

The History of Colonoscopy and Lower Bowel Endoscopy

Jerome D. Waye

Division of Gastroenterology, Icahn School of Medicine at Mount Sinai, New York, NY, USA

The history of colonoscopy begins with the development of the flexible fiberoptic upper intestinal endoscope by Dr. Basil Hirschowitz in 1967 [1]. Although the side-viewing flexible gastroscope was not intended to be used in the colon, physicians soon became interested in the flexibility of this new instrument to look into the large intestine. In the beginning, intubation deep into the large intestine was not easy, since the colon has multiple bends and twists that could not be conquered with the rigid sigmoidoscope that was the only tool available to examine the lower bowel. Physicians have for centuries tried to examine body orifices as noted by speculum devices discovered in the ruins of Pompeii, buried under volcanic ash after the eruption of Mount Vesuvius in the first century AD.

Further development of instruments for internal exploration did not appear in the literature until 1805 when Phillipp Bozzini [2] tried to see inside parts of the human body using a candle as a light source in a device called the “lichtleiter.” A reflecting mirror with a viewing aperture allowed the operator to see, through a rigid tube without optics, into the body illuminated by the reflected flaming wick. He described detailed observation of the rectum, vagina, and uterine cervix of a corpse and was successful in demonstrating its use in a living patient. His book on observations using the light conductor was published in 1807.

Several decades later (1853), in France, Desormeaux [2] developed a similar instrument that he called an “endoscope” where the light source was a mixture of alcohol and turpentine. The flame’s brightness was reflected through an angled mirror with a small hole in the center directed into a viewing tube that was inserted into the rectum (see Figure 1.1). He also predicted that it should prove possible to observe the stomach.

Kussmaul used Desormeaux’s endoscope to observe a cancer of the upper esophagus after which he developed a

longer (47 cm) brass insertion tube with a diameter of 1.3 cm and showed its efficacy by having a sword-swallower come to the university and successfully ingest the instrument (1868) although the light was inadequate for clinical usefulness. The illumination problem was solved when Edison invented the electric light bulb in 1879. It took years until the advantages of the light bulb and its miniaturized derivatives filtered into the imagination of physicians who desired to examine the inside of the living human body.

In 1895, Kelly [3] invented a device for direct visualization of the distal colon and called it a sigmoidoscope. This was a 10-inch-long open-ended tube with a rounded obturator, which permitted the 2 cm diameter tube to be pushed past the anal sphincter muscles. He used reflected light using a mirror attached to a headband. This device is now recognized as the 25 cm rigid metal (or plastic) tube used for inspection of the rectosigmoid region (see Figure 1.2).

Visualization of the proximal colon was not possible with any of the instruments that had been developed to provide a view into the distal large intestine. The twists and angulations of the rectosigmoid colon precluded the ability to push a rigid tube much further beyond the distal most sigmoid. Because of the relative ease of accessibility, access to the upper intestinal tract was pursued, and multiple instruments had been developed for gastric visualization. It was not until 1958 that a “sigmoidocamera” was developed by Matsunaga and Tsushima in Japan [4] after modifying the commercialized Olympus type II gastrocamera. In their description, a conventional sigmoidoscope was first inserted into the sigmoid colon, and the sigmoidocamera passed through it to take pictures. In 1960, Niwa [5] developed the prototype of a new, longer colonocamera, which reached the splenic flexure, the first time that observation of the proximal colon had been possible. It should be noted that this camera was constructed in the fashion of all the rigid and “semiflexible” gastroscopic devices that had lateral or side-viewing ports, made to deflect the viewing angle in the stomach, since a straightforward view would not expose the walls of the distended gastric lumen. This concept extended to the colon, although the lumen is considerably narrower, and photos were often too close to the wall.

While gastrocamera and colocamera development proceeded in Japan, the opinion of most gastroenterologists was

Waye’s Colonoscopy: Principles and Practice, Third Edition. Edited by Douglas K. Rex, Evelien Dekker and Michael J. Bourke.
© 2027 John Wiley & Sons Ltd. All rights reserved, including rights for text and data mining and training of artificial intelligence technologies or similar technologies. Published 2027 by John Wiley & Sons Ltd.
Companion website: www.wiley.com/go/Rex/ColonoscopyPrinciplesandPractice/3e

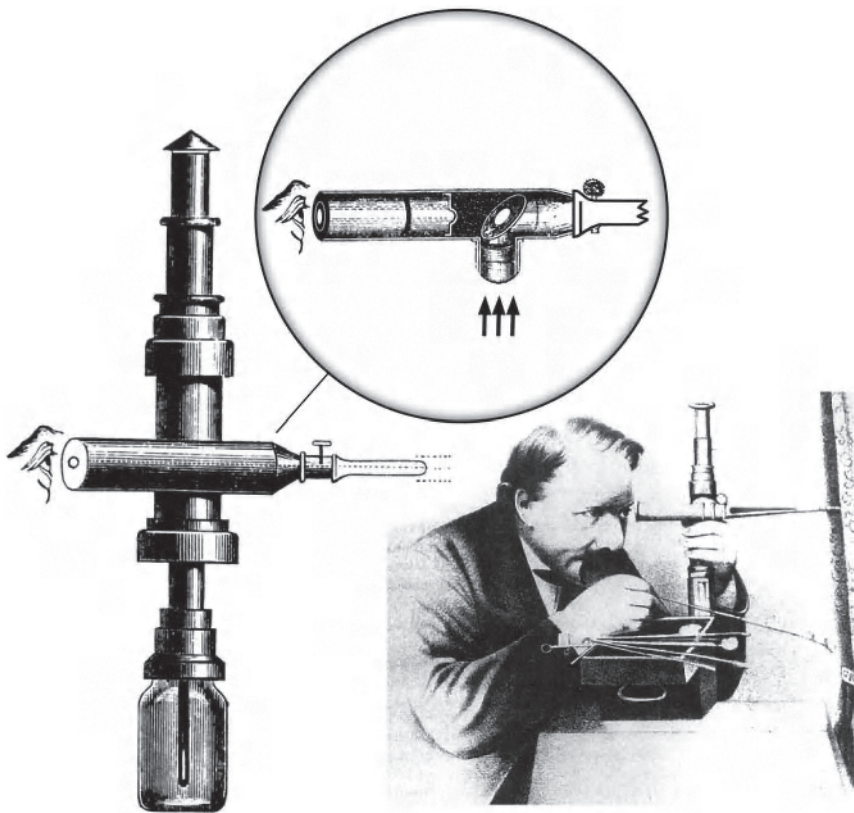


Figure 1.1 Desormeaux's "endoscope" (1853) with (inset) cross-section showing the lens-less view through a perforated mirror, reflecting light from the source.

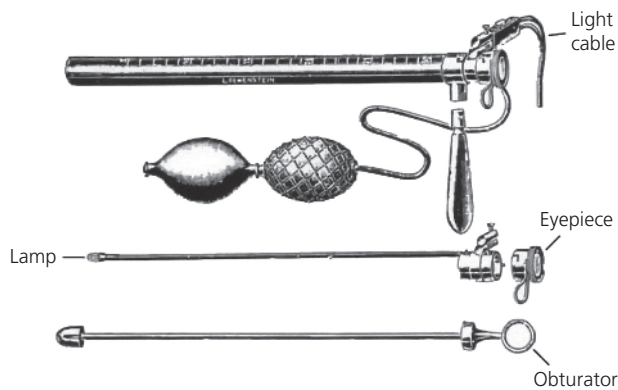


Figure 1.2 Rigid 25cm sigmoidoscope with light source and obturator. With eyepiece inserted rubber bulb can inflate lumen with air.

that the colonic angulations, folding, and twists prohibited the advancement of an instrument retrograde into the colon. In the meantime, Hopkins and Kapany in the United Kingdom, in 1954 [2], had demonstrated crude image transmission down a short fiberoptic bundle and speculated on its potential use for gastroscopy. Hirschowitz, Peters, and Curtiss, at the University of Michigan, developed a fiberoptic viewing bundle by 1957 and used it to perform the first flexible gastroscopy [1]. With the introduction of this flexible instrument (see Figure 1.3), a new capability for colonic visualization was realized.



Figure 1.3 Original side viewing Hirschowitz gastroscope with insufflation bulb and transformer. There is no tip deflection. The white lever near the eyepiece is for visual focus.

Two Italian gastroenterologists, Provenzale and Revignas [6], in 1968, devised a method that allowed them to pull a flexible "Hirschowitz" gastroscope into the colon using an orally ingested string. Their technique began with the patient swallowing a long-weighted string. When that was passed by the patient (1–3 days), the weight was

removed, and a small loop was fashioned at the end of the string. A second long string was threaded through the loop. The original long string was pulled back from the mouth until the loop, and the midpoint of the doubled over (second) string was located at the ileocecal valve while the two ends of the second string protruded from the anus. The side-viewing gastroscope was attached to one of the ends, and by pulling the other end of the string, using the loop in the first string as a fulcrum, the scope was pulled up into the colon, permitting some mucosal visualization. This cumbersome technique did not achieve much success.

Among other developments employing the ability to use flexible instruments to look into the colon, in 1961, a young doctor, Dr. Bergein Overholt, was given the specific task of developing a flexible instrument to replace the rigid sigmoidoscope. His story is:

In 1961, I graduated from the University of Tennessee Medical School and was accepted into the internship program at the University of Michigan, Ann Arbor, beginning my training in May of 1961. I knew at that time that I wanted to specialize in gastroenterology. However, during that year, the United States was deeply involved with the Cuban crisis, and many physicians in training were about to be drafted into military service. In order to complete our training before we served our country, I and many of my medical training peer group pursued enrollment in government programs that provided medical training deferments. I interviewed for such a program with the Cancer Control Program of the US Public Health Service (CCP-PHS).

It is important to note that my dad, a physician, fortuitously had sent me an article on "glass fiber optics that could see around corners" one week before my interview. The gastroscope was mentioned in that article.

The CCP-PHS administrator interviewing me was behind his desk doubled over in discomfort. He asked that I excuse his being in such a position, but that he had significant abdominal pain. He went on to explain. Earlier that day 3 (!) separate surgeons had tried to reach a polyp in the upper part of his descending colon with a 40-cm (yes, 40 cm) rigid sigmoidoscope. "They hurt me a great deal." Without thinking, I blurted out "what we need is a flexible fiberoptic sigmoidoscope." He looked up and asked, "What did you say?" I repeated, "flexible fiberoptic sigmoidoscope." He was visibly surprised and asked me to describe it.

Although I had never thought about such an instrument, I immediately responded:

- A flexible endoscope
- Four-way tip control to allow movement around bends and curves in the colon
- Fiber optics to carry light to the distal end of the scope
- Fiber optics to carry the image
- A channel that allowed for suction as well as passage of small probes such as biopsy forceps



Figure 1.4 The first functional fibersigmoidoscope four-way angling: Eder Instrument Co. (Overholt, 1963).

- A small channel throughout the length of the scope to allow passage of air for insufflation and for passage of water to cleanse the optical end of the scope

Such an instrument and those words were completely new to me. I had never considered such a device, but the words "came to me from above" and were spontaneous and flowed freely. There might have been some recollection of the article to which I thought I had paid little attention.

The administrator introduced me to the Chief of the CCP who said that if the Chairman of the GI Department of Michigan would endorse the idea and supervise me in the development of the scope, CCP would fund its development.

H. Marvin Pollard, MD, was Chief of GI at Michigan. He was fully supportive of the project. Unbeknownst to me, Dr Pollard was very knowledgeable about fiberoptic endoscopes as he was intimately involved in the development of the world's first flexible gastroscope, which was used at Michigan earlier that same year by its developer, Dr Basil Hirschowitz.

The CCP-PHS contracted with six US companies to develop a prototype flexible fiberoptic sigmoidoscope using the design criteria that I suggested. As anticipated, there were many challenges in attempting to describe the twists, angles, and turns of the three-dimensional (3D) anatomy of the sigmoid colon to nonclinical engineers. Radiologists had recently published their cytology collecting device, a barium-impregnated silicone foam enema, which expanded and solidified in 5–10 min. We used their technique to make a cast of the rectosigmoid area to demonstrate the anatomy of the lower colon, which was extremely helpful in explaining the complex anatomy to the design team.

The first clinically usable instrument (see Figure 1.4) was provided by Eder Instrument Company (Chicago). I used it in the spring of 1963 to reach a proximal descending colon malignancy. At that time, I was a first-year medical resident and was supervised by a senior GI fellow. It was a long, difficult, and tedious procedure, and after 40 minutes, I reached the cancer. After withdrawal, the senior GI fellow looked at me and said, "Overholt, this scope will go nowhere."

However, it did. Shortly thereafter, fiber optics were greatly improved as was the four-way tip control. Insertion techniques were developed and improved. The scopes were lengthened, and colonoscopy procedures routinely reached the cecum.

In May 1967, Overholt, who later became president of ASGE, presented [7] the first series of 40 patients to undergo flexible sigmoidoscopy at the A/S/G/E meeting in Colorado Springs, Colorado. By 1969, Overholt [8] reported favorably on the utility of the newly introduced Olympus colonoscope (model CF-SB).

While Overholt was designing a flexible instrument for colon intubation, Japanese endoscopists were also working on similar projects. In 1964, Olympus developed its first flexible fiberoptic gastroscope. Attempts at colon intubation with this scope were unsuccessful, as it was a lateral viewing instrument that was difficult to pass beyond the distal sigmoid. A prototype “colonofiberscope” was made in 1965 [9]. Its angle of view was 35° with fiberoptic illumination, but it was a passive bundle 2m in length, with no angulation mechanism. Partly because the shaft was too stiff, insertion into the descending colon was very difficult, and when inserting into the proximal sigmoid, the tip tended to press into the colonic wall, losing the view. In 1967, Olympus produced another instrument that was shorter and had only up/down angulation but was more easily passed into the sigmoid colon. Later, the length of the shaft was extended, and this became the basis of the CF-B-type short colonofiberscope commercially manufactured by Olympus.

In 1967, the Olympus Company brought the first colonoscopes to the United States. The Japanese representative was well-trained and demonstrated the technique of colonoscopy and showed how to clean the instrument with soap and water after which he left the scope for a week at each institution he visited.

Within a short time, instruments for colonoscopy became longer, and reaching the cecum became a goal for every insertion of a scope into the rectum. Doctors who learned how to manipulate the scope around multiple bends in the colon began to teach others. Because this entire field of colonoscopy was new, there were no guidelines as to how to insert the scope nor how to withdraw. Each practitioner developed their own methods of intubation, some of which were quite good, and some were not so good. At the

inception of colonoscopy, every practitioner used fluoroscopy to ascertain the location of the instrument’s tip and to see the convolutions of the scope in the abdomen. As intracolonic anatomic landmarks became recognized, the value of fluoroscopic control steadily lessened.

All fiberoptic colonoscopes had forward vision with the image focused on a lens at the head of the scope. The ergonomics of the design necessitated the eyepiece be held close to the eye with the left hand, which also manipulated the two dial controls on the head and delivered air or suction. Intubation and withdrawal were a function of the right hand on the shaft. With body motions and near-constant twisting of the scope during the procedure, continual vision was usually maintained by resting the eyepiece on the observer’s malar eminence to keep it steady, often resulting in a deep impression below the operator’s left eye after a day of procedures. The delicate, tiny glass fibers that transmitted the image had evolved somewhat from the original format used in the Hirschowitz gastroscope. However, with the twisting and turning of the scope during its passage through the colon, considerable force was exerted on the shaft, and some of the glass fibers inevitably were fractured and broken, causing tiny black spots in the image where transmission was lost. Sometimes, an entire row of fibers was damaged, and a streak of black became a prominent part of the image. With greater use, more fibers were broken, and the image became a mosaic of black spots (see Figure 1.5). When diagnostic accuracy was impaired, the scope was returned to the manufacturer for fiberoptic bundle replacement.

When instruments for colon exploration were first developed, gastroenterologists had no idea as to how to prepare the colon for examination. They turned to the surgeons who routinely cleaned the colon prior to operating on the large bowel. Castor oil and enemas were the mechanical agents used following 2 days of clear liquid diet. This combination resulted in poor cleansing of the proximal colon since enema fluids rarely reached beyond the sigmoid. GI doctors adapted the surgeon’s shorthand for ordering the prep, using the phrase: “Triple H enemas,” which everyone knew

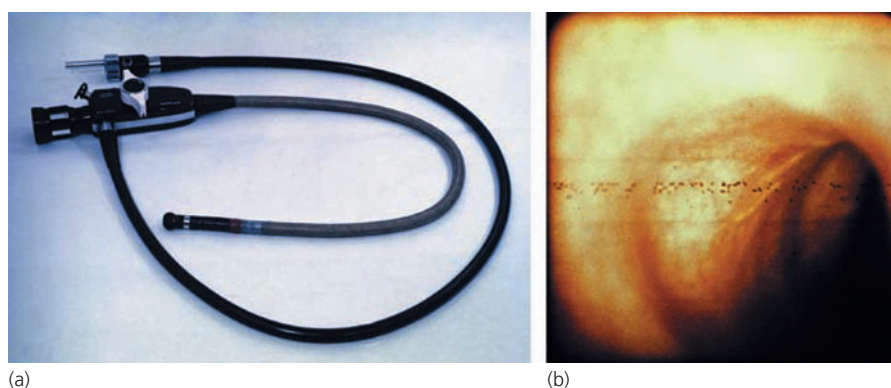


Figure 1.5 (a) Colonofiberscope with two-way tip angulation (Olympus 1968). (b) photo taken by camera with multiple broken glass fibers.

meant: “High, Hot and a Hell of a lot.” Still, the right colon was not well prepped, and considerable washing and suctioning were needed in the attempt to see what was under the coarse semi-liquid stool that coated the walls.

When colonoscopic polypectomy was first introduced, one of the major concerns was the possibility of intracolonic explosions [10] since the combustible gases, hydrogen and methane, are produced in the colon by bacteria. Explosion of these gases by an electric spark can be prevented by intensive bowel preparation, which cleans out the bacterial population for all practical purposes. Considerable anxiety surrounded polypectomy in the early period, and several journal articles were published on this subject, especially since the right colon was not well cleansed by the prep prescribed at that time. Fortunately, this proved not to be a significant problem.

One of the men who worked on developing the fiberoptic gastroscope, Dr Larry Curtis, became employed by an instrument company, American Cystoscope Manufacturers, Inc. (ACMI), and used his skill and knowledge to develop their line of colonoscopes. Mr. Rheinhold Wappler, the son of the original owner, was a pilot and had become enamored with the joystick guidance of his airplane. He considered that the single control could do everything—climb, dive, roll, turn, etc. When the company became interested in developing a colonoscope, Rheinhold insisted that their instrument have a single lever that, if pushed forward, the tip would bend upward, and if rotated, the tip would move laterally. ACMI built that colonoscope and it behaved as advertised. This scope had only a few adherents since the joystick was manipulated with the right hand while the head of the scope was held in the left, with no capability for the operator to advance the instrument into the colon nor to torque it around colon folds. The procedure became a two-person technique with the second doctor handling the scope shaft. Since only one person had visualization capability, there had to be constant communication between the one who could see and the shaft manipulator.

This was the only United States instrument manufacturer to attempt the introduction of a fiberoptic colonoscope into the enlarging marketplace.

The growth of flexible endoscopy, both colonoscopy and upper intestinal endoscopy, was both rapid and inevitable. Not all gastroenterologists embraced endoscopy, however, and some objected to its widespread use. Academic gastroenterologists looked askance at endoscopists. During the retirement address of the president of the American Gastroenterological Association, Dr. Fred Kern [11] showed a slide (published in the AGA Journal *Gastroenterology*) of a cartoon showing a circle of endoscopists lying on their side with each holding a scope up to their eye while the other end of the scope was in the rectum of the endoscopist in front and so on around the circle (Figure 1.6). This denigration of endoscopy was an ongoing criticism, which lasted for many years until training in upper and lower endoscopy became incorporated into the curriculum of essentially all gastroenterology fellows.

In the beginning, guiding the flexible scopes through the tortuous colon was a formidable task, and the operator rarely had any clue as to the area reached or what to do when the instrument could not be advanced further due to recurrent looping, which could not be overcome by further air insufflation or deflation, twisting, or torque of the scope or angulation of the dial controls. Fluoroscopy was employed extensively to locate the position of the colonoscope's tip and was also frequently used to guide intubation using the air column as the target. As familiarity with the colon anatomy grew with each procedure, the role of fluoroscopy rapidly diminished. However, fluoroscopy had taught endoscopists that the reason for failure to advance the scope beyond the sigmoid was almost invariably due to loops that formed in the sigmoid and were recurrent as well as persistent. Attempts at avoiding loops included adding a 30–40 cm stiff sleeve onto the shaft prior to intubation and then sliding that well-lubricated tube over the scope into the anus and upward in an attempt to keep the shaft straight [12]. The employment of these proved to be

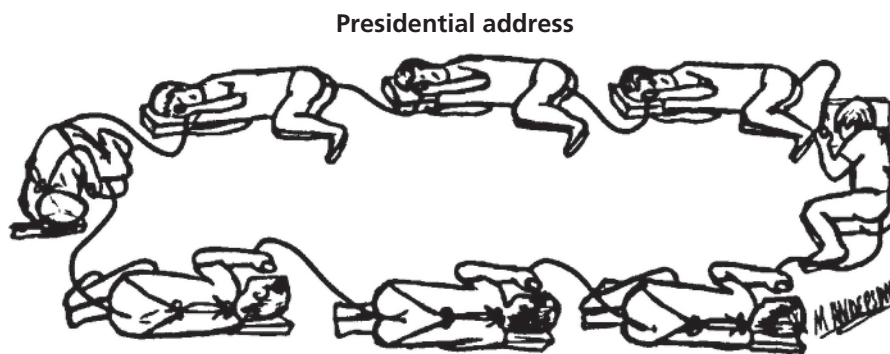


Figure 1.6 Cartoon depicting endoscopists in AGA Presidential Address by Dr. Fred Kern.

quite contentious with pro-overtubers insisting on their usefulness and others arguing against them. Within a few years, these disappeared as techniques of intubation developed further. Earlier pioneers [13] in developing successful techniques still in use include, among others, Overholt, Shinya, and Wayne in the United States; Niwa and colleagues in Japan; Salmon and Williams in England; and Deyhle in Germany.

Colonoscopy morphed from a purely diagnostic procedure to become a therapeutic tool when a young Japanese doctor, Hiromi Shinya [14], performed the first colonoscopic polypectomy in 1970 at the Beth Israel Hospital in New York. The introduction of snare polypectomy has been heralded [15] as the greatest achievement of the great era of endoscopic development. The introduction of snare polypectomy was met with considerable criticism from surgeons, which quickly dissipated since Shinya was a surgeon, and his mentor was the director of surgery. The original snare was fashioned using a long, braided, and flexible wire whose two ends were threaded into a catheter having a diameter that fits into the suction/biopsy channel of the colonoscope. When the loose distal ends protruded from the catheter, they were pulled so that the proximal looped end was withdrawn completely into the catheter, forming a kink at the tip instead of a loop. A snare was created by pushing the two distal wires into the catheter again, and the proximal end that extruded was no longer a smooth loop but had become a sharp point from being forcibly pulled into the small-bore catheter. When several centimeters of the pointed wire were pushed out, a “D”-shaped loop was fashioned by holding both loose wires at the distal end of the catheter and pulling back one. A loop of any size could be made by pushing both wires out and then pulling one back. Transecting a polyp by pulling the ends of the wire was difficult as the snare operator had to hold the catheter with the left hand and pull the wires with the right. To act as a handle for traction, a metal surgical clamp was placed onto the wires. Electrosurgical current was delivered by holding an electrode from the electrosurgical unit (ESU) onto the clamp with the rubber-gloved right hand (there was no attachment for the connection). The operator, who could see what was happening, activated the current with a foot switch and instructed the assistant how quickly to pull the snare through the polyp as the assistant was holding the catheter with the left hand while the right hand pulled on the clamp and held the wire connection. Excellent communication was necessary between the colonoscopist and the assistant. The snare was subsequently redesigned, and its entry into the armamentarium of endoscopy spawned an entire field of accessory instruments for injecting, sewing, and ligating as well as for hemostasis.

Polypectomy became an integral part of the colonoscopy procedure, and whenever a polyp was seen, it was removed. During the early years, instruments had not yet been developed for treating bleeding if it followed the removal of a polyp. There were no clips, no bands, and no needles for injection of hemostatic agents. Ice water enemas were the

only treatment for immediate postpolypectomy bleeding and were used frequently. Fortunately, most bleeding stopped spontaneously with or without the use of these enemas. Gastroenterologists became adept at polyp removal, and better preps led to the perception that once all polyps had been removed and the cecum reached, the colon was thoroughly evaluated. The growth rate of polyps was unknown, and a repeat colonoscopy was always performed in 1 year after polyp removal since it was common for “new” polyps to be found during that follow-up examination. It was not until 1984 that Dr Sidney Winawer [16] enrolled several colleagues to participate in a randomized clinical trial, the National Polyp Study, that showed there was no difference in outcome whether a follow-up was performed in 1 or 3 years after an index polypectomy. This study became famous for its focus on colon polyps over 40 years and proving that colon polyps lead to colon cancer. Over the years, many guidelines concerning the use of colonoscopy have been developed from observations and studies compiled by the NPS group.

Prior to colonoscopy, the only way to evaluate the large intestine was through the barium enema, which used fluoroscopy and X-ray to image a contrast instilled into the colon. Radiologists vied with colonoscopists for supremacy in polyp discovery. One of the studies performed in the National Polyp Study was to evaluate the findings of polyps on both examinations using a blinded technique where the colonoscopist called out the findings on each bowel segment as it was evaluated while the study coordinator had the results of the recent barium enema, which had been reviewed by the NPS radiology team. The barium enema was only about 50% accurate in identifying polyps of all sizes, including those over 1 cm in diameter, a miss rate that was considered unacceptable, resulting in the almost complete cessation of this radiologic examination [17].

Visualization of intraluminal events became an issue as the use of upper and lower endoscopy grew and became useful tools for both diagnosis and therapy. Flexible fiberoptic “lecture scopes” were developed as add-ons to the eyepiece. This markedly enhanced the role of the assistant, as well as had a positive impact on the training of endoscopists who were now able to observe the actual advancement of the scope as it was maneuvered around the colon folds, twists, and turns.

Within a short time, TV cameras were developed to attach to the eyepiece of fiberoptic scopes so the image could be transmitted to a nearby monitor, allowing several observers to watch intraluminal events.

In 1983, a surprise development occurred during Digestive Disease Week (DDW) in the United States. Drs Michael Sivak and David Fleischer of the Cleveland Clinic announced their series of colonoscopies using a video chip at the distal end of the scope, which transmitted the image to a monitor with no optical fiber bundle. Their submitted abstract:

COLONOSCOPY WITH A VIDEO ENDOSCOPE. PRELIMINARY EXPERIENCE WITH A NEW TYPE OF ENDOSCOPE. M. V. Sivak Jr. and D. E. Fleischer. Department of Gastroenterology, Cleveland Clinic Foundation, Cleveland, Ohio.

A revolutionary change in endoscope design has become possible as a result of advancement in microelectronics. We tested a prototype colonoscope (Welch-Allyn) which has no eyepiece. The image bundle and lens system are replaced by a sensing device that transmits the image electronically through the endoscope to a video processor for display by a standard television monitor. Endoscopic examination is performed entirely by observation of this monitor. The tip deflection control system with locking capability and the biopsy-suction and air-water insufflation mechanisms are similar to those of conventional endoscopes. The examination may be videotaped, or by a freeze frame capability selected still pictures can be taken. We evaluated this instrument to determine its diagnostic and therapeutic capabilities. Colonoscopy was performed in 31 consecutive patients for a variety of reasons. We had no prior experience with the instrument. Insertion into the cecum was intended in each case and was achieved in 21 patients. Failure was due to poor preparation in 5, incorrect sensor orientation in 2, obstructing carcinoma in 2, and unmanageable sigmoid loop formation in 1 patient. Two polyps were treated successfully by "hot biopsy" technique, and 3 by snare-polypectomy. No complications occurred. The instrument was acceptable for diagnostic and therapeutic colonoscopy in virtually all respects. No major changes in insertion technique were required. The television image was excellent, with true color and very good resolution of detail. Electrical interference during electrosurgery was barely detectable on the monitor. Abdominal wall trans-illumination occurred less often than desired. There was some increase in eye fatigue. The instrument could be held comfortably at waist-level height. Cleaning and maintenance were not complicated. All patients, although sedated, were aware of the television image and none objected to this. The system offers unique advantages for documentation, review of findings, objective comparison of repeated examinations, and teaching.

This announcement stunned the audience and changed forever the way endoscopes were made. The fiberoptic light bundle remained unchanged, as did water, suction, and biopsy channels; in addition, the deflection and locking mechanisms were similar [13].

Dr Michael Sivak recalled the circumstances that led up to the video breakthrough:

My first contact with Welch Allyn was via a telephone call on Monday, October 12, 1982. The company had built a "new" type of endoscope and wanted to show it to me.

I had been practicing at the Cleveland Clinic for six or seven years. My first encounter with an endoscope occurred in 1972 as a fellow. Endoscopy has come a very long way in a short span of time. In

particular, the coherent fiberoptic bundle had been brought to a remarkable level of technical sophistication by Japanese manufacturers, notably the Olympus Optical Company. I enjoyed a special relationship with Olympus, wherein they consulted me on technical matters in exchange for granting us early access to new technology. Thus, the call from Welch Allyn presented something of a political-ethical dilemma. But, since the relationship with Olympus was not exclusive, I told them to come ahead. I knew Welch Allyn had (and continues to have) a splendid reputation as a corporate citizen and innovative company. It was worth a look.

Understand that all of this occurred before the digital age: no internet, no email, no texting, no digital images, no app for that, no PowerPoint, no Wi-Fi, analog TV, images communicated via 35 mm photographic film, typewriters still in use, etc.

Welch Allyn arrived with the instrument on Thursday, November 11, 1982, brought by two people: Lorne Elder (sales manager) and Kenneth Heinz (project manager). They called it a video endoscope. They explained the basic design of the instrument, highlighting the incorporation of a charge-coupled device (CCD). The CCD ("chip") had been invented at Bell Laboratories in 1969 (13 years earlier). The CCD is "color-blind"; it measures photons but not wavelength(s). Consequently, illumination was by sequencing three colors (red, blue, and green) generated with a rotating wheel with corresponding filters (making the output compatible with the cathode-ray television of the time). The sequenced images were processed by a relatively compact light-source/processor, which was hardwired to a television monitor. The imaging could be directed to a videocassette machine (convenient), but photographs were made by holding a camera up to the TV monitor (cumbersome).

Prior to introducing me to the instrument, Welch Allyn had recruited six gastroenterologists in upstate New York to evaluate the instrument. I was provided with three pages of records of procedures that included endoscopists' comments. Approximately 70 procedures had been performed.

One of the gastroenterologists was James Tifft, a graduate of our program who performed his first examination on September 10, 1982. Dr Tifft advised Welch Allyn to seek a more formalized trial of the instrument with one or more well-recognized endoscopists. Apparently, happy to say, he included me.

Welch Allyn, despite contact with local area physicians, seemed to know very little about gastrointestinal endoscopy, that is, the larger structure of professional GI organizations. In particular, they were unaware of Digestive Disease Week (DDW) as the major worldwide forum for GI endoscopy. I recall specifically telling Lorne and Ken that DDW was the place to introduce the instrument to the GI community at large. But, the deadline for abstracts for the forthcoming DDW was January 15, 1983, and it was already mid-November.

Our approach was to organize a formal, IRB-approved trial with informed consent from potential patients, together with thorough recordkeeping and reporting. It took some time to get all of this in place. Consequently, the first formal study included only 31 patients.

The plan was to use the video colonoscope in everyday practice as a true test of its suitability. But, in looking at the instrument, numerous questions arose: was it mechanically sound or would it break during use, would the color of the images be true (endoscopic diagnosis is based in part on color), would the handling characteristics be acceptable or would it be difficult to insert (highly subjective, but no less important), would it be safe during electro-surgery or would there be capacitance-coupling effects potentially detrimental to the endoscopist and/or patient, not to mention instrument electronics, would the resolution (detail) be sufficient for accurate diagnosis, and, by no means inconsequential, how would patients react to seeing their inner colon (we took a certain pride in being able to talk to patients during the procedure, especially toward its conclusion). Most of these questions are answered in the paper by David Fleischer and me [18].

The paper was presented at 4 PM, Wednesday, May 25, 1983, at the Sheraton-Shoreham Hotel, Washington, DC, as #19 (the last one) on the program. Wednesday was the final day of DDW (although the ASGE Post Graduate course followed; incidentally, I was the course director—big week). There had been a lot of “buzz” during the meeting about the “new” instrument, including large crowds at the Welch Allyn exhibit. Nevertheless, I remember quite well how astounded I was (I don’t astound easily) at the size of the audience. Packed! There was no standing room left. As I stood to speak, I distinctly remember thinking the fire marshal would not like this.

I continued to work with Welch Allyn after May 1983. One of the many early discussions concerned the control section. Because the endoscope was no longer connected to the head (eye) of the endoscopist, the control section (tip deflection, suction, accessory port, etc.) could be changed in radical ways; a pistol grip, for example. My advice on this question was based on the pervasive mindset of physicians; if it ain’t broke, don’t try to fix it.

One of the overriding problems was the handling characteristics of the instruments; simply put, they were more difficult to use than corresponding Olympus instruments. For example, a particular concern was tip deflection; specifically, resistance offered by the instrument increased progressively as the tip approached maximum deflection. On one occasion, William (Bill) Allyn visited our unit, and it is possible I might have allowed him to maneuver the instrument in a patient (can’t recall exactly). In a subsequent case, I could even have permitted Bill to deflect the tip of an Olympus endoscope while in use. If this happened, doubtless it helped to make the point.

I don’t know if this is true, but it seemed there was some resistance to advice and suggestions among Welch Allyn engineers. In February 1986, I flew to Skaneateles Falls to meet with them.

The meeting was devoted to a wide-ranging survey of GI endoscopy, including my forecast(s) for the future. Another theme was the issue of disinfection and the fully immersible endoscope. I attempted to describe what they were up against with the Japanese endoscope companies. By this time, Olympus had fielded a more advanced video endoscope with color imaging built into the CCD. Incidentally, my relationship with Olympus seemed better than ever; Mr Hiroshi Ichikawa, an old friend at Olympus, told me later that

the company was impressed that I had kept the video endoscope development process secret.

I would be remiss if I did not mention that Welch Allyn was a family business run by brothers Bill and Lew Allyn. I was always deeply impressed by the company and all that it had accomplished, especially the guys who actually invented and probably hand-built the first video endoscopes: Dominick Danna, Richard Newman, and William Moore. It was an honor to meet them.

By 1989, Welch Allyn was out of the GI endoscopy business. Fortunately, the Welch Allyn name continues, and they still have facilities in Skaneateles Falls, NY, USA.

The sweep of history is sometimes slow and methodical, and at other times abrupt, innovative, and simultaneously destructive. As mentioned, the fiberoptic endoscope—specifically the coherent optical bundle—had reached an exquisite state of engineering by 1982, approaching the physical limits of what was theoretically achievable. Comes the “chip” endoscope, and all of that was gone in short order.

When I first met the video colonoscope, my thinking was directed toward possibilities for innovative imaging methods based on the interactions of tissue and light. This was not in the cards. The first and foremost effect was to make colonoscopy easier for the colonoscopist. Second, although the digital age had not yet arrived, the CCD endoscope was nevertheless ready and waiting. The gut was no longer a private domain for the endoscopist.

Among young endoscopists, especially fellow trainees, there is not much of an appreciation or even awareness of the historical course of events, especially “how things used to be.” If anything, the historical record confirms for them just how “bad,”—primitive even—GI endoscopy must have been in the past. Regrettable, but no matter. For me, it is an honor to have played a small role in the grand sweep of history.

Dr Sivak was the Director of Endoscopy at the Cleveland Clinic and became president of the American Society for Gastrointestinal Endoscopy (ASGE). He was a pioneer and a leader in our field.

As the colon preparation improved over the years and imaging improved considerably, total visualization of the colon lumen was the accepted outcome of a colonoscopic examination. The finding of another adenoma on a 1-year follow-up was considered to be a new growth, and no one suspected that a polyp could have been present in the colon and not discovered by the examiner. The report by Hixson *et al.* [19] in 1990 that 15% of polyps up to 1 cm were missed during colonoscopy was overlooked by everyone, and attention was not directed to this article until the report by Rex *et al.* in 1997 [20]. This article described colonoscopic findings of overlooked polyps discovered on two back-to-back colonoscopies performed on the same day. They reported an overall miss rate for adenomas of 24% with 13% for those of 6–9 mm and 6% for adenomas of 1 cm or larger. There was considerable interest in this article and reluctant acceptance

that colonoscopy can miss some polyps as described by one of the most outstanding experts in the field. Since then, others [21] have corroborated the initial publication of overlooked lesions, and this has driven the need for a higher level of quality control in colonoscopy.

Threading a 6-foot tube through a twisted and convoluted organ using external force and tip flexion inevitably resulted in trauma to the colon wall with through-and-through puncture of the thin-walled structure. A review of colonoscopy complications [22] informs that the term “complication” has been largely replaced by the phrase “adverse event” and is defined as an event that prevents completion of the planned procedure and/or results in unplanned admission to hospital, prolongation of existing hospital stay, another procedure (needing sedation/anesthesia), or subsequent medical consultation (see Section 9). The term complication carries an implication of direct causality between medical care and the occurrence of an adverse event (AE). Cardiopulmonary AEs are the most common type of endoscopy-related events, accounting for over 60% of unplanned events during endoscopy. These range from minor events, such as transient hypotension, hypoxia, or vasovagal episodes, to more significant events, such as respiratory distress, cardiac dysrhythmia, and vascular-related diseases.

Transient bacteremia may occur during colonoscopy through translocation of endogenous bacterial flora and ranges from 0% to 25% after sigmoidoscopy and colonoscopy. However, this is usually asymptomatic, and no causal link has been found with clinical infection. There is no role for routine prophylactic antibiotics before diagnostic endoscopy.

Colonic perforation may result from mechanical force (shearing stress), barotrauma, or a direct result of polypectomy. Iatrogenic perforation has been reported in 0.03–0.8% of diagnostic and screening colonoscopies and flexible sigmoidoscopies. A systematic review and meta-analysis of population-based studies (2023) found a higher rate of perforation in colonoscopies with polypectomies (0.8/1000), compared to colonoscopies without polypectomies (0.4/1000) [22]. A review [23] published in 1980 stated that perforation occurred (at that time period) almost twice as frequently as current studies have shown, with a frequency of 0.8% in diagnostic colonoscopy. The authors stated that the cause of this adverse event was “slide-by manipulation, the alpha maneuver, or straightening of the sigmoid loop.”

From the onset of colonoscopy, loops have always been a problem during intubation when pushing the scope around the tight bends and convolutions of the sigmoid created enlarging loops, which impeded progress. During the development of colonoscopes, a 1.3 cm external scope diameter was the industry standard for “adult” instruments, although some are now smaller. This scope was relatively stiff and was associated with some patient discomfort when loops were created within the sigmoid. A thinner diameter scope, which

has become known as the “pediatric” scope, was more flexible and subsequently developed by all manufacturers with an external diameter of 1 cm (or thinner) but with all the other torque stable and tip control mechanisms as the larger caliber “adult” scope. The two models are usually interchangeable, but some operators prefer one or the other when performing colonoscopy.

Early attempts at controlling loops included the overtube and “stiffening wires,” the latter of which were inserted into the suction/biopsy channel. When the wire was stiffened, the colonoscope became stiffer as well. This did not result in satisfactory loop avoidance, but in 2000, a stiffening mechanism was built into Olympus colonoscopes [12], which is applied by twisting a tensioning ring installed between the control body and the shaft. The shaft characteristics are designed to be only slightly stiffer than a pediatric-type colonoscope when set to “floppy,” but firmer than an “adult” scope when “stiff.” The stiffening control has been applied to multiple colonoscopes by various manufacturers and is useful for maintaining a straight scope.

When colonoscopy was developed, fluoroscopy was always used to ascertain the tip’s position. As techniques and landmarks were developed, the use of fluoroscopy was mostly phased out. However, some thought it useful to know where loops were forming and how to remove them to advance the instrument when forward motion was not possible. Two different groups [24, 25] in the United Kingdom developed “3D magnetic imaging” systems, and these have been incorporated into some colonoscopes. Small electromagnet generator coils are installed inside the scope at about 5 cm intervals from the tip; each coil activates at a different frequency so sensor coils in a receiver dish close to the patient detect the magnetic fields produced by each coil, and a computer displays a 3D image of the endoscope shape. These images showing the bends in the scope can be displayed related to the patient’s position, prone, supine, or lateral. A hand coil detector is available for use during abdominal manipulation to ensure that the assistant’s hand pressure is correctly located over a loop. There remain some outstanding endoscopists who are proponents of the magnetic imager and others who are convinced that the cecum can be reached in almost every patient without the need for an external device for determining loop positioning.

The use of an assistant’s external hand pressure on the abdomen [26] was one of the early aids for colonoscopy intubation. This is useful since there are multiple areas where the colon is in an anterior position. When pressure is given that results in further tip intubation, that pressure is to be maintained while advancement proceeds, after which pressure is relaxed.

Another change in the conduct of colonoscopy since its beginning is the use of sedation.

In the United States, almost all colonoscopies are performed using propofol administered by an anesthetist. In

other parts of the world, conscious sedation is given intravenously by the endoscopic team, using midazolam and fentanyl. When colonoscopy was first introduced, no sedation was used, but it soon became evident that some form of sedation was useful and was provided by a combination of meperidine and diazepam, the latter frequently causing a chemical phlebitis of varying severity. However, the literature is replete with descriptions of controlled trials using no sedation [27], with the majority of patients tolerating the procedure and not reporting it to be uncomfortable. It has been shown that the use of water infusion during the intubation phase lessens colon lengthening and looping, rendering the procedure less uncomfortable, and often avoiding or reducing the need for sedation [28].

Colonoscopy is usually started with the patient in the left lateral position, and some endoscopists perform the entire procedure without moving the patient. Some endoscopists move the patient frequently during the examination, according to the location of the scope during the intubation phase [29]. Change of position is easy if the patient is not sedated, may be cumbersome with conscious sedation, and can be very difficult with the use of propofol anesthesia. Thus, the propofol era has increased the relative reliance on abdominal pressure and reduced reliance on position change to advance the colonoscope.

Improvements in colonoscopy occurred rapidly, with the evolution of instrumentation, making variable stiffness colonoscopes and thinner, more flexible scopes. New techniques were developed along with the introduction of accessories for hemostasis, injection of various materials into the colon wall, preoperative marking of lesions, lesion retrieval devices, and so much more. A marked increase in colonoscopy usage was noted in 1985 [30] when the President of the United States, Ronald Reagan, was found on colonoscopy to have a carcinoma of the right colon not discovered during a screening sigmoidoscopy. This not only increased the awareness of colon cancer, the increased risk associated with a positive family history of colon cancer that he had, but also showed the benefit of the colonoscope in diseases of the large bowel. Throughout the 1990s, it was common for US endoscopists to perform colonoscopy for minimal or probably insignificant symptoms in what was essentially screening colonoscopy. In 2000, large cross-sectional screening studies from the US Veterans Administration system and the Eli Lilly employee program demonstrated that screening colonoscopy is safe and has a high yield for precancerous polyps [31, 32]. These studies were supported by a strong pro-screening colonoscopy editorial [33], and a short time later, the US Congress legislated that the Center for Medicare and Medicaid Services initiate reimbursement of screening colonoscopy beginning July 1, 2001. This initiated an era of colonoscopy screening in the United States and some other countries that continues today and was largely responsible for a

30% decline in the US colorectal cancer incidence. In the first decade of this century [34], screening colonoscopy programs in Germany and Poland made important contributions to our understanding of cancer prevention by colonoscopy [35, 36].

As the use of colonoscopy increased, the quality of the examination became an important issue [37]. At first, a quality measure was the percentage of cecal intubation, which was corroborated by endophotos of cecal landmarks. As attention was focused on the performance of total colonoscopy, some published literature from the United Kingdom were received with alarm. Only 71% of patients had a total examination in at least 90% of examinations; another report found that in one-third of colonoscopies, total intubation failed in at least 90% of cases [38, 39]. To their great credit, the British Society of Gastroenterology stepped in and formed the Joint Advisory Group, which developed strict guidelines for training and for criteria as to who could engage in colonoscopy [40].

Another quality issue was raised in a report that showed slower scope withdrawal resulted in a higher polyp yield than rapid withdrawal [41]. This finding resulted in an accepted standard minimal withdrawal time of 6 minutes, although reports of longer withdrawal times have shown an even greater polyp yield. The finding of adenomas during a person's first surveillance colonoscopy has become a major criterion [42] for the accuracy of a colonoscopist. The established minimal finding was initially that adenomas should be found in 25% of examinations in males and 15% in females during screening colonoscopy. The term now used is the adenoma detection rate (ADR). The ADR has continually increased with the use of antispasmodics, distal attachment devices, enhanced colonoscopy technologies, better optics, and artificial intelligence [43]. As more experience is gained, experts have increased their findings that over 50% of persons will have adenomas detected on their first screening colonoscopy, and the recommended thresholds for minimum adequate performance have been steadily increased [44].

Careful reprocessing of reusable colonoscopes has resulted in a practical zero transmission of infection from one patient to another. However, proper cleaning and disinfection of instruments are only part of the actual cost of each procedure. It is estimated that the cost per colonoscopy including purchase, maintenance, and cleaning is between US\$188.64 at high-volume centers (3000 annual procedures) and US\$501.16 at low-volume units (1000 annual procedures) [45]. This cost per procedure does not include the facility fee nor the salaries of gastrointestinal nurses and assistants.

A meta-analysis [46] showed that distal add-on devices achieved a better ADR compared to standard colonoscopy among individuals undergoing screening for colon cancer. The ASGE issued the first colonoscopy guidelines in 2000 [47]. This pioneered the establishment of quality

indicators for screening colonoscopy for colorectal cancer detection and prevention to enhance colonoscopy quality and establish benchmarks for colonoscopy performance. The US Multi-Society Task Force (USMSTF) first published a comprehensive list of quality indicators in 2002 [48] with key indicators including ADR, adequate bowel preparation, cecal intubation rate, and withdrawal time (see Chapters 48–55).

Multiple recent advances [49] have increased the diagnostic yield of colonoscopy, including distal attachment devices such as Endocuff Vision™ and amplify EYE and G-EYE to optimize viewable mucosa and improve visual gaze. A recently conducted meta-analysis has shown improved ADRs when comparing Endocuff-assisted colonoscopies with conventional colonoscopies [50]. Similarly, G-EYE has a reusable balloon, allowing centralizing colonoscope optics, straightening folds, and minimizing slippage [51]. Narrow band imaging (NBI), blue light imaging (BLI), linked color imaging (LCI), flexible spectral imaging color enhancement (FICE), I-scan, and texture and color enhancement are all forms of virtual or electronic chromoendoscopy that can enhance precancerous lesion detection. Techniques such as water immersion colonoscopy in comparison to air insufflation help facilitate cecal intubation and reduce colonic distension and patient discomfort. These technical advances have utility with enhanced adenoma detection, mucosal resection, and role in procedures such as sigmoid volvulus detorsion.

Currently, colonoscopy is also indicated as a therapeutic intervention for several gastrointestinal (GI) pathologies, such as localization and treatment of lower gastrointestinal bleeding, dilation of colonic stenosis, management of large bowel perforation, foreign body removal, and multiple other pathologies. Therapeutic colonoscopy is also used to treat acute obstructions, including malignant colonic obstructions or strictures, by placing a self-expanding metal stent (SEMS), placement of a decompression tube, or tumor debulking. For patients with cecal or sigmoid volvulus, colonoscopy may provide an initial urgent treatment procedure. Colonic stenosis can also be treated with a colonoscopic procedure using either balloon dilation or electro-incision. Michael Bourke in Sydney, Australia, defined the optimal methods and achievable outcomes of endoscopic mucosal resection (EMR) for large non-pedunculated polyps (see Chapter 26). Binmoeller [52] showed that EMR can be performed without submucosal injection by filling the lumen with water and floating the lesion away from the muscularis propria (see Chapter 29). Japanese endoscopists [53] have taught the world how to perform endoscopic submucosal dissection (ESD) for en bloc removal of large laterally spreading polyps [54]. Full-thickness resection of submucosally invasive cancer can be accomplished with a low incidence of adverse effects.

Several new developments in instrumentation have occurred, with multiple angled viewing chips at the tip combined with multiple side-by-side images on monitors [55],

high-definition computer chips, and overlay of artificial intelligence programs that detect polyps (CAdE) [48] or predict their histology (CAdx) [56]. The emergence of artificial intelligence (AI) in endoscopy offers promising opportunities to improve the quality and efficacy of colonoscopies [56]. Additionally, AI-assisted quality control systems aim to standardize the endoscopic examination process [57].

Although colonoscopy is relatively new to the field of medicine, having been introduced in the early 1970s, it has become a powerful instrument whose impact has grown beyond the specialty of gastroenterology and has affected many areas of medicine, including surgery, pathology, pediatrics, oncology, and especially screening. It has evolved from a fluoroscopy-dependent difficult procedure to a safe and efficient powerful tool in the fight against colorectal cancer. The technological developments, slow at first, have expanded in the twenty-first century. The colonoscope is an important device in the armamentarium of medical and surgical endoscopists and has achieved worldwide acceptance. The future will see further advances in technology and therapeutic applications (see Chapter 61).

References

- 1 Hirschowitz BI. A personal history of the fibroscope. *Gastroenterology* 1979; **76**(4): 864–9.
- 2 Edmonson JM. History of the instruments for gastrointestinal endoscopy. *Gastrointest Endosc* 1991; **37**: S27–56.
- 3 Kelly HA. A new method of examination and treatment of diseases of the rectum and sigmoid flexure. *Ann Surg* 1895; **21**(6): 468–78.
- 4 Matsunaga F, Tsushima H. Prototype sigmoidocamera and its clinical application [in Japanese]. *Clin All Round* 1958; **7**: 1378.
- 5 Niwa. Photographing mucosa of the colon and other organs [in Japanese]. *Gastroenterol Endosc* 1960; **2**: 77–8.
- 6 Provenzale L, Revignas A. An original method for guided intubation of the colon. *Gastrointest Endosc* 1969; **16**(1): 11–7.
- 7 Overholt BF, Pollard HM. Cancer of the colon and rectum. Current procedures for detection and diagnosis. *Cancer* 1967; **20**(3): 445–50.
- 8 Overholt BF. Clinical experience with the fibersigmoidoscope. *Gastrointest Endosc* 1968; **15**(1): 27.
- 9 Niwa H. The limits of endoscopy and ways of overcoming them: endoscopy of the colon [in Japanese]. *Gastroenterol Endosc* 1965; **7**: 403–8.
- 10 Ragins H, Shinya H, Wolff WI. The explosive potential of colonic gas during colonoscopic electrosurgical polypectomy. *Surg Gynecol Obstet* 1974; **138**(4): 554–6.
- 11 Kern F. Gastroenterology-1976: good news and bad news. Presidential address. *Gastroenterology* 1976; **71**(4): 537–41.
- 12 Shah SG, Saunders BP. Aids to insertion: magnetic imaging, variable stiffness, and overtubes. *Gastrointest Endosc Clin N Am* 2005; **15**(4): 673–86.
- 13 Achord JL, Raman Muthusamy V. *The History of Gastrointestinal Endoscopy*. Elsevier.

- 14 Wolff WI, Shinya H. A new approach to the management of colonic polyps. *Adv Surg* 1973; **7**: 45.
- 15 Sivak MV. Polypectomy: looking back. *Gastrointest Endosc* 2004; **60**(6): 977–82.
- 16 Winawer SJ, Zauber AG, O'Brien MJ, Geenen J, Waye JD. The national polyp study at 40: challenges then and now. *Gastrointest Endosc* 2021; **93**(3): 720–6.
- 17 Winawer SJ, Stewart ET, Zauber AG, *et al*. A comparison of colonoscopy and double-contrast barium enema for surveillance after polypectomy. National polyp study work group. *N Engl J Med* 2000; **342**(24): 1766–72.
- 18 Sivak MV, Fleischer DE. Colonoscopy with a Video Endoscope: preliminary experience. *Gastrointest Endosc* 1984; **30**(1): 1–5.
- 19 Hixson LJ, Fennerty MB, Sampliner RE, McGee D, Garewal H. Prospective study of the frequency and size distribution of polyps missed by colonoscopy. *JNCI J Natl Cancer Inst* 1990; **82**(22): 1769–72.
- 20 Rex DK, Cutler CS, Lemmel GT, *et al*. Colonoscopic miss rates of adenomas determined by back-to-back colonoscopies. *Gastroenterology* 1997; **112**(1): 24–8.
- 21 Shah S, Park N, Chehade NEH, *et al*. Effect of computer-aided colonoscopy on adenoma miss rates and polyp detection: a systematic review and meta-analysis. *J Gastroenterol Hepatol* 2023; **38**(2): 162–76.
- 22 Waddingham W, Kamran U, Kumar B, Trudgill NJ, Tsiamoulos ZP, Banks M. Complications of colonoscopy: common and rare—recognition, assessment and management. *BMJ Open Gastroenterol* 2023; **10**(1): e001193.
- 23 Shahmir M, Schuman BM. Complications of fiberoptic endoscopy. *Gastrointest Endosc* 1980; **26**(3): 86–91.
- 24 Williams CB, Saunders BP, Bell GD, Bladen JS, Gillies DE, Guy CM. Real-time magnetic three-dimensional imaging of flexible endoscopy. *Gastrointest Endosc Clin N Am* 1997; **7**(3): 469–75.
- 25 Bladen JS, Anderson AP, Bell GD, Rameh B, Evans B, Heatley DJ. Non-radiological technique for three-dimensional imaging of endoscopes. *Lancet* 1993; **341**(8847): 719–22.
- 26 Waye JD, Yessayan SA, Lewis BS, Fabry TL. The technique of abdominal pressure in total colonoscopy. *Gastrointest Endosc* 1991; **37**(2): 147–51.
- 27 Thiis-Evensen E, Hoff GS, Sauar J, Vatn MH. Patient tolerance of colonoscopy without sedation during screening examination for colorectal polyps. *Gastrointest Endosc* 2000; **52**(5): 606–10.
- 28 Leung F. Insights into water exchange colonoscopy. *Gastroenterol Hepatol (N. Y.)* 2022; **18**(11): 664–6.
- 29 Waye JD, Thomas-Gibson S. How I do colonoscopy. *Gastrointest Endosc* 2018; **87**(3): 621–4.
- 30 Marwick C. Reagan case sparks interest in colon cancer. *J Am Med Assoc* 1986; **255**(19): 2535.
- 31 Lieberman DA, Weiss DG, Bond JH, Ahnen DJ, Garewal H, Chejfec G. Use of colonoscopy to screen asymptomatic adults for colorectal cancer. Veterans affairs cooperative study group 380. *N Engl J Med* 2000; **343**(3): 162–8.
- 32 Imperiale TF, Wagner DR, Lin CY, Larkin GN, Rogge JD, Ransohoff DF. Risk of advanced proximal neoplasms in asymptomatic adults according to the distal colorectal findings. *N Engl J Med* 2000; **343**(3): 169–74.
- 33 Podolsky DK. Going the distance—the case for true colorectal-cancer screening. *N Engl J Med* 2000; **343**(3): 207–8.
- 34 Edwards BK, Noone AM, Mariotto AB, *et al*. Annual report to the nation on the status of cancer, 1975–2010, featuring prevalence of comorbidity and impact on survival among persons with lung, colorectal, breast, or prostate cancer. *Cancer* 2014; **120**(9): 1290–314.
- 35 Pilonis ND, Spychalski P, Kalager M, *et al*. Adenoma detection rates by physicians and subsequent colorectal cancer risk. *J Am Med Assoc* 2024; **333**: 400.
- 36 Heisser T, Hoffmeister M, Tillmanns H, Brenner H. Impact of demographic changes and screening colonoscopy on long-term projection of incident colorectal cancer cases in Germany: a modelling study. *Lancet Reg health Eur* 2022; **20**: 100451.
- 37 Rex DK, Schoenfeld PS, Cohen J, *et al*. Quality indicators for colonoscopy. *Gastrointest Endosc* 2015; **81**(1): 31–53.
- 38 Taylor KM, Aaraj K, Rouse T, Harris AW. Prospective audit of colonoscopy quality in Kent and Medway, UK. *Endoscopy* 2008; **40**(4): 291–5.
- 39 Bowles CJA, Leicester R, Romaya C, Swarbrick E, Williams CB, Epstein O. A prospective study of colonoscopy practice in the UK today: are we adequately prepared for national colorectal cancer screening tomorrow? *Gut* 2004; **53**(2): 277–83.
- 40 Siau K, Crossley J, Dunkley P, *et al*. Colonoscopy direct observation of procedural skills assessment tool for evaluating competency development during training. *Am J Gastroenterol* 2020; **115**(2): 234–43.
- 41 Barclay RL, Vicari JJ, Doughty AS, Johanson JF, Greenlaw RL. Colonoscopic withdrawal times and adenoma detection during screening colonoscopy. *N Engl J Med* 2006; **355**(24): 2533–41.
- 42 Rex DK, Petrini JL, Baron TH, *et al*. Quality indicators for colonoscopy. *Am J Gastroenterol* 2006; **101**(4): 873–85.
- 43 Samnani S, Khan R, Heitman SJ, *et al*. Optimizing adenoma detection in screening-related colonoscopy. *Expert Rev Gastroenterol Hepatol* 2023; **17**(6): 589–602.
- 44 Rex DK, Anderson JC, Butterly LF, *et al*. Quality indicators for colonoscopy. *Gastrointest Endosc* 2024; **100**(3): 352–81.
- 45 Larsen S, Kalloo A, Hutfless S. The hidden cost of colonoscopy including cost of reprocessing and infection rate: the implications for disposable colonoscopes. *Gut* 2020; **69**(2): 197–200.
- 46 Manti M, Tziatzios G, Facciorusso A, *et al*. Effect of add-on devices with projections on screening colonoscopy: a systematic review and meta-analysis. *Ann Gastroenterol* 2023; **36**(5): 533–40.
- 47 Eisen GM, Chutkan R, Goldstein JL, *et al*. Guidelines for colorectal cancer screening and surveillance. *Gastrointest Endosc* 2000; **51**(6): 777–82.
- 48 Rex DK, Bond JH, Winawer S, *et al*. Quality in the technical performance of colonoscopy and the continuous quality improvement process for colonoscopy: recommendations of the U.S. Multi-society task force on colorectal cancer. *Am J Gastroenterol* 2002; **97**(6): 1296–308.
- 49 Gangwani MK, Aziz A, Dahiya DS, Nawras M, Aziz M, Inamdar S. History of colonoscopy and technological advances: a narrative review. *Transl Gastroenterol Hepatol* 2023; **8**: 18–8.
- 50 Aziz M, Haghbin H, Gangwani MK, *et al*. Efficacy of Endocuff Vision compared to first-generation Endocuff in adenoma detection rate and polyp detection rate in high-definition colonoscopy: a systematic review and network meta-analysis. *Endosc Int Open* 2021; **9**(1): E41–50.
- 51 Shirin H, Shpak B, Epshtein J, *et al*. G-EYE colonoscopy is superior to standard colonoscopy for increasing adenoma detection

- rate: an international randomized controlled trial (with videos). *Gastrointest Endosc* 2019; **89**(3): 545–53.
- 52 Binmoeller KE, Weilert F, Shah J, Bhat Y, Kane S. “Underwater” EMR without submucosal injection for large sessile colorectal polyps (with video). *Gastrointest Endosc* 2012; **75**(5): 1086–91.
- 53 Yahagi N. Is a traction device an almighty tool for overcoming the difficulties of endoscopic submucosal dissection? *Endoscopy* 2024; **56**(3): 212–3.
- 54 Aziz M, Haghbin H, Sayeh W, *et al.* Comparison of artificial intelligence with other interventions to improve adenoma detection rate for colonoscopy: a network meta-analysis. *J Clin Gastroenterol* 2024; **58**(2): 143–55.
- 55 Facciorusso A, Del Prete V, Buccino V, Della VN, Nacchiero MC, Muscatiello N. Full-spectrum *versus* standard colonoscopy for improving polyp detection rate: a systematic review and meta-analysis. *J Gastroenterol Hepatol* 2018; **33**(2): 340–6.
- 56 Patel HK, Mori Y, Hassan C, *et al.* Lack of effectiveness of computer aided detection for colorectal neoplasia: a systematic review and meta-analysis of nonrandomized studies. *Clin Gastroenterol Hepatol* 2024; **22**(5): 971–980.e15.
- 57 Spadaccini M, Schilirò A, Sharma P, Repici A, Hassan C, Voza A. Adenoma detection rate in colonoscopy: how can it be improved? *Expert Rev Gastroenterol Hepatol* 2023; **17**(11): 1089–99.