9 Anastomotic Construction

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Key Concepts

- Anastomotic construction represents a fundamental and essential skill restoring intestinal continuity and preserving bowel function and continence.
- It encompasses a broad range of methods and configurations and can be performed utilizing a spectrum of operative platforms.
- While anastomosis may be a heterogeneous endeavor, consistent fundamental principles must be preserved in all its forms.
- Stapling technologies represent a challenge for surgeon knowledge and understanding their use in clinical practice given the numerous innovations and specific tissue–device interactions.
- Colonic mobilization techniques bringing bowel into proximity to the distal limb while preserving blood supply represents an essential and critical skill for anastomotic construction. Surgeons must be familiar with advanced techniques for mobilization to achieve anastomosis.

Introduction

Anastomotic construction represents one of the fundamental activities of the intestinal surgeon. Following closely behind the principal goal of resection of the pathologic condition, restoration of a functional intestinal tract invariably remains an important aspect of a patient's sense of well-being and health as well as their perception of a successful operation. Fortunately, a healed and functional anastomosis is common, and the inability to perform an anastomosis remains a relatively rare phenomenon. This current perspective belies the early history of surgery of the intestinal tract where anastomotic failure and mortality were exceedingly high (Fig. 9.1) [1]. Advances in surgical technique and scientific discovery were critical to safe anastomotic construction.

Intestinal anastomosis encompasses a broad range of surgical activity: the multitude of pathologic conditions requiring resection, the variety of anatomic segments that can be resected, the numerous permutations of suture materials, and the array of anastomotic configurations. Adding to the complexity of this topic, we must also consider the different means of access to the peritoneal cavity, including laparotomy or minimally invasive approaches such as laparoscopy or robotic surgery.

In spite of remarkable technological advances, anastomotic leak continues to plague our best efforts even 20 years into the twenty-first century. It continues to be a most feared complication. The morbidity of leak is far reaching, often involving reoperation, lengthy hospital stay, loss of function, poorer oncologic outcomes, or even operative mortality [2]. Unfortunately, anastomosis outcomes vary, in part based on surgeon performance [3, 4]. This is particularly sobering as perhaps there are few operative outcomes that affect a surgeon's personal measure of competence and self-esteem. As individual surgeons, we are acutely aware of the dire implications for our patients who suffer an anastomotic leak. Therefore, the topic of anastomotic construction represents an audacious and humbling endeavor for the authors to embark upon.

The objective is pragmatic and straight forward: to discuss general principles and technical options for anastomotic construction. Going forward, we trust and will rely upon the reader's tolerance and understanding where philosophies and techniques may differ from their own. In the end, we hope that author and reader alike will have subjected themselves and their operative technique to scrutiny and honest appraisal, and will consider the following with intellectual rigor and openness.

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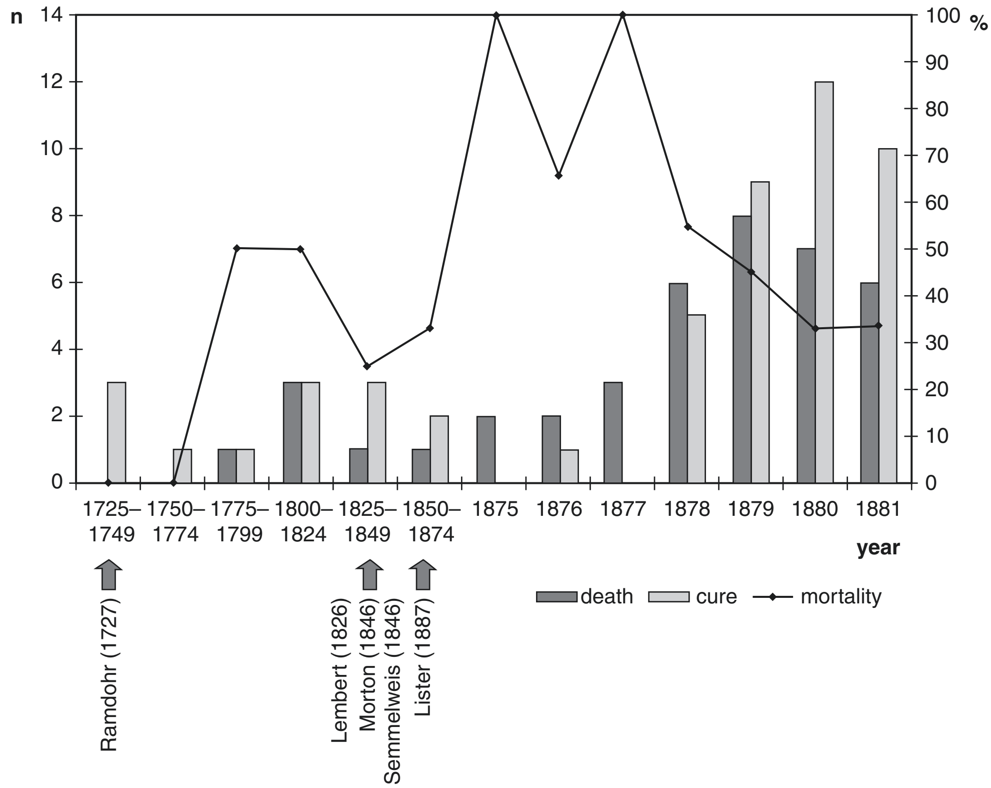


Fig. 9.1 Mortality of gastrointestinal anastomoses performed between 1727 and 1881. Reused with permission [1]. (Copyright © 2005 Springer Nature)

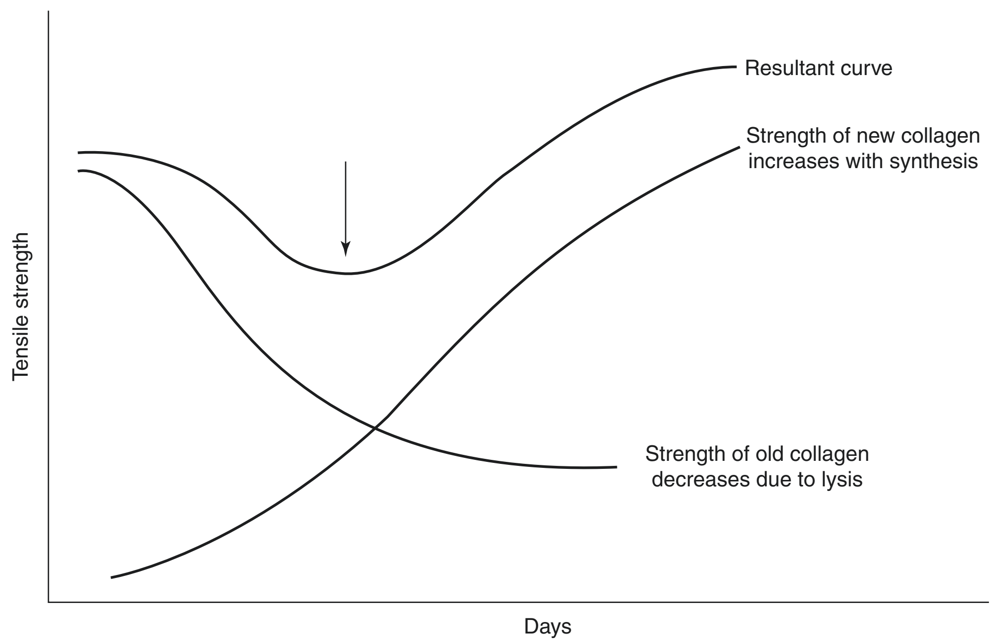


Fig. 9.2 Wound healing in gastrointestinal tract is the fine balance during "lag" phase between collagen synthesis and collagenolysis. Line labeled "resultant curve" shows this balance. Weak time period depicted on graph (arrow) can be prolonged or exacerbated by local or systemic factors that upset equilibrium. (Reused with permission [6]. Copyright © 2006 John Wiley and Sons)

Physiology of Anastomotic Healing

Intestinal anastomotic healing proceeds through the well-elucidated phases described for other models of tissue injury and repair [5, 6]. The status of collagen and tensile strength is critical to anastomotic integrity (Fig. 9.2). However, differences exist as a result of the unique anatomic and physiologic properties of the intestinal tract. Anatomically, the intestinal tract has four layers with characteristics that play unique role in anastomotic healing. The exceptions to this are importantly, the esophagus and the lower aspect of the rectum, both of which notably are lacking serosal layers. Anastomoses involving these specific organs prove more challenging and are marked by higher leak rates [6].

The importance of the serosa was highlighted by Lembert [1, 7, 8]. He popularized the critical idea that apposition of the serosa and inversion of the mucosa was critical to anastomotic healing. Halsted's canine investigations revealed that the submucosal layer contained the highest concentration of collagen and possessed the greatest tensile strength. He emphasized the role of submucosal purchase during intestinal suturing, and the Halsted stitch actually omitted the mucosa. The incorporation of the submucosa provides the initial tensile strength to an anastomosis during *the lag or inflammatory phase* when collagen degradation predominates. During this inflammatory phase, the clotting cascade is activated by platelets and release of inflammatory mediators, causing a fibrin plug to occur at the mucosal defect and assisting in hemostasis. Neutrophils migrate to the wound and essentially clean up the necrotic tissues. Collagenolysis liberates amino acids, especially proline and lysine, which become available for later collagen synthesis. Therefore, the anastomosis is weakest during the first 2 days after surgery, as integrity of the anastomosis relies entirely upon the suture material approximating the submucosa until collagen synthesis occurs [5, 6].

At day 2–4, the proliferative phase begins. This phase is marked by collagen synthesis. Fibroblasts are generally responsible for this activity, but unique to healing in the intestinal tract, smooth muscle cells also contribute to collagen synthesis [6]. Smooth muscle cells from the muscularis mucosae and the muscularis propria contribute to this production. Tensile strength develops as a result, and compared to soft tissue repair, this occurs much more rapidly in the gastrointestinal tract. Similar to cutaneous healing, neither process achieves pre-injury tensile strength. It is estimated that at 1-week small bowel anastomoses achieve nearly 100% of the expected strength. Colonic anastomoses obtain about 50% of their ultimate anastomotic strength in the same time frame [5, 6]. Finally, the remodeling phase of healing is marked by collagen maturation and cross-linking, increasing the tensile strength of the anastomosis.

Epithelial repair, otherwise known as g*astrointestinal restitution*, occurs rapidly as a result of migration of crypt cells from adjacent unwounded epithelium. The integrity of the epithelial layer can be complete by day 3 if mucosal apposition occurs [5]. Critical to this process is restoration of the inner mucus layer. Crypt goblet cells secrete a viscous mucus layer that serves as an important inner protective layer of the mucus layer of the intestinal tract separating the commensal bacterial flora of the microbiome from the epithelium and healing anastomosis [9–11]. One of the major concepts recently introduced regarding anastomotic healing has been the revelation of local changes in the microbiome. The development of pathogenic intestinal bacteria results in collagenolytic activity that undermines tensile strength and anastomotic healing [10–12]. The importance of commensal bacteria and potential deleterious local effects such as these highlight the critical aspect of gastrointestinal restitution and restoration of the mucus layer barrier to the healing of intestinal anastomosis.

In summary, gastrointestinal anastomoses progress through the various phases of healing with important specific differences resulting in rapid restoration of tensile strength and restitution. Anastomotic construction techniques should minimize parameters prolonging the inflammatory phase and collagenolysis: avoidance of tension, minimize necrosis, airtight closure, approximation of the submucosa, and preservation of perfusion. These parameters give rise to the basic tenets of anastomotic construction.

Fundamental Principles for Anastomotic Construction

Anastomotic construction depends on joining two ends of bowel that are healthy and well-perfused. The physical union is airtight and without any tension. Operative technique should involve anatomic mobilization by dividing named vessels and preserving blood supply, minimally traumatic dissection, precise and secure approximation, all while maintaining aseptic technique. Importantly, these fundamental concepts must be preserved across the various operative platforms—open and minimally invasive—knowing that potential advantages and challenges exist for each approach and for specific steps. Regardless of platform, the anastomosis generally represents one of the final operative steps and, independent of the time required for the preceding steps, requires focused attention to detail and meticulous technique.

Operative Planning

Operative decision making necessitates preoperative planning. One of the keys to successful operations depends on the preparation of the surgeon and team so that each step has been imagined, contemplated, and specific details considered. In particular, the principal objective –surgical treatment of the pathologic condition and the planned appropriate extent of resection – must be clearly defined. Localization of pathology preoperatively is a critical item for anticipating segmental or extended resection. Endoscopic description of the segment can be inaccurate and tattoos are potentially helpful in intraoperative localization, but not in preoperative planning. Endoscopic clip placement with X-ray can be helpful (Fig. 9.3). The plan for mesenteric resection and division/preservation of named vessels is dependent on precise localization, and therefore should be a major part of preoperative planning.

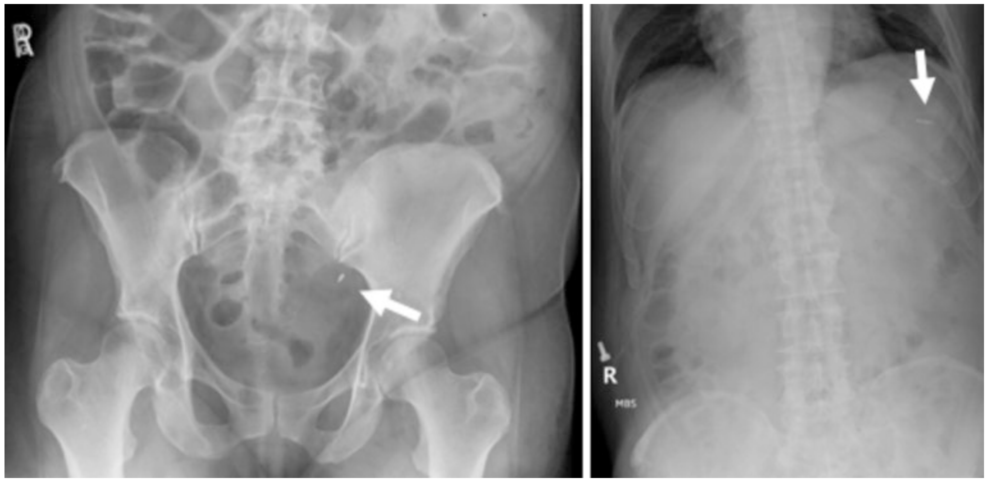


Fig. 9.3 Note white arrows indicating endoscopic clip placed at 60 cm from anal verge seen on plain X-ray in two different patients. Clip placement with radiograph can provide accurate preoperative localization for purposes of specific operative planning

After appropriate resection has been defined, one can then turn attention to the anticipated anastomosis. Several issues must be considered. Are the two bowel ends mobile or is one fixed (rectal or anal)? [13] Is there significant physical distance separating the ends? What specific techniques need consideration to enable adequate mobilization for tension-free anastomosis? How are the respective mesenteries oriented in relation to one another, and how will the anastomosis configuration be affected? Finally, what specific methods for actual bowel anastomosis will be used?

Successful healed anastomoses depend on careful preoperative planning, and a critical aspect of this preparation includes anticipation of obstacles and contingency strategies. Familiarity with multiple operative methods and the ability to adapt to variances in anatomy, pathologic findings, or operative conditions is critical. One must possess versatility or "surgical agility."

Mobilization

While remaining cognizant of the steps of anastomotic construction, the operative team must conduct the planned resection for the specific pathologic condition. Resection extent should not be influenced or potentially compromised by the anticipated anastomosis and potential concerns of bowel length and reach. One should not succumb to the allure of what is technically expedient. The savvy surgeon acknowledges that only after appropriate resection should one be concerned with the task of anastomosis, confident that he or she possesses the skill to mobilize the residual bowel and achieve a tension-free anastomosis.

Proximity refers to bringing the two segments in space for tension-free anastomosis. Tension threatens the initial anastomotic integrity, which for several days is entirely dependent upon the tensile strength of sutures or staples [6]. Tension also leads to ischemia that diminishes conditions for healing [14]. One of the fundamental aspects of anastomotic construction therefore is a tension-free anastomosis.

Small Bowel Mobilization

Small bowel resections represent the simplest bowel resection and typically do not require any significant mobilization given the intraperitoneal nature of the bowel and attached mesentery. The two limbs of bowel for anastomosis can be brought into proximity easily for a tension-free anastomosis.

Small bowel mobilization can be important in certain situations. One should be aware of the particular challenge of an extracorporeal anastomosis during right colectomy. Exteriorization of the proximal transverse colon will be affected by omental adhesions and gastrocolic adhesions. The entire hepatic flexure should be mobilized, by dividing the gastrocolic ligament and dissection off the sweep of the duodenum. Other features that affect the ability to perform this anastomosis in proper fashion include: the size of the omentum especially in the obese patient, a large specimen, shortened mesentery, and increased abdominal wall thickness. Each of these factors must be taken into account when considering specimen extraction site and size of incision.

Small bowel mobilization techniques, however, are critical when performing ileoanal anastomosis [15–17]. The root of the mesentery must be dissected to the pancreas and proximal aspect of the superior mesenteric artery. Relaxing incisions, or "step ladder incisions," can be made anterior and posterior in the mesentery or windows within the mesentery (Fig. 9.4) [18]. Finally, transillumination of the mesentery can identify arcades providing points of safe mesenteric vessel transection, again enabling further lengthening of the mesentery for additional reach of the ileal reservoir for anal anastomosis [19]. A recent cadaveric and angiographic study using fresh human cadavers examined various mobilization techniques and mesenteric division strategies for gaining length for ileal pouch anastomotic construction. This study validated the effectiveness of step ladder incisions technique [20].

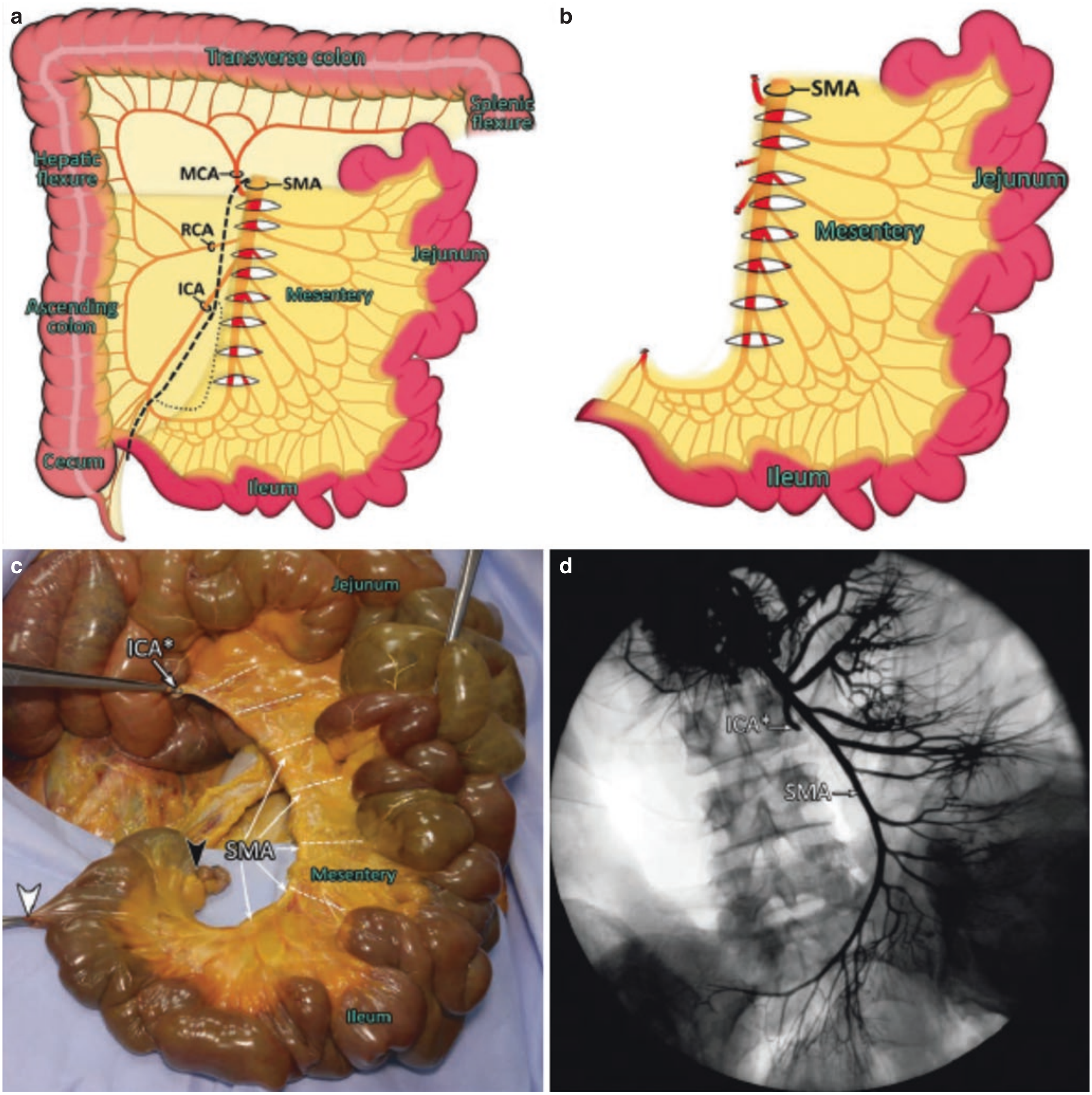


Fig. 9.4 Mesenteric lengthening 1. (**a**) incision of mesocolon and ligation levels of colic vessels during proctocolectomy are included by dashed line. Stepladder incisions are shown on the mesentery. (**b**) Appearance of the small intestine mesentery after proctocolectomy, and mesenteric lengthening is demonstrated. (**c**) Relaxing transverse incisions made on the small intestine mesentery are shown on the cadaver by dashed lines. The SMA and its ileal/jejunal branches in the mesentery were visualized by injecting diluted barium sulfate (white arrowhead, apex of the pouch; black arrowhead, transection point of the terminal ileum). (**d**) Angiographic image of the SMA and branches after mesenteric lengthening is shown. *Ligated vessels; ICA, ileocolic artery; MCA, middle colic artery; RCA, right colic artery; SMA, superior mesenteric artery. (Reused with permission from Ismail et al. [18]. Copyright © 2018 Wolters Kluwer)

Colonic Mobilization

Mobilization is a central issue for resections involving the left side of the colon and rectum. This is because one end of the anastomosis is essentially anatomically fixed [13]. A critical skill for the intestinal surgeon must be mastery of proximal mobilization of the residual left and more proximal colon following left-sided or rectal resection. Essentially, anastomotic construction requires full anatomic dissection and mobilization of the left colon. Whether or not splenic flexure mobilization is necessary for left-sided colonic resection or low anterior resection is often debated. What should not be debated, however, is the necessity of mastering this maneuver so that when called upon one can perform precise execution with proficiency.

Splenic Flexure Mobilization

This requires sophisticated knowledge of and operative technique for dissection of the anatomic tissue planes and division of embryologic adhesions (Fig. 9.5). The major steps include dissection of the left colon and transverse colon mesenteries completely off the retroperitoneum back to the midline aorta. Attachments to the kidney, stomach, spleen, and inferior border of the pancreas are divided, mobilizing the mesentery back to the inferior mesenteric vein.

High ligation of the inferior mesenteric artery provides upwards of 10 cm of additional length when compared to low ligation [21]. Division of the inferior mesenteric vein at the base of the pancreas produces substantial length [21]. This is an essential step to obtain adequate mobilization and mesenteric length for low pelvic anastomosis (Fig. 9.6).

Maximal mobilization can be further gained by mobilization of attachments to the pancreas beyond the inferior mesenteric vein, as the axis can be further shifted well to the right of the ligament of Treitz to where the middle colic artery arises (Figs. 9.7 and 9.8a, b). Complete dissection of the omentum off of the transverse colon—essentially separating the gastrocolic ligament—enhances release.

Finally, there often exists a hinge-like embryologic conformation of the mesentery of the splenic flexure that must be divided or released to straighten the mesentery (Fig. 9.9). This “unhinges” the angled conformation of the bowel at the splenic flexure (Figs. 9.10, 9.11, and 9.12) and creates a straightened mesentery and splenic flexure that can then descend (Figs. 9.13 and 9.14a, b) in a straight line from the middle colic vessels. This enables the descending colon conduit to reach well below the symphysis pubis to achieve a tension-free anal anastomosis.

Again, while some may choose to debate its necessity in all cases of low anterior resection [22], it would be folly to question the value of possessing the skill to perform full mobilization of the splenic flexure and familiarity with specific details for straightening the left colon [23]. While it is generally accepted that anastomotic leak following low anterior resection appears to correlate with decreasing anastomotic height—that is, the lower the anastomosis the higher the leak rate—master surgeons are able to defy such trends. Remarkably low rates of leak with left-sided anastomoses can be achieved consistently irrespective of anastomotic level [24], and the senior author of this series suggests that the key to low pelvic anastomosis is complete splenic flexure mobilization (personal communication).

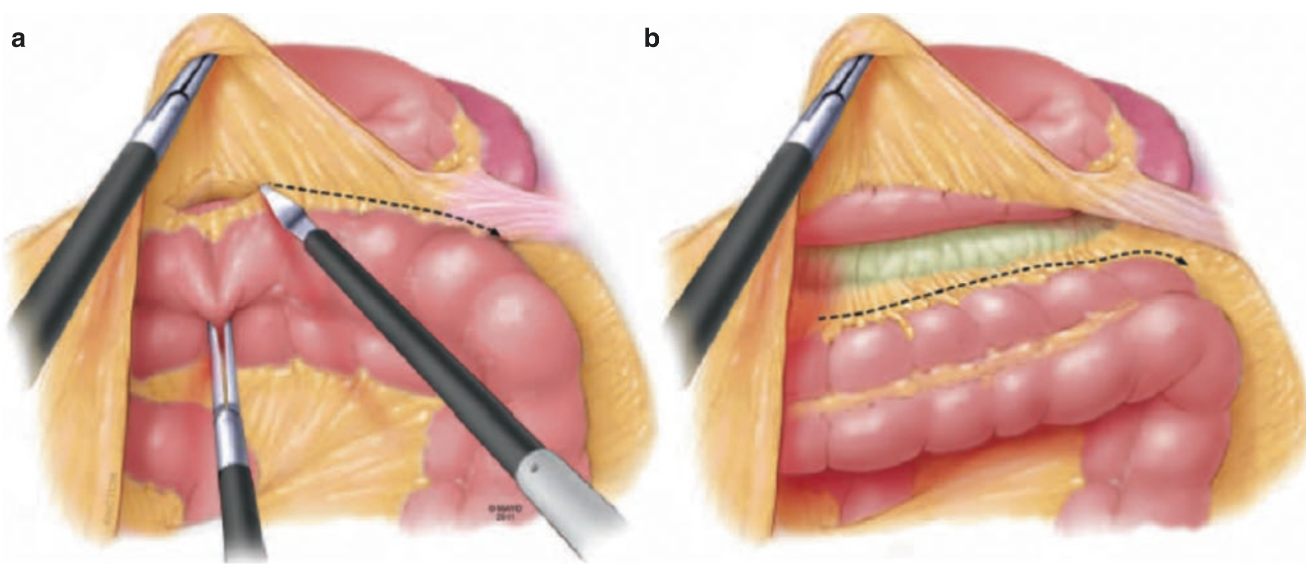


Fig. 9.5 Mobilization of splenic flexure, medial to lateral approach. The greater omentum is reflected superiorly and a transverse incision is made along the gastrocolic ligament releasing the transverse colon and entering the lesser sac. Care must be taken to avoid dissection posterior to the pancreas, where troublesome bleeding may occur. As dissection continues laterally, the renocolic and splenocolic ligaments are divided, as well as any other retroperitoneal attachments of the flexure. The spleen often remains out of view with this approach. (Reused with permission Merchea et al. [93]. Copyright © 2012 John Wiley and Sons)

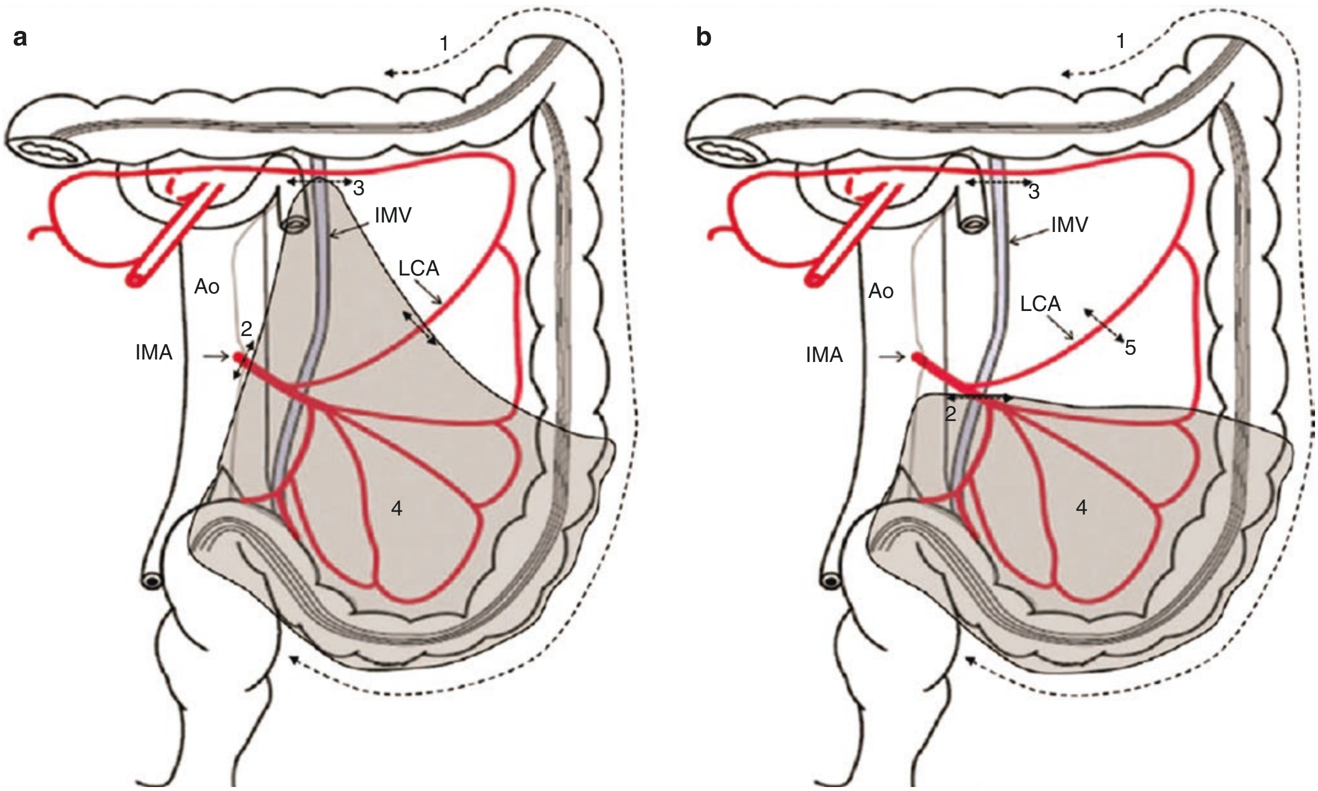


Fig. 9.6 View of the two procedures performed. High tie on left (**a**). Low tie on right (**b**). A, HT. Step 1, mobilization of the splenic flexure, descending colon, and sigmoid to the rectosigmoid junction; step 2, IMA division at its origin 1 cm distant from the aorta; step 3, IMV division at the lower part of the pancreas; step 4, sigmoidectomy with appropriate lymphadenectomy, including section of LCA. B, LT. Step 1, mobilization of the splenic flexure, descending colon, and sigmoid to the rectosigmoid junction; step 2, division of the IMA and IMV 1 cm distally to the origin of the LCA; step 3, IMV division at the lower part of the pancreas; step 4, sigmoidectomy with appropriate lymphadenectomy; step 5, secondary division of LCA; HT, high tie; LT, low tie; Ao, aorta; IMA, inferior mesenteric artery; LCA, left colic artery; IMV, inferior mesenteric vein; dimmed area, extent of resection. (Reused with permission [21]. Copyright © 2012 Wolters Kluwer)

Special Mobilization Techniques

In some instances involving extended resections of the left and transverse colon, or in cases of reoperation where prior left-sided resections have previously taken place, advanced mobilization techniques are available to bring bowel ends into proximity for anastomotic construction. Repeat low anterior resection often requires consideration for extraordinary mobilization to achieve anastomotic construction [25].

Retroileal Anastomosis or Ileal Mesenteric Window

First described by Toupet, the transverse colon can go underneath the small bowel through a surgically created "window" in the small bowel mesentery between the superior mesenteric artery and the ileocolic artery (Fig. 9.15) [26]. The maneuver requires complete splenic flexure mobilization to the root of the middle colic artery, dissecting the transverse colon mesentery at its root allowing the mesentery to pivot at the most proximal extent. This occasionally requires the cecum to be mobilized off the retroperitoneum as well as the root of the small bowel mesentery to facilitate the mesenteric window creation. Transillumination of the mesentery can be performed to identify the major vessels of the small bowel mesentery [27–29]. There is a bare area between the superior mesenteric artery and the ileocolic artery. A 4–5 cm long defect should easily accommodate the transverse colon and attached mesentery (Fig. 9.15). The mesentery should be straight and parallel to the longitudinal axis of the colon with a preserved marginal artery. The "cut edge" or divided edge of the mesentery of the transverse colon points left as the bowel descends to the right of the aorta through the mesenteric window toward the pelvis (Fig. 9.15a–d). This maneuver has also been performed using the laparoscopic platforms [30–32].

Right Colon De-Rotation (Deloyer's Procedure)

Infrequently, following extended resection, the right colon may be chosen as the conduit for anastomosis to the rectum or anal canal. The conduit blood supply is based upon the ileocolic artery and necessitates dissection to the origin of the ileocolic artery. This provides mobility of the mesentery to rotate without acute kinking of the vessel [33]. The de-rotation can also be described as an inversion of the cecum and terminal ileum [34]. The cecum and attached terminal ileum are rotated along the axis of the ileocolic artery in the sagittal plane, with the cecum moving superiorly and the ascending colon caudally (Figs. 9.16 and 9.17) The dorsal surface of the mesentery and ascending colon become ventral in position following de-rotation (Figs. 9.18, 9.19, and 9.20). Mobility of the mesentery and length of the ileocolic artery can enable reach of the conduit to the low pelvis and even the anal canal for ultra-low anastomosis. Functionally, preservation of colonic reservoir, water-absorptive surface area, and maintenance of the ileocecal valve improves post-operative function [34]. In a series of 48 patients, 67% of patients reported fewer than three bowel movements per day [35]. The maneuver has also been described laparoscopically [36]. In terms of safety, anastomotic leak rates in this series indicate predictable safe anastomotic healing. Appendectomy should be performed given the new location of the cecum in the mid-right side of the abdomen.

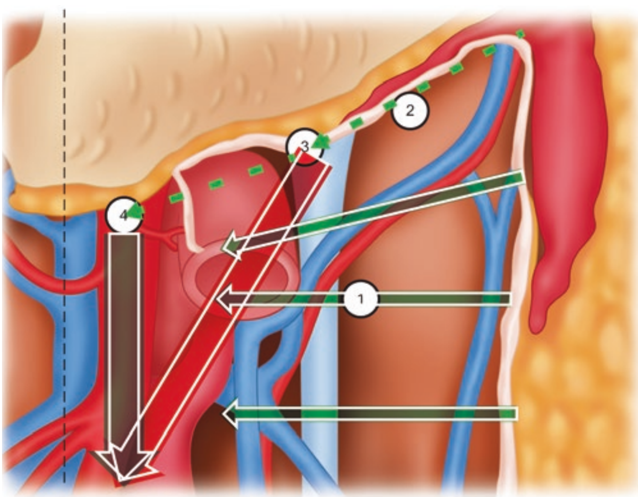


Fig. 9.7 More length obtained after additional mobilization from IMV to the middle colic artery. 1 Mobilize off Gerota's fascia to aorta; 2 Mobilize off inferior border pancrease; 3 Divide IMV; 4 Dissect to the middle colic vessel

Perfusion

One of the central principles of anastomotic construction remains preservation of blood supply and tissue perfusion following mobilization. Again, like tension, this fundamental concept seems empirical. Mastery of mesenteric anatomy, precise identification of named vessels, and meticulous dissection technique enable mobilization resulting in well-perfused bowel ends for anastomotic construction. Clinical assessment of bowel for anastomosis is therefore a critical skill. Color, motility, and visible bleeding from the mucosa represent basic means for assessment of the bowel perfusion and viability.

One approach in the case of left colectomy or low anterior resection, for example, is to purposefully dissect and skeletonize the marginal artery at the distal descending colon. The vessel is transected in order to observe brisk pulsatile arterial bleeding prior to precisely performing proximal resection (Fig. 9.21). This clinical assessment of adequate blood supply provides reliable information for anastomotic construction [24]. If such bleeding is not present, one proceeds proximally on the mesentery until brisk arterial inflow is

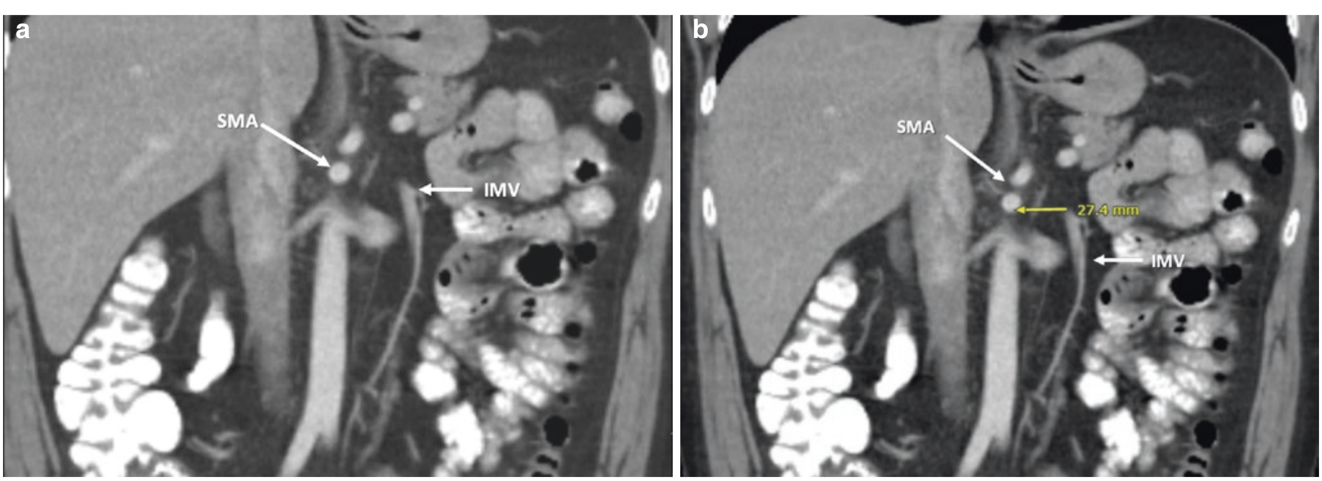


Fig. 9.8 (**a**, **b**) Additional distance mobilizing to the SMA/middle colic vessels

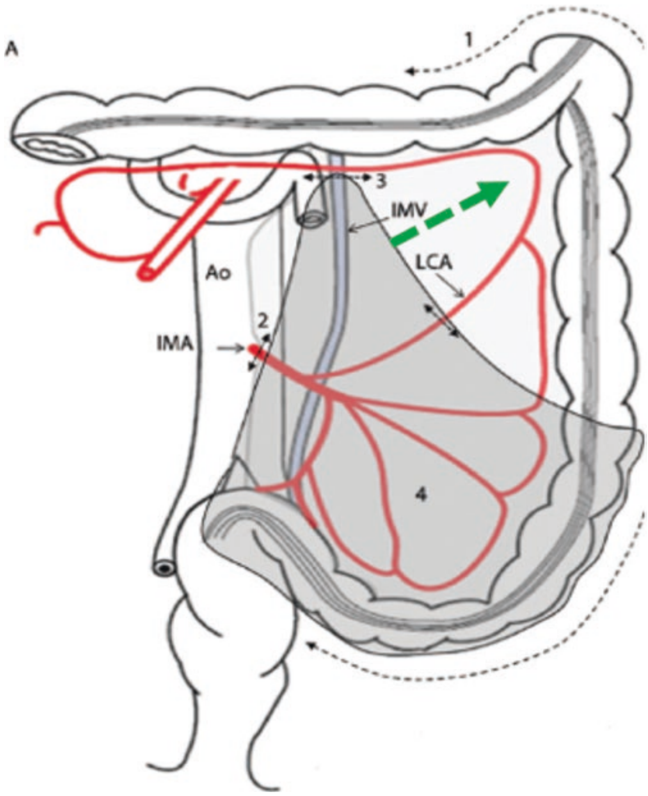


Fig. 9.9 LT. Step 1, mobilization of the splenic flexure, descending colon, and sigmoid to the rectosigmoid junction; step 2, division of the IMA and IMV 1 cm distally to the origin of the LCA; step 3, IMV division at the lower part of the pancreas; step 4, sigmoidectomy with appropriate lymphadenectomy; step 5, secondary division of LCA. Green arrow indicates incision of mesentery releases splenic embryologic conformation and straightens distal transverse colon and left colon; HT, high tie; LT, low tie; Ao, aorta; IMA, inferior mesenteric artery; LCA, left colic artery; IMV, inferior mesenteric vein; dimmed area, extent of resection. (Reused with permission [21]. Copyright © 2012 Wolters Kluwer). Schematic correlating to images in Figs. 9.10, 9.11, and 9.12

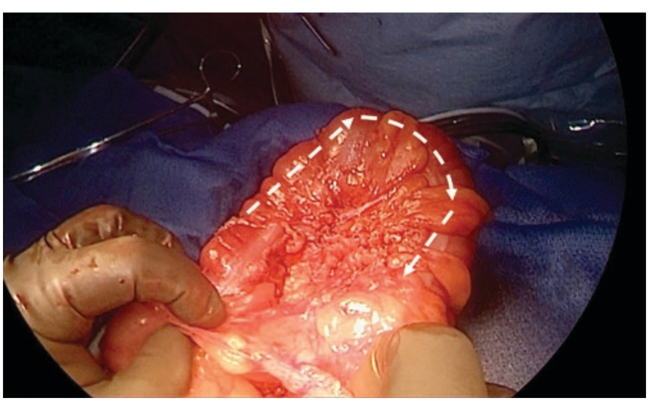


Fig. 9.10 Splenic flexure 180-degree conformation – due to residual omental adhesion. (Photos courtesy of HDV)

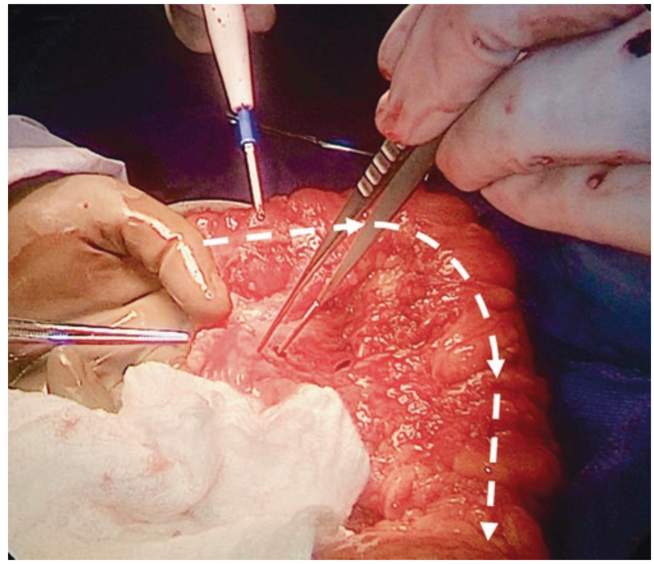


Fig. 9.11 Splenic flexure 90-degree conformation

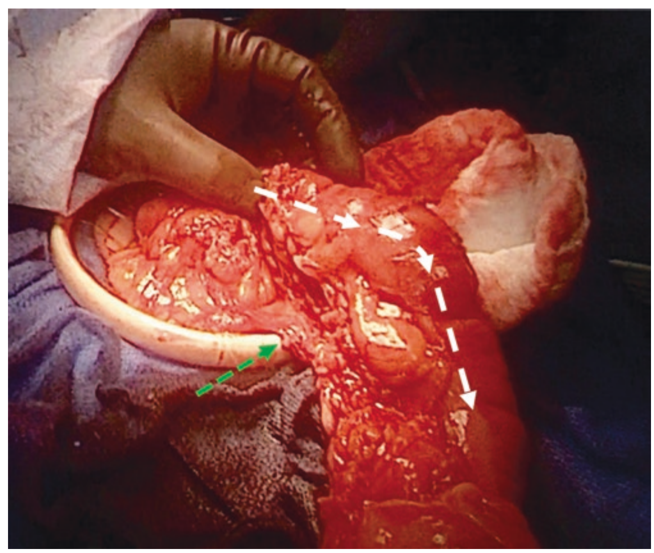


Fig. 9.12 Splenic flexure released and straightened. Green arrow indicates point of relaxing incision of mesentery up to marginal artery

present; this would identify the appropriate point of proximal bowel division. The value of clinical assessment cannot be overstated, and experience would indicate that it is reliable for anastomotic construction [24].

Indocyanine green fluorescence angiography is an intraoperative technique that is increasingly used to assess viability of the intestinal bowel during anastomotic construction (Fig. 9.22) [37–39]. ICG absorbs near-infrared (NIR) light at 800 nm and emits fluorescence. As ICG binds extensively to plasma proteins and is confined to the intravascular compartment, tissue microperfusion is indicated by the presence of fluorescence [40]. This technique has been employed during both open and minimally invasive surgery operations. Although the test is a subjective assessment and not yet routinely quantitative, additional information can be obtained to assess perfusion. The PILLAR II trial was a prospective multicenter clinical trial evaluating the utility of ICG fluorescence. Decisions regarding proximal resection were altered in 8% of cases [41]. Additional studies are necessary to determine if anastomotic leak can be reduced based on its use [42]. ICG may prove to be a useful adjunct to clinical assessment and provide means for confirming more precise resection of nonviable bowel, thereby confirming surgical decision making critical to anastomotic construction.

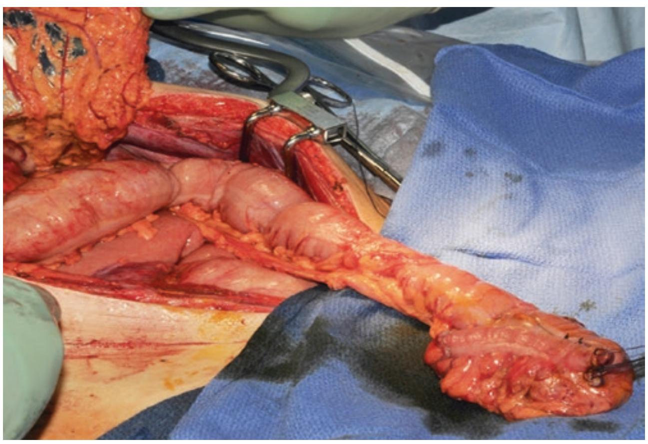


Fig. 9.13 Straight descent of colon with attached mesentery—arrow denotes relaxation of mesentery of the splenic flexure. (Photo courtesy of HDV)

Anastomosis Configuration

The configuration of anastomosis refers to the form in which the bowel ends relate to one another. End-to-end anastomosis, end-to-side, side-to-end, and side-to-side anastomoses are the general anastomotic configurations described. Choice of configuration is often a matter of pragmatism. Certain configurations are technically practical, physically sensible, and aesthetically more pleasing. The configuration should restore continuity in a manner that does not create tension on the mesentery or on the physical union of the bowel ends. It is important to consider that anastomoses are constructed with the patient supine. In the upright position, the mesentery and attached bowel will be affected by gravity, thereby impacting anastomotic construction and possibly tension.

Small bowel anastomosis can be performed end-to-end or side-to-side. The side-to-side anastomosis can be in the configuration of the traditional antiperistaltic functional end-to-end or it can be made in isoperistaltic fashion.

Following right colectomy, size discrepancy of the bowel must be addressed if an end-to-end anastomosis is chosen. This can be accommodated by performing a Cheatle slit along the antimesenteric aspect of the smaller bowel to then match the size of the larger bowel for end-to-end anastomosis (Fig. 9.23). Another way to compensate for size discrepancy is to perform a side-to-side anastomosis. An example of this is anastomosis between the ileum and the transverse colon following right colectomy. Classically, the two ends of bowel are aligned in antiperistaltic fashion (Fig. 9.24a–d) with anastomosis performed at the antimesenteric aspect of the bowel. Side-to-side can also be performed in isoperistaltic configuration (Fig. 9.25), and this method has been gaining popularity with minimally invasive surgical techniques.

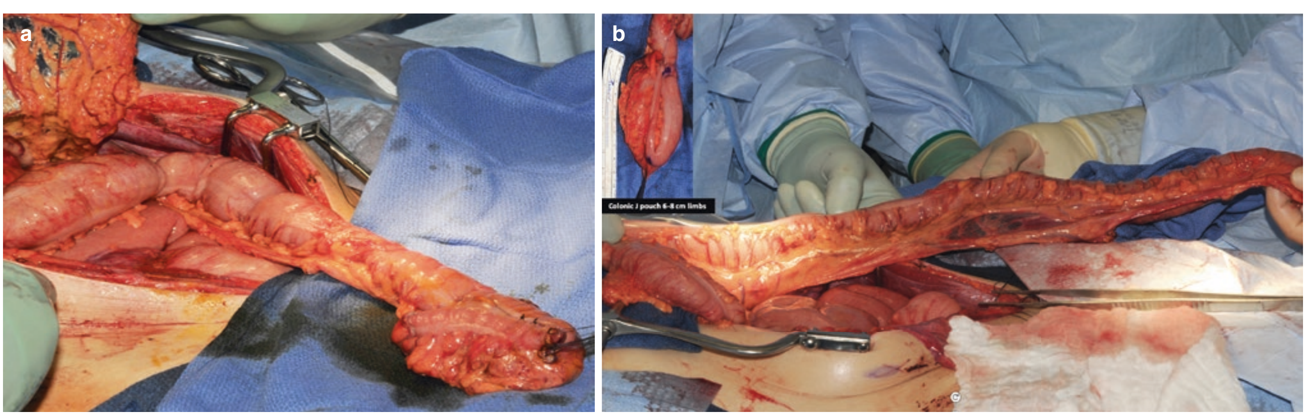
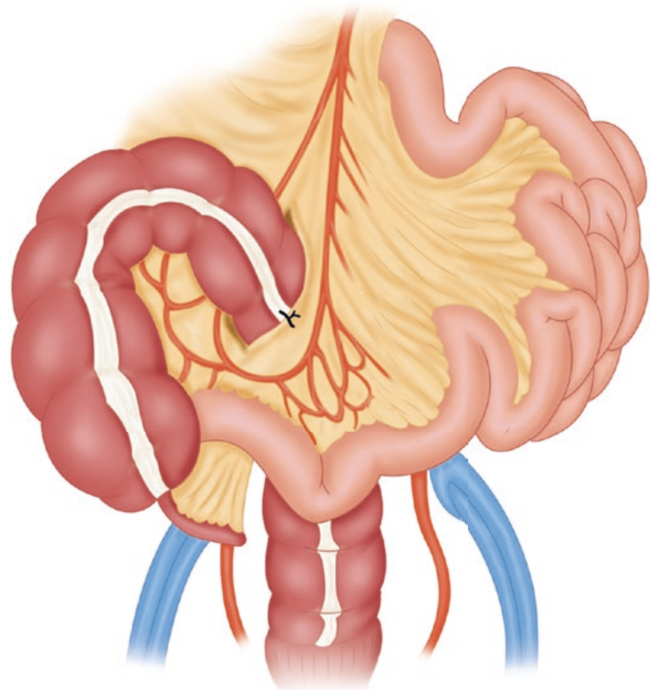


Fig. 9.14 (**a**) After resection, a straight length of colon from transverse colon to descending colon after resection easily resulting in (**b**) colon J-pouch and hand-sewn anastomosis. (Photo courtesy of HDV)

Fig. 9.15 Illustration of the Ileal mesenteric window between the superior mesenteric artery and the ileocolic artery



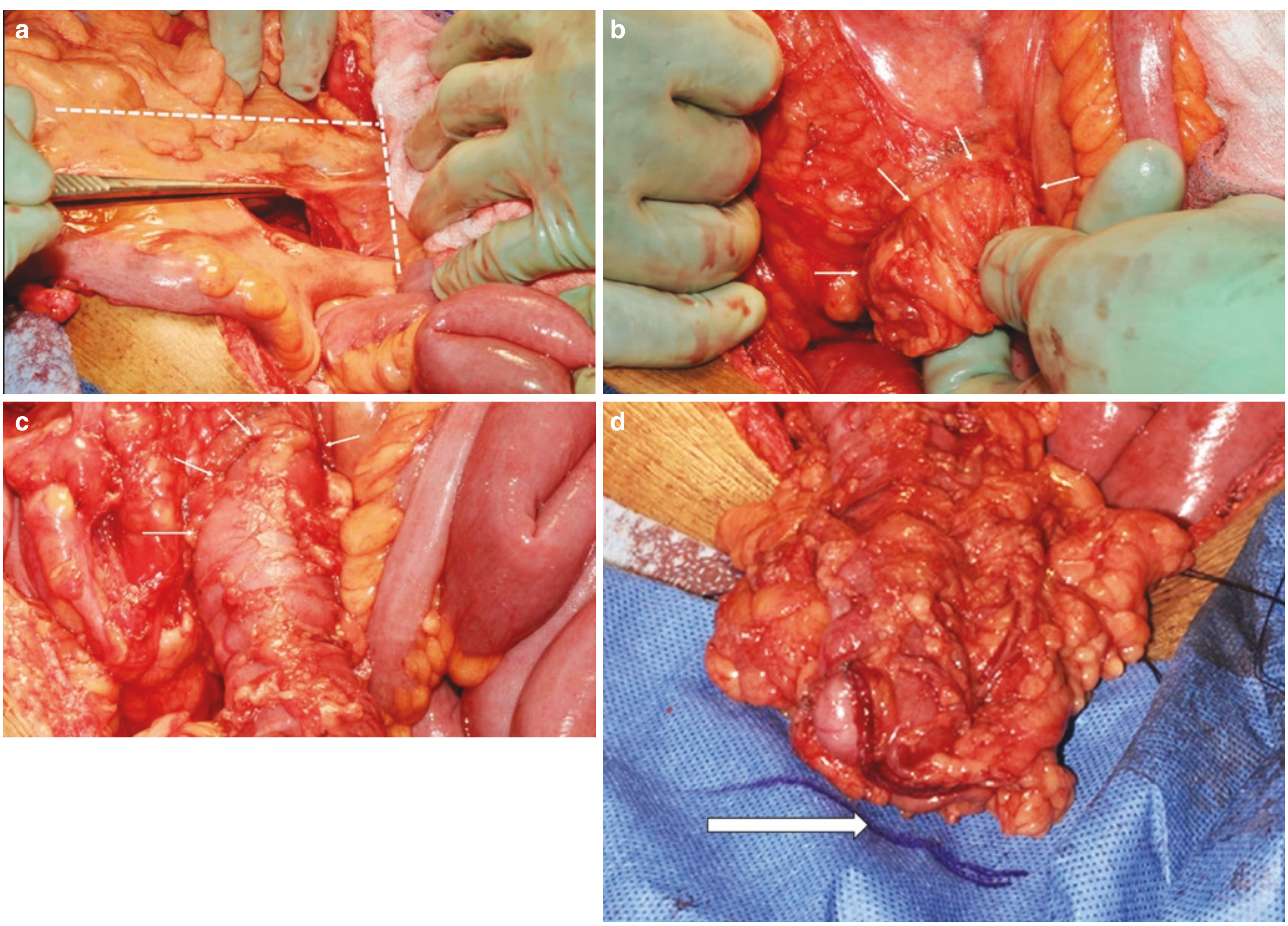


Fig. 9.16 (**a**) Mesenteric window. (**b**) Transverse colon. Arrows delineates mesenteric defect through which transverse colon passes. (**c**) Transverse colon traverses window. Arrows delineates mesenteric defect through which transverse colon traverses. (**d**) Transverse colon after retroileal window. Arrow denotes inferior aspect of symphysis pubis for coloanal anastomosis. (Photos courtesy of HDV)

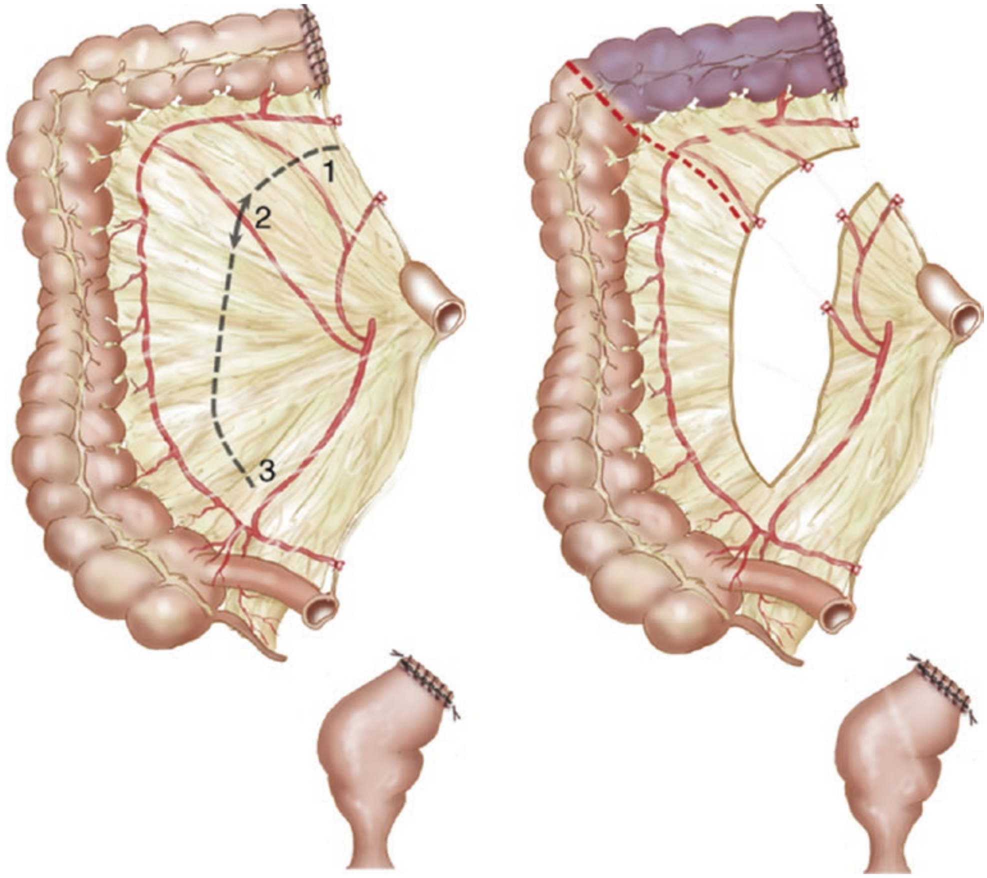


Fig. 9.17 Middle colic and right colic arteries divided likely requiring sacrifice additional portion transverse colon. Ascending colon supplied by ileocolic artery. Dissection of right colon mesentery off retroperitoneum to SMA. (Reused with permission [33]. Copyright © 2018 Elsevier)

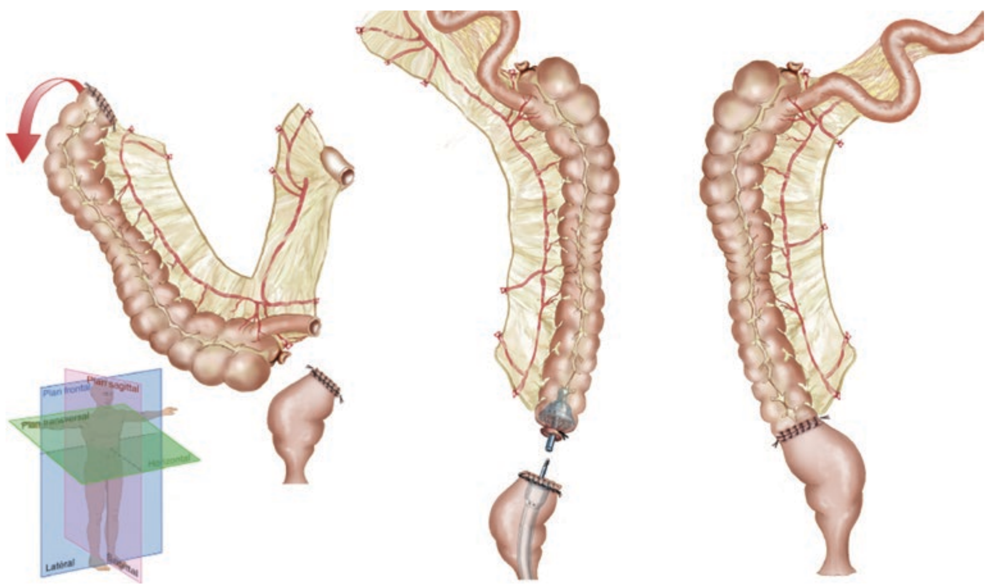


Fig. 9.18 Appendectomy performed. Right colon mesentery rotated in the sagittal plane counterclockwise with cecum placed in the right upper quadrant and ventral surface of right colon now dorsal. Ileum enters cecum from left to right. (Reused with permission [33]. Copyright © 2018 Elsevier)

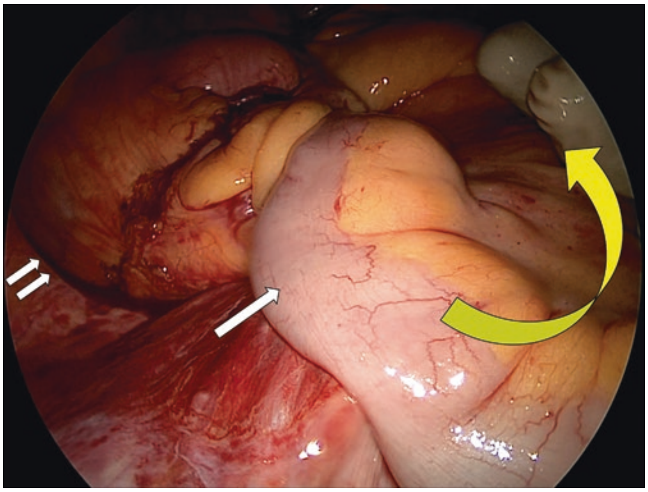


Fig. 9.19 Double arrow – cecum. Single arrow – terminal ileum. View of ileocolic junction prior to de-rotation. Yellow arrow denotes anticipated movement upon de-rotation in sagittal plane. (Photo courtesy of HDV)

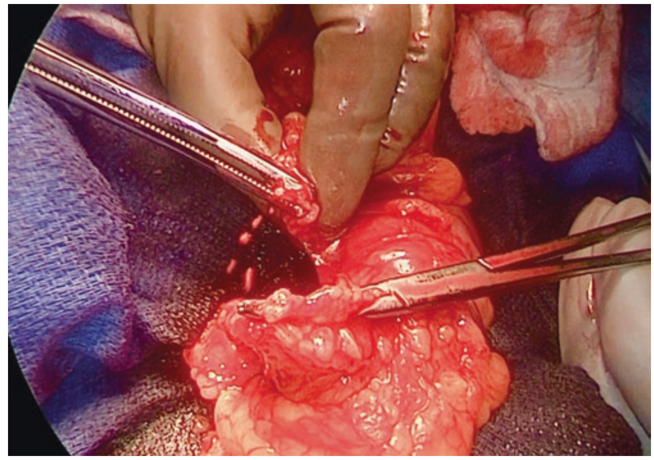


Fig. 9.21 Clinical assessment of perfusion of bowel for anastomosis. Pulsatile arterial bleeding from divided marginal artery. (Photo courtesy HDV)

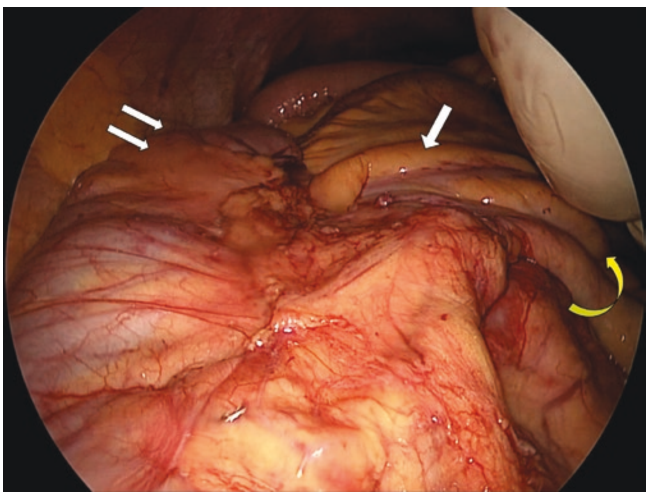


Fig. 9.20 Dorsal surface of colon and mesentery now ventral following de-rotation in sagittal plane. Double arrow – cecum now in right upper quadrant. Single arrow – terminal ileum. Yellow arrow – denotes rotation of ileocolic pedicle and mesentery in sagittal plane. (Photo courtesy HDV)

Finally, size discrepancy can be addressed by an end-to-side or side-to-end configuration (Fig. 9.26). The advantage to an end ileum to side of transverse colon is that this can be performed utilizing circular stapler without any intersecting staple lines (Figs. 9.27, 9.28, and 9.29).

A relatively recent novel anastomotic configuration is the Kono-S anastomosis configuration. This technique was described as a specific method for anastomosis in the treatment of Crohn's disease. It is a variation of a side-to-side configuration that involves the antimesenteric side of both portions of bowel. The bowel is divided proximally and distally resecting the involved Crohn's disease. The mesentery of the bowel to be resected is divided directly adjacent to the mesenteric edge of the bowel, thereby preserving blood supply and enteric nerves [43]. The bowel is transected with staplers placed transversely across the intestine wall perpendicular to the mesentery. The ends of the divided bowel are sutured together acting as a "column," excluding the anastomosis from the mesentery. The antimesenteric aspect of each portion of bowel is opened longitudinally and the anastomosis is performed transversely in Heineke-Mikulicz fashion (Figs. 9.30 and 9.31). Cohort studies demonstrate acceptable safety when compared to traditional side-to-side anastomosis and this technique has been associated with a lower incidence of recurrent disease [44, 45].

In the case of extended right colectomy with anastomosis to the distal third of the transverse colon, mobilization of the splenic flexure reduces the distance the ileum must traverse in spite of the mobility of the intraperitoneal ileum. In this case, isoperistaltic side-to-side appears to be advantageous. When subtotal colectomy is performed, one can mobilize the sigmoid colon and transpose it to the right lower quadrant and hypogastrium. Then, ileal to sigmoid colon anastomosis side-to side-configuration can be performed with the ileum resting in the native or in vivo position (Figs. 9.32 and 9.33).

Colocolonic anastomosis is rare. Splenic flexure tumors can present technical challenge in terms of extent of resection and

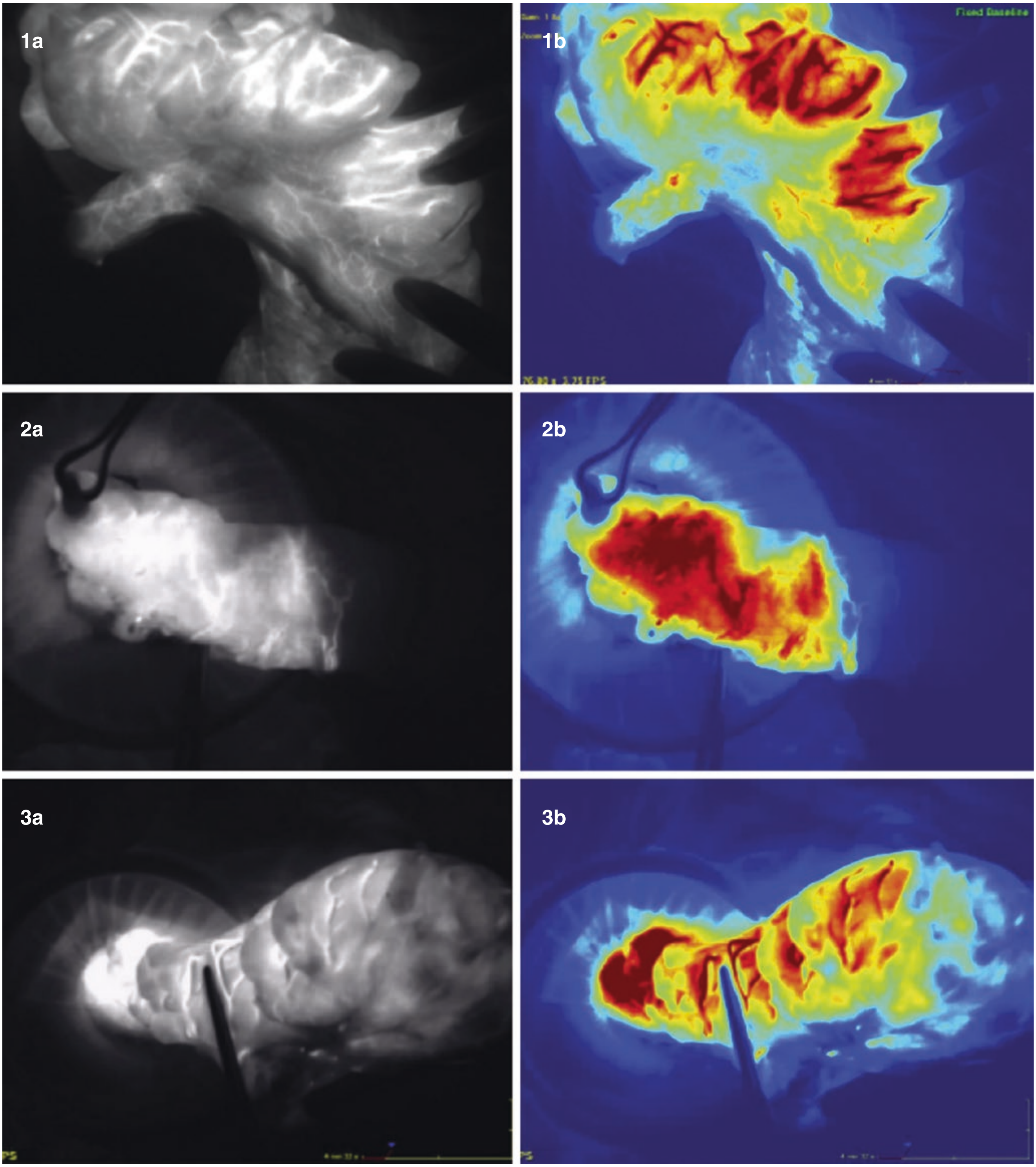


Fig. 9.22 Panels (1**a** and **b**) showed a typical well-perfused left colon during ICG fluorescence angiogram perfusion assessment of the exteriorized left colon without division of the marginal artery. Panels (2**a** and **b**) showed a demarcation of perfusion at where the marginal artery was divided. Panels (3**a** and **b**) showed a perfusion gradient across the exteriorized left colon. (Reused with permission [40]. Copyright © 2019 Elsevier)

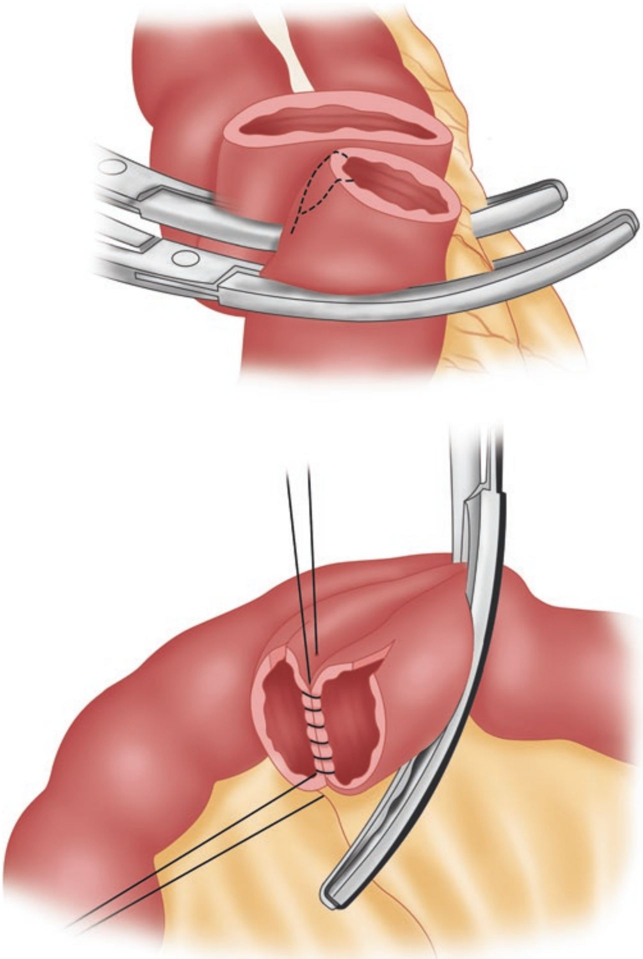


Fig. 9.23 Cheatle slit (anastomotic technique, suture). (Photo courtesy HDV)

the residual bowel present for anastomosis [46, 47]. While the optimal resection may be debatable, splenic flexure resection has been described leaving mid-transverse colon and sigmoid colon for anastomosis. In this instance, side-to-side anastomosis can be performed, but the mesenteric mobility and the more rigid nature of bowel wall do not lend itself well to side-to-side anastomosis. The authors prefer an end-to-end anastomosis as it appears to lay neatly (Fig. 9.34). This can be performed with circular or linear staplers or can be hand-sewn.

Pelvic anastomoses are considered the most challenging technically and can be influenced by unique considerations that may dictate anastomotic configuration. A pelvic end-to-end anastomosis may be necessary as a result of bowel length or surgeon preference. While pelvic reservoirs may be the preference of the surgeon, a narrow pelvic inlet can limit the size of the conduit or proximal bowel that can traverse the pelvic floor for anastomosis. This is most commonly found in the male pelvis or obese individuals. Conversely, that being said, a wide pelvis may easily accommodate either a colonic J-pouch or a side-to-end anal anastomosis should a pelvic reservoir be desired.

Anterior resection or sigmoid colectomy with anastomosis to the upper rectum generally is performed in an end-to-end fashion (Fig. 9.35). Occasionally, size mismatch can make side of colon to end of rectum technically appealing. The same is true for ileorectal anastomosis where one can choose side-to-end versus end-to-end reconstruction.

Low Pelvic Anastomosis

Low pelvic anastomosis can occasionally be limited by reach or size of pelvic inlet. However, functional challenges can result from straight coloanal anastomosis prompting use of reservoir reconstruction. Low anterior resection syndrome can be a debilitating functional consequence of low colorectal or coloanal anastomosis, affecting quality of life of patients following treatment for mid to low rectal cancer.

Pelvic reservoirs such as the colonic pouch (Fig. 9.36) or the side-to-end anastomosis with 5 cm efferent colonic end (Fig. 9.37) appear to provide functional benefit in regard to stool frequency and urgency [48–51, 52]. Some argue that by 2 years after surgery, the function of a straight anastomosis ultimately will approximate that of a colonic J-pouch [53, 54]. Other series indicate that colonic pouch continues to provide functional advantage even at 5 years [6, 48, 55]. Even if a straight anastomosis achieves equivalency at 24 months, a patient suffering from LAR syndrome for 24 months can be so discouraged that they elect to return to a stoma. Poor function is second only to anastomotic leak as a cause for conversion from an existing low pelvic anastomosis to permanent colostomy [56, 57]. In any case, a colonic reservoir like a J-pouch does not by itself obviate the possibility of LAR syndrome and upwards of 30% of patients may still experience increased frequency and urgency.

Some have concerns about the increased complexity of reconstruction with a colonic pouch and the additional staple line. A recent ACS-NSQIP study revealed that colonic J-pouch compared to straight anastomosis was associated with fewer reoperations, organ space infection, and increased ICU usage [58]. In general, in regard to anastomotic leak colonic J-pouch anal anastomosis compares favorably to straight anastomosis in spite of the perception of a more complex anastomosis [50, 59, 60]. The anastomosis is side-

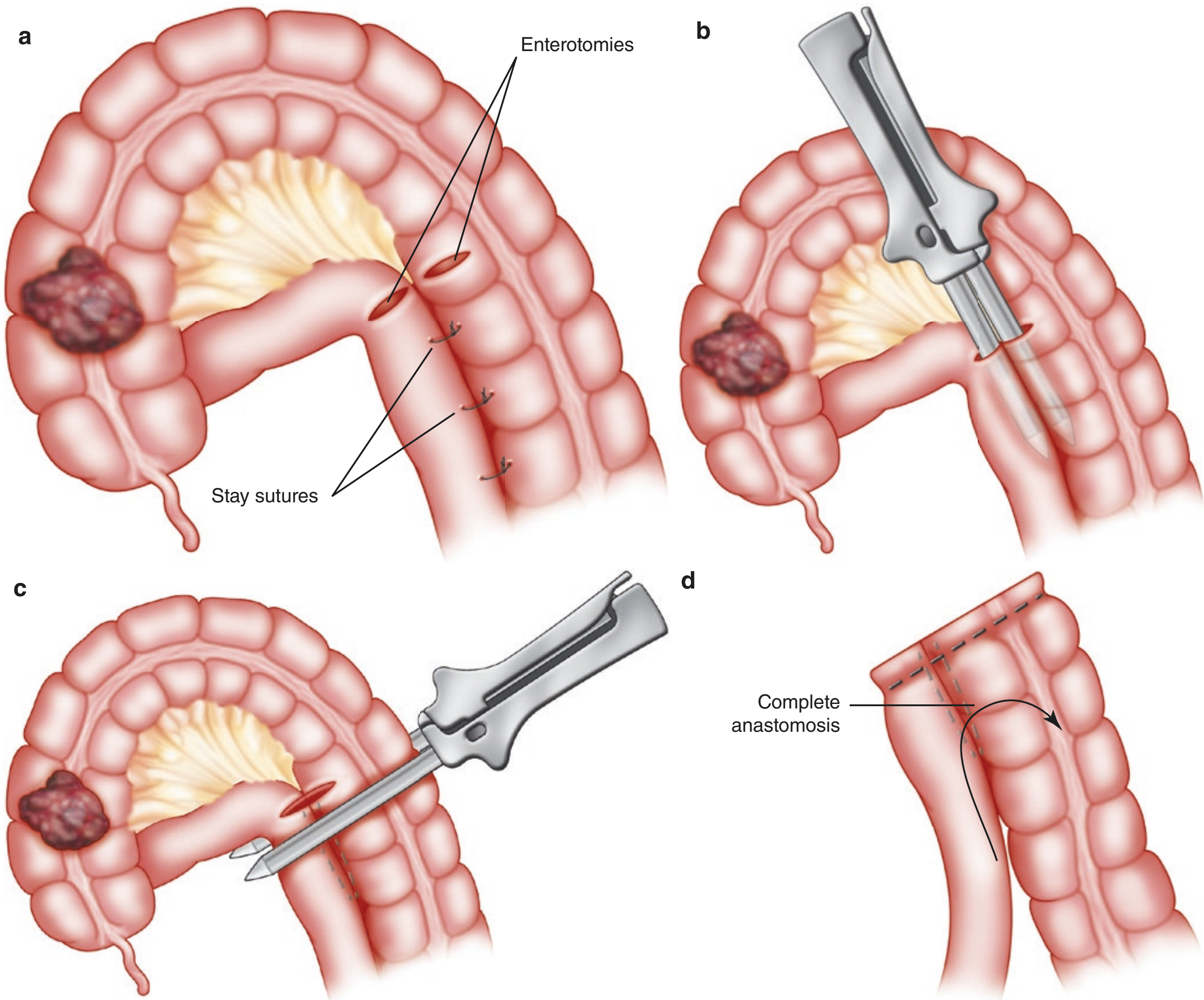


Fig. 9.24 Barcelona anastomosis: (**a**) Stay sutures are placed and two antimesenteric enterotomies are made. (**b**) A linear stapler is used to construct the common wall. (**c**) An additional firing of the linear stapler is used to complete the anastomosis and resect the specimen. (**d**) Completed anastomosis. (Reused with permission from Hunt SR, Silviera ML. Anastomostic construction. Steele et al. [94]. Copyright © 2016 Springer Nature)

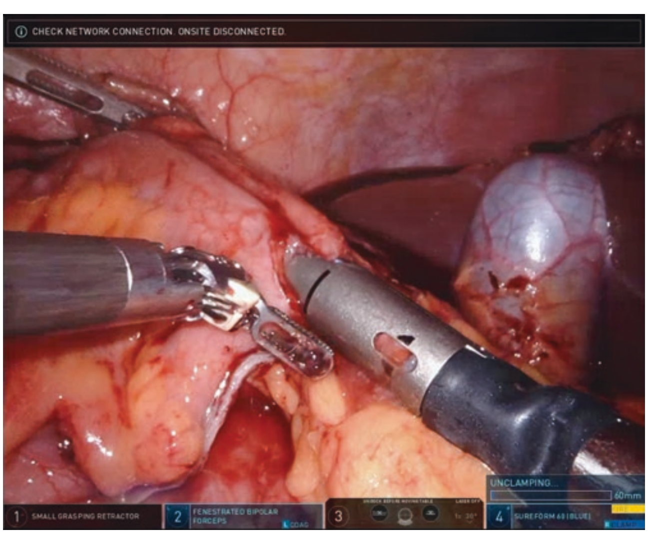


Fig. 9.25 Robotic isoperistaltic side-to-side ileal—transverse colon anastomosis. (Photo courtesy of Drew Gunnells, MD)

to-end with more reliable perfusion of the proximal aspect of colon conduit compared to the end of colon. The mass of the mesentery resulting from the side-to-side pouch construction fills the dead space of the presacral area of the pelvis, further reducing areas for fluid accumulation, which theoretically assists in reducing pelvic sepsis.

All of these features are shared by the side of colon to end of anorectum reconstruction (STE; "Baker-type anastomosis"). A technical aspect is that the efferent limb distal to the STE anastomosis should be 5–6 cm long. Compared to a colonic J-pouch, the bowel function appears equivalent [61, 62] and is superior to a straight anastomosis [60]. In terms of morbidity, there is no difference when compared to a colonic J-pouch. STE, however, may be faster to perform than a colonic pouch [61, 62]. The additional time to construct a neorectal reservoir should be balanced against the potential long-term benefits.

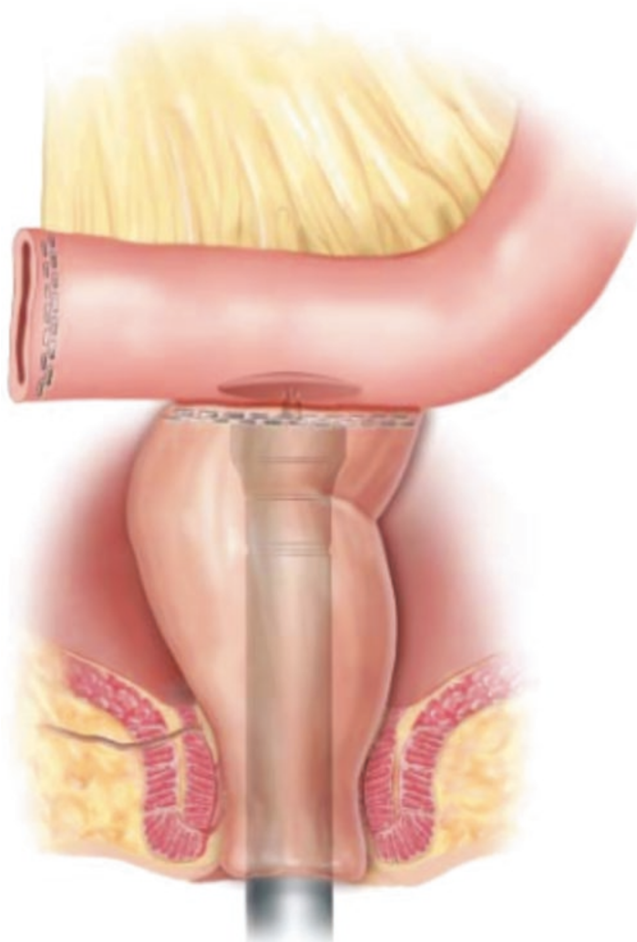


Fig. 9.26 Stapled end-to-side ileorectal anastomosis. (Reused with permission from Wexner SD, Fleshman JW, eds. Colon and Rectal Surgery: Abdominal Operations. Wolters Kluwer, 2018. Copyright © 2018 Wolters Kluwer)

Fig. 9.27 End-to-side ileocolonic anastomosis after right colectomy. (Photos courtesy of HDV)

Fig. 9.28 End-to-side ileocolonic anastomosis after right colectomy. (Photos courtesy of HDV)

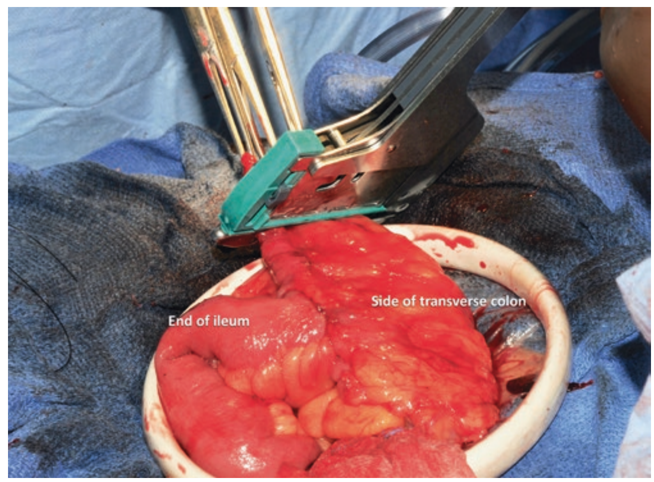


Fig. 9.29 Completed end-to-side ileocolonic anastomosis after right colectomy. (Photo courtesy of HDV)

Methods for Anastomotic Construction

Multiple methods of anastomotic construction exist but can be broadly divided into hand sewn or stapled. In some respect, this is naïve as more often than not both major methods are combined to greater or lesser degrees. A two-layered hand-sewn intestinal anastomosis may first be preceded by bowel transection with linear cutting staplers. Similarly, a robotic isoperistaltic side-to-side small bowel to colon anastomosis following right colectomy often involves hand-suturing the common defect closed. While technique and method often can seem to be polarized, the reality is that anastomotic construction techniques require understanding and mastery of both major categories.

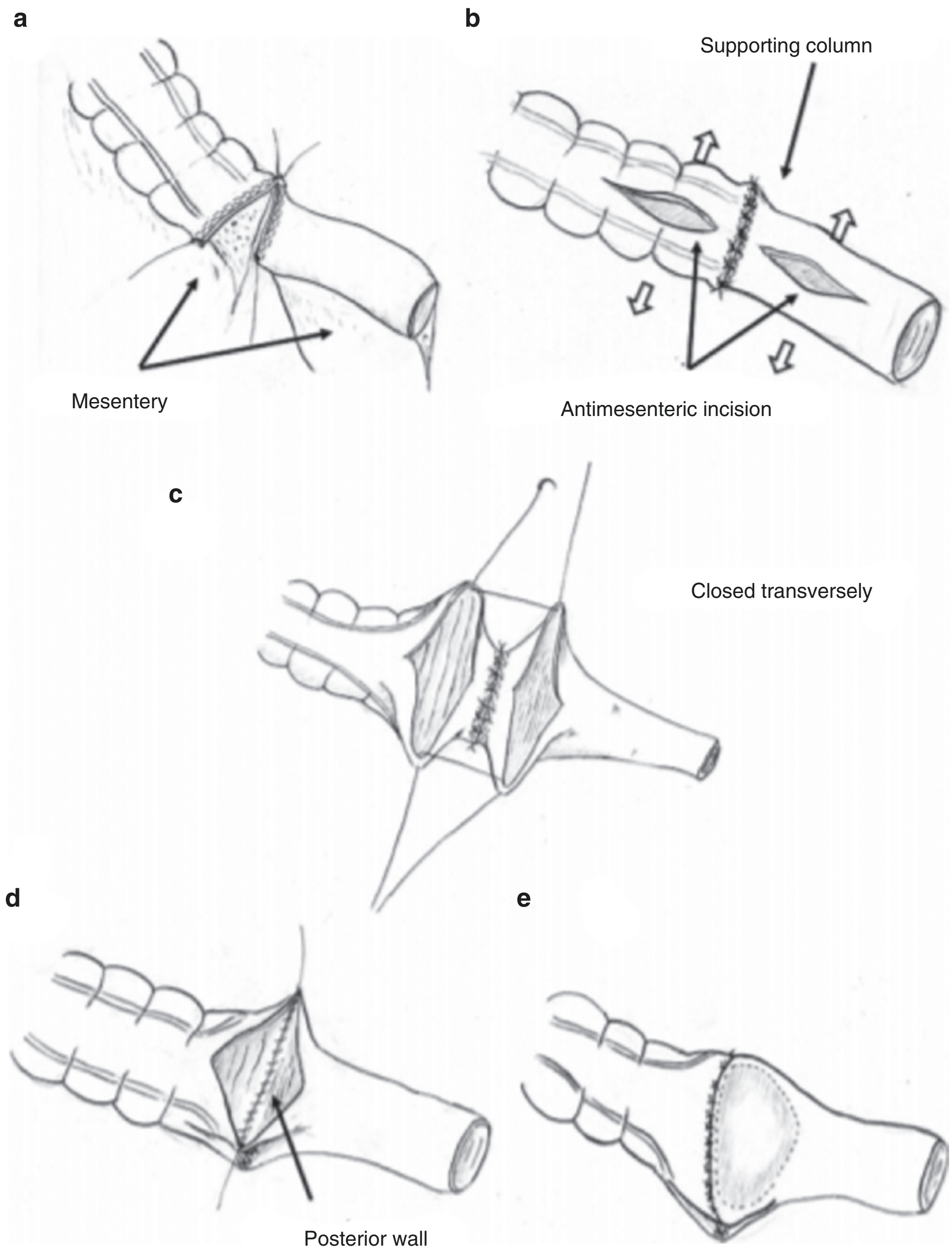


Fig. 9.30 Kono-S anastomosis for Crohn's disease. (**a**) The bowel was divided with a linear stapler perpendicular to the mesentery. Each stapled line was connected and reinforced (supporting column). (**b**) Antimesenteric longitudinal incisions (7–8 cm) were performed on each stump, starting within 0.5–1 cm away from the staple line. (**c**) Antimesenteric orifice was closed transversely. (**d**) Single layer running suture was used as posterior wall. (**e**) Anterior wall was closed in two layers with running and interrupted sutures. (Reused with permission [15]. Copyright © 2018 Springer Nature)

Sutured Anastomosis

Hand-sutured anastomoses historically represent the earliest form of intestinal anastomotic construction [1, 7, 8]. It continues to be a mainstay of surgical practice. The ability to consistently perform the precise technique requires tremendous technical discipline, concentration, and manual dexterity, given the fact that tissues are neither uniform nor static. Certainly, proficiency and skill range from workman-like to that of an artisan depending on surgeon traits: innate dexterity, meticulous attention to detail, and intense concentration. To do it well requires practice and experience. The technique has evolved over time and can be applied for any potential type of anastomosis involving small or large bowel, rectum or anus, and performed using any configuration. Thus, the hand-sewn method for anastomotic construction must be considered a fundamental and dependable technique, and intestinal surgeons must be unwavering in their commitment to mastering this technique.

Specific aspects of sutured anastomosis have been examined and investigated including: suture material, inverted versus everted technique, continuous versus interrupted, single- versus two-layered, and importance of tissue pur-

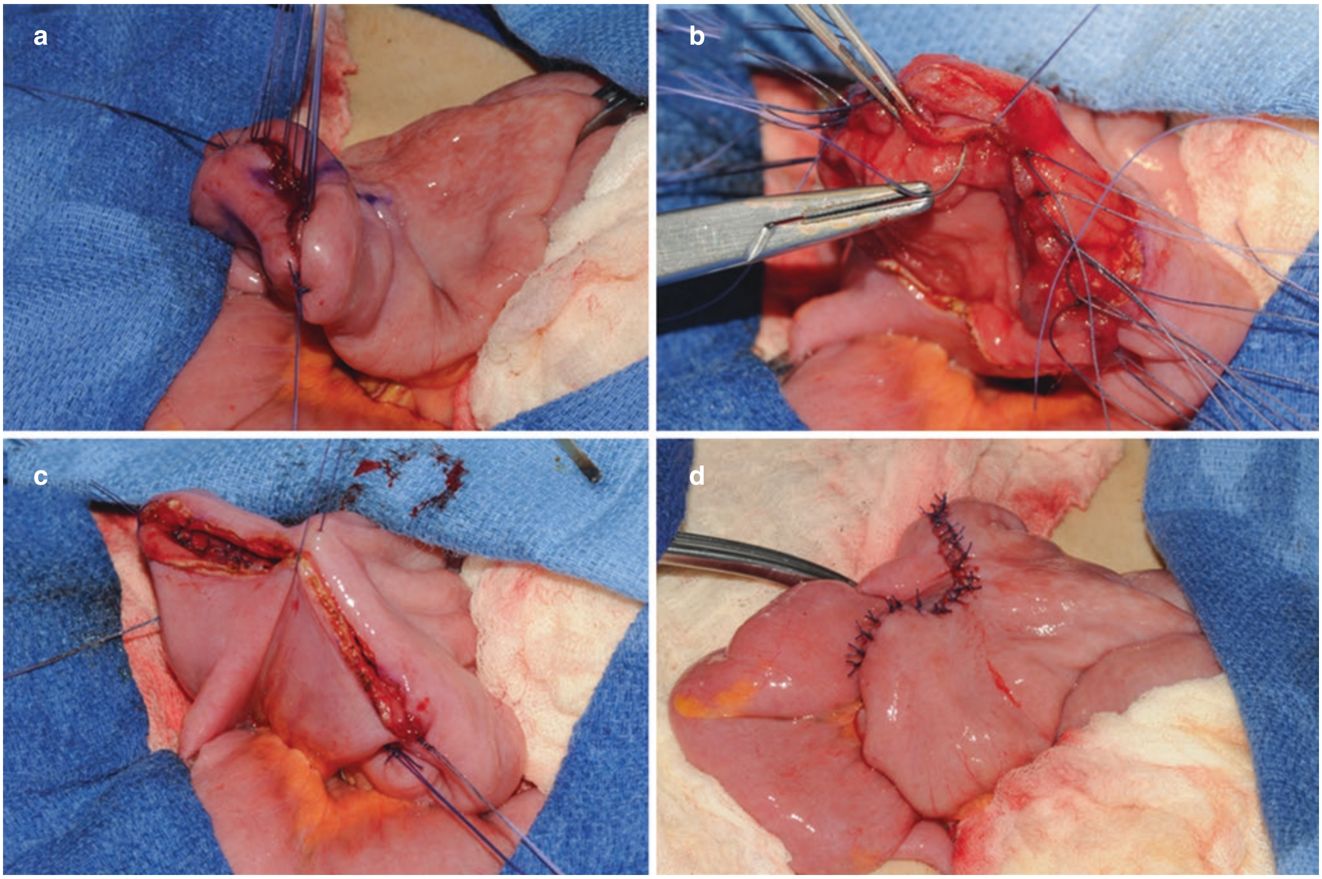


Fig. 9.31 Kono-S anastomosis. (**a**) Column of staple lines approximated. (**b**) Back wall of single layered interrupted simple sutures. (**c**) Anterior layer stay sutures. (**d**) Completed Kono-S hand-sewn anastomosis. (Photos courtesy of HDV)

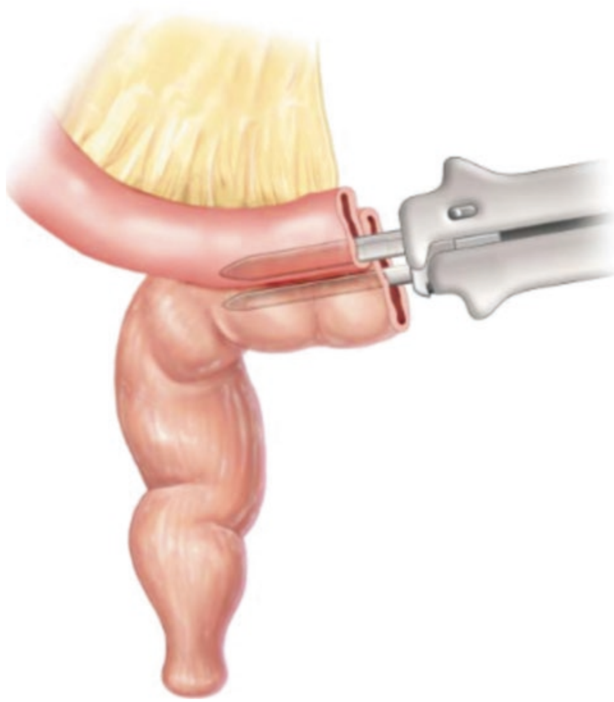


Fig. 9.32 Side-to-side functional end-to-end ileocolic anastomosis. (Reused with permission from Wexner SD, Fleshman JW, eds. Colon and Rectal Surgery: Abdominal Operations. Wolters Kluwer, 2018. Copyright © 2018 Wolters Kluwer)

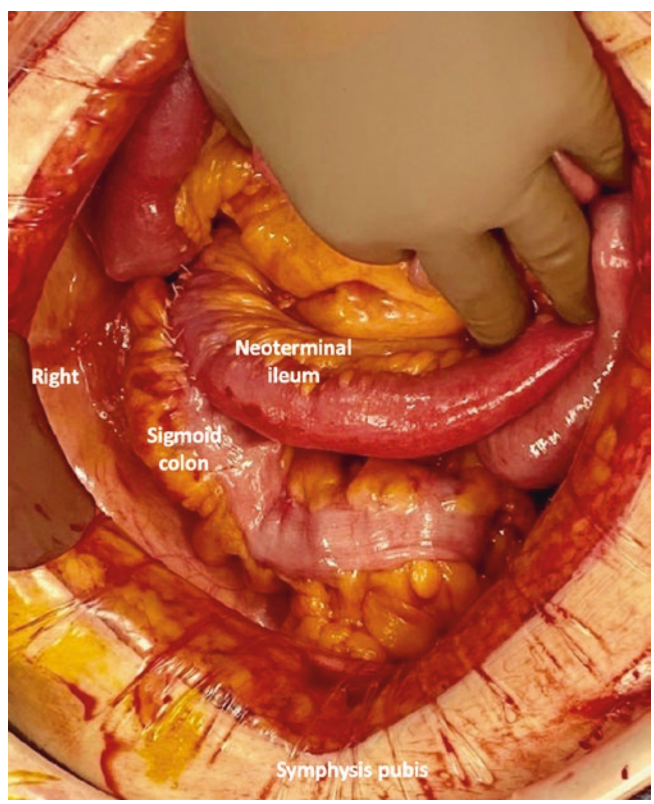


Fig. 9.33 Ileosigmoid side-to-side anastomosis configuration following transposition of sigmoid colon to right lower quadrant. (Photo courtesy of HDV)

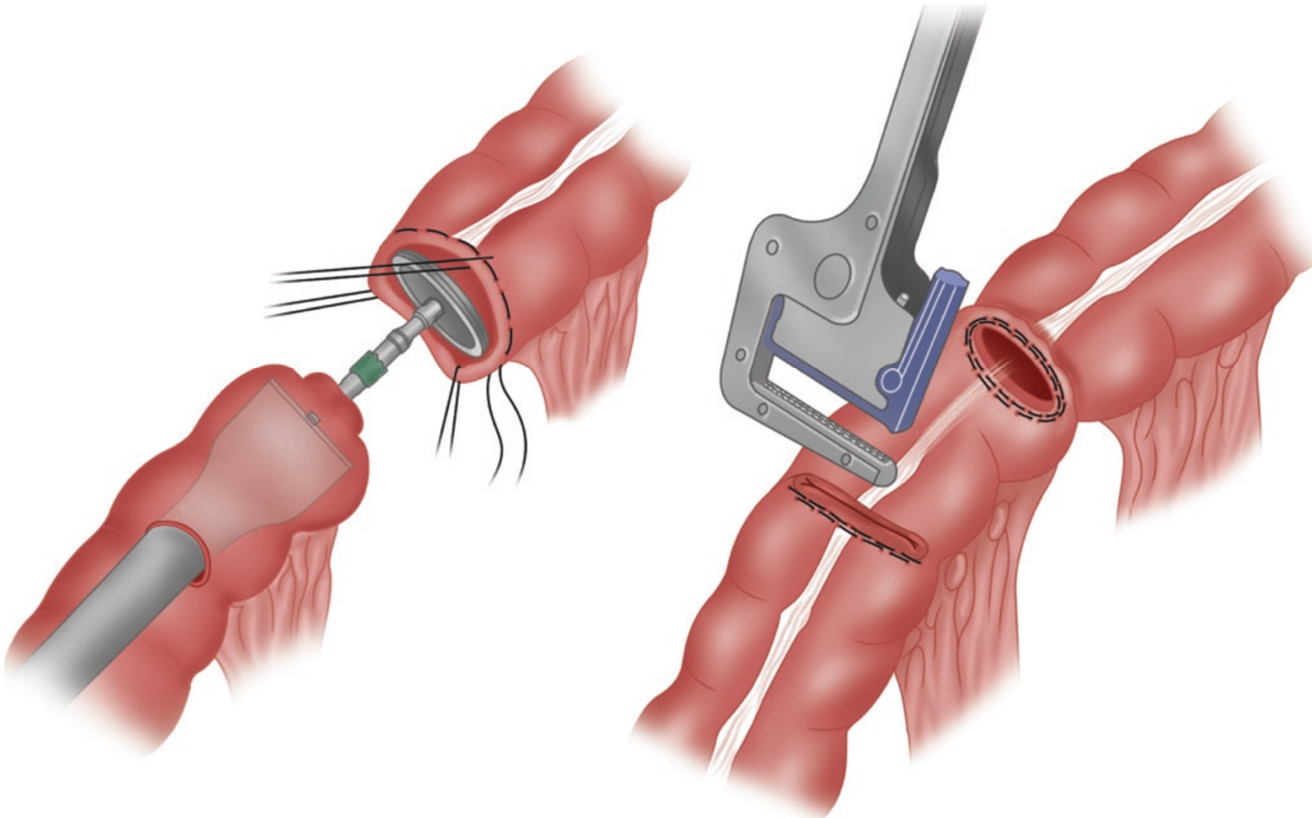


Fig. 9.34 Colocolonic end-to-end anastomosis

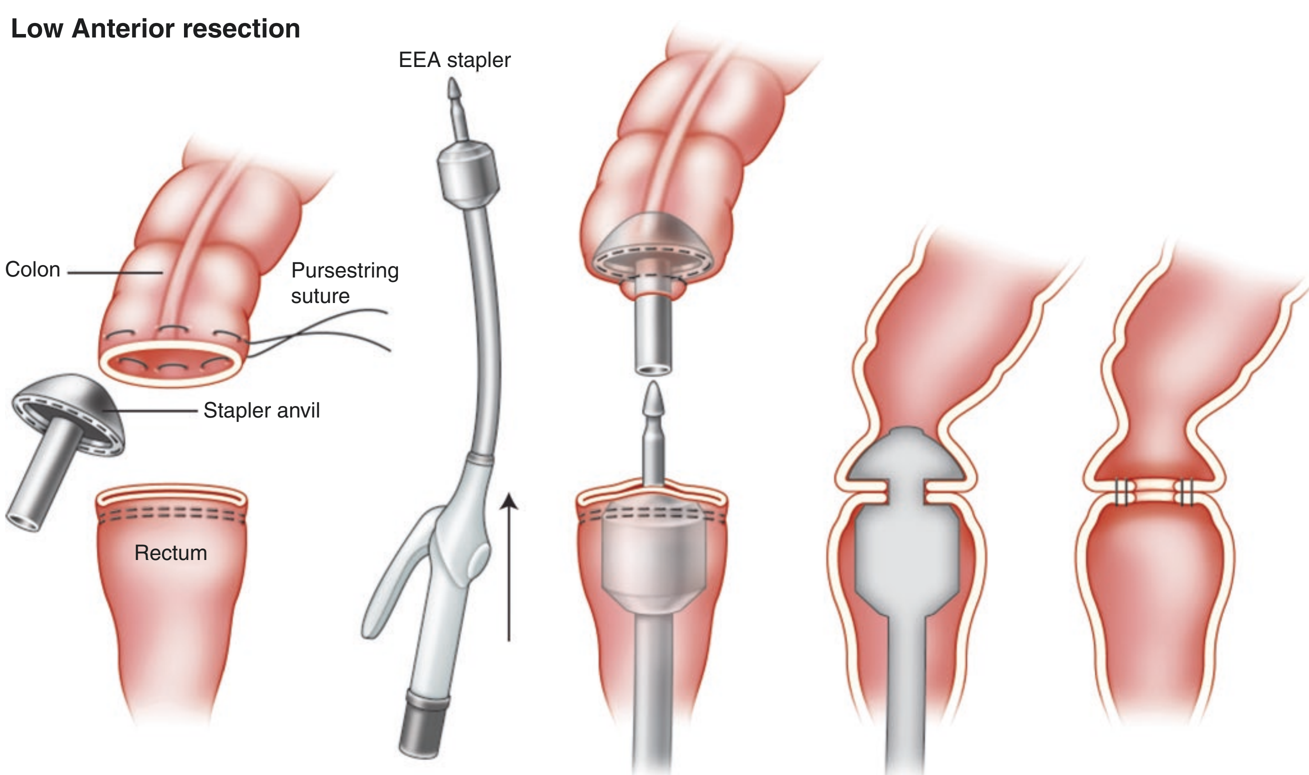


Fig. 9.35 Stapled colorectal anastomosis following a low anterior resection, the EEA stapler is used to construct an end-to-end anastomosis. (Reused with permission from Hunt SR, Silviera ML. Anastomostic construction. Steele et al. [94]. Copyright © 2016 Springer Nature)

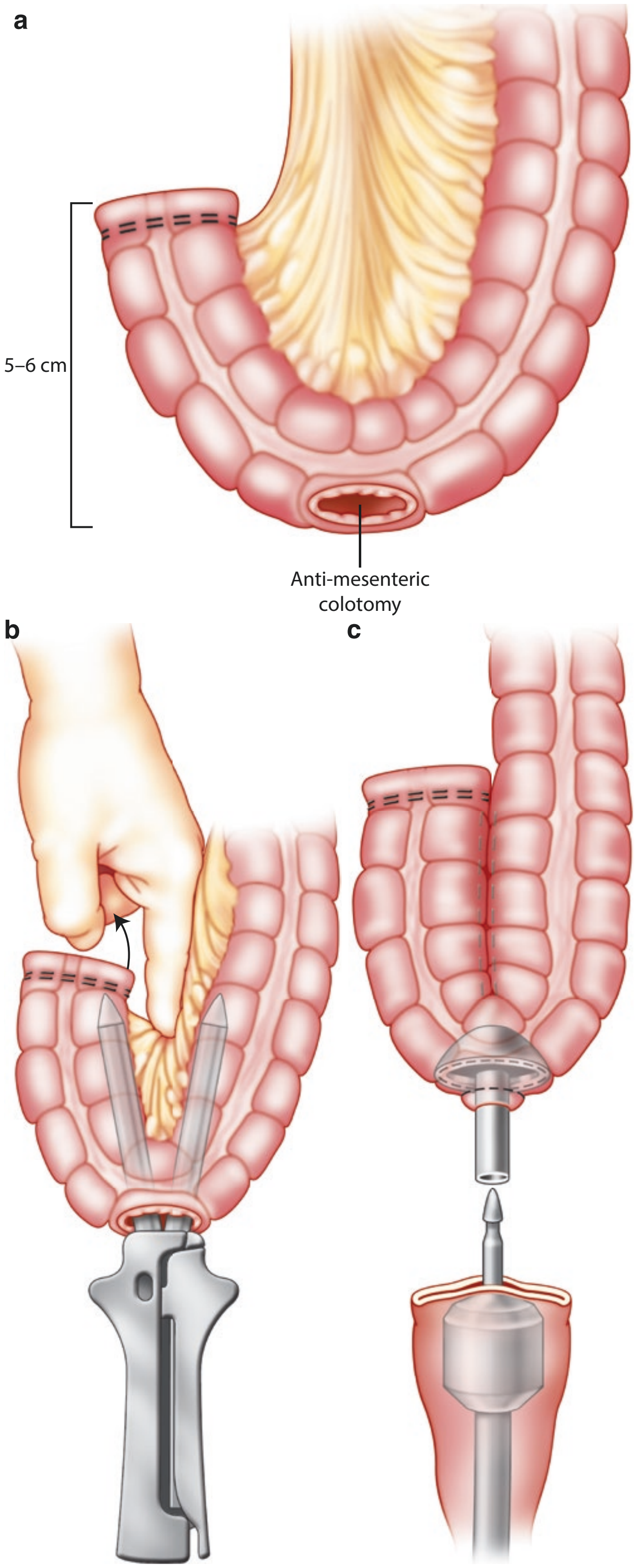


Fig. 9.36 Colonic J-pouch. (**a**) 5–6 cm colonic J-pouch is formed, and a colotomy is made on the antimesenteric portion of the bowel wall. (**b**) The pouch is formed using a linear stapler with 1–2 loads ensuring the colon mesentery is pulled out of the staple line. (**c**) The colorectal anastomosis is constructed using an EEA stapler. (Reused with permission from Hunt SR, Silviera ML. Anastomostic construction. Steele et al. [94]. Copyright © 2016 Springer Nature)

chase and travel [63, 64]. Both animal and clinical investigations have played a role in clarifying optimal practice [64]. Slieker et al. performed a systematic review exploring the scientific evidence for anastomosis and must be credited for the comprehensive effort to clarify the basis for hand-sutured anastomotic construction [66]. The spectrum of variables was examined: suture material, inverting or everting, layers incorporated and size of tissue purchase, distance traveled, and tension of tying. In addition, the number of layers of anastomosis—single- versus two-layered—is often discussed and debated. At times, the seemingly innumerable variables of hand-sutured anastomosis understandably perplex and intimidate the novice surgeon.

In regard to suture material, several features should be considered. Compared to braided suture, monofilament causes less local trauma as it passes through tissues and is less prone for adherence of bacteria [8, 63, 64]. However, monofilament suture has its detractors. Some argue that it is more expensive. It can be challenging to handle due to "memory" or its tendency to return to its original shape. Finally, in contrast to braided suture, knot tying with monofilament is less forgiving given the tendency for a knot to slip.

Slowly absorbable suture (either polyglycolic acid or polydioxanone sulfate) as opposed to rapidly absorbable suture such as chromic catgut provides adequate tensile strength for an adequate period of time and persists well into the remodeling phase of healing [63, 64]. Permanent suture is not necessary as slowly absorbable suture's durability persists until maximal tensile healing has occurred. Finally, some sutures such as linen or silk cause more local tissue inflammation [63, 64] that can affect phases of healing [5, 6].

Inverting anastomosis was popularized by Lembert and involves the apposition of serosa to serosa that results in the mucosal layer being inverted [7]. Everting anastomoses compared to inverting create larger stomata but are criticized for greater local inflammation and resulting adhesions [65]. Interestingly, bowel transected by a stapler is closed without inversion. Studies generally showed equivalency in leak; therefore, the everted sutured anastomosis generally has been abandoned [9].

In terms of tissue purchase, in addition to Lembert's emphasis on the serosa, Halsted highlighted the importance of the submucosal layer in intestinal suturing [9]. He showed that this layer offered the greatest collagen content and the highest degree of inherent tensile strength compared to the other layers. Suture material provides the tensile strength for an anastomosis during the lag or inflammatory phase when collagenolysis prevails. On the other hand, mucosa does not provide any intrinsic strength. Optimal size of recommended purchase varies and may not be well-founded. A range from 3 to 4 mm has been offered and one should take into consideration the caliber of the bowel lumen and thickness of tissues [1, 9]. There remain multiple types of suture techniques involving the type of bite. A

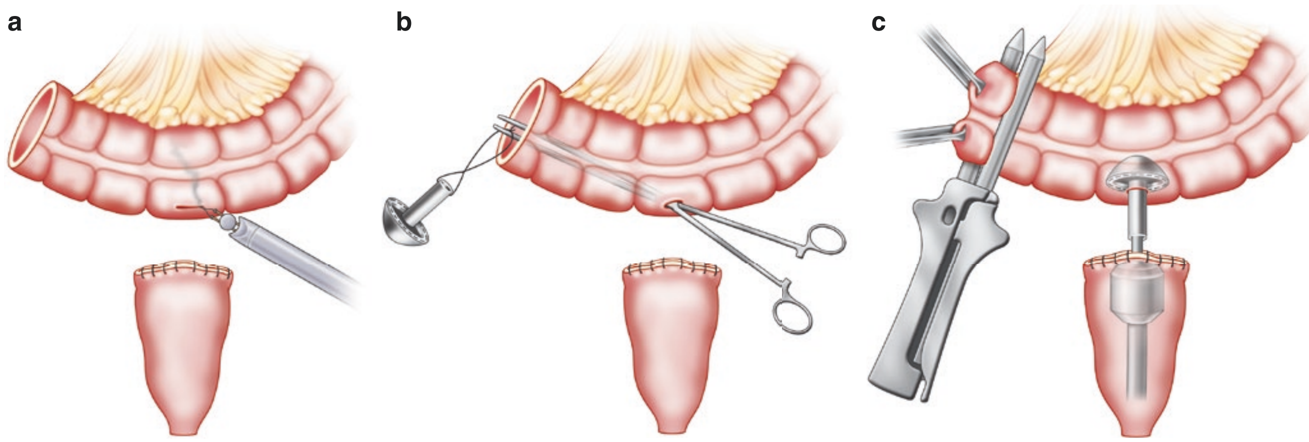


Fig. 9.37 Side-to-end coloanal anastomosis. (**a**) Colotomy is made proximal to the open end of the colon. (**b**) The EEA anvil is passed through this opening. (**c**) The colonic opening is closed using a linear stapler, and the anastomosis is performed using an EEA stapler. (Reused with permission from Hunt and Silviera [95]. Copyright © 2016 Springer Nature)

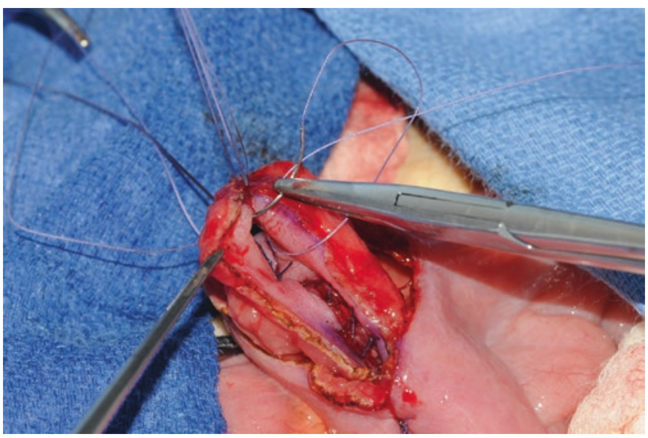


Fig. 9.38 Simple interrupted suture—3 mm bite serosa, submucosa with small purchase of mucosa (back wall of Kono-S anastomosis). (Photo courtesy of HDV)

simple suture encompassing all layers is most commonly practiced with strong emphasis on serosal and submucosal purchase that inverts the mucosa (Fig. 9.38).

The degree of tension placed on sutures during tying should account for tissue swelling and edema that will occur in the early phase of healing. Too much tension leads to ischemia, necrosis, and potential loss of tensile strength. Halsted instructed that one should avoid tying so tightly that tissues appeared "anemic" or strangled. Tying should feel secure with no visible gaping or separation, but with an approximation that will accommodate the ensuing edema.

Sutured anastomosis can be performed using interrupted or continuous suturing technique. Continuous suturing is faster. No difference in outcome can be identified comparing the two techniques [66].

Czerny modified Lembert's technique by adding an inner layer approximating the mucosa (Fig. 9.39). This continues to be a very popular approach to hand-sutured anastomosis. The posterior first rows are interrupted Lembert sutures. The bowel is opened and the inner layer is approximated in continuous fashion full thickness bites posteriorly. The anterior portion of this closure is often performed with the Connell stitch. Finally, the second layer anteriorly is completed using interrupted Lembert sutures. However, the two-layered method takes longer than single layer [67]. In addition, critics point out that two layers result in aperture stenosis relative to one layer, and studies have revealed greater degrees of ischemia and necrosis [66]. Finally, two-layer anastomoses require greater operative time and are therefore felt to be inferior to single-layered in most instances [67]. A Cochrane Database Review revealed that single-layer was equivalent to two-layer technique in terms of anastomotic leak, perioperative complications, mortality, and hospital stay [68]. A recent small, randomized prospective study confirmed these findings [69]. A randomized prospective multicenter trial in Germany unfortunately suffered from slow recruitment and failed to accrue the intended cohort. Thus, the group could not produce conclusive evidence to resolve the debate, but its publication certainly points to the profession's continued interest in establishing a best practice [70].

Hand-sewn anastomosis continues to be an important method and an essential skill for anastomotic construction. In many ways, this technique is the most versatile of method, as it can be performed for a variety of anatomic segments and creates the spectrum of configuration types. Although there are differing opinions regarding suture material and other variables, the reality is that hand-suturing technique must be relied upon in the most challenging situations or anastomosis types. When stapler instruments fail, hand-sewn anastomosis techniques should be the fail-safe technique as a contingency. Following mucosectomy or intersphincteric resection for low rectal cancer, hand-

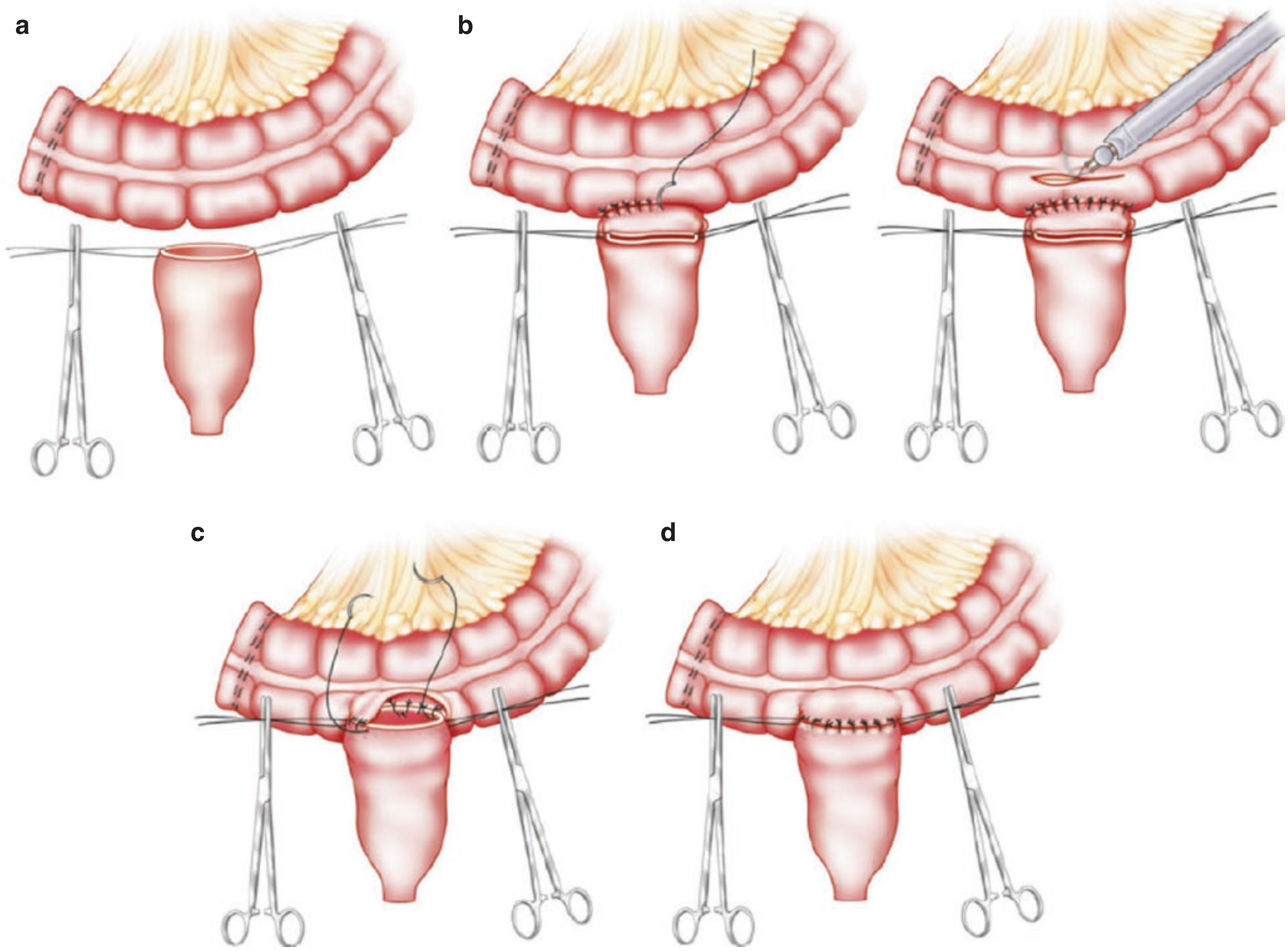


Fig. 9.39 Hand-sewn colorectal anastomosis. (**a**) The distal end of the colon is closed, and stay sutures are placed on the rectum. (**b**) A posterior layer of sutures are placed (left) and a colotomy is made (right) to match the size of the opening on the rectal stump. (**c**) The anastomosis is constructed using two continuous running sutures. (**d**) The anterior suture line is oversewn with interrupted sutures. (Reused with permission from Hunt and Silviera [95]. Copyright © 2016 Springer Nature)

sewn anal anastomosis is generally the relied upon method to achieve the most technically challenging of colorectal anastomoses—the anastomosis within the anal canal (Fig. 9.40). While there continues to be a spectrum of practice regarding suture material and specific technique, hand-sewn anastomosis remains a critically important skill that requires constant practice and focused dedication to attain mastery.

Stapled Anastomosis

Surgical staplers are now a mainstay of modern surgical practice and a major enterprise for medical industry, with sales projected to be four billion dollars in the United States by 2022 [71]. While hand-sutured anastomosis represented the first technique for anastomotic construction, it was initially fraught with high morbidity and mortality [1]. Multiple scientific and technical advances occurred that enabled evolution of safe hand-sewn anastomoses. Surgeons recognized the challenges in precision and reproducibility of the hand-sutured technique [7]. Mechanical methods for anastomotic construction were pursued to address this issue. Introduced in 1917 by Hultl, the original tissue stapler design proved heavy and unwieldy. However, this first iteration established fundamental design concepts including the importance of tissue compression, creation of B-shaped staples, and the presence of two overlapping rows of staples that secure an airtight seal while possessing gaps that ensure perfusion (Fig. 9.41). Remarkably, modern day staplers continue to depend on these essential concepts, and staple shape remains a measure of accurate stapler performance [72]. Surgical staplers revolutionized anastomotic construction, and Hultl's modest design represented a major paradigm shift in operative technique.

Modern stapling technology comes in three distinct types: linear or transverse noncutting, linear cutting, and circular

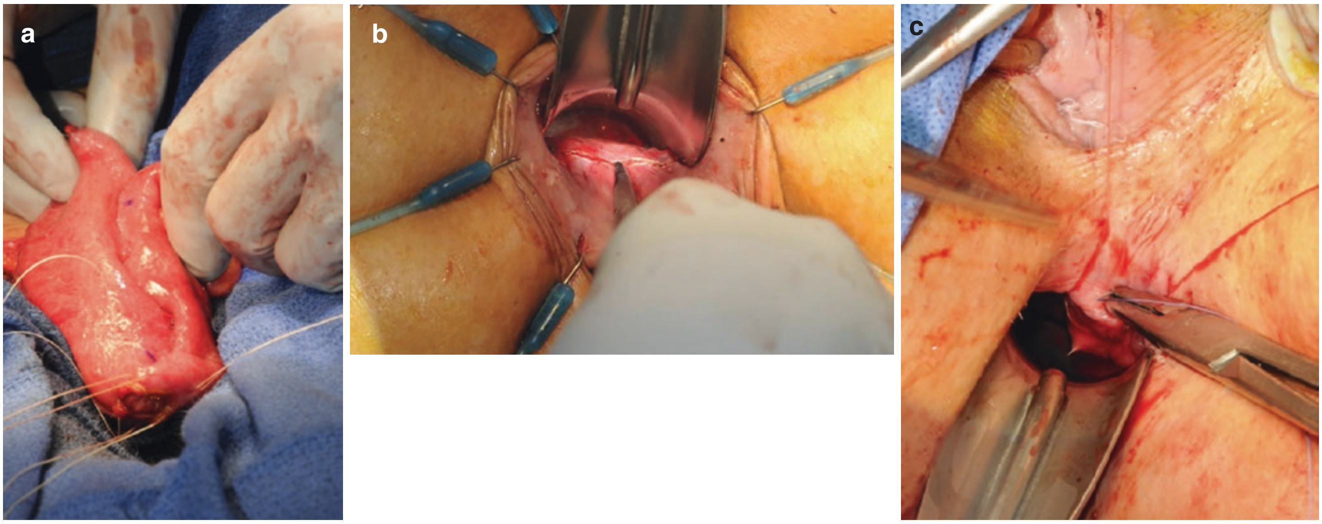


Fig. 9.40 Ileal J-pouch anal anastomosis after mucosal proctectomy. (**a**): Ileal J pouch; (**b**): Mucosal proctectomy for familial polyposis; (**c**): Hand-sewn anal anastomosis. (Photos courtesy of HDV)

cutting models. Various manufacturers and unique characteristics may differentiate staplers. Each stapler type has been used for anastomotic construction. The linear noncutting and transverse staplers are primarily used for bowel resection or closure of a defect or lumen. Linear cutting staplers and circular staplers are the types usually employed for anastomosis. Just as staplers often require some element of suturing, anastomotic construction often requires using a combination of different stapler types. Understanding specific design characteristics therefore must be appreciated. Stapled anastomosis can be undertaken for both open and minimally invasive platforms, though important technical variations are required to perform anastomotic construction.

The titanium staple is permanent and incites the lowest levels of tissue reaction and inflammation compared to other suture material [64, 73]. When shaped properly, staples provide greater levels of tensile strength than suturing.

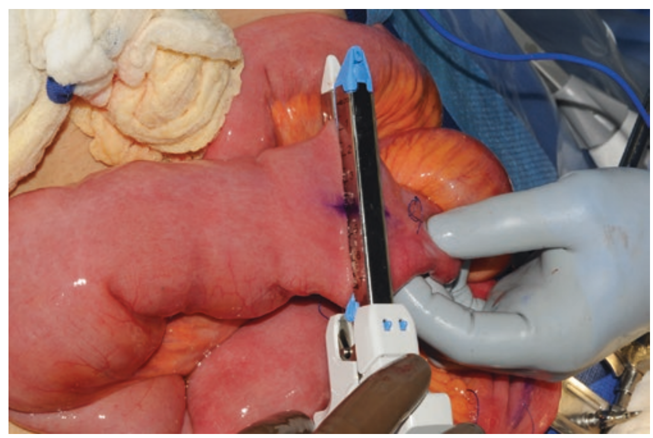


Fig. 9.41 Bowel transection in preparation for Kono-S anastomosis. (Photo courtesy of HDV)

Types of Tissue Staplers

Linear noncutting staplers (Fig. 9.42) place two overlapping staggered rows of staples to produce airtight compression with an array that allows perfusion. Following stapling, the tissue must then be divided manually. A variation of the transverse stapler is the Contour® (Ethicon), a curve-shaped stapler head designed for pelvic transection of the rectum, which provides three staple lines with knife cutting to leave one row on the specimen side of the resected rectum. This closes the specimen to prevent contamination.

Cutting staplers, either linear or circular, also provide the same staggered overlapping staple lines and then are cut between rows of staples with an internal knife leaving staples on both sides of the cut. These staplers are utilized for the actual construction of intestinal anastomosis. Linear cutting staplers vary in length, staple height, and number of rows of staples created. Generally, linear cutting staplers enable creation of side-to-side bowel anastomosis. Staplers have been modified specifically for laparoscopic and now robotic surgery by placing the end effector at the tip of a thin shaft that traverses access ports into the peritoneal cavity. In addition, linear cutting staplers provide an increased number of rows (from four to six), leaving three rows on either side of the cut. Circular staplers differ in diameter. Based on stapler manufacturer, the device can be chosen based on staple height or the device can be closed to a point that corresponds to the desired staple height. One can perform anastomoses in a variety of configurations though its greatest contribution to anastomotic construction has been performing end-to-end low pelvic anastomoses.

Compression and Tissue Stapling

Compression between the stapler head and anvil causes tissue thinning as water is forced out of intracellular and extracellular spaces. Initial resistance of tissue to load compression ultimately results in stress relaxation of tissues [72]. Proper staple formation occurs as a result of adequate compression

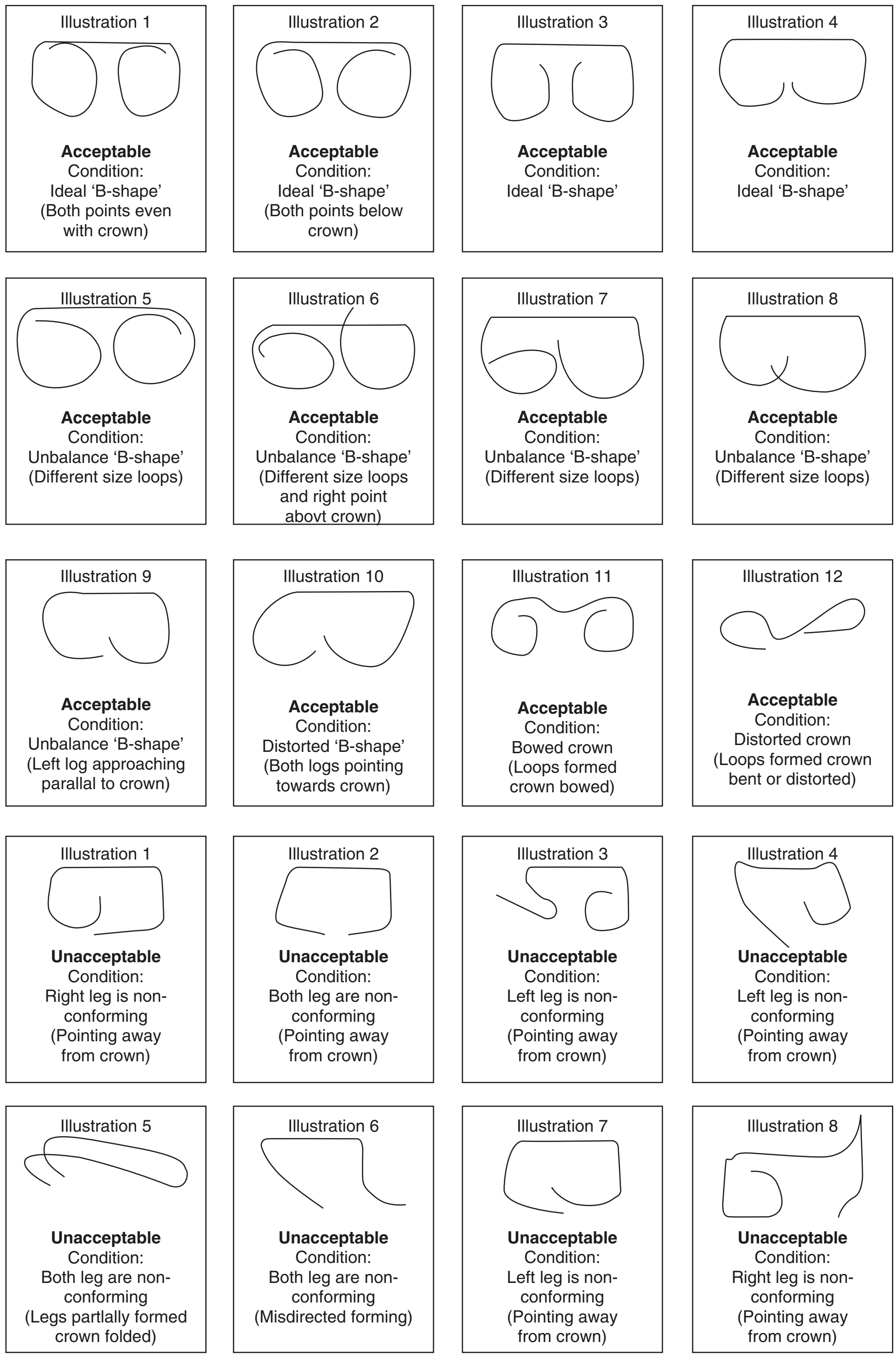


Fig. 9.42 Acceptable and unacceptable staple forms produced after firing of staples into tissue to create an anastomosis. **Note:** Presence of unacceptable forms can compromise integrity and strength of the staple line resulting in an increased rate of leaks and bleeding. (Reprinted from *Am J Surg*. Akiyoshi et al. [96]. Copyright © 2011 Elsevier)

and tissue thinning. Excessive compression can result in tissue tearing and loss of tissue purchase by staples [73] (Baker photo of staple line dehiscence). Approximation of the anastomosis is maintained by proper staple formation and tensile strength of the metal. Compression develops by different mechanisms. Linear and circular staplers provide load to tissues by parallel closure of the stapler head to the anvil. Minimally invasive linear cutting staplers use a cantilever mechanism. The latter may explain differences in compression created near the apex of the stapler as opposed to the distal tip, and accordingly, staple formation can be affected [74].

One of the initial decisions by surgeons regarding linear stapler use is the staple height specific for the organ and anticipated thickness. Staple height can be varied with taller staples with thicker diameters used for increasing thickness of tissue (Fig. 9.43). General recommendations regarding staple height are suggested for various intestinal segments. Inappropriately short staple height relative to tissue thickness can result in tearing, with evidence of this ranging from visible serosal laceration to complete staple line failure [72, 74, 75].

Nakayama et al. examined linear cutting staplers and the role of pre-compression on staple formation in a porcine model utilizing gastric tissue. Several important observations are worthy of mention from this seminal work. First, pre-compression improved staple formation, and there was a correlation between longer duration of compression and more consistent staple form. Second, there was obvious mismatch of staple height where the blue cartridge was used on the thickest bowel (pylorus). Poor staple form occurred irrespective of pre-compression, and thus gross mismatch could not be overcome by varying actual stapler execution. While it can be difficult to precisely know tissue thickness and to what degree pathologic conditions may alter typical wall thickness, slight inaccuracies of staple choice may be addressed by purposefully prolonged tissue precompression prior to staple firing. Third, the tip of the stapler formed staples less consistent than the base. Thus, the area furthest from the action point where precompression develops may experience some decremental level of load on the tissue. Again, increasing precompression time was found to also improve staple formation at the tip. Finally, inspection of the staple line formation comparing the two sides—proximal and distal side ("specimen-side" and "patient-side")—revealed that the staple formation was reliable between the two sides. This suggests that in the clinical setting, following staple firing and complete transection, reviewing the specimen side of the staple line of transection one can infer the status of the staple line left in vivo [74].

Rectal transection in open surgery can typically be accomplished with a single firing of a 30-45 mm transverse staple. Multiple applications of the linear cutting stapler are frequently necessary for rectal transection in laparoscopic or robotic surgery. This appears to be a risk factor for anastomotic leak. Poorly formed staples at the tip of the linear staple line represent a potential hazard. This "migratory" staple can result in stapler malfunction and jamming [72]. Prior to subsequent stapler firings, the in vivo and specimen side staple lines are inspected. If present, the "migratory" staple should be removed.

Another feature unique to laparoscopic linear cutting staplers is the interval firing stroke mechanism. Unlike linear cutters designed for open use, multiple strokes complete the staple line for each cartridge. Compression can be influenced by the speed of stroke firing [75]. In addition to a period of precompression time, interstroke waiting also may impact reliable staple formation [76]. Motorized powerized firing mechanisms perform this aspect of stapling on newer versions of linear staplers. Davinci Sureform linear cutting stapler® (Intuitive) can alter the stroke firing sequence as a result of its tissue thickness sensor, and mid-stroke the mechanism can pause allowing more compression to occur prior to completion. The Signia Stapling System® (Medtronic) similarly assesses compression characteristics of the tissue and alters stroke firing. Future studies will be required to see if these features will improve rates of staple formation, especially at the distal end of staple lines in particular. What is clear is that manufacturers are appropriately focusing efforts on these challenging issues of tissue thickness, compression, and firing stroke mechanism to improve staple formation.

Circular staplers revolutionized stapling to the mid-to-low rectum following low anterior resection, but can be

Fig. 9.43 Dimensions of commonly available staple cartridges that are used to accommodate different tissue thicknesses for appropriate tissue management. (Reused with permission from [83]. Copyright © 2014 Dove Press)

Color	Rows	Tissue type	Open staple height	Closed staple height
Grey	6	Mesentery	2.0 mm	0.75 mm
White	6	Vascular	2.5 mm	1.0 mm
Blue	6	Standard	3.5 mm	1.5 mm
Gold	6	Standard/thick	3.8 mm	1.8 mm
Green	6	Thick	4.1 mm	2.0 mm

employed for end-to-side or side-to-end anastomoses for both pelvic and abdominal anastomosis construction. Interestingly, the circular stapler creates compression differently than the linear cutter in that it staples and cuts upon one single firing. Anastomotic donuts of excised tissue produce the final lumen of the bowel approximation. The mucosa is inverted and two or three rows (depending on manufacturer) of staggered staples are inserted.

Nakayama investigated double stapling and found that the circular stapler produced reliable B- shaped staples irrespective of precompression time or degree of closure of instrument [76]. The authors comment that this most likely is due to the parallel closure mechanism by which compression occurs. Inspection of anastomotic donuts for the presence of all layers as well as intact rings is recommended to assess staple line integrity. Air leak testing is a necessary adjunct for pelvic anastomosis [77]. Videoendoscopy allows for visual inspection as well as air leak testing.

In summary, strategies for safe use of staplers (depending on brand and model) includes assessing tissue thickness and estimating appropriate cartridge load and staple height. Consider waiting longer than the recommended 15 seconds and perhaps as long as 1 minute prior to firing the stapler. Similarly, pausing in between strokes may allow for additional compression and more reliable staple formation. If sequential stapler fires are required to completely transect the entirety of the bowel, look carefully at the staples at the tip for a possible aberrantly formed, loose "crotch" staple that should be removed prior to stapling. After transection, inspection of the specimen side of the staple line can be assessing for staple line integrity, staple formation, and evidence of serosal tearing to alert to possible threatened anastomotic construction. An additional investigation following rectal transection and prior to double stapling is to perform endoscopy with air leak testing [77–79]. While it remains to be seen if the suggestions will translate into better outcomes, consideration for safe practice seems reasonable.

While favored for their consistent and reproducible construction, stapled anastomoses may leak. This holds true even in the case of ileocolic anastomosis, considered to be one of the lower risk anastomoses. In recent large European comparative studies, stapled anastomotic construction has been identified as a factor for leak [80–82]. Errors have been identified during technical performance and these potentially affect patient outcomes [72, 83, 84]. It is important to point out that stapler end effector takes place housed within an instrument, which in the case of laparoscopic or robotic platforms, is separate and at a distance from the surgeon. This is inherently a danger point in anastomotic construction. Automation and physical separation reduce the ability of surgeons to be involved in the actual staple insertion, and the technology impacts our ability to inspect the granular details of an anastomosis. This lack of access to the staple line may diminish surgeon vigilance. Therefore, stapled anastomotic construction requires detailed understanding of the instrument–tissue interaction, and similar to hand-sutured technique, execution of a stapled anastomosis requires focused attention to detail [83].

Compression Ring Anastomosis

This technique is not commonly performed in North America and is currently not performed by either author. However, we remain aware of its use in other centers around the world. Interestingly, some form of compression anastomosis method has been available since the early history of surgical anastomosis construction. First introduced in the nineteenth century by Denans and later refined and popularized by the Murphy Button, this mechanical instrumentation to achieve anastomosis has undergone multiple evolutions and innovations. The idea rests on a sutureless rejoining of the two ends of bowel with a ring left in vivo that acts to physically compress the circumference of the layers of one end of the bowel wall to the other. Ischemia and necrosis occur slowly over time during which the physiology of healing results in regaining intrinsic tensile strength and bowel integrity. The initial integrity of the anastomosis is based upon the purchase of the tissue by the device's circumferential purchase and the compression exerted. The device that can be either metallic or biodegradable eventually passes transanally.

There is no foreign body retained within the wall itself, and the theoretic benefit is less inflammation due to a reduction in the lag or inflammatory phase of healing. Experimental studies in a porcine model demonstrate initial bursting pressures exceeding stapled anastomoses [85]. Histopathology studies have revealed diminished numbers of inflammatory cells as well as less scar formation compared to stapled anastomosis [86]. Interestingly, fewer adhesions were also noted to the anastomosis [86]. The ring, which can be comprised of absorbable or permanent materials, will then be passed per anus with the resumption of fecal flow.

A recent meta-analysis examined compression compared to conventional (hand-sewn and stapled) colorectal anastomosis. Ten RCT's included nearly 2000 patients in the analysis. There were no significant differences in anastomotic leak, stricture formation, or mortality. There was a shorter time to return of bowel function in the compression group but there was no difference in terms of length of hospital stay. No significant difference was seen in post-operative morbidity except for a higher rate of bowel obstruction in the compression group, OR – 1.87. The authors concluded that there was no significant advantage of compression anastomosis over conventional [87].

In summary, compression ring method continues to be a technology available for anastomotic construction and may offer potential benefits from a healing model perspective.

The Conundrum of Best Practice and Continuing Challenge

Clarifying the best practice for anastomotic construction represents one of the most compelling areas of interest. Staplers, though more costly than suture materials, generally offset this difference by being faster. Most identify anastomotic leak as the critical parameter given the tremendous morbidity and increased mortality. In addition, leaks represent a tremendous financial burden due to increased consumption of health-care resources as well as the loss of productivity for those suffering from leak.

Comparison studies looking at hand-sewn versus stapled anastomoses generally do not show any clear-cut difference. A Cochrane Database Review has examined this topic most recently in 2012. The review included nine randomized controlled trials (1233 patients, 622 with stapled, and 611 with the hand-sewn technique) comparing the safety and effectiveness of stapled versus hand-sewn colorectal anastomosis surgery. Meta-analysis was performed. Outcome measures were mortality, anastomotic dehiscence, narrowing (stricture), hemorrhage, need for reoperation, wound infection, anastomosis duration (time taken to perform the anastomosis), and hospital stay. No significant statistical differences were found except that stricture was more frequent with stapling ($P < 0.05$), and the time taken to perform the anastomosis was longer with hand-sewn techniques [88].

Interestingly, looking specifically at ileocolic anastomosis, a prior Cochrane Database Review suggested superiority of the stapled technique over hand-sewn. This systematic review found seven randomized controlled trials with a total of 1125 participants (441 stapled, 684 hand-sewn) comparing these two methods. The leak rate for stapled anastomosis was 2.5%, significantly lower than hand-sewn, 6%. For the sub-group of 825 patients with cancer in four studies, stapled had fewer leaks compared with hand-sewn, being 1.3% and 6.7% respectively. Of note, in 264 noncancer (including patients with Crohn's disease) patients in three studies, there were no differences for the reported outcomes. Overall, there was no significant difference in the other outcomes of stricture, anastomotic bleeding, time of anastomosis, re-operation, mortality, intra-abdominal abscess, wound infection, and length of stay [89].

However, since this review several reports continue to examine this topic of technical differences. The HASTA trial examined ileostomy closure, comparing hand-sewn to stapled anastomosis [90]. This multicenter prospective randomized controlled trial compared 337 randomized patients undergoing closure of loop ileostomy after low anterior resection for rectal cancer in 27 centers. The primary endpoint was the rate of bowel obstruction within 30 days after ileostomy closure. Rate of anastomotic leakage was not different (stapler: 3.0%, hand suture: 1.8%, $P = 0.48$). The overall rate of postoperative ileus after ileostomy closure was 13.4%. Seventeen of 165 (10.3%) patients in the stapler group and 27 of 163 (16.6%) in the hand suture group developed bowel obstruction within 30 days postoperatively [odds ratio (OR) = 1.72; 95% confidence interval (CI): 0.89–3.31 = 0.10]. Operative times were shorter in stapled group.

Several large European studies assessed outcomes of right colectomy including anastomotic leak. Data from the German Society for General and Visceral Surgery registry from 2010 to 2017 were analyzed [91]. A total of 4062 patients who had undergone open right hemicolectomy for colonic cancer were analyzed. All patients had an ileocolic anastomosis, 2742 hand-sewn and 1320 stapled. Baseline characteristics were similar. No significant differences were identified in anastomotic leakage—stapled 3.9% versus hand-sewn 3.0%. No difference was seen in postoperative ileus, reoperation rate, surgical-site infection, LOS, or death. The stapled group had a significantly shorter duration.

A Danish nationwide database examined 1414 patients undergoing right hemicolectomy for adenocarcinoma with primary anastomosis between October 2014 and December 2015 [82]. There were 391 (28%) in the stapled group and 1023 (72%) in the hand-sewn group. Forty-five patients (3.2%) developed anastomotic leak; 21 of 391 (5.4%) and 24 of 1023 (2.4%) in the stapled and hand-sewn groups, respectively ($P = 0.004$). This difference was confirmed in multivariable analysis (adjusted OR: 2.91; 95% CI, 1.53–5.53; $P < 0.001$) and after propensity score matching (OR: 2.41; 95% CI, 1.24–4.67; $P = 0.009$). Thirty-day mortality was 15.6% (7/45) and 2.1% (29/1369) in patients with and without anastomotic leak ($P < 0.001$).

Finally, a multicenter international European cooperative study recently published findings examining right colectomy [92]. This study reports the morbidity and mortality rates for right-sided colon cancer and identifies predictors for unfavorable short-term outcome after right hemicolectomy. This included all patients undergoing elective or emergency right hemicolectomy or ileocecal resection over a 2-month period in early 2015. Predictors for anastomotic leak and 30-day postoperative morbidity and mortality were assessed using multivariable mixed-effect logistic regression models after variables selection with the Lasso method. Of the 2515 included patients, an anastomosis was performed in 97.2% ($n = 2444$): hand-sewn in 38.5% ($n = 940$) and stapled in 61.5% ($n = 1504$) cases. The overall anastomotic leak rate was 7.4% (180/2444), 30-day morbidity was 38.0% ($n = 956$), and mortality was 2.6% ($n = 66$). Patients with anastomotic leak had a significantly increased mortality rate (10.6% vs. 1.6% no-leak patients; $P > 0.001$). At multivariable analysis, the following variables were associated with anastomotic leak: longer duration of surgery (OR = 1.007 per min; P = 0.0037), open approach (OR = 1.9; P = 0.0037), and stapled anastomosis (OR = 1.5; P = 0.041).

Ileocolic anastomosis is generally considered a straightforward operation with relatively simple anastomotic construction options. These reports highlight the continued issue of anastomotic leak and the absence of differences in outcomes based on technique. Tension and the need for mobilization are far less an issue compared to left-sided resection. Despite our perception of technologic improvement in stapling devices and their broad use, anastomotic construction and unanticipated outcomes continue even with our best efforts. Hand-sewn anastomosis continues to provide arguable equivalent results when compared to stapling techniques. Anastomotic construction continues to be a compelling and challenging topic for study in an effort to improve our understanding of best practice in surgical technique. The hope is that we can reduce the role of the surgeon's performance as a factor in undesired outcomes. The heterogeneity of this endeavor requires a vast array of operative techniques and methods. The reality is that some operations, including the most challenging ones we undertake, require a hand-sewn technique. Surgeons must possess and master a broad skillset that enables judicious adaptation and execution of the various techniques appropriate for each unique operation. Most importantly, we do so firmly intent and focused on adhering to the fundamental principles defining safe anastomotic construction: precise, tension-free, and secure approximation of well-perfused, healthy bowel.

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