Advanced Colonoscopy and Endoluminal Surgery

Sang W. Lee
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Preface

Advanced endoscopic procedures and endoluminal interventions have continued to experience tremendous growth in both community and academic settings. Many technical advances in endoscopic tools and platforms have transformed the way we treat patients with colon and rectal diseases. As surgeons explore less invasive surgical techniques and gastroenterologists more complex therapeutic endoscopic procedures, the convergence of interests will lead to further innovations and evolution of the way we treat our patients.

Although surgeons such as Hiromi Shinya and William Wolff pioneered therapeutic endoscopy, we have largely relinquished the practice of endoscopy to our gastroenterology colleagues. However, as endoscopic tools become more practical and sophisticated, endoscopy is finding its way back to the operating rooms as an adjunctive surgical tool. The ability to assess the integrity of the surgical anastomosis, locate benign and malignant colonic neoplasms, and control bleeding, among other things, is becoming invaluable during lower intestinal surgery. More and more surgeons are realizing the importance of incorporating endoscopic skills to their surgical armamentarium.

Frank Veith, in his presidential address to the Society for Vascular Surgery in 1996, emphasized that in order for vascular surgeons to adapt to the changing medical environment at the time, they must acquire endovascular skills. At that time vascular surgeons found themselves at a crossroad. Without fully embracing therapeutic endovascular surgical techniques, vascular surgeons were at risk of being left out. As surgeons who care for patients with colon and rectal diseases, we wonder whether we are at the same crossroad. Do we need to fully embrace endoscopic and endoluminal surgery in order to stay relevant?

In this textbook, we try to provide an overview of basic to advanced endoscopic techniques. Each chapter includes a narrative by the authors on his/her technical details and "tips and tricks" that they utilize in dealing with complex technical situations. Additionally, where appropriate, links to online downloadable videos will give an up-front look into technical aspects of EMR, ESD, endoscopic stent placement, and CELS. We feel very fortunate to include many world experts in the area of endoscopy as authors of our textbook. We are truly grateful for their time and contributions. We hope our textbook will stimulate further discussions and lead to better patient outcomes.

Los Angeles, CA — Sang W. Lee, M.D.
Philadelphia, PA — Howard M. Ross, M.D.
Woodbury, NY — David E. Rivadeneira, M.D.
Cleveland, OH — Scott R. Steele, M.D.
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Sang W. Lee
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Finally and most importantly, I would like to thank my wife, Crystal, for her support, encouragement, and unwavering love and my sons, Eric and Ryan, for making me a better person and making everything worthwhile.

Howard M. Ross
I am happiest when a group I am involved with truly works together—selflessly, efficiently, and synergistically. My friends, the editors of this book, have made my career so much more rewarding than I would have ever guessed. Thank you all so much. Thanks also to my incredible family. Molly, Leo, Emily, and Stacy you are the best!

Scott R. Steele
I would like to first thank my co-editors for their outstanding work and Sang for coming up with this idea and leading the way. I would again like to thank our developmental editor, Elektra McDermott, for another extraordinary job at seeing this work through to completion and taking care of all the details. Finally to my family for continuing to support me and allow me to pursue these endeavors—Michele, Marianna, Piper, and Flynn.

David E. Rivadeneira

> "*Curiouser and curiousers*"
> *Alice from Alice in Wonderland*

To Sang W. Lee for his vision and dedication. To my fellow co-editors Sang W. Lee, Scott R. Steele, Daniel L. Feingold, and Howard M. Ross, I continue to be inspired and learn from all of you. To Elektra McDermott—the ultimate cat herder—thank you for getting us all together. To my family, Anabela, Sophia, and Gabriella, thank you for your unwavering support and love.

Daniel L. Feingold
I dedicate this book to my wife, Tonja, and to our children Judah, Ethan, Noa, and Lily. Your love, support, and inspiration make it all possible.

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History of Colonoscopy

1

Jeanette Zhang and Howard M. Ross

Key Points

- Philipp Bozzini is often credited as the father of endoscopy. He foresaw that direct observation would allow for improved understanding of human physiology and disease processes and enhance the treatment of such diseases.
- Application of advances in upper gastrointestinal endoscopes is largely responsible for the evolution of the current colonoscope.
- Flexible endoscopes and fiber-optic technology were noteworthy breakthroughs in endoscopic designs.
- Numerous endoscopic techniques utilizing the colonoscope have been developed to treat a host of benign and malignant colorectal diseases.

Bozzini and the Lichtleiter

Philipp Bozzini is considered by many the father of endoscopy. Born in Mainz, Germany, in 1773, Bozzini's goal was to examine the inner cavities of the human body in designing the Lichtleiter, or "light conductor." He recognized the importance of direct observation in the ability to understand the physiology and function of human organs [1]. With his design, he also foresaw the ability to perform new procedures and to make existing procedures safer by allowing, for instance, the removal of rectal polyps or cervical tumors to be done under direct visualization rather than to depend on luck.

The original Lichtleiter consisted of a vase-shaped lantern made of tin and covered with leather [2, 3]. Within this housed the light source, a wax candle, on a spring device designed to keep the flame at a constant height. A concave mirror was placed to project light through an aperture, onto which various tubular specula could be attached. The mirror directed light toward the hollow organ and avoided reflection toward the observer's eye [4]. On the opposite side was another fenestration onto which an eyepiece was attached for the observer (Fig. 1.1). The tubular specula were made of brass or silver and modified based of the organ they were meant for: urethra, vagina, rectum, and so on [1]. His conductors were straight to avoid deviating from the straight lines on which light rays travel. In order to observe objects at an angle, for instance behind the nasopharynx, he used a mirror to bend the light. He did note, however, that bending the light compromised the clarity of the image [1].

Dr. Bozzini first introduced his creation to the public in Frankfurt in 1804 [3]. He also sent a description of the Lichtleiter to Archduke Karl of Austria, and with his support, experiments with the instrument were conducted at the Vienna Josephs Academy. These concerned mostly diseases of the rectum and uterus, though in one experiment a stone was visualized in the urinary bladder of a female cadaver. Unfortunately, as a result of political rivalry between medical institutions, Joseph Andreas Stifft, who was at the time the Director of Medical Studies and President of the Vienna Medical Faculty, deemed the Lichtleiter a "mere toy" [2]. With this criticism, Bozzini's invention was soon forgotten. However, the principles embodied by his design would be carried into future endoscopic inventions.

Evolution of Upper Gastrointestinal Endoscopy

Early Advances

The development of colonoscopy would largely not be possible were it not for technologic advances in upper gastrointestinal endoscopy. Therefore, noteworthy breakthroughs

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Fig. 1.1 Bozzini's original Lichtleiter. Courtesy of Archives of the American College of Surgeons, "The Bozzini Endoscope," Online April 6, 2011

Fig. 1.2 Examining cystoscope according to Nitze's Kystoskop no II, prograde and sliding optics. Created by Josef Leiter, Vienna. Courtesy Int. Nitze-Leiter Research Society for Endoscopy, Vienna/Reuter Collection © International Nitze-Leiter Research Society for Endoscopy, Vienna. Reused with permission

will be reviewed here. Early endoscopic advances were largely modifications of instruments based on Bozzini's Lichtleiter. John Fisher in the United States and Segales in France illuminated body cavities using a system of mirrors to reflect candlelight [5]. In 1824 Fisher added a double convex lens to sharpen and enlarge the viewed image [6]. Antonin Desormeaux is credited with developing the first open-tube endoscope [5, 6]. He used a lamp fueled by a combination of alcohol and turpentine for continuous illumination. Another significant advance was the use of a condenser lens to concentrate the illumination on a single spot [7]. However, a significant drawback of this system was the thermal tissue injuries from the heat created by the light source.

In 1877 Maximilian Nitze introduced his cystoscope, which is often considered the first practical endoscopic instrument (Fig. 1.2). He used a platinum wire loop lamp with a water cooling system for illumination [6]. Significant advances he incorporated were placing the light source at the tip of the instrument to improve illumination and enlarging the field of view by using an optical system [8]. After Thomas Edison's invention of incandescent light in 1879, Nitze incorporated a miniaturized version of the filament globe into his device.

Edison's invention proved significant for the future of endoscopes, as the use of incandescent light eliminated the need for the then-used platinum loop lamp and its unwieldy cooling system. Johann von Mikulicz and Josef Leiter in 1881 introduced an esophagoscope that consisted of a straight tube with a small bulb at the distal end of the instrument [6]. Mikulicz also added to Nitze's model by adding a mirror to create an angular field and an air canal to allow for insufflation [7]. The result of this combination was a greater field of view to examine otherwise collapsed cavities. Six years later Leiter produced what he called the panelectroscope. By reflecting light from an electric lamp built into the handle, the panelectroscope served as a universal light source for all endoscopic tools.

The next series of developments involved inclusion of optical systems to the rigid endoscope. In 1896 Theodor Rosenheim produced a gastroscope with three concentric tubes: the innermost contained an optical system, the middle carried the light source consisting of a platinum wire loop lamp and water cooling system, and the outermost with a scale to demarcate the distance inserted [6]. Hans Elsner built on Rosenheim's design by adding a rubber tip to the end of the straight tube, which facilitated introduction of the instrument. However, its use was hampered by difficulty viewing through the lens once it was soiled. In 1922 Rudolf Schindler created his rigid gastroscope, a later version of which contained an air outlet to clear the lens.

Semiflexible Endoscopes

Beginning in the 1930s came a period that saw the development of semiflexible endoscopes. Schindler was an integral character during this era. The first recorded flexible esophagoscope, however, was by Kelling in 1898 [7]. The lower third of his instrument could be flexed up to a 45° angle. Schindler's breakthrough came about in 1932 in the form of the semiflexible gastroscope (Fig. 1.3). The distal half of this endoscope was constructed from a spiral of bronze with a protective covering of rubber [6]. Key to his design, though, was the discovery that using a tube filled with very thick lenses with short focal distances allowed for bending in several planes without distortion of the transmitted image. Schindler introduced an updated version 4 years later that

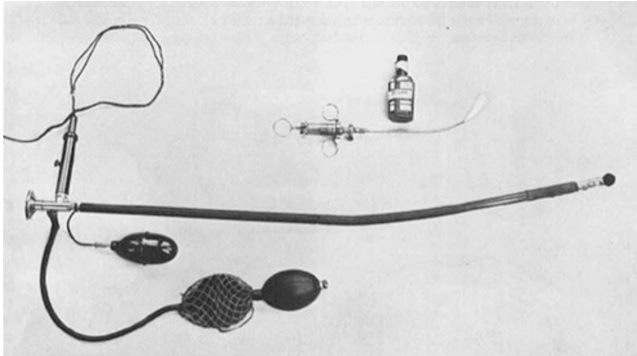

Fig. 1.3 The Wolf-Schindler flexible gastroscope. With permission from Taylor H. Gastroscopy: Its history, technique, and clinical value, with report on sixty cases. British J Surg. 1937 Jan;24(95):469–500. [19] © John Wiley and Sons

used an electric globe as the light source [7]. The maximal bending angel was only 30°, as greater angles would not allow for image transmission, and thus there were significant blind spots not visualized by the endoscope.

A bevy of productivity by American manufacturers was responsible for a number of advancements over the next decade. William J. Cameron's "omni-angle" flexible gastroscope included a mirror within the scope's tip that could be flipped, allowing the viewer to scan the stomach without moving the endoscope [7]. Donald T. Chamberlin helped create an instrument with a controllable tip. This ushered in an era of endoscopes that could more thoroughly examine the stomach by minimizing blind spots that had been problematic in previous models, such as Schindler's.

Fiber-Optic Endoscopy

The next revolution in endoscopic development came with the discovery of fiber-optic technology. This yielded a portfolio of instruments with improved flexibility, improved light transmission, and greater field of view [6]. Basil Hirschowitz was responsible for the first "fiberscope" in 1957 (Fig. 1.4). Soon several improvements were made using Hirschowitz's model as a foundation. Philip A. LoPresti introduced a channel for suction and air or water to keep the lens clean. Longer versions of the endoscope were created in order to reliably visualize the duodenum. Eventually four-way control of the instrument tip and deflection angles up to 180 ° were possible, further improving the field of vision. In introducing further functionality to the endoscope, the "masterscope" was designed such that a smaller fiberscope could be inserted for use in diagnostic or surgical procedures.

Fig. 1.4 The Hirschowitz Fiberscope. With permission from Wilcox CM. Fifty years of gastroenterology at the University of Alabama at Birmingham: A festschrift for Dr. Basil I. Hirschowitz. Am J Med Sciences. 2009 Aug;338(2):1–5. [20] © Wolters Kluwer

Development of the Colonoscope

Early Lower Gastrointestinal Endoscopy

Inspection of the lower gastrointestinal tract dates back to simple anal and rectal specula found in the ruins of Pompei [6]. The majority of advances beyond that, however, did not come until after the advances in fiber-optic upper endoscopy instruments. The first rigid sigmoidoscope by Howard A. Kelly in 1894 used a simple lamp to reflect light off a head mirror down a tube. James P. Tuttle later integrated an electric lighting system. In general, these rigid instruments were effective in examining the first 20 to 25 centimeters of the lower gastrointestinal tract.

Beginning in the 1960s, fiber-optic technology found its way into sigmoidoscopes and colonoscopes as well. Many of the early prototypes were developed and marketed in Japan. In the United States, Robert Turell was one of the first to create a fiber-optic illumination system for use in rigid sigmoidoscopes [6]. Bergein Overholt introduced a flexible fiber-optic sigmoidoscope with the goal of improving patient comfort during the procedure. As such, his instrument allowed for deeper entry and therefore examination of a greater length of the sigmoid and descending colon. Olympus would soon after introduce a colonoscope that included a four-way controllable tip.

The First Colonoscopies

Oshiba and Watanabe published the first results with colonoscopy in 1965 [4]. Luciano Provenzale and Antonio Revignas are credited with performing the first complete colonoscopy in Sardinia, Italy in 1965 [6]. Their unique approach involved having a patient swallow the end of a piece of polyvinyl tubing. This eventually exited the anus, to which they then attached a Hirschowitz gastroscope and pulled it through the colon all the way to the cecum. Reports by numerous endoscopists detailing their experiences with colonoscopy and the safety of the procedure were then published. In 1977, Bohlman and colleagues published a trial demonstrating the superior diagnostic yield of flexible endoscopes compared to their rigid counterparts.

Endoscopic Photography

Advances in imaging enhanced the practical applications afforded by the endoscope. Taking photos of hollow organs being examined dates back to the nineteenth century with Nitze creating a cystoscope onto which glass plates with a light-sensitive coating could be mounted [7]. The plates could be moved into the light, and photographs could be created with a 3–5 s exposure time. Lange and Meltzung made attempts with a small internal camera attached to a rubber tube that the patient could swallow [6, 7]. The electric wiring for the globe, mechanical cameral trigger, and air channel for insufflation were all contained within the rubber tubing. Henning and Keilhack in 1938 used a Schindler gastroscope and overburned the globe to create a flash, producing the first color photos of the stomach [4].

Successful endoscopic photography was not achieved until the development of external photographing apparatuses. In 1948, Harry Segal and James Watson created an external device for taking color photographs through a semi-flexible gastroscope. The key to this was the development of a system in which changes in light supply, gastroscope prism, and camera shutter could occur in synchrony [6].

The gastrocamera was developed in Japan in the early 1950s and introduced in the United States later that decade [6]. This instrument contained all components of a proper camera attached to a control unit: a lens, flash, air valve, and film capsule. The major disadvantages of the gastrocamera were the inability to directly view what was being photographed and the time required to develop the film. The former was remedied by Olympus in 1963 when they introduced an instrument with features of both fiber-optic technology and a gastrocamera packaged within one [6]. H. H. Hopkins contributed to the emergence of endoscopic documentation by replacing interspersed air in previous optical relay systems with glass rods [4]. His system provided superior light transmission, a wider viewing angle, and improved image quality with higher resolution. Furthermore, his system could be housed within a smaller diameter endoscope. With the improved light transmission, practitioners found that attaching a 35-mm camera to the eyepiece could yield high-quality images, and the gastroscope fell out of favor [6].

Fig. 1.5 Improved ergonomics with the use of video endoscopy. Endoscopists could view images with both eyes on a screen and work with the endoscope at the waist level. "Video Monitor," online June 16, 2010 © Society of American Gastrointestinal Endoscopic Surgeons (SAGES). Used with permission

Video Endoscopy

Soulas was one of the first to perform video endoscopy in France in 1956 [7]. Prior to the development of miniaturized versions of video equipment, endoscopes were attached to regular television cameras, and through this method images were transmitted to a television monitor. In 1960 Melbourne, Australia, a team created a miniaturized camera 45 mm by 120 mm long that could be attached to a regular endoscope and transmit black and white images to a screen.

Charge-coupled device (CCD) image sensors were a major breakthrough for video endoscopy. The sensor was fitted at the tip of instruments, where the entire imaging process could take place [7]. The old lens and fiber-optic bundles were replaced by wires. It could then transmit the image electronically to a video processor, which was then projected onto a television monitor [6]. These advances allowed for increased flexibility of instruments and improved image quality. This would also become the basis of standard technology for larger flexible endoscopes in the future [4].

Numerous advantages for the practitioner came with video endoscopy, most notably being improved viewing of an enlarged image with both eyes at a convenient distance on a screen, simultaneous viewing by members of an entire team, and improved ergonomics for the endoscopist (Fig. 1.5) [4, 6]. Furthermore, the convenient images and video recordings that could be captured improved documentation not only for medical purposes but also for educational functions.

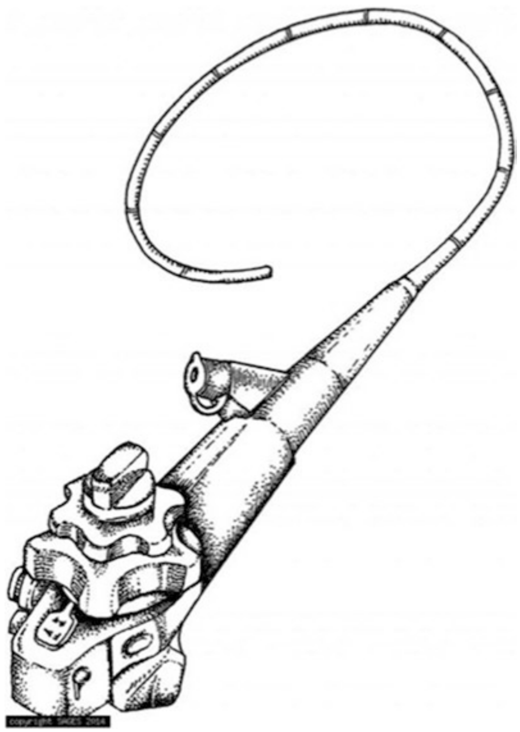

Fig. 1.6 Flexible endoscope with controllable tip. "Rotating wheels on the headpiece of the endoscope," online June 16, 2010 © Society of American Gastrointestinal Endoscopic Surgeons (SAGES). Used with permission

The Modern Colonoscope

The modern day colonoscope uses fiber-optic cables to transmit light to the lumen from a separate light source [9]. Images are retrieved digitally using a CCD chip at the tip of the instrument. It includes suction, air or water insufflation, as well as biopsy capabilities. The shaft of the colonoscope is typically 12 to 14 mm in diameter and consists of a distal flexible portion and a relatively rigid proximal section. The distal-most 9 cm comprises the controllable bending section, allowing 180° of up/down and 160° of left/right angulation (Fig. 1.6). Furthermore, the shaft is torque stable, meaning rotational forces applied by the operator proximally are transmitted distally to the tip of the instrument.

Variations of this standard colonoscope also exist for specific clinical situations [9]. Pediatric colonoscopes are smaller in diameter and are more flexible. The distal bending section is also shorter, allowing the instrument to adapt to the narrower lumen and more angulated colon in children. Pediatric instruments can also be useful in certain adult patients, for instance, in cases of strictures or postsurgical adhesions narrowing the lumen. Colonoscopes with variable stiffness shafts also exist. A dial controls a coiled tensioning wire within the shaft, thereby altering the rigidity. There are mixed reports on whether this feature facilitates insertion of the instrument.

Additional technologic advances have further improved the discriminatory capabilities of endoscopes. For example, the use of narrow band imaging (NBI) to distinguish between vascular patterns of neoplastic vs. non-neoplastic colorectal polyps has recently been investigated. NBI uses blue light with narrow band filters to image superficial tissue structures and emphasizes the vascularity of the mucosa. In a randomized prospective study, Tischendorf and colleagues evaluated colonic and rectal polyps using this technology and compared their classification of polyps with histological findings [10]. Benign polyps were noted to have thin-caliber vessels with a uniform branching pattern, whereas malignant polyps were characterized by dilated, corkscrew vessels with increased vascularity and nonuniform branching patterns. The authors found they were able to identify neoplastic vs. non-neoplastic polyps with high accuracy. Specifically, classification based on vascular patterns visualized with NBI had a sensitivity and specificity of 93.7% and 89.2%, respectively. The implementation of technologies such as NBI could even further expand the diagnostic capabilities of the modern colonoscope.

The Colonoscope as a Therapeutic Instrument

Alongside all advances in the physical design and image quality of endoscopes came attempts to improve their interventional capabilities. Desormeaux was one of the first to conduct operative endoscopic procedures in living patients [7]. Nitze used movable loops for operation within the urinary bladder [8]. Bevan performed esophageal foreign body removals using reflected candlelight [4]. Kussmaul in 1870 achieved the same goal using reflected sunlight. Boisseau de Rocher in 1889 developed an endoscope with separate ocular and sheath components, allowing manipulation techniques needed to perform diagnostic procedures [5]. William Wolff and Hiromi Shinya saw the therapeutic potential of the colonoscope, removing colonic polyps with a wire loop snare in the 1970s [6].

Endoscopic Resection of Early-Stage Malignancies

Developments in endoscopic technique have established the colonoscope as more than a mere screening or diagnostic tool. Endoscopic mucosal resection (EMR) has been used, largely in East Asia, for removal of premalignant lesions and superficial malignancies of the gastrointestinal tracts. Several variations of this technique exist, but all begin with marking the periphery of the lesion with electrocautery then performing a submucosal injection to lift and help identify the lesion [11, 12]. Normal saline with epinephrine is the most frequently used injection [11]. In the "strip biopsy" technique, forceps are used to lift the lesion followed by excision using a polypectomy snare. A double-channel endoscope is required for this. Similarly, a double snare polypectomy technique has also been described, where one snare is used to lift and strangulate the lesion while the second is used to resect [12].

Use of EMR can often be limited by the size of the lesion, as en bloc resection of larger lesions may not be feasible with available instruments, and the lesion may require piecemeal removal. Endoscopic submucosal dissection (ESD) is a more technically challenging approach that can be used in such situations. ESD also begins with marking the periphery of the lesion and lifting via a submucosal injection. A circumferential incision is then made around the margin, into the submucosa [13]. A variety of knives are available to accomplish this [14]. Electrocautery is then used to free the lesion from the underlying deep layers. Larger lesions can be resected as there is no size limitation from the use of snares as is the case with EMR.

The indications for EMR and ESD are similar, namely, premalignant lesions or early-stage adenocarcinomas without nodal involvement [11, 14]. Complete resection via endoscopic means should be technically possible. These approaches may be considered in certain cases of advanced cancer in which patients may be poor candidates for a larger operation, or for palliation of an obstructing or bleeding mass. Both techniques allow for histological examination of the specimen, an advantage over ablative techniques.

A recent meta-analysis compared the outcomes and safety profiles of EMR and ESD. The group found that ESD was associated with higher en bloc resection and curative resection rates compared to EMR, regardless of lesion size [13]. On subgroup analysis, these findings also held true specifically with colorectal lesions and when broken down by size categories (<10, 10–20, and >20 mm). ESD was also found to have a lower local recurrence rate compared to EMR. The main reported complications of both techniques are procedure-related bleeding and perforation. ESD was associated with a longer operative time and higher rates of bleeding and perforation. Cao and colleagues reported the management of most perforations required a true operation. Others report experiencing mostly microperforations that were definitively managed endoscopically via closure of the defect with a clip [14].

Transanal Techniques

Transanal endoscopic microsurgery (TEM) and transanal minimally invasive surgery (TAMIS) are newer techniques available for the local excision of rectal lesions. Use of these techniques has been advocated in benign rectal neoplasms as well as select T1 rectal cancers with favorable histology and low risk of nodal metastasis [15]. Similar to purely endoscopic techniques, they may also be used with more advanced disease in patients unable to tolerate a more extensive procedure, such as low anterior resection or abdominoperineal resection, and for palliative purposes.

TEM involves dilation of the anal sphincter with a 4 cm operating sigmoidoscope that can accommodate optics, suction, and ports for instruments [16]. The rectum is insufflated using carbon dioxide to improve the field of view. Various endoscopic surgical instruments are available, and they allow the surgeons to reach further into the rectum than possible with traditional transanal excision. The technique has a steep learning curve and requires significant setup and rather expensive equipment.

TAMIS evolved as a hybrid between TEM and single-incision laparoscopy that was meant to be more affordable and technically feasible than TEM [15]. Transanal access is achieved with the SILS Port (Covidien, Mansfield, MA) or Gel-POINT Path (Applied Medical, Rancho Santa Margarita, CA). As with TEM, pneumorectum is established to improve the field of view. The procedure can then be carried out using standard laparoscopic instruments. Some have reported using a colonoscope or another flexible tipped scope for visualization rather than a standard laparoscope [15].

A meta-analysis found that TEM had higher rates of negative margins and en bloc resection and lower rates of local recurrence compared to traditional transanal excision [17]. Similar findings have been reported for TAMIS [15]. Though the data thus far has been promising, large-volume randomized controlled trials are still lacking.

Colonic Stenting

Colonic stents can be used in the management of acute large bowel obstructions. Briefly, possible indications for colonic stenting include inoperable obstructing colorectal tumors, obstruction from mass effect by pelvic tumor, malignant fistulae, anastomotic leaks or strictures, and recurrent benign strictures [18].

Self-expanding metal stents (SEMS) are inserted through the anus under endoscopic or sometimes fluoroscopic guidance. They have a predictable shape after deployment and come in several variations. Covered stents are more rigid and resist tumor ingrowth [18]. Uncovered stents, on the other hand, are more flexible and easier to place, but are more prone to tumor ingrowth. All are designed to prevent migration.

Overall, stenting is a relatively low-risk procedure [18]. Technical failure mostly comes in the form of the inability to pass the guidewire across the strictured area. Early complications include perforation and bleeding, which is often self-limiting. Late complications include stent migration, re-obstruction, erosion or fistulization. The benefits include providing palliation to patients with inoperable tumors or providing a bridge to surgery. The latter allows for preoperative stabilization and optimization of the patient, potentially avoiding the high morbidity and mortality associated with an emergent operation. Palliative stenting can improve quality of life in patients with obstructing tumors who are poor surgical candidates.

Conclusions

Endoscopic instruments have come a long way since Bozzini introduced his Lichtleiter. Modern diagnostic and therapeutic applications of colonoscopy are numerous, and as technological advances and novel instruments continue to be produced, the potential continues to grow.

References

1. Bush RB, Leonhardt H, Bush IM, Landes RB. Dr. Bozzini's Lichtleiter: a translation of his original article (1806). Urology. 1974;3(1):119–23.
2. Rathert P, Lutzeyer W, Goddwin WE. Philipp Bozzini (1773-1809) and the Lichtleiter. Urology. 1974;3(1):113–8.
3. Engel RME. Philipp Bozzini—the father of endoscopy. J Endourol. 2003;17(10):859–62.
4. Berci G, Forde KA. History of endoscopy: what lessons have we learned from the past? Surg Endosc. 2000;14:5–15.
5. Spaner SJ, Warnock GL. A brief history of endoscopy, laparoscopy, and laparoscopic surgery. J Laparoendosc Adv Surg Tech A. 1997; 7(6):369–73.
6. Edmonson JM. History of the instruments for gastrointestinal endoscopy. Gastrointest Endosc. 1991;37(2):S27–56.
7. Gross S, Kollenbrandt M. Technical evolution of medical endoscopy. Acta Polytechnica. 2009;49(2–3):15–9.
8. Mouton WG, Bessell JR, Maddern GJ. Looking back to the advent of modern endoscopy: 150th birthday of Maximilian Nitze. World J Surg. 1998;22(12):1256–8.
9. Brown GJE, Saunders BP. Advances in colonic imaging: technical improvements in colonoscopy. Eur J Gastroenterol Hepatol. 2005; 17(8):785–92.
10. Tischendorf JJW, Wasmuth HE, Koch A, Hecker H, Trautwein C, Winograd R. Value of magnifying chromoendoscopy and narrow band imaging (NBI) in classifying colorectal polyps: a prospective controlled study. Endoscopy. 2007;39:1092–6.
11. Conio M, Ponchon T, Blanchi S, Filiberti R. Endoscopic mucosal resection. Am J Gastroenterol. 2006;101:653–63.
12. Marc G, Lopes CV. Endoscopic resection of superficial gastrointestinal tumors. World J Gastroenterol. 2008;14(29):4600–6.
13. Cao Y, Liao C, Tan A, Gao Y, Mo Z, Gao F. Meta-analysis of endoscopic submucosal dissection versus endoscopic mucosal resection for tumors of the gastrointestinal tract. Endoscopy. 2009;41: 751–7.
14. Tanaka S, Terasaki M, Kanao H, Oka S, Chayama K. Current status and future perspectives of endoscopic submucosal dissection for colorectal tumors. Dig Endosc. 2012;24:73–9.
15. DeBeche-Adams T, Nassif G. Transanal minimally invasive surgery. Clin Colon Rectal Surg. 2015;28:176–80.
16. Middleton P, Suterland LM, Maddern GJ. Transanal endoscopic microsurgery: a systematic review. Dis Colon Rectum. 2005;48(2): 270–84.
17. Clancy C, Burke JP, Albert MR, O'Connell PR, Winter D. Transanal endoscopic microsurgery versus standard transanal excision for the removal of rectal neoplasms: a systematic review and meta-analysis. Dis Colon Rectum. 2015;58(2):254–61.
18. Katsanos K, Sabharwal T, Adam A. Stenting of the lower gastrointestinal tract: current status. Cardiovasc Intervent Radiol. 2011;34: 462–73.
19. Taylor H. Gastroscopy: its history, technique, and clinical value, with report on sixty cases. Br J Surg. 1937;24(95):469–500.
20. Wilcox CM. Fifty years of gastroenterology at the University of Alabama at Birmingham: a festschrift for Dr. Basil I. Hirschowitz. Am J Med Sci. 2009;338(2):1–5.

Anatomic Basis of Colonoscopy

2

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Key Points

- Critical knowledge of colorectal anatomy is imperative to performing appropriate endoscopic examinations.
- Appreciation for anatomic variations can help in progress during colonoscopy.
- Mural findings and internal clues are appropriate adjuvants in helping the endoscopist proceed with forward advancement and eventual cecal intubation.
- Looping during colonoscopy is common. Various types of loops can be encountered, and appreciation of these formations is mandatory. Having a standardized protocol for preventing and reducing these loops is fundamental in assurance of forward progression and intubation while minimizing patient discomfort and morbidity.
- Observation and verification of certain anatomic landmarks throughout the colon are helpful for providing a roadmap to continued intubation. Similarly, photography of some of these landmarks is required to document successful complete colonoscopy.

Background

Colonoscopy is an effective and efficient tool in the diagnostic and therapeutic management of colon and rectal diseases and allows for complete mural examination and management of the anus, rectum, colon, and terminal ileum. First described by Drs Wolff and Shinaya in 1971 [1–3], numerous exponential advancements in optics, imaging modalities, mechanics, techniques, and instrumentation have made colonoscopy a gold standard in detection and prevention of deaths from colorectal cancer [4–7]. Indeed colonoscopy has also been found to have particular advantages in colorectal cancer screening, surveillance of inflammatory bowel diseases, and management of volvulus and other benign diseases [8]. Mastery of anatomic landmarks and impressions during the procedure is fundamental to the performance of endoscopy and allows for improved and optimal maneuverability, insertion and withdrawal, and also maximizing enhanced diagnostic and subsequent therapeutic yield. Knowledge of normal anatomy and its variants are critical to the appreciation of pathological changes or abnormalities, including polyps, diverticuli, carcinomas, and fistulae, among other findings (Fig. 2.1).

Recent advancements in CT colonography and fluoroscopy have been helpful in better defining anatomic landmarks and in facilitating colonoscopy by reducing looping and straightening and shortening maneuvers [9]. Furthermore, utilization of good basic technique and an appreciation and implications of standardized approach to difficult intubation (redundancy, difficult sigmoid, poor tolerance to sedation) help to yield improved maneuverability and successful colonoscopy [9–11].

Technique for colonoscopic advancement will be further discussed in other chapters in greater detail, particularly as it relates to interventions such as biopsy, polypectomy, endoscopic mucosal resections and endoscopic submucosal dissections, and also tattooing.

Above all, certain standards in endoscopy should be followed to assure patient safety and successful colonoscopy. These including being gentle, minimal blind pushing, keeping the lumen within view, periodic and frequent withdrawal motions for straightening, and avoidance of mucosal whitening or reddening ("redout") by scraping or sliding by the wall of the colon. Pain and incomplete colonoscopy are generally due to loop or bowing formation and resultant mesenteric

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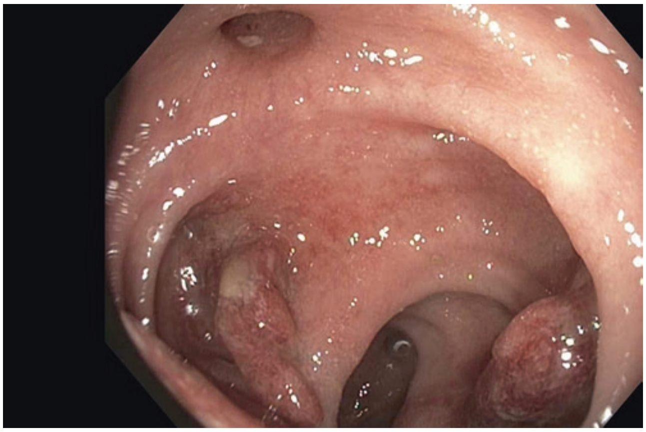

Fig. 2.1 Pseudopolyps and diverticuli. This is a picture taken during evaluation of the sigmoid colon in a patient with long-standing ulcerative colitis. Note the inflammatory appearance of the enlarged polyps, the excavating diverticuli, and the burnt out appearance of the wall of the remaining colon

stretching and, in some occasions, irritable bowel disease. Abdominal pressure to prevent and reduce looping with patient repositioning is a useful sometimes necessary adjunct in successful colonoscopic advancement.

Anatomic Variations

Difficulty in successful colonoscopy is generally related to anatomic variations as it relates to redundancy in the colon or its retroperitoneal attachments leading to looping of the instrument. This looping can lead to stretching of the mesentery and significant pain, and occasionally incomplete colonoscopy. One study of 100 patients reported looping in 73% of patients with a total of 165 loops noted [9]. A fundamental understanding of the anatomy and variations thereof can aid the operator in achieving a maximal rate of successful cecal intubations.

Using intraoperative assessments, Saunders and his group found that colonic length is significantly greater in women (155 vs. 145, $p = 0.005$), with the most pronounced difference noted in the transverse colon, where the colon may dip into the pelvis more often in women than in men (62% vs. 26%, $p < 0.001$) [12, 13].

Similarly, portions of the colon that are typically presumed to be fixed (ascending and descending colon and the hepatic and splenic flexures) have been noted to have variable degree of mobility and freedom. Roughly 8–9% of the descending and ascending colons were mobile as a result of a redundant and non-fixed mesentery. One-fifth of patients had a mobile splenic flexure. The transverse colon reached the symphysis pubis in 29% of patients. Lastly, in approximately 20% of patients, the sigmoid colon had variable adhesions as a result of diverticular disease or pelvic surgery or congenital adhesions [13]. The redundancy in the sigmoid and transverse colon can lead to difficulty in successfully advancing and overcoming these portions as a result of looping or bowing. Indeed, this can occur in up to 91% of patients, with N-type bowing of the sigmoid in 79% and deep transverse bowing in up to 34% [14, 15].

Lastly, based on operative findings, ethnic variations in colonic length have been suggested with patients from Asia and the Far East noted to have longer colons (P = NS), but Caucasians/Western populations observed to have more sigmoid adhesions ($p < 0.05$), longer descending mesocolons ($p = 0.01$), more mobile splenic flexures ($p < 0.016$), and longer transverse colons reaching the symphysis pubis or lower ($p < 0.001$) [16].

Interestingly, when comparing CT colonography and colonoscopy, considerable variance in overall length were noted, with a shorted distance observed on colonoscopy (167 cm vs. 93.5 cm), though this may be related to experience of the endoscopist and also the accordion-like effect of successful intubation. Furthermore, colonography was able to observe and document a higher number of acute angle flexures and tortuosity. In the same cohort of patients undergoing both modalities, while looping occurred in 73 of 100 patients, fluoroscopic-assisted straightening maneuvers were successful in 95%. Successful cecal intubation was precluded in only 2 of 100 patients due to an obstructing sigmoid carcinoma and a redundant colon [9].

Mural Findings and Internal Cues Helpful in Advancement

Small clues can be helpful in locating the lumen and directing forward advancement of the colonoscope. The lumen is located at the center of converging/radially oriented folds (not seen around diverticular orifices). The darkest side of a mucosal view or the darkest area of a fluid-filled colon should be nearest to the center of the colon and lumen. Aiming toward these areas with gentle insufflation should help in achieving proximal progression.

Curved arcs on inspection can also provide clues in determining where to progress within the channel of the colon. Arcs may be caused by haustral folds or reflections of the circular muscles fibers under the mucosal surface or highlights reflected off the surface of the microscopic innominate grooves. Enlarged muscle fibers run longitudinal along the colon (tenia coli) and may be used as a direction of orientation (similar to a white line/stripe along a highway). These are prominent and can be most easily seen along the transverse colon, splenic flexure, and particularly in the cecum.

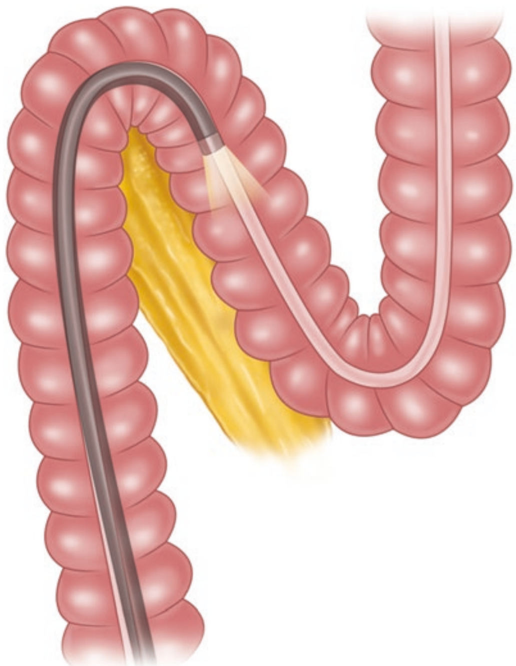

Fig. 2.2 Formation of sigmoid N-loop during colonoscopy. Note how the long mesentery allows stretching of the sigmoid colon. Minimal angulation of the tip will be helpful in advancement of the scope until the loop can be reduced

While progressing through difficult angulation or tortuous folds, a phenomenon called "redout" may be observed—with complete loss of any anatomic landmarks available to guide forward travel. To overcome this, standard guidelines in procedural endoscopy recommend additional gentle insufflation while pulling back with maintenance of current. This will generally smooth out the bend, shortening the colon that is past the tip, and straightening the forward colon while decreasing disorientation (the latter due to reduction of angulation). One exception to the rule may be encountered during creation of N-loops of the sigmoid, where steep/acute angulation of the tip with forward advancement may lead to exacerbation of the bowing/looping distal to the tip (walking-stick phenomenon). In these cases, a slight reduction in angulation may be helpful during forward pushing (Fig. 2.2).

Positioning

Traditionally, colonoscopy is generally performed in the left lateral decubitus position with the hips and knees flexed at 60°–90°. Rare exceptions exist—including intubation and endoscopy through ileostomies or colostomies—and in these situations, the patient is usually in the supine position. Occasionally, as noted above and detailed further throughout the manuscript, application of manual pressure and repositioning into the right lateral or occasionally supine and/or prone positions may help with preventing looping and ultimate cecal intubations [17, 18].

In the left lateral position, the descending colon is typically fluid filled. In the right lateral position, the descending colon is more air filled. With this knowledge, positioning into the supine or right lateral position while navigating the sigmoid and descending colon can lead to forward progress. Once progress has been made, repositioning into the standard left lateral decubitus position may allow continued intubation.

Stool and fluid can also be helpful in determining location of the lumen in the colon. Liquid effluence is generally dependent. Articulation of the tip away from a flat air fluid level will generally guide the operator toward the lumen. Similarly, stool coming through an orifice is generally coming through the main lumen. Care should be taken, however, not to confuse a scybalum-filled diverticulum with the lumen of the colon.

Looping

Looping is very common during forward progression of colonoscopy. These are generally formed due to redundancies in the colon and/or hypermobile mesenteries, typically seen in the sigmoid and transverse colon [19]. Paradoxical movement and loss of 1:1 relationship of tip/shaft advancement are generally caused by sharp angulation and loop formation and are the first signs of loop formation. Typical findings include slippage with paradoxical motion and loss of sensitivity or resistance changes on advancement. Forward pushing at this stage will only increase the size of the loop, cause distention of the colon, further stretch the mesentery, and subsequently increase pain experienced by the patient.

Appreciation of the formation and direction of these loops with an understanding of the underlying anatomy will allow the operator to subsequently reduce these loops, straighten the bowel, and continue with forward progression. The most typical loop is the N-loop (or spiral loop) formed during advancement through the sigmoid colon (80%). The alpha (α)-loop is encountered in about 10% of cases with an anterior/ventral-oriented sagittal loop formation (Fig. 2.3). Lastly, deep transverse looping is noted in approximately 30% of cases (Fig. 2.4). More atypical loops caused by mobile colonic attachments include the reverse α-loop (5%, posterior/dorsal counterclockwise looping of the sigmoid or descending colon requiring strong counterclockwise torque retraction for reduction), reverse splenic flexure loop (3%, ventral left sided angulation and then reorientation to the right), gamma-loop of the transverse colon (1%), and a reverse sigmoid spiral (1%, with the scope oriented initially

Fig. 2.3 Scope view image of an alpha (α)-loop. Note the appearance typical of a sigmoid volvulus. Pushing through this loop until the descending colon is reached and then reduction with clockwise torqueing and withdrawal will lead to a straightened path for the colonoscope and future ease in progression and navigation of the splenic flexure

Fig. 2.4 Common loops formed during colonoscopy include the (**a**) sigmoid N-loop (sometimes called bowing), (**b**) α-loop with medialization of the sigmoid colon by volvulus formation, and (**c**) deep transverse colon loop

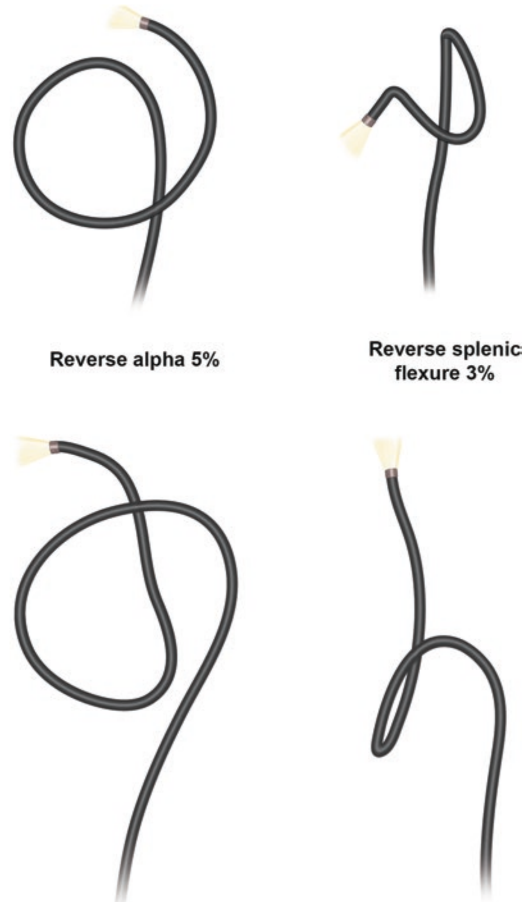

Fig. 2.5 Less common and difficult loops encountered during colonoscopy. These include (in counterclockwise order from top left) (**a**) reverse α-loop, (**b**) deep gamma (γ)-loop of the transverse colon, (**c**) reverse splenic flexure loop, and (**d**) reverse sigmoid spiral loops. Approach to reduction is discussed in the text

anterior and ventral in the caudal orientation and then followed in a cephalad posterior dorsal position leading to medialization, rather than lateral positioning of the sigmoid and descending colon) (Fig. 2.5).

Reduction of Loops

An appreciation loop formation and protocoled regimen to reduce these loops are imperative in allowing continued progression and reduction of pain and other morbidities associated with colonoscopy. These loops are generally overcome by gently withdrawing of the colonoscope and while maintaining the angulation (up-down/left-right), detorqueing the scope in clockwise direction with the wrist. This maneuver prevents slippage. On subsequent advancement, the operator should then try clockwise torqueing. Occasionally, anticlockwise torqueing and retraction followed by anticlockwise torqueing and advancement may be necessary if the above maneuvers are repeatedly unsuccessful. Lastly, changing positioning or abdominal pressure application may be useful with incorporation of the above steps [17]. Successful manipulation of these loops will be met by forward 1:1 or great advancement of the tip and the shaft of the colonoscope. Real-time magnetic image-guided endoscopy can sometimes be used as an adjunct to help visualize and subsequently reduce looping during scope advancement [14, 15]. This tool may be particularly helpful in the early learning phases of colonoscopy.

Additional steps pertinent to progression of the colonoscopy procedure as they relate to the particular segment of anatomy will be discussed below.

Anatomy

The following will describe various key anatomic landmarks that should be appreciated during advancement and progression of the procedure leading to a successful colonoscopy.

Anus

The first landmark to be visualized and assessed is the perianal area and anal canal. This area of the intestinal canal is frequently overlooked and, in the case of colonoscopy, poorly visualized. Care should be made to grossly evaluate for any external diseases perianally and exclude noteworthy entities such as anal carcinoma (squamous cell, melanoma, etc.), fissures, fistulae, and abscesses. Hemorrhoids are typical findings and should be documented accordingly. In the setting of suspected inflammatory bowel disease, careful visual inspection for waxy elephant ear Crohn's tags should be performed and documented. These are commonly mistaken for benign hemorrhoids. A digital rectal examination of the anorectal canal is then performed to assure no significant mass or excavating lesion exists, as well as provides an assessment for any stricture or stenosis. These can be related to intrinsic inflammatory bowel disease such as Crohn's disease, or may be related to postoperative healing, or carcinoma. If any of these are found, cautious biopsies may be indicated. Care should be utilized however to prevent fistula formation in this vicinity. In some cases, a bimanual examination may be warranted if a mass or penetrating lesion or fistula is suspected. Once visual and digital rectal examination is performed, the colonoscopy can then be initiated.

Once the tip of the colonoscope is inserted within the anorectal canal, using variations of either air, carbon dioxide (CO_2), or water insufflation/instillation, the rectum is then visualized. Typically, there may be residual stool or fluid in the rectal vault from the preparation. This should be sufficiently suctioned out for appropriate evaluation of the anorectal and rectal mucosa.

Rectum

Key Landmarks

- Dentate line
- Rectal valves/folds

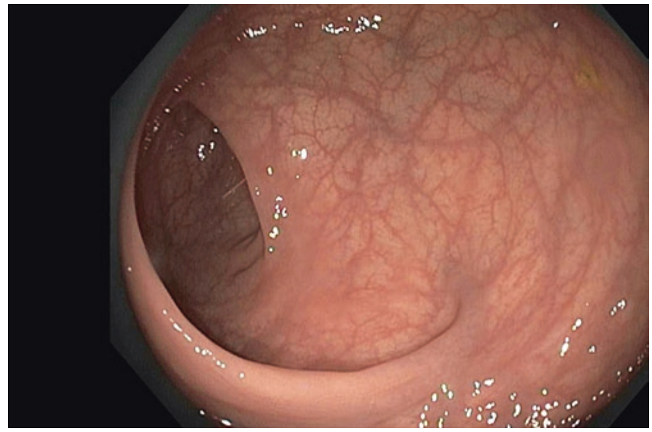

Fig. 2.6 Rectal fold/valves—in this colonoscopic image, the mid and distal folds can be appreciated on the left and right side, respectively. The upper/proximal rectum is in the background, while the mid and then upper portions of the distal rectum are seen in the foreground

The rectum is approximately 15 cm long and, for clinical descriptive purposes, can be divided into approximately 5 cm thirds (proximal, mid, and distal). These portions of the rectum will be demarcated by incomplete haustral valves or folds of Houston (upper/proximal/first, middle/second, lower/distal/third) that can be used as landmarks when describing any atypical lesions (carcinomas, polyps). The proximal/upper fold is considered the uppermost/cephalad extent of the rectum and denotes the rectosigmoid junction (Fig. 2.6). The authors recommend not utilizing only numerical designation but rather descriptive terms (distal or lower instead of first) as this avoids confusion in terms of location and orientation. When commenting on findings, it is helpful to both note the location of these lesions based on distance from the anal verge (or preferably dentate) and also the location related to these rectal folds or valves (i.e., "6 cm above the anal verge, on and distal to the lower/distal rectal fold"). This is significantly important when surgical approaches are to be considered or when imaging is later performed and needs to be correlated to endoscopic findings.

Occasionally, lesions may not be able to be endoscopically managed at the time of index colonoscopy. Advanced endoscopic therapeutic interventions such as endoscopic mucosal resection or endoscopic submucosal dissection may benefit the patient with benign polypoid disease. Surgical (or combined endolaparoscopic) management may also be warranted for malignancy or medically refractory disease. Anticipating the need for these above modalities, photodocumentation with location and anatomic landmarks is critical for the referred physician or surgeon. Furthermore, it may be appropriate to inject a submucosal tattoo on the distal/anal side of the lesion. This should be done using three areas of injection circumferentially around the wall of the colon. The only area that would not definitively need tattooing is a lesion in the cecum. Rectal lesions are helpful to tattoo in case regression is noted after neoadjuvant chemoradiation therapy.

Progression through the retroperitoneal rectum is generally straightforward with mostly forward pushing, insufflation, and gentle clockwise torqueing required at times. Once the proximal rectum has been traversed, it may be helpful to gently pull back and unloop and reduce any redundancy and excess scope previously inserted.

Rectosigmoid and Sigmoid Colon

Key Landmarks

- Upper rectal valve/fold
- Diverticuli
- Tortuosity in women and patients with long-standing constipation
- Stenoses/strictures due to diverticular disease

At approximately 15–20 cm above the anal verge, the endoscopist will encounter the rectosigmoid and then distal sigmoid colon. This is also the area where the colon is now located within the peritoneal cavity above the peritoneal reflection. Care should be taken in this vicinity as there are commonly located and experienced tortuosities and angulations, strictures/stenoses, and significant diverticular disease in this vicinity (Fig. 2.7). Furthermore, redundancy of the colon in this area may lead to excessive looping of the endoscope. Overly aggressive forward movement and/or twisting may lead to mechanical trauma along the wall of the colon. Barotrauma related to over distention with air is also a significant risk in this area. Both of these are common causes of perforation, particularly in this area. The cecum is also a very common area for perforation due to barotrauma as it relates to LaPlace's law with this proximal-most portion of the colon having a larger radius and thinner wall/tension. Perforations rates are typically less than 0.1%, but may reach 18% based on indication for therapeutic procedure being performed in these areas [20–30].

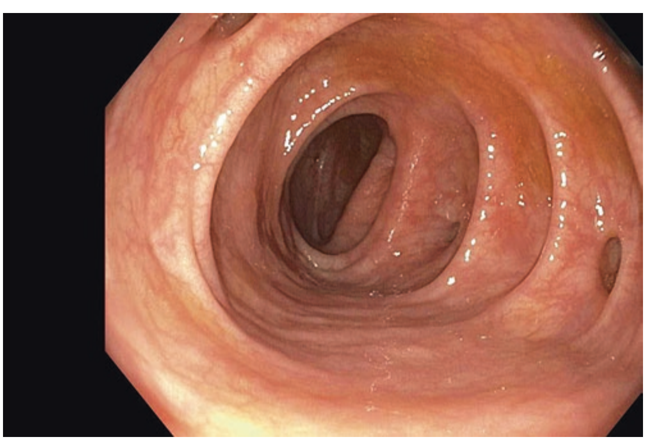

Fig. 2.7 Sigmoid colon with diverticuli. Note the excavating lesions noted on the sides of the wall of the sigmoid colon. Also, the endoscopist should appreciate the larger and darker center lumen that should be used as a guide to advance the scope. In this image, fluid is noted on the upper right, signifying the dependent portion of the colon

During advancement in this area, care should be made to use judicious insufflation and at the same time also aspiration techniques utilized to draw in the more proximal lumen while telescoping and advancing the colonoscope further into the colon. Excessive inflation of the colon can lengthen and distend the colon and, in some cases, enhance twisting or angulation and kinking of the colon and prevent advancement. In general, during advancement, right and left knobs should be used sparingly, and instead, mechanical twisting or torqueing of the shaft of the scope with the operator's wrist is preferred when trying to negotiate turns. Up-down knob manipulation is very helpful however in centering the scope in the lumen and advancing proximally.

First described in 1986 and 2002, the use of carbon dioxide insufflation [31] and/or water instillation [32] has been found to reduce distention and patient discomfort while facilitating advancement of the colonoscope [33–42]. Most recently, the use of warm water irrigation for colonic distention has been shown to aid in navigating through the left colon with extensive diverticulosis by help differentiating the lumen from the mouths of the diverticuli. Warm water colonic distension has also been shown to decrease sedation requirements and patient pain/discomfort [43, 44]. The potential disadvantages associate with water-aided colonoscopy technique is lower adenoma detection rate in the water-filled portions of the colon and longer procedure time [45–49].

In certain cases due to narrowed, angulated, or fixed sigmoid colons, a pediatric colonoscope or a thin upper endoscope can be used in combination of position changes (supine) and abdominal pressure (one or two hands pushing down and to the left and utilizing up to four hands to cover the entire abdomen). In some cases, guidewire exchanges may be utilized. For redundant sigmoid colons, the use of various enteroscopes and/or endoscopic straighteners can also be utilized [11, 50]. Variable stiffness endoscopes have recently been utilized to help in navigating and advancing the scope.

During insertion and navigation through the tortuous rectosigmoid and sigmoid colons and into the otherwise straight descending colon, combinations of right-oriented clockwise wrist twisting/torqueing and de-twisting and pullback/straightening maneuvers may be particularly useful as well. Sometimes, multiple to-and-fro motions may be required to successful navigate through the sigmoid with minimal looping. It is helpful to gain a masterful handling of the colonoscope. Being able to reposition the scope so that pathological

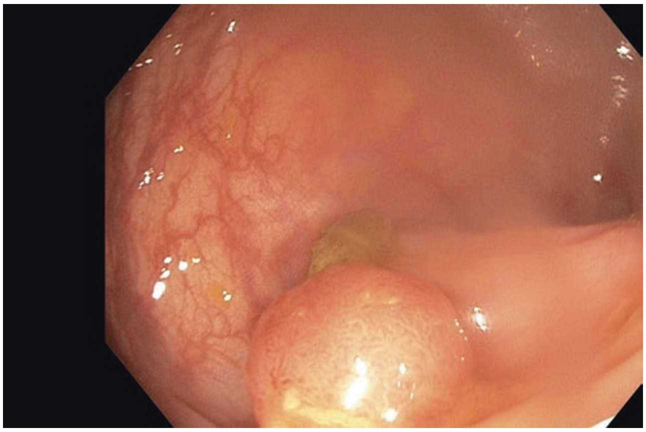

Fig. 2.8 A sessile polyp positioned at 6 o'clock. Note the villous architecture on the mucosal surface and benign appearance of the colon wall

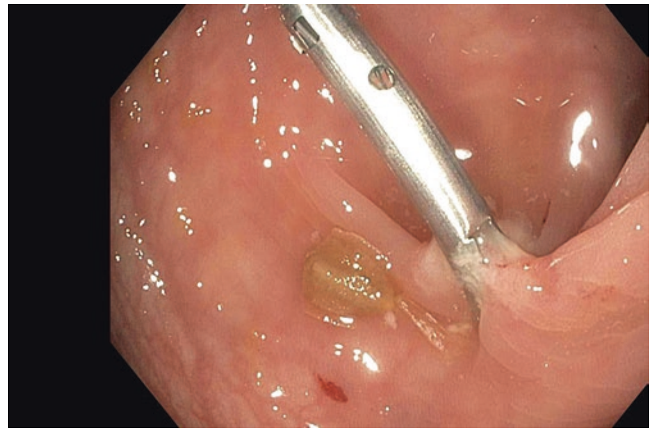

Fig. 2.10 A clip applied to the base of the resection specimen after snare excision of the sigmoid polyp

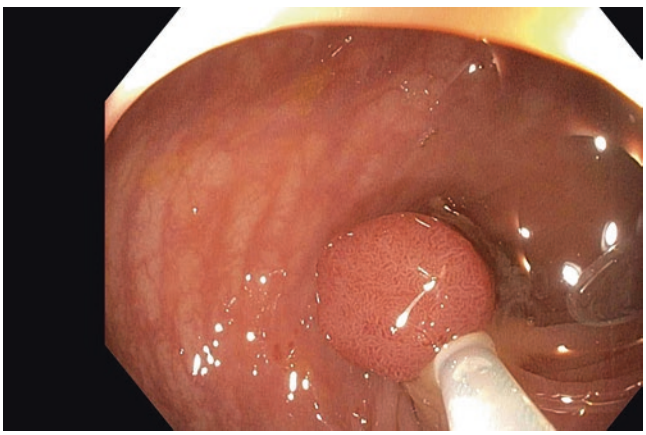

Fig. 2.9 The same polyp being resected with the technique of snare polypectomy

findings and working ports are localized at the 4–8 o'clock position will allow for improved ability for diagnostic and therapeutic interventions, such as biopsy, snare and clip applications (Figs. 2.8, 2.9, and 2.10).

Looping in the sigmoid colon is very common and can lead to difficult if not incomplete colonoscopy. Redundancy of the sigmoid colon leading to looping is correlated with female gender, increasing age, low body mass index, prior hysterectomy, and history of constipation [9, 51–53]. Looping can generally be overcome by following good standard endoscopic procedures without special techniques, using combinations of withdrawal-suctioning torqueing (clockwise vs. counterclockwise rotations of the endoscopy shaft) to straighten out the affected colon [9].

N- or spiral loops are commonly formed with straight pushing advancement motions through a long and mobile sigmoid mesentery. Interestingly there is minimal pain since the long colon is otherwise not particularly stretched. An alpha (α)-loop is endoscopically quite advantageous. This α-loop is equivalent to a sigmoid volvulus formation caused during endoscopy due to a very long and mobile sigmoid and a fixed retroperitoneal descending colon. If advancement of the scope is easy without acute bends or discomfort, initially the operator should continue and push through the volvulus or α-loop. Once the proximal to mid-descending colon has been intubated, reduction of an α-loop by withdrawal with simultaneous clockwise rotation will yield a straightened colon that is pressed along the posterior abdominal wall/retroperitoneum allowing for further advancement and forward progress without looping or pain [54, 55]. In rare instances, a longitudinal "split" external straightener or overtube device can be utilized to overcome looping [10, 11]. In general, a median of 2.1 (range 1–6) straightening maneuvers may be necessary to reach the cecum [9].

Care must also be taken to avoid intubation of a diverticulum during insertion. Whenever advancing the endoscope, occasional pullback technique to visualize the central larger lumen may be useful to avoid inadvertent mechanical injury or barotrauma and subsequent perforation in this area.

Descending Colon

Entry into the descending colon is generally accomplished with a back-and-forth motion with clockwise torqueing of the colonoscope [55]. Alpha (α)-loops of the sigmoid colon are suspected when there is more pain than anticipated (secondary to mesenteric twisting and torsion) or paradoxical motion of the tip of the scope. This α-loop needs to be reduced prior to proceeding with scope advancement past the splenic flexure to minimize pain and increase successful cecal intubation rates. This can generally be performed by withdrawing the scope and slowly and gradually rotating the scope clockwise. This should then straighten out the sigmoid and descending colon and aide in further scope advancement

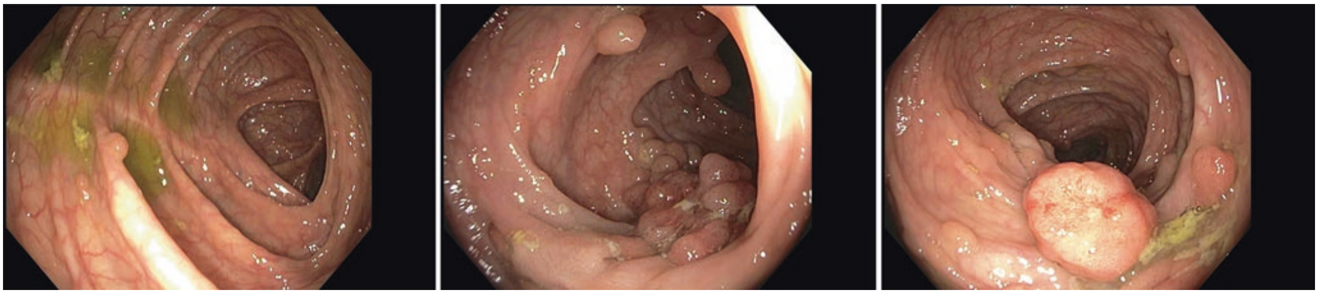

Fig. 2.11 Transverse colon with multiple adenomatous polyps of various sizes. Notice the triangular shape of the colon lumen formed by the thickened muscular teniae coli. This patient has familial adenomatous polyposis and found to have at least 544 adenomatous polyps throughout his colon and rectum

(noted by successful entry into the transverse colon without paradoxical movements).

Typically, once the scope has been manipulated through the sigmoid colon, the descending colon is seen as a straight path lumen with few diverticuli, if any, and generally without angulation. The circular appearance is related to the thick circular muscles lining the wall of the descending colon. This is principally related to the attachments to the retroperitoneal white line of Toldt laterally along the left abdominal wall and the mesentery to the retroperitoneum overlying Gerota's fascia.

Splenic Flexure

Key Landmarks

Sharp turn/angulation

Bluish hue of adjacent spleen

Proximal transverse colon/triangular haustra

Pressure applications are most used and helpful in overcoming the angulations and redundancies in the flexures (splenic and hepatic). The splenic flexure is generally more redundant than the hepatic flexure. In some instances, a bluish-gray hue may be noted through the thin wall of this flexure, and this corresponds to the spleen that may be intimately attached to the colon. Rough forward advancement without appropriate finesse may lead to traumatic splenic rupture and hemorrhage [56–59]. Changing position to the partial right lateral decubitus may help traverse the distal descending colon and splenic flexure.

The best clue signifying successful passage of the splenic flexure is progression from a fluid-filled descending colon to an air-filled, triangular-shaped transverse colon.

Once past the splenic flexure, at the distal transverse colon, attempts should be made to withdraw and reduce any looping or extraneous endoscope within the colon. This is generally helped by the fixation by the phrenocolic ligaments.

The splenic flexure acts as a fulcrum allowing forward progression through the transverse colon while withdrawing, through upward/cephalad lifting of the colon due to a cantilever effect. Similarly, using gravity as an assistant, the right lateral decubitus position helps in forward progression past the splenic flexure and through the transverse colon.

Keys to traversing the splenic flexure involve a few fundamental steps: (1) pull back the shaft to 50 cm with clockwise torque until there's a catapult-like resistance or slippage of the tip; (2) de-angulate the tip; (3) deflate the colon to keep colon short and supple and adaptable; (4) apply hand pressure over the lower abdomen to prevent looping; (5) torque the shaft clockwise to put torsional straightening force on the sigmoid loop while adjusting angulation to keep lumen in view; and (6) gently push in motion. Occasionally positioning the patient on the back and/or right-side down can also be utilized.

Reverse splenic flexure looping occurs when the descending colon is completely mobile and the colonoscope goes the wrong way around the splenic flexure and through the transverse colon. The scope pushes through a deep transverse loop with an acute angulation at the hepatic flexure. By counterclockwise de-torqueing and withdrawal using the splenophrenic ligament as a fulcrum, the descending colon is then twisted back in its typical anatomic lateral position, and the scope is then passed through the flexure in a conventional manner.

Transverse Colon

Key Landmarks

Triangular haustra

Prominent teniae coli

Tortuosity and redundancy noted in women and patients with long-standing constipation.

The transverse colon, proximal to the splenic flexure, is commonly identified by the triangular appearance of the lumen due to the prominent longitudinal muscles of the tenia coli and relatively thin circular muscle fibers (Fig. 2.11). The teniae function as a useful guide for the colonic axis and direction of progression. The transverse colon is attached and dependent via its retroperitoneal mesentery just caudal to the pancreas. The transverse colon can reach down to the symphysis pubis, particularly in women or those patients with long-standing constipation [55]. Advancement through the mid- and distal-transverse colon is generally aided using various combinations of tip flexion and also abdominal wall compression. Traditionally, once the mid-transverse colon is reached, pulling back with clockwise rotation will lead to advancement through the proximal transverse colon through paradoxical movement as a result of a cantilever-type effect with the splenic flexure functioning as a fulcrum resulting in the shortening, straightening, and elevation of the colon. Repeated in-and-out push-pull movements may be helpful during this phase. In certain cases, a particularly long transverse colon and mesocolon may lead to the formation of a gamma (γ)-loop with a clockwise volvulus. This is particularly difficult to navigate and generally will require careful withdrawal back to the splenic flexure and reinsertion. In some cases, repositioning the patient in supine or prone position may help straighten the colon for advancement.

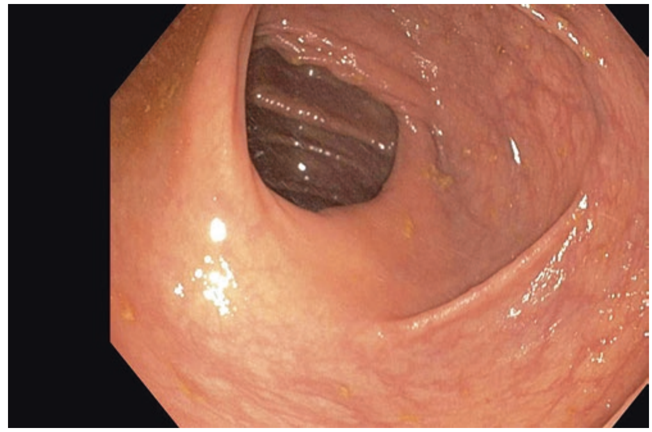

Fig. 2.12 This is a view as the ascending colon is being paradoxically intubated immediately after navigating through the hepatic flexure while withdrawing the scope

Hepatic Flexure and Ascending Colon

Key Landmarks

Bluish hue of liver

Once reaching the proximal transverse colon, while the patient is in the left lateral decubitus position, suctioning allows the colon to collapse onto the scope and advancement ensues. The hepatic flexure has an acute hairpin turn and requires masterful steering and manipulation to traverse and steer around. Overcoming the angulation of the hepatic flexure can be typically performed through a combination of torqueing (counter-) clockwise to gain a few additional centimeters of length, suctioning of the distended colon to collapse and shorten the flexure/bend, and pulling/withdrawing back on the endoscope. This generally leads to an accordion-like bowel slipping onto the shaft with prompt scope advancement (in a paradoxical fashion by withdrawal) into the cecum (Fig. 2.12). The application of abdominal pressure at various points (left upper abdomen, centrally, or right sided) may also be helpful. If the patient is lightly sedated, deep inspiration may help lower the diaphragm and flexure. In some cases, even with right lateral decubitus positioning, it may be difficult to overcome the presumed hepatic flexure. With this scenario, one must suspect that indeed, the scope is positioned at the splenic flexure in this case. One common way to determine this is based on fluid contents. In the left lateral decubitus position, the splenic flexure will have dependent fluid, whereas the hepatic flexure should be dry. (see picture "ascending colon from distal hepatic flexure"). Occasionally, the bluish hue from the liver may be seen through the thin-walled hepatic flexure (Fig. 2.13).

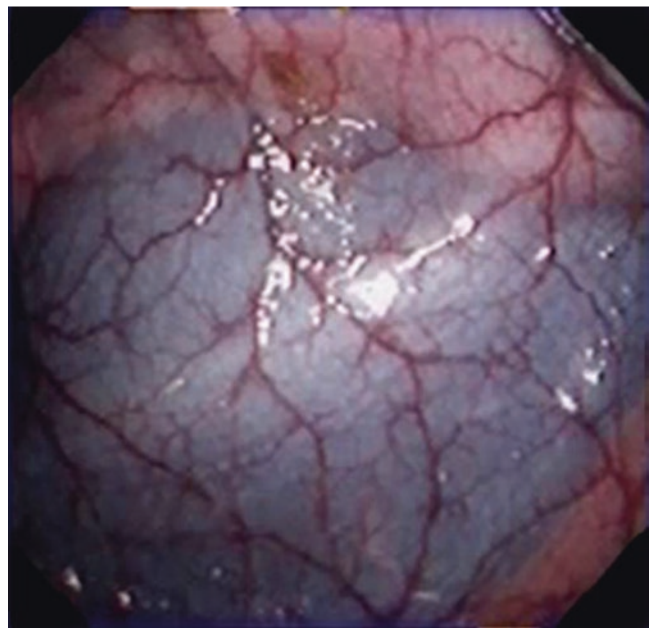

Fig. 2.13 The bluish hue discoloration visible through the thin-walled colon represents blood within the liver as the hepatic flexure is being traversed. A similar appearance can also be noted while traversing the splenic flexure—and this represents the spleen. Particular care should be utilized in these areas to avoid injury to the capsule of these vascular organs and ensuing hemorrhage

Cecum/Ileocecal Valve/Appendiceal Orifice

Key Landmarks

Ileocecal valve (ICV)

Appendiceal orifice (AO)

Once the hepatic flexure has been traversed, suctioning action and simultaneous clockwise rotation during withdrawal will lead to an accordion-like slippage of the ascending colon onto the scope with eventual intubation of the cecum. There may be additional maneuvering required at the