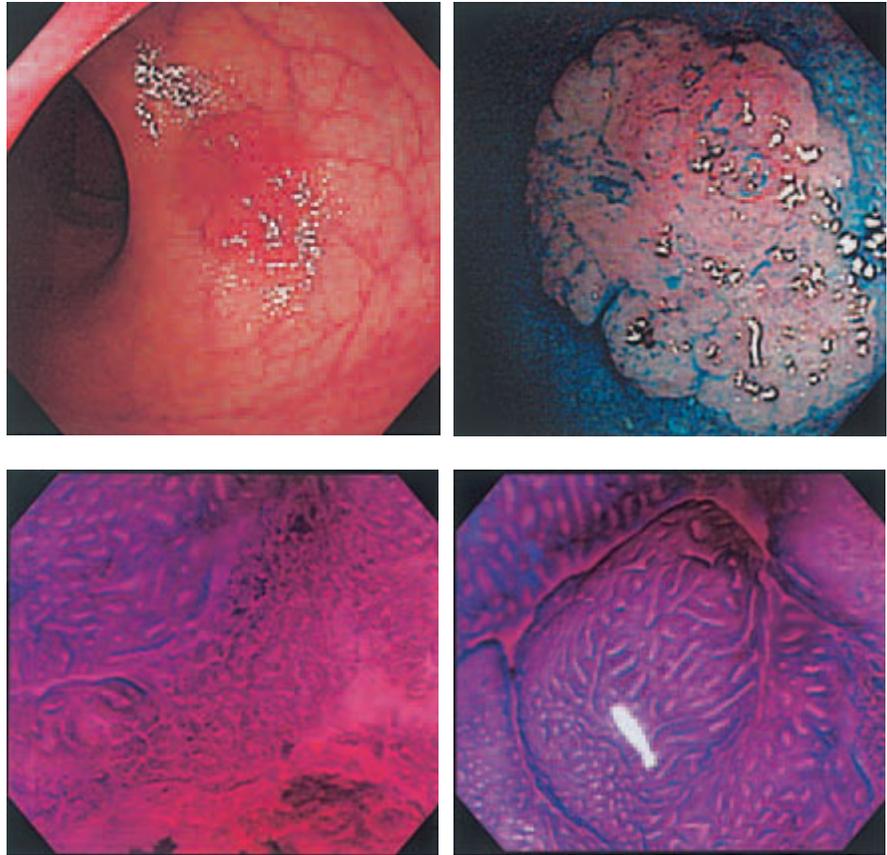


Fig. 1.29 Dye-spray, staining, and magnification of a 9-mm malignant polyp. (a) Initial view of lesion (b) Close-up after indigo carmine spray. (c) Magnified view after cresyl violet staining—deformed crypts in depressed area suggest malignancy. (d) Adjacent elevated area—appearances typical of benign adenoma.

has minimal peristalsis and less adherent mucus, all of which characteristics facilitate magnifying endoscopy.

Magnifying endoscopy may provide a good view, but the images are flat and monotonous if not processed correctly, making it difficult to identify surface irregularity. The use of dye can make pathologic changes stand out either by contrast or staining (see Chapter 43). With the contrast method, dye solution (0.1–0.2% aqueous solution of indigo carmine food dye) accumulates in depressed areas and grooves and highlights the margin even of very slight protrusions, allowing lesions to be more easily identified, compensating for the disadvantage of magnifying endoscopy. Vital staining is usually by methylene blue (0.05–0.1%) or crystal violet (0.05%), and these dyes are absorbed by the surface epithelium, particularly the cells surrounding crypts.

In the colon, the shape of the crypts not only reflects the histologic characteristics of lesions but can also suggest the depth of invasion of carcinomas, helping to determine whether a lesion is suitable for endoscopic resection. Classification of types of colonic polyps by surface appearance started in 1975 with description of four types on examination with a dissecting microscope. Tada in 1978 reclassified these into three types on the basis of magnifying endoscopy [46], later adding a fourth type when the crypts are absent in advanced

carcinomas. These findings were forgotten and not applied to magnifying endoscopic examination for many years. Interest in Tada's classification was revived with increasing interest in superficial type cancer, especially by Kudo *et al.* (1992) [47] who used the previous classification of types I–V. There are some exceptions to the classification system, i.e. the fine surface architecture of the colon does not always correspond to deeper histologic changes, so magnification serves only as a partial aid to diagnosis (Fig. 1.29).

Enhancement

Endoscopic images comprise an extremely large amount of potential imaging information. With electronic scopes, imaging information consists of different electronic components. Manipulation of electronic information such as color, clarity, and color intensity may improve diagnostic capability (see Chapter 22). At first, enhancement was used for overall modification and for processing of gentle curves. Because light/dark enhancement effectively highlighted the outline of lesions, it was used for the diagnosis of superficial type lesions and the identification of minute structural changes on magnifying endoscopy (Fig. 1.30). It also became possible to enhance specific frequency bands, i.e. specific colors such as hemoglobin.

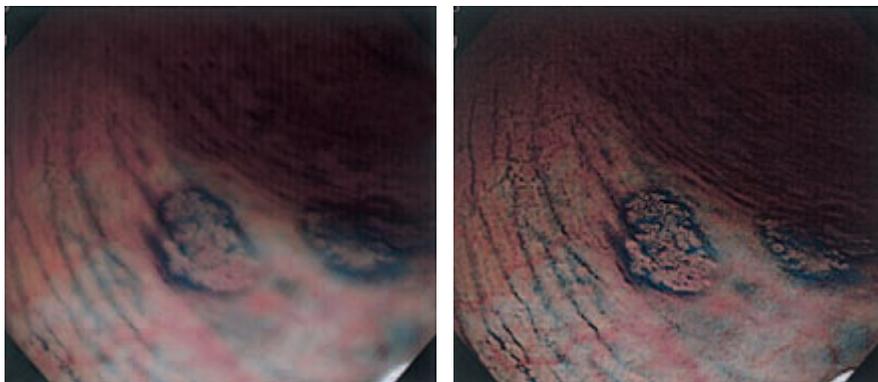


Fig. 1.30 (a) Hyperplastic polyp without image edge enhancement. (b) Same polyp as in (a) after image edge enhancement.

Moreover, the color of a lesion could be enhanced without modifying the color tone of the surrounding mucosa, so making lesions more easily identified.

Autofluorescence and infrared light

The use of light outside of the visible spectrum was attempted during the days of fiberoptic endoscopy, but was found to be impractical. Electronic scopes have been revived for research purposes, and the ease of processing electronic information may lead to the future development of electronic scopes.

Autofluorescence (see Chapter 44) is a technique that uses minute quantities of fluorescence inherent in tissue. This technique has received considerable attention because it does not require the use of fluorescein or other dyes. The observed findings are displayed with the use of an absorption filter. Minute quantities of fluorescence in the range of 500–600 nm can thereby be visualized. This technique is useful for the detection of tumors with high autofluorescence.

Infrared light has a wavelength of about 1000 nm and can be detected by the endoscope CCD. In particular, blood vessels can be clearly observed by the intravenous injection of indocyanine green (ICG) and the use of an appropriate filter, compatible with the degree of infrared light absorption. Even deep blood vessels that cannot be observed on conventional examination can be visualized. This feature is useful for determination of the presence and distribution of nutrient vessels before tumor resection.

Endoscopic ultrasonography

Attempts to use ultrasonography for diagnosis during endoscopy date back to the days of the fiberoptic endoscope. An ultrasound transducer (radial or linear) is incorporated into the tip of the scope (see Chapter 45). Ultrasonic waves are delivered perpendicularly to the scope axis. For radial scanning the transducer must be rotated mechanically, whereas for linear scanning, ultra-

sonic waves are delivered in a single direction from the side of the scope. To attach a transducer to the scope the length of the rigid part of the tip of the scope has to be longer, especially so for linear scanning, making the passage of the scope through curved sections of the intestine more difficult. Radial scanning of the colon was therefore introduced initially.

Until the development of specialized instruments for colonic endoscopic ultrasonography (EUS), side-viewing scopes designed for EUS of the stomach were used in the colon. Placement was through an overtube put in position over a conventional colonoscope, which was then withdrawn after the EUS gastroscope was inserted, and scanning performed during withdrawal under degassed water. Forward-viewing EUS colonoscopes were then developed (CF-UM3, Olympus, Fig. 1.31). The presence of the fiberoptic bundles and instrumentation channel limited radial imaging to 300°. The scope had a control panel located between the control body and the eyepiece, containing the transducer rotation motor and EUS switches. At first there were two kinds of transducers: a 7.5-MHz one and a 12-MHz one, but later it became possible to switch frequencies. EUS video



Fig. 1.31 Tip of EUS radial colonoscope (Olympus CF-UM3)—can be used with or without water balloon in place.



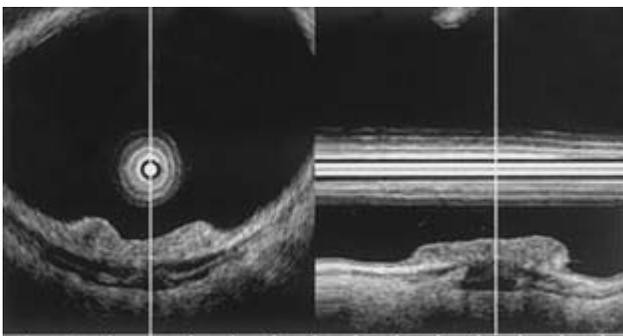
Fig. 1.32 EUS colonoscope (Olympus CF-UMQ 230).

colonoscopes were similar, but smaller and somewhat lighter (Fig. 1.32).

EUS probes had to pass through the biopsy channel of the scope, so their diameter was limited to 3.2 mm or less. This made it technically impossible to develop a 7.5-MHz probe, although 12- and 20-MHz probes were possible. Recently, 30-MHz probes have become commercially available (Fig. 1.33). Scanning is by mechanical radial rotation, obtaining transverse images of the intestine. Even small lesions can be targeted and diagnosis of the depth of invasion of superficial type lesions is facilitated by the use of a 20- or 30-MHz transducer. EUS is not suited for the evaluation of abnormalities outside the colon wall because of attenuation of the ultrasound beam at a distance.

Helical scanning can be achieved by moving the transducer of the ultrasonic probe at a constant rate to allow tomography or three-dimensional reconstruction. Up to 160 tomographic images covering a region of 4 cm can be saved in a computer and dual plane reconstruction then results in findings quite similar to those obtained

Fig. 1.34 (a) Helical EUS radial and longitudinal scan views of depressed polyp. (b) Three-dimensional reconstruction of helical EUS scan. (c) Endoscopic view.



(a)

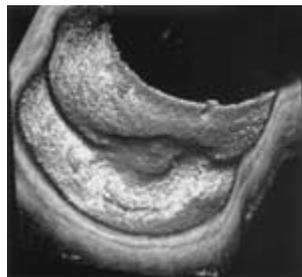


Fig. 1.33 EUS probe with motor-driven rotating transducer inside.

by linear scanning. Transverse and longitudinal images of a lesion can be displayed instantaneously (Fig. 1.34) or incorporated into a graphic display, displaying both types of images simultaneously. Dramatic images, including three-dimensional scans, can now be produced (Fig. 1.34b).

Summary

The long history of rigid endoscopy was essentially limited to the rectosigmoid area, but later transformed by the introduction of the electric light bulb. Gastrocamera technology had limited impact on colonic diagnosis, but gave Japanese manufacturers the mechanical expertise to produce torque-stable shafts and superior angulation and control mechanisms. Introduction of fiberoptics from the USA in 1957 and a sustained period of prototype development during the 1960s and 1970s resulted in the highly sophisticated fibercolonoscopes available at the end of the millennium. The invention of the CCD brought application of digital electronics to videocolonoscopy, through CCD and a further new dimension. Other supportive innovations and parallel methodologies continue to be developed, but still more are needed to guarantee the future of colonoscopy.



(b)



(c)

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