Scott R. Steele · Tracy L. Hull · Neil Hyman
Justin A. Maykel · Thomas E. Read
Charles B. Whitlow *Editors*

The ASCRS Manual of Colon and Rectal Surgery

Third Edition

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Preface

In continuation with the first two volumes, the third edition of the American Society of Colon and Rectal Surgeons' (ASCRS) Manual is again abstracted from and a companion to the third edition of the *ASCRS Textbook of Colon and Rectal Surgery* (Steele, Hull, Read, Saclarides, Senagore, Whitlow, eds. New York: Springer, 2016). The manual serves as a readily available, easy-to-access, and succinct resource for all providers caring with colorectal disease.

The collective goal for the third edition of the *ASCRS Textbook of Colon and Rectal Surgery* was to provide a valuable resource for surgeons and health-care providers who care for patients with colorectal disease at all stages of their careers. In line with previous editions, we aimed to build upon the collective experience and expertise from national and international experts in the field, providing a completely revamped, up-to-date tome covering the wide breadth of colorectal disease organized around the "pillars" of colorectal surgery including perioperative care (including endoscopy), anorectal disease, benign disease (including inflammatory bowel disease), malignancy, pelvic floor disorders, and a "miscellaneous" section that covers aspects both inside and beyond the operating room that are pertinent to providers at every level. In addition, each chapter contains several *key concepts* that succinctly depict the major learning objectives for individual sections and are in line with the Core Curriculum for Colon and Rectal Surgery provided by the Association of Program Directors in Colon and Rectal Surgery and the key topics used by the American Board of Colon and Rectal Surgery.

Each chapter in the manual has been abstracted, edited, and reviewed by the textbook authors and manual editors. Many diagrams, figures, and algorithms have been retained from the textbook, as they are felt to help with patient care. In an effort to continue to build and expand upon the education platform across the ASCRS, the manual serves as a bridge between the journal (*Diseases of the Colon and Rectum*), the ASCRS textbook, and other resources such as CARSEP and CREST. Further information, including more in-depth technical, scientific, and expert opinion, as well as references, are available and can always be accessed through any of our other resources and

programs. It is our sincere wish that this manual will serve as a relevant and practical tool to provide information and recommendations and ultimately help improve the care and outcome for our patients.

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Part I

Perioperative/ Endoscopy

1 Anatomy and Embryology of the Colon, Rectum, and Anus

Joseph C. Carmichael and Steven Mills

Key Concepts

- The dentate line represents a true division between embryonic endoderm and ectoderm.
- The location of the anterior peritoneal reflection is highly variable and can be significantly altered by disease such as rectal prolapse.
- The right and left ischioanal space communicate posteriorly through the deep postanal space between the levator ani muscle and anococcygeal ligament.
- The junction between the midgut (superior mesenteric artery) and the hindgut (inferior mesenteric artery) leads to a potential watershed area in the area of the splenic flexure.
- There is a normal, three-stage process by which the intestinal tract rotates during development beginning with herniation of the midgut followed by return of the midgut to the abdominal cavity and ending with its fixation.

Anatomy of the Anal Canal and Pelvic Floor

- The "anatomic" anal canal begins at the dentate line and extends to the anal verge.
- The "surgical" anal canal extends from the anorectal ring to the anal verge.
- The surgical anal canal is formed by the internal anal sphincter (IAS), external anal sphincter (EAS), and puborectalis (Fig. 1.1).
- The surgical anal canal is longer in males than in females. It averages 4.4 cm in males and 4.0 cm in females. Its length does not change with age.
- MR imaging shows that the anterior and posterior external anal sphincter length (not including puborectalis) was significantly shorter in women.
- The anal canal forms proximally where the rectum passes through the pelvic hiatus and joins with the puborectalis muscle and be thought of as a "tube within a tube."
- The inner tube is the visceral smooth muscle of the IAS and longitudinal layer that is innervated by the autonomic nervous system.
- The outer muscular tube consists of somatic muscles including the components of the puborectalis and EAS and is responsible for voluntary control.
- The EAS extends distal to the IAS, and the anal canal terminates at the anal verge where the superficial and subcutaneous portions of the external anal sphincter join the dermis.

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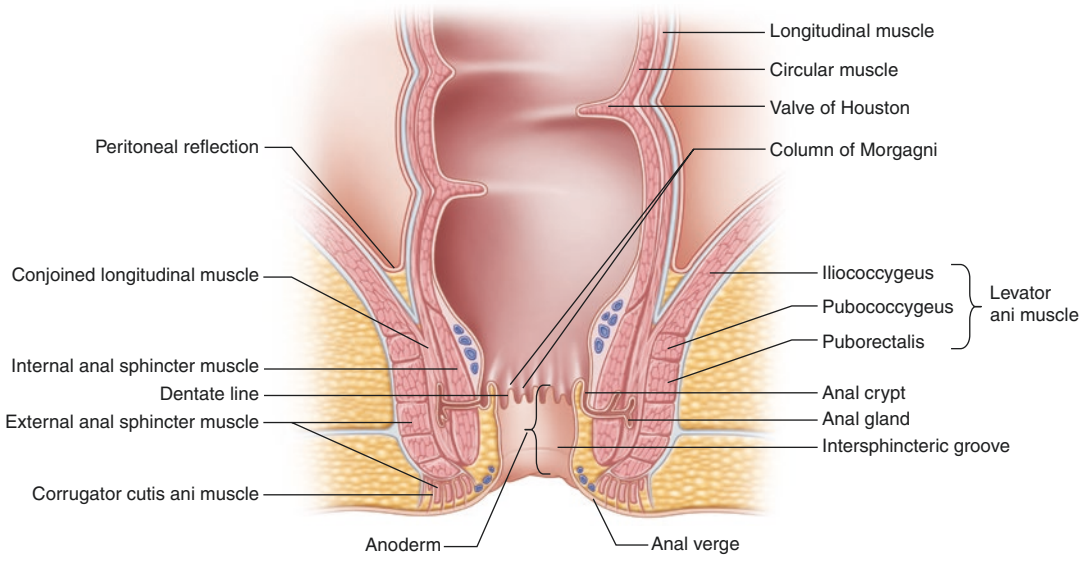


Fig. 1.1 Anal canal

Anal Canal Epithelium

- The proximal anal canal is lined by the columnar epithelium of the rectal mucosa.
- Six to twelve millimeter proximal to the dentate line, the anal transition zone (ATZ) begins, which is an area of gradual transition of columnar epithelium to squamous epithelium.
- The columns of Morgagni are redundant columns of tissue with anal crypts at their base. This forms the rippled dentate line (or pectinate line) which can be most easily identified – anal crypts are connected to underlying anal glands which are the presumed source of sepsis in the majority of anorectal abscesses and fistula. On average, there are six anal glands surrounding the anal canal (range 3–12) that are more concentrated in the posterior quadrants.
- All glands have a crypt but not all crypts have a gland. Some crypts are connected to multiple glands. The anal gland ducts proceed inferior and lateral from the anal canal and enter the submucosa where two-thirds enter the internal anal sphincter and half terminate in the intersphincteric plane.
- Distal to the dentate line, the anoderm begins and extends for approximately 1.5 cm. Anoderm has squamous histology and is devoid of hair, sebaceous glands, and sweat glands. At the anal verge, the anal canal lining becomes thickened and pigmented and contains hair follicles – this represents normal skin.
- The dentate line represents a true division between embryonic endoderm and ectoderm. Proximal to the dentate line, the innervation is via the sympathetic and parasympathetic systems, with venous, arterial, and lymphatic drainage associated with the hypogastric vessels. Distal to the dentate line, the innervation is via somatic nerves with blood supply and drainage from the inferior hemorrhoidal system.

Internal Anal Sphincter

- The internal anal sphincter is the downward continuation of the circular smooth muscle of the rectum. It terminates approximately 1 cm proximal to the distal aspect of the external anal sphincter producing a palpable

intersphincteric groove on physical exam. Imaging studies show that the IAS is approximately 2 mm in thickness and 35 mm in length on average.

Conjoined Longitudinal Muscle

- The anatomy and function of the perianal connective tissue plays a significant role in normal anorectal function. The conjoined longitudinal muscle (or conjoined longitudinal coat) lies in between the internal and external anal sphincters. It begins at the anorectal ring as an extension of the longitudinal rectal muscle fibers and descends caudally joined by fibers of the puborectalis muscle.
- At its most caudal aspect, some of the conjoined longitudinal muscle fibers (referred to as *corrugator cutis ani muscle*) traverse the distal external anal sphincter and insert into the perianal skin, and some enter the fat of the ischiorectal fossa. Some fibers of the conjoined longitudinal muscle interlace in a network within the subepithelial space and have been referred to as Treitz's muscle. They have also been referred to *corrugator cutis ani*, *musculus submucosae ani*, *mucosal suspensory ligament*, and *musculus canalis ani*.
- Possible functions of the conjoined longitudinal muscle include attaching the anorectum to the pelvis and acting as a skeleton that supports and binds the internal and external sphincter complex together.

External Anal Sphincter

- The external anal sphincter (EAS) is composed of striated muscle that forms an elliptical tube around the internal anal sphincter and conjoined longitudinal muscle.
- Goligher demonstrated that the external anal sphincter was truly a continuous sheet of skeletal muscle extending up to the puborectalis and levator ani muscles. While the external anal sphincter does not have three distinct anatomic layers, it is not uncommon to see the proximal portion of the EAS referred to as deep EAS, the midportion referred to as the superficial EAS, and the most distal aspect as the subcutaneous EAS.
- The mid-EAS has posterior attachment to the coccyx via the anococcygeal ligament, and the proximal EAS becomes continuous with the puborectalis muscle. Anteriorly, the proximal EAS forms a portion of the perineal body with the transverse perineal muscle.
- There are gender differences in the morphology of the anterior external anal sphincter that have been demonstrated on imaging. The normal female external anal sphincter has a variable natural defect (in 75% of nulliparous women) occurring along its proximal anterior length below the level of the puborectalis sling. Knowledge of this is important in interpreting anal ultrasound for fecal incontinence.
- The external anal sphincter is innervated on each side by the inferior rectal branch of the pudendal nerve (S2 and S3) and by the perineal branch of S4. There is substantial overlap in the pudendal innervation of the external anal sphincter muscle on the two sides which enables reinnervation to be partially accomplished from the contralateral side following nerve injury.

Perineal Body

- The perineal body represents the intersection of the external anal sphincter, superficial transverse perinei, deep transverse perinei, and bulbospongiosus (also referred to as bulbocavernosus) muscles (Fig. 1.2). Recent research suggests that the transverse perinei (TP) and bulbospongiosus (BS) muscles contribute significantly to anal incontinence. It has been proposed that the EAS, TP, and BS muscles be collectively referred to as the "EAS complex muscles."

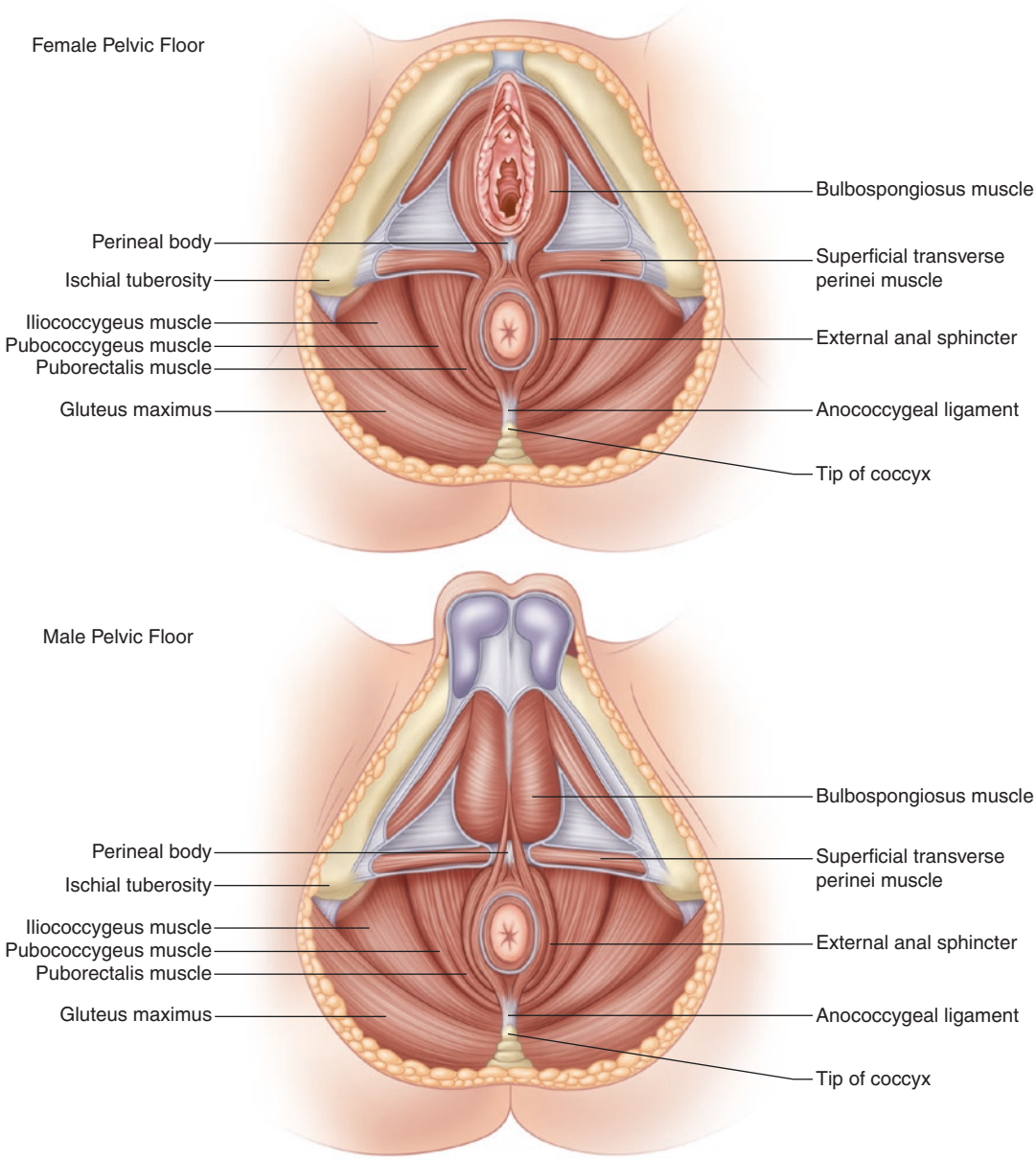


Fig. 1.2 Pelvic floor muscles

Pelvic Floor Muscles

- In addition to the anal sphincter and perineal body, the levator ani (LA) muscles contribute to pelvic organ support.
- The LA has three subdivisions including the pubococcygeus (aka pubovisceral), puborectalis, and iliococcygeus.
- In vivo MRI measurements in women have shown distinct, visible muscle fascicle directions for each of the three LA component muscles. Embryology studies have also demonstrated that the puborectalis muscle is a portion of the LA muscle and shares a common primordium with the iliococcygeus and pubococcygeus muscles.

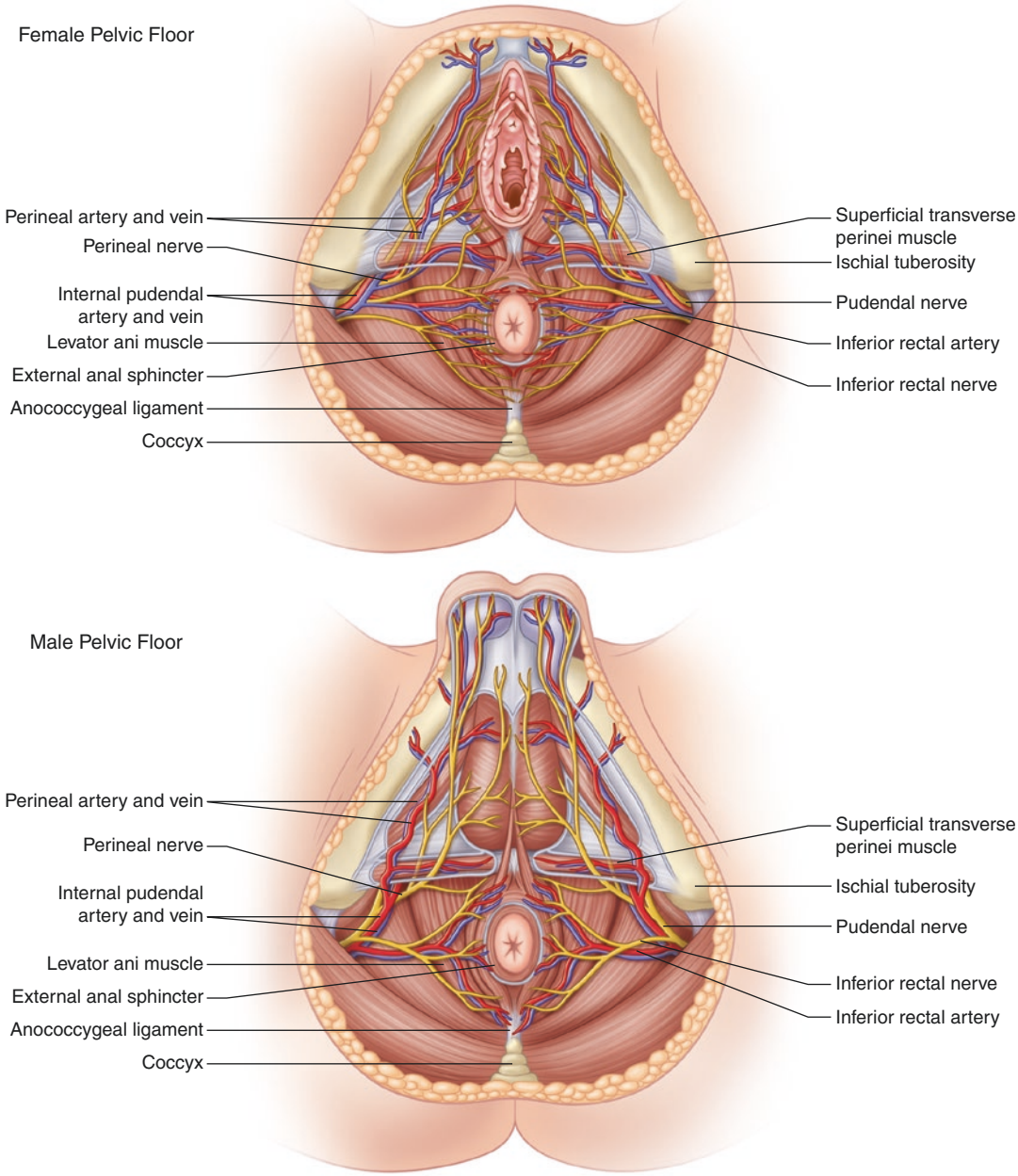


Fig. 1.3 Pelvic floor nerves and blood supply

- Contemporary cadaveric studies suggest that the LA muscles are innervated by the pudendal nerve branches: perineal nerve and inferior rectal nerve as well as direct sacral nerves S3 and/or S4 (i.e., levator ani nerve). The pubococcygeus muscle and puborectalis muscle are primarily innervated by the pudendal nerve branches, while the iliococcygeus muscle is primarily innervated by the direct sacral nerves S3 and/or S4 (Fig. 1.3).

Puborectalis Muscle

- The puborectalis muscle (PRM) fibers arise from the lower part of the symphysis pubis and from the superior fascia of the urogenital diaphragm and run alongside the anorectal junction. Posterior to the rectum, the fibers join forming a sling. The "anorectal ring" is composed of the upper borders of the internal anal sphincter and puborectalis muscle. Contraction of the PRM sling causes a horizontal force that closes the pelvic diaphragm and decreases the anorectal angle during squeeze. This is widely considered the most important contributing factor to gross fecal continence.

Iliococcygeus Muscle

- Iliococcygeus muscle (ICM) fibers arise from the ischial spines and posterior obturator fascia, pass inferior/posterior and medially, and insert into the distal sacrum, coccyx, and anococcygeal raphe. The ICM, along with the pubococcygeus muscle, contributes to "lifting" of the pelvic floor.

Pubococcygeus Muscle

- The pubococcygeus muscle (PCM) lies medial to the PRM. PCM fibers arise from the anterior half of the obturator fascia and the high posterior pubis. The PCM fibers intersect with fibers from the opposite side and form the anococcygeal raphe (or anococcygeal ligament). PCM fibers insert in the distal sacrum and tip of the coccyx, and portions contribute to the conjoined longitudinal muscle. The PCM forms the "levator hiatus" as it ellipses the lower rectum, urethra, and either the vagina in women or the dorsal vein of the penis in men. The levator hiatus is connected to the intrahiatal organs by a fascial condensation called the "hiatal ligament" (Fig. 1.4). The hiatal ligament arises circumferentially around the hiatal margin as a continuation of the fascia on the pelvic surface of the levator muscle. Enlargement of the levator hiatus has been implicated as a cause of female pelvic organ prolapse.

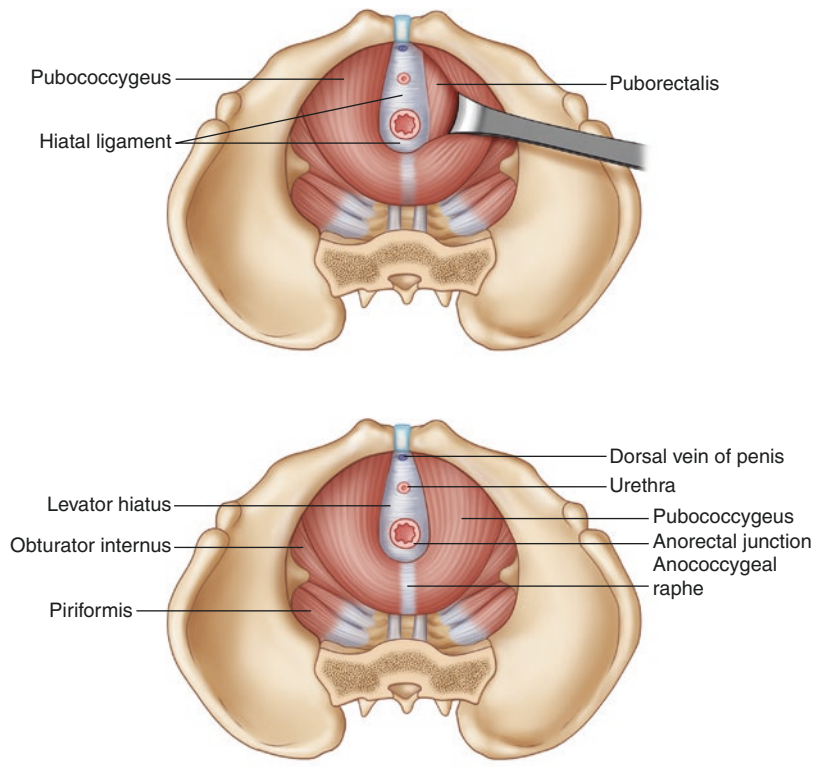


Fig. 1.4 Pelvic floor anatomy, abdominal view

Anatomy of the Rectum

- The rectum is of variable length but is commonly described as the upper (12–15 cm), middle (7–12 cm), and lower (0–<7 cm) rectum. While not anatomically distinct, the divisions are important when considering surgical treatment of rectal cancer. The upper rectum can be distinguished from the sigmoid colon by the absence of taenia coli and epiploic appendages.
- The majority of the rectum is extraperitoneal. Anteriorly and laterally the upper rectum is covered by a layer of visceral peritoneum down to the peritoneal reflection. The location of the anterior peritoneal reflection is highly variable but on average is 9 cm from the anal verge in females and 9.7 cm in males.

Mesorectum

- In anatomic terms, the prefix "meso" refers to two layers of peritoneum that suspend an organ, and the suffix applied indicates the target organ (e.g., mesocolon). Therefore the term mesorectum is a misnomer except in patients with a mobile suspended rectum as can be seen in rectal prolapse.
- The mesorectum is a term employed by surgeons to describe the fascial envelope of the rectum that is excised during surgical treatment of rectal cancer. Indeed, failure to completely excise this envelope intact has been associated with an increased incidence of local recurrence of rectal cancer. The mesorectum is contained within the fascia propria. The fascia propria is an upward projection of the parietal endopelvic fascia that lines the walls and floor of the pelvis. The fascia propria encloses the perirectal fat, lymphatics, blood vessels, and nerves.

Presacral Fascia

- The presacral fascia is a thickened portion of the parietal endopelvic fascia overlying the sacrum that covers the presacral veins and hypogastric nerves (Fig. 1.5). It extends laterally to cover the

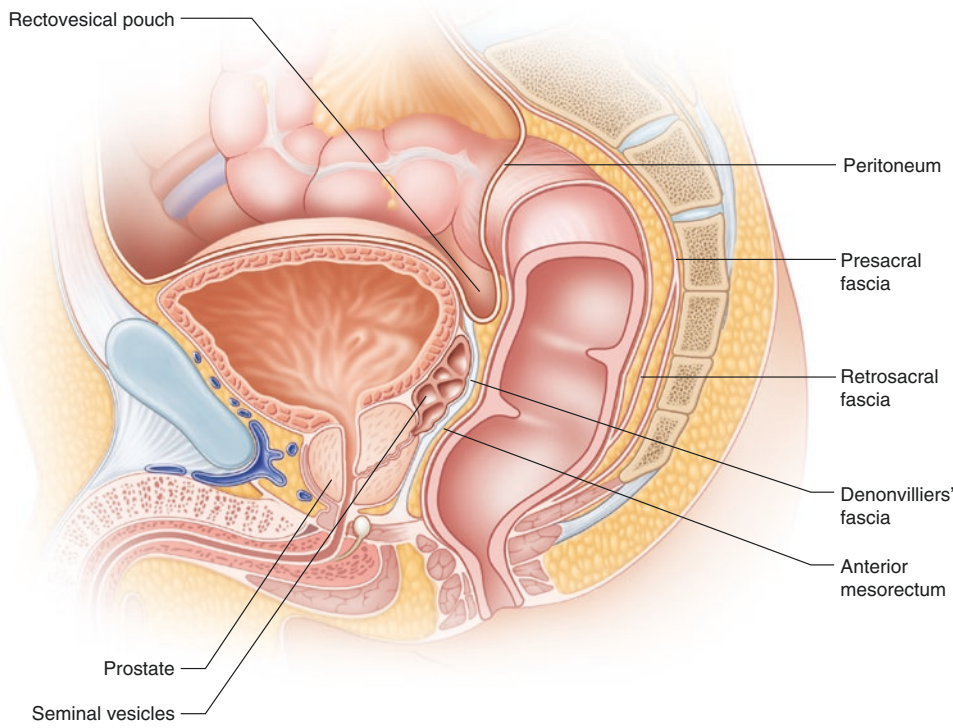


Fig. 1.5 Fascial relationships of the rectum

piriformis and upper coccyx. As the presacral fascia extends laterally, it becomes continuous with the fascia propria and contributes to the lateral ligaments of the rectum. Caudally, this fascia extends to the anorectal junction covering the anococcygeal ligament. During total mesorectal excision, the fascia propria is elevated sharply off the presacral fascia. Leaving the presacral fascia intact eliminates the possibility of causing substantial presacral bleeding.

Retrosacral Fascia

- The retrosacral fascia originates at the third and fourth portion of the sacrum and extends anteriorly to the posterior layer of the fascia propria 3–5 cm proximal to the anorectal junction. This tough fascia layer is surgically relevant as it must be sharply incised during total mesorectal excision. The space posterior to the retrosacral fascia is referred to as the supralevator or retrorectal space.

Waldeyer's Fascia

- There is significant confusion about what Waldeyer's fascia represents as the eponym has been used to describe the presacral fascia, the rectosacral fascia, or all fascia posterior to the rectum. In Waldeyer's original description of pelvic fascia, there was no particular emphasis on the presacral component. While the debate continues regarding "Waldeyer's fascia," it is important to simply understand that the phrase can have the potential to mean presacral fascia, retrosacral, or retrorectal fascia.

Denonvilliers' Fascia

- Denonvilliers' fascia arises from the fusion of the two walls of the embryological peritoneal cul-de-sac and extends from the deepest point of the rectovesical pouch to the pelvic floor. It was originally described by Denonvilliers in 1836 as a "prostatoperitoneal" membranous layer between the rectum and seminal vesicles.
- Denonvilliers' fascia is also present in females as part of the rectovaginal septum and is sometimes referred to as rectovaginal fascia. It is found immediately beneath the vaginal mucosa and is clearly what most would consider as part of the vaginal wall. It merges superiorly with the cardinal/uterosacral complex in females or the rectovesical pouch in males. It merges laterally with the endopelvic fascia overlying the levator muscle and distally with the perineal body. It contains collagen and some strands of smooth muscle and heavy elastin fibers.
- Microscopically, Denonvilliers' fascia has two layers, but they are not grossly discernable. In the anterior rectal plane, the mesorectum is contained by the fascia propria which lies dorsal to Denonvilliers' fascia.
- The cavernous nerves run in neurovascular bundles at the anterolateral border of Denonvilliers' fascia.

Lateral Ligaments

- There are two controversial points regarding the lateral ligaments of the rectum. Do the lateral ligaments exist? What do they contain?
- In his seminal description of abdominoperineal resection in 1908, William Ernest Miles refers to division of the lateral ligaments of the rectum.
- One modern cadaveric dissection study identified the presence of a middle rectal artery in only 22% of specimens.
- Total mesorectal excision, as popularized and described by Heald, involves sharp dissection along the fascia propria circumferentially to the pelvic floor. While acknowledging that the middle rectal vessels are "divided as far from the carcinoma as possible," Heald does not mention "lateral ligaments" of the rectum at all.
- One review of the anatomy of the lateral ligament states that it is a common misconception

that the lateral ligaments contain the middle rectal artery. It appears that the lateral ligaments comprise "primarily nerves and connective tissue" and their division without bleeding attests to the absence of a "significant accessory rectal artery in this location in the majority of patients."

- In another cadaveric study, the lateral ligaments of the rectum were identified as trapezoid structures originating from mesorectum and anchored to the endopelvic fascia at the level of the midrectum. It was recommended that, as lateral extensions of the mesorectum, the ligaments must be cut and included in the total mesorectal excision (TME) specimen. It was further noted that the lateral ligaments did not contain middle rectal arteries or nerve structures of importance. Other modern cadaveric investigations note the rarity of middle rectal arteries and the absence of clinically relevant neurovascular structures in the lateral ligaments.

Valves of Houston

- The rectum has been classically described to have three distinct, semicircular, inner folds called valves of Houston (Fig. 1.1) with the superior and inferior valves located on the left side of the rectum and the more prominent middle rectal valve on the right.
- Anatomic variation is common, with only 45.5% of patients having the classic "three valve anatomy"; 32.5% will have only two valves, and 10.25% will have four valves.

Anorectal Spaces

- Several anorectal spaces are created by the various myofascial relationships in the pelvis. They are important in understanding how anorectal sepsis can spread throughout the pelvis.

Perianal Space

- The perianal space contains external hemorrhoid cushions, the subcutaneous external anal sphincter, and the distal internal anal sphincter. The perianal space is in communication with the intersphincteric space (Fig. 1.6). Its cephalad boundary is the dentate line, and its lateral boundaries are the subcutaneous fat of the buttocks. It is contained by fibers extending from the conjoined longitudinal muscle often referred to as *corrugator cutis ani* muscle fibers. Otherwise, the perianal space is contained by anoderm.

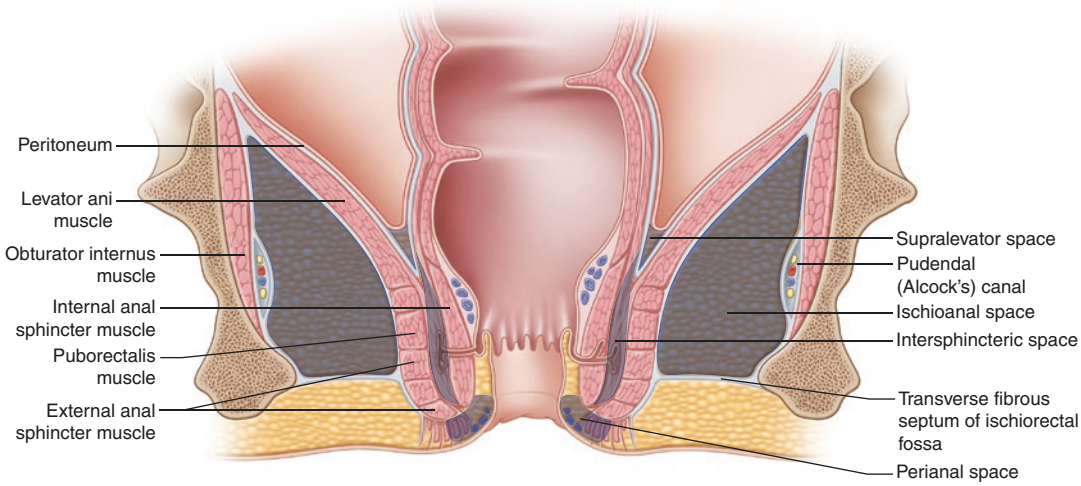


Fig. 1.6 Perianal and perirectal spaces, coronal view

Intersphincteric Space

- The intersphincteric space is the potential space that lies between the internal and external anal sphincters and is continuous with the perianal space. It is of clinical importance as cryptoglandular infections tend to begin in this area and expand elsewhere to create anal fistulas.

Submucous Space

- This space lies between the medial border of the internal anal sphincter and the anal mucosa proximal to the dentate line. It is continuous with the submucosa of the rectum. This area contains internal hemorrhoid vascular cushions.

Ischioanal/Ischiorectal Space

- The ischioanal (also referred to as ischiorectal) space is the largest anorectal space. It has been described as a pyramid shape with its apex at the levator muscle insertion into the obturator fascia. Its borders are as follows:
  - Medial – the levator ani muscle and external anal sphincter
  - Lateral – obturator internus muscle and obturator fascia
  - Posterior – the lower border of the gluteus maximus muscle and the sacrotuberous ligament
  - Anterior – the superficial and deep transverse perineal muscles
  - Caudal – the skin of the perineum
- The ischioanal fossa contains the adipose tissue, pudendal nerve branches, and superficial branches of the internal pudendal vessels.
- The right and left ischioanal space communicate posteriorly through the deep postanal space between the levator ani muscle and anococcygeal ligament (Fig. 1.7). When the ischioanal and perianal spaces are regarded as a single space, it is referred to as the ischioanal fossa.

Supralevator Space

- The upper boundary of the supralevator space is the peritoneum, the lateral boundary is the pelvic wall, the medial boundary is the rectum, and the inferior boarder is the levator ani muscle (Fig. 1.8).

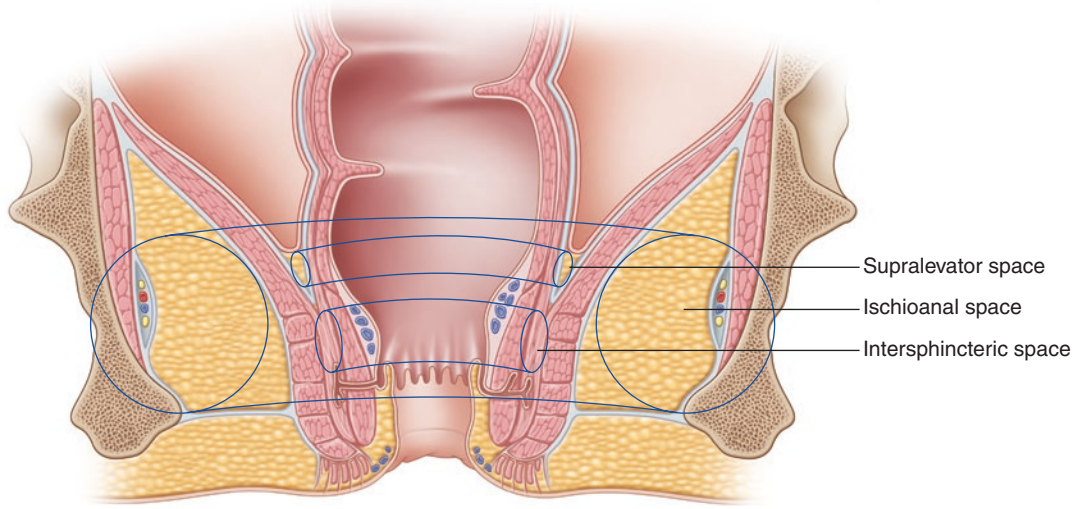


Fig. 1.7 Communication of the anorectal spaces

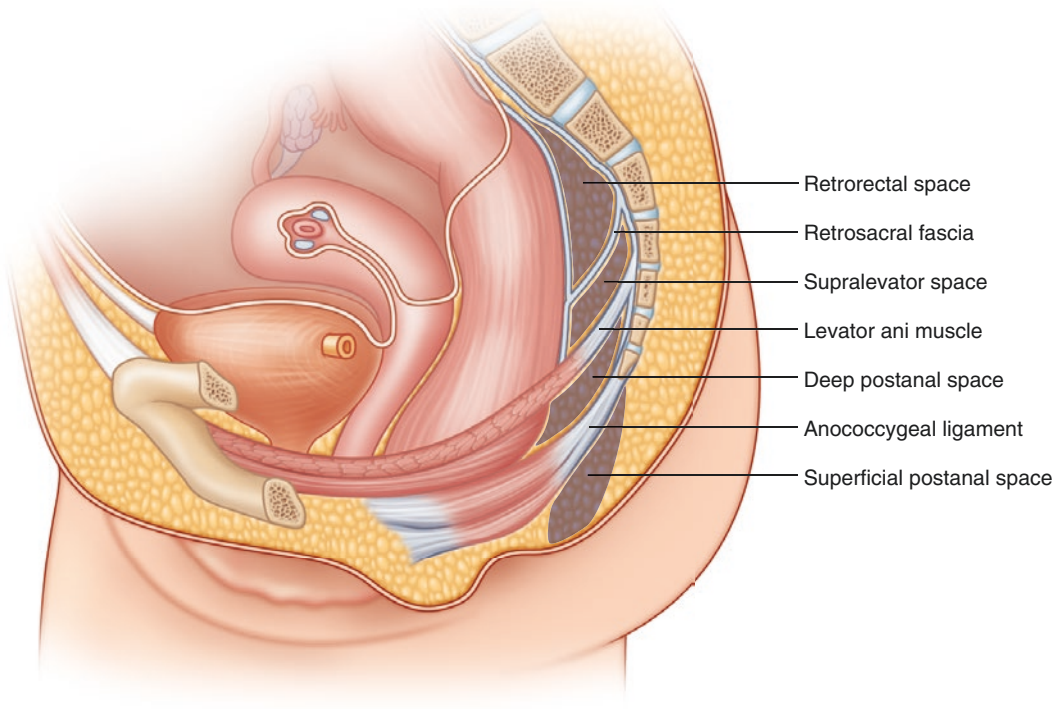


Fig. 1.8 Perianal and perirectal spaces, lateral view

Superficial and Deep Postanal Spaces

- These spaces are located posterior to the anus and inferior to the levator muscle. The superficial postanal space is more caudal and is located between the anococcygeal ligament and the skin. The superficial postanal space allows communication of perianal space sepsis.
- The deep postanal space (retrosphincteric space of Courtney) is located between the levator ani muscle and the anococcygeal raphe. This space allows ischioanal sepsis to track from one side to the other resulting in the so-called "horseshoe" abscess.

Retrorectal Space

- The retrorectal space is found between the presacral fascia and fascia propria. It contains no major blood vessels or nerves. It is limited laterally by the lateral ligaments of the piriformis fascia and inferiorly by the rectosacral fascia. The fascia propria and presacral fascia come together at the apex of this space.

Rectal Blood Supply

- The rectum is supplied by the superior, middle, and inferior rectal (hemorrhoidal) arteries (Fig. 1.9). Both the middle and inferior hemorrhoidal vessels are paired arteries, while the superior rectal artery is not.

Superior Rectal Artery

- The superior rectal artery (SRA) is the continuation of the inferior mesenteric artery as it crosses the left iliac vessels. The SRA gives off a rectosigmoid branch and an upper rectal branch and bifurcates into right and left terminal branches. On average, eight terminal branches of the SRA have been identified in the distal rectal wall.

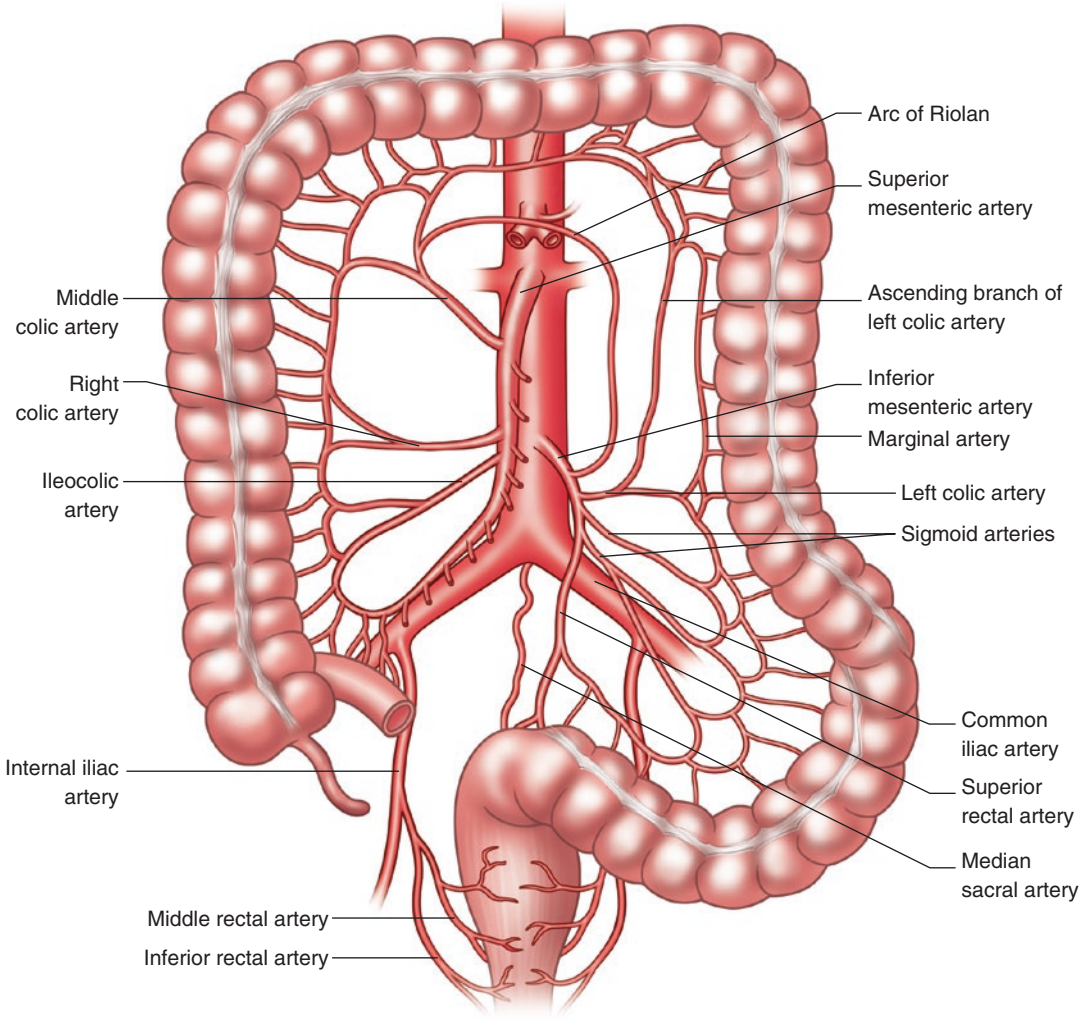


Fig. 1.9 Arterial anatomy of the colon and rectum

Middle Rectal Artery

- The middle rectal artery (MRA) has been variably noted in many studies. It may be found on one or both sides of the rectum and has been noted to be present 12–28% of the time. The MRA originates from the anterior division of the internal iliac or pudendal arteries.

Inferior Rectal Artery

- The inferior rectal arteries (IRA) are paired vessels that originate as branches of the internal pudendal artery that receives its blood supply from the internal iliac artery. The artery originates in the pudendal canal and is entirely extrapelvic (caudal to the levator ani) in its distribution. The IRA traverses the obturator fascia and the ischiorectal fossa and pierces the wall of the anal canal in the region of the external anal sphincter.

Venous and Lymphatic Drainage of the Rectum and Anus

- Venous drainage from the rectum and anus occurs via both the portal and systemic systems. Middle and inferior rectal veins drain to

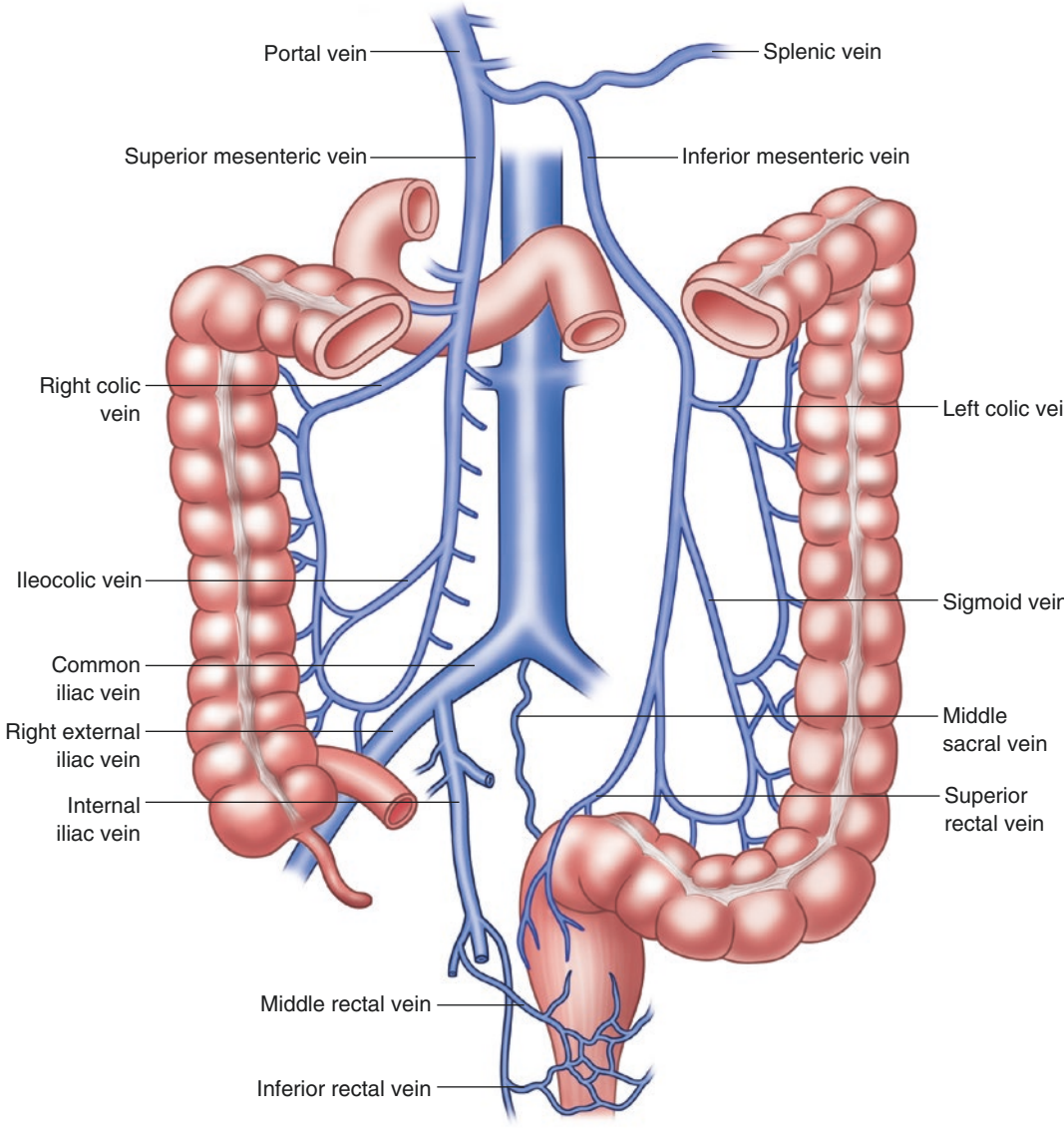


Fig. 1.10 Venous anatomy of the colon and rectum

the systemic systems via the internal iliac vein, while the superior rectal vein drains the rectum and upper anal canal into the portal system via the inferior mesenteric vein (Fig. 1.10).

- Lymphatics from the upper two-thirds of the rectum drain to the inferior mesenteric lymph nodes and then to the para-aortic lymph nodes.
- Lymphatic drainage from the lower third of the rectum occurs along the superior rectal artery and laterally along the middle rectal artery to the internal iliac lymph nodes.
- In the anal canal, lymphatic above the dentate drains to the inferior mesenteric and internal iliac lymph nodes. Below the dentate line, lymphatics drain along the inferior rectal lymphatics to the superficial inguinal nodes.

Innervation of the Rectum and Anus

- Sympathetic fibers arise from L1, L2, and L3 and pass through the sympathetic chains and join the preaortic plexus (Fig. 1.11). From there, they run adjacent and dorsal to the inferior mesenteric artery as the mesenteric plexus and innervate the upper rectum.
- The lower rectum is innervated by the presacral nerves from the hypogastric plexus. Two main hypogastric nerves, on either side of the rectum, carry sympathetic information from the hypogastric plexus to the pelvic plexus. The pelvic plexus lies on the lateral side of the pelvis at the level of the lower third of the rectum adjacent to the lateral stalks (described above).
- Parasympathetic fibers to the rectum and anal canal originate from S2, S3, and S4 to penetrate through the sacral foramen and are called the nervi erigentes. These nerves course laterally and anteriorly to join the sympathetic hypogastric nerves and form the pelvic plexus on the pelvic sidewall. Postganglionic mixed parasympathetic and sympathetic nerve fibers supply the rectum, genital organs, and anal canal.
- The periprostatic plexus is considered a subdivision of the pelvic plexus and supplies the prostate, seminal vesicles, corpora cavernosa,

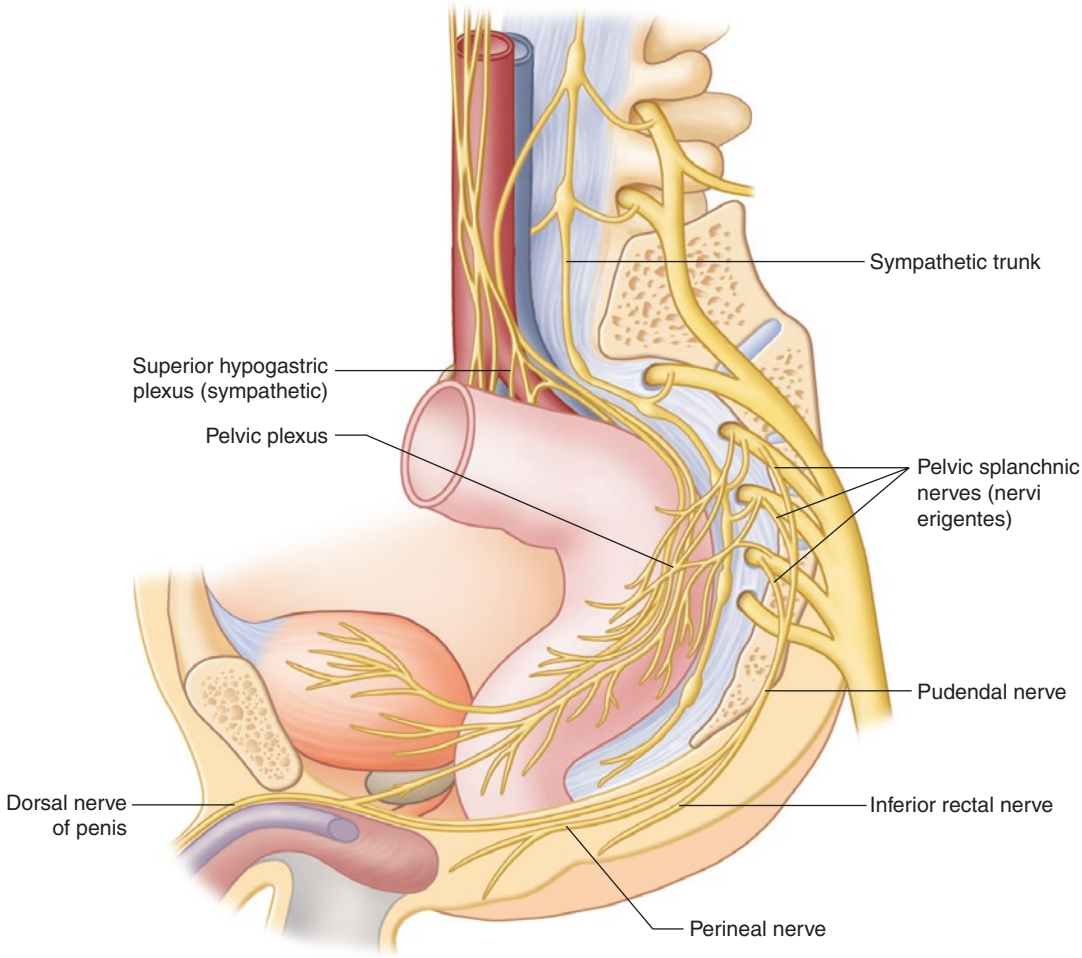


Fig. 1.11 Nerves of the rectum

vas deferens, urethra, ejaculatory ducts, and bulbourethral glands.
- The internal anal sphincter is innervated by sympathetic (L5) and parasympathetic (S2, S3, and S4) nerves following the same route as the nerves to the rectum as noted above.
- The external anal sphincter is innervated on each side by the inferior rectal branch of the internal pudendal nerve (S2 and S3) and by the perineal branch of S4.
- Anal sensation is mediated by the inferior rectal branch of the pudendal nerve.

Anatomy of the Colon

- The colon is a long tubular organ consisting of muscle and connective tissue with an inner mucosal layer. Its diameter differs depending by segment, generally decreasing from about 7 cm in the cecum to 2.5 cm in the sigmoid colon. The average length is about 150 cm.
- The right and left sides of the colon are fused to the posterior retroperitoneum (secondarily retroperitonealized), while the transverse colon and sigmoid colon are relatively free within the peritoneum. The transverse colon is held in position via its attachments to the hepatic and splenic flexures and is further fused to the omentum.
- The appendices epiploicae are non-mesenteric fat protruding from the serosal surface of the colon. They are likely residual from the antimesenteric fat of the embryologic intestine that dissipates (unlike the omentum on the stomach).
- The taenia coli are three thickened bands of outer, longitudinal muscle of the colon and are separately named: *taenia libera* to represent the anterior band, *taenia mesocolica* for the posteromedial band, and *taenia omentalis* for posterolateral band. They run along the full length of the colon but are not as long as the bowel wall. This difference in length results in outpouchings of the bowel wall between the taeniae referred to as haustra. The haustra are further septated by the plicae semilunares.

Cecum

- The proximal-most portion of the colon is termed the cecum, a sac-like segment of the colon below (proximal to) the ileocecal valve. At its base is the appendix, and terminating in the posteromedial area of the cecum is the terminal ileum (ileocecal valve).
- The ileocecal valve is a circular muscular sphincter which appears as a slit-like ("fish-mouth") opening noted on an endoscopic evaluation of the cecum. The valve is not competent in all patients, but when present, its competence leads to the urgency of a colon obstruction as it develops into a closed-loop obstruction. Regulation of ileal emptying into the colon appears to be the prime task in ileocecal valve function.

The Appendix

- The appendix is an elongated, true diverticulum arising from the base of the cecum and of variable length (2–20 cm). Its blood supply is via the appendiceal vessels contained within the mesoappendix. The most common location of the appendix is medial on the cecum toward the ileum, but it has great variability in its location including pelvic, retrocecal, preileal, retroileal, and subcecal.

Ascending Colon

- From its beginning at the ileocecal valve to its terminus at the hepatic flexure where it turns sharply medially to become the transverse colon, the ascending colon measures on average, about 15–18 cm.
- Its anterior surface is covered in the visceral peritoneum, while its posterior surface is fused with the retroperitoneum.
- The lateral peritoneal reflection can be seen as a thickened line termed the white line of Toldt, which can serve as a surgeon's guide for mobilization of the ascending colon off of its attachments to the retroperitoneum, most

notably the right kidney (Gerota's fascia) and the loop of the duodenum located posterior and superior to the ileocolic vessels.
- The right ureter and the right gonadal vessels pass posteriorly to the ascending mesocolon within the retroperitoneum.

Transverse Colon

- The transverse colon traverses the upper abdomen from the hepatic flexure on the right to the splenic flexure on the left. It is generally the longest section of colon (averaging 45–50 cm) and swoops inferiorly as it crosses the abdomen.
- The entire transverse colon is covered by visceral peritoneum, but the greater omentum is fused to the anterosuperior surface of the transverse colon. Superior to the transverse mesocolon, inferior to the stomach, and posterior to the omentum is the pocket of the peritoneal cavity termed the lesser sac, with the pancreas forming the posterior-most aspect.
- The splenic flexure is the sharp turn from the transversely oriented transverse colon to the longitudinally oriented descending colon. It can be adherent to the spleen and to the diaphragm via the phrenicocolic ligament.

Descending Colon

- The descending colon travels inferiorly from the splenic flexure for the course of about 25 cm. It is fused to the retroperitoneum (similarly to the ascending colon) and overlies the left kidney as well as the back/retroperitoneal musculature.
- Its anterior and lateral surfaces are covered with visceral peritoneum, and the lateral peritoneal reflection (white line of Toldt) is again present.

Sigmoid Colon

- The sigmoid colon is the most variable of the colon segments. It is generally 35–45 cm in length. It is covered by visceral peritoneum, thereby making it mobile. Its shape is considered "omega-shaped," but its configuration and attachments are variable.
- Its mesentery is of variable length but is fused to the pelvic walls in an inverted V shape creating a recess termed the intersigmoid fossa. Through this recess travel the left ureter, gonadal vessels, and often the left colic vessels.

Rectosigmoid Junction

- The end of the sigmoid colon and the beginning of the rectum is termed the rectosigmoid junction. It is noted by the confluence of the taenia coli and the end of appendices epiploicae.
- It is the narrowest portion of the large intestine, measuring 2–2.5 cm in diameter. Endoscopically, it is noted as a narrow and often sharply angulated area above the relatively capacious rectum and above the three rectal valves.
- A recent evaluation of the rectosigmoid junction utilizing anatomic and histologic studies as well as radiographic evaluation concluded that there was an anatomic sphincter at the rectosigmoid junction. [Microscopic evaluation of the area does reveal thickening of the circular muscle layer as it progresses toward the rectum. Though not identifiable externally, radiologic evaluation can identify the area as a narrow, contractile segment].

Blood Supply

- Although the blood supply of the colon is variable, it receives blood supply from two main sources, branches of the superior mesenteric artery (SMA) (cecum, ascending and transverse colon) and branches of the inferior mesenteric artery (IMA) (descending and sigmoid colon) (Fig. 1.9).
- Just proximal to the splenic flexure, the branches of the left branch of the middle colic artery anastomose with those of the left colic

artery. This watershed area represents the border of the embryologic midgut and hindgut.
- The cecum and right colon are supplied by the terminus of the SMA, the ileocolic artery. The right colic artery is less consistent. If present (absent in 20%), it either arises directly from the SMA, from the ileocolic, or from other sources.
- The transverse colon is supplied via the middle colic artery, which branches early to form right and left branches. The middle colic artery originates directly from the SMA. The left colon and sigmoid colon are supplied by branches of the IMA, namely, the left colic and a variable number of sigmoid branches.

Superior Mesenteric Artery

- The superior mesenteric artery (SMA) is the second, unpaired anterior branch off of the aorta (Fig. 1.9). It arises posterior to the upper edge of the pancreas (near the L1 vertebrae), courses posterior to the pancreas, and then crosses over the third portion of the duodenum to continue within the base of the mesentery.
- From its left side, the SMA gives rise to up to 20 small intestinal branches, while the colic branches (ileocolic, right colic, middle colic) originate from its right side.
- The most constant of the colic branches is the ileocolic vessel which courses through the ascending mesocolon where it divides into a superior (ascending) branch and an inferior (descending) branch.
- The middle colic artery arises from the SMA near the inferior border of the pancreas. It branches early to give off right and left branches. The right branch supplies the hepatic flexure and right half of the transverse colon. The left branch supplies the left half of the transverse colon to the splenic flexure. In up to 33% of patients, the left branch of the middle colic artery can be the sole supplier of the splenic flexure.

Inferior Mesenteric Artery

- The inferior mesenteric artery (IMA) (Fig. 1.9) is the third unpaired, anterior branch off of the aorta, originating 3–4 cm above the aortic bifurcation at the level of the L2–L3 vertebrae. As the IMA travels inferiorly and to the left, it gives off the left colic artery and several sigmoidal branches.
- After these branches, the IMA becomes the superior hemorrhoidal (rectal) artery as it crosses over the left common iliac artery. The left colic artery divides into an ascending branch (splenic flexure) and a descending branch (the descending colon). The sigmoidal branches form a fairly rich arcade within the sigmoid mesocolon (similar to that seen within the small bowel mesentery).

The Marginal Artery and Other Mesenteric Collaterals

- The major arteries noted above account for the main source of blood within the mesentery, but the anatomy of the mesenteric circulation and the collaterals within the mesentery remain less clear.
- The marginal artery (of Drummond) (Fig. 1.9) has been shown to be discontinuous or even absent in some patients, most notably at the splenic flexure (Griffiths' critical point), where it may be absent in up to 50% of patients. This area of potential ischemia is the embryologic connection between the midgut and hindgut.
- Another potential site of ischemia is at a discontinuous area of marginal artery located at the rectosigmoid junction termed Sudeck's critical point. This has been confirmed by a recent fluorescence study; however its clinical importance remains in doubt.

Venous Drainage

- Venous drainage of the colon largely follows the arterial supply with superior and inferior mesenteric veins draining both the right and left halves of the colon (Fig. 1.10). They ultimately meet at the portal vein to reach the intrahepatic system.
- The superior mesenteric vein (SMV) travels parallel and to the right of the artery.

- The inferior mesenteric vein (IMV) does not travel with the artery but rather takes a longer path superiorly to join the splenic vein. It separates from the artery within the left colon mesentery and runs along the base of the mesentery where it can be found just lateral to the ligament of Treitz and the duodenum before joining the splenic vein on the opposite (superior) side of the transverse mesocolon. Dissecting posterior to the IMV can allow for separation of the mesenteric structures from the retroperitoneal structures during a medial-to-lateral dissection.

Lymphatic Drainage

- The colon wall has a dense network of lymphatic plexuses. These lymphatics drain into extramural lymphatic channels that follow the vascular supply of the colon.
- Lymph nodes are plentiful and are typically divided into four main groups. The *epiploic* group lies adjacent to the bowel wall just below the peritoneum and in the epiploicae. The *paracolic* nodes are along the marginal artery and the vascular arcades. The *intermediate* nodes are situated on the primary colic vessels. The *main* or *principal* nodes are on the superior and inferior mesenteric vessels.
- Once the lymph leaves the main nodes, it drains into the cisterna chyli via the para-aortic chain.

Nervous Innervation

- The colon is innervated by the sympathetic and parasympathetic nervous systems and closely follows the arterial blood supply.
- The sympathetic innervation of the right half of the colon originates from the lower six thoracic splanchnic nerves which synapse within the celiac, preaortic, and superior mesenteric ganglia. The postganglionic fibers then follow the SMA to the right colon.
- The sympathetic innervation for the left half originates from L1, L2, and L3. Parasympathetic fibers to the right colon come from the posterior (right) branch of the vagus nerve and celiac plexus. They travel along the SMA to synapse with the nerves within the intrinsic autonomic plexuses of the bowel wall. On the left side, the parasympathetic innervation comes from S2, S3, and S4 via splanchnic nerves.

Embryology

Anus and Rectum

- The colon distal to the splenic flexure, including the rectum and the anal canal (proximal to the dentate line), is derived from the hindgut and therefore has vascular supply from the inferior mesenteric vessels (Fig. 1.9).
- The dentate line (Fig. 1.1) is the fusion plane between the endodermal and ectodermal tubes. The cloacal portion of the anal canal has both endodermal and ectodermal components that develop into the anal transitional zone. The terminal portion of the hindgut or cloaca fuses with the proctodeum (an ingrowth from the anal pit).
- The cloaca originates at the portion of the rectum below the pubococcygeal line, while the hindgut originates above it. Before the fifth week of development, the intestinal and urogenital tracts are joined at the level of the cloaca. By the eighth week, the urorectal septum migrates caudally to divide the cloacal closing plate into an anterior urogenital plate and a posterior anal plate. Anorectal rings result from a posterior displacement in the septum and the resultant smaller anal opening. By the tenth week, the anal tubercles fuse into a horseshoe-shaped structure dorsally and into the perineal body anteriorly. The external anal sphincter forms from the posterior aspects of the cloacal sphincter earlier than the development of the internal sphincter. The internal sphincter develops from enlarging fibers of the circular muscle layer of the rectum. The sphincters migrate during their development with the internal sphincter moving caudally, while the external sphincter enlarges cephalad. Meanwhile, the longitudinal muscle descends into the intersphincteric plane.

- In females, the female genital organs form from the Müllerian ducts and join the urogenital sinus by the 16th week of development.
- In males, the urogenital membrane obliterates with fusion of the genital folds, while the sinus develops into the urethra.

Colon and Small Intestine

- The endodermal roof of the yolk sac develops into the primitive gut tube. This initially straight tube is suspended upon a common mesentery. By week 3 of development, it has three discernible segments, namely, the foregut, midgut, and hindgut. The midgut starts below the pancreatic papilla to form the small intestine and the first half of the colon. The distal colon, rectum, and anal canal develop from the hindgut.
- There is a normal process by which the intestinal tract rotates (Fig. 1.12). The first stage is the physiologic herniation of the midgut, the second stage is its return to the

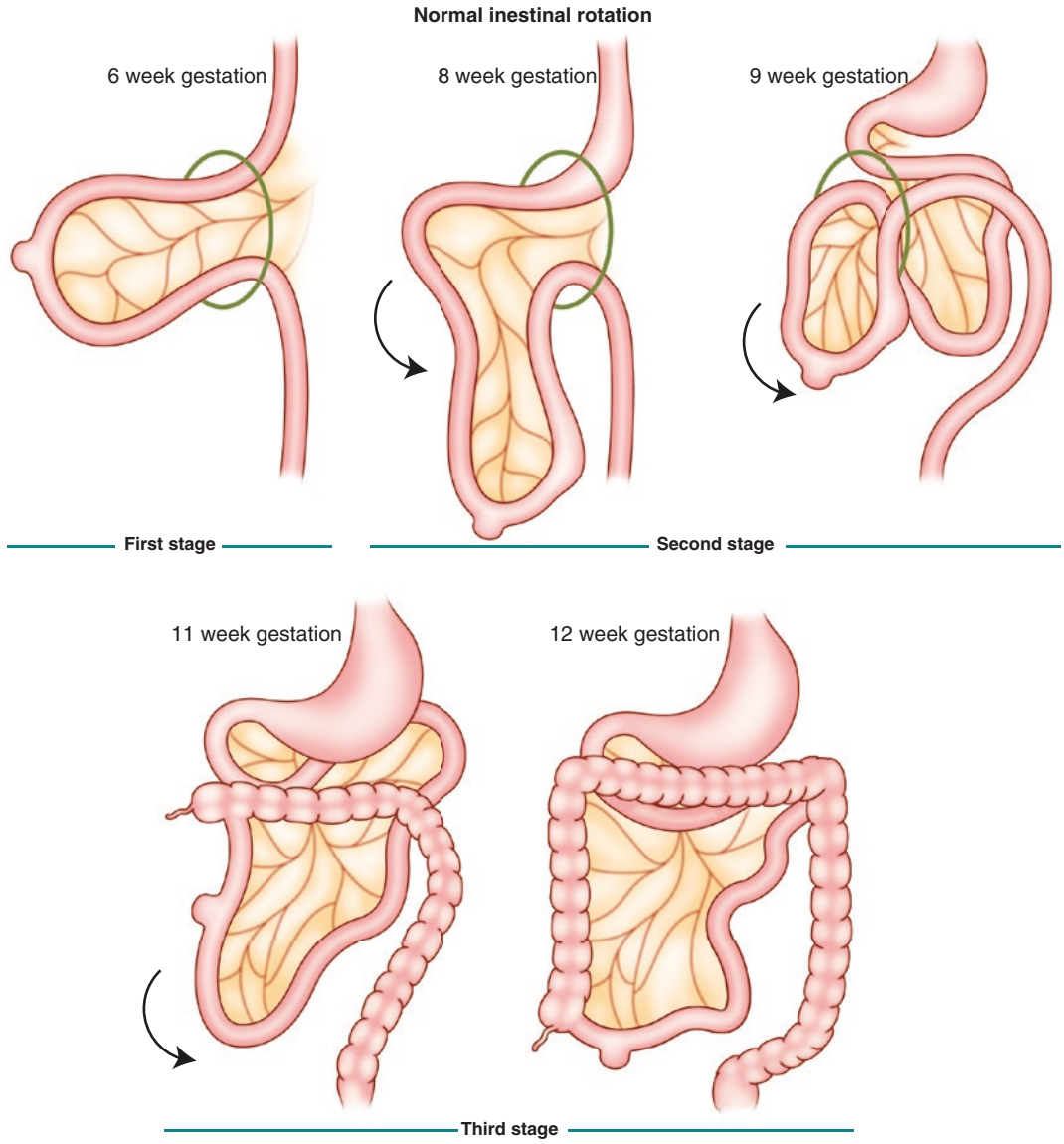


Fig. 1.12 Summary of normal intestinal rotation during development

abdomen, and the third stage is the fixation of the midgut. Abnormalities in this normal process lead to various malformations. The physiologic herniation (first stage) occurs between weeks 6 and 8 of development. The primitive gut tube elongates over the superior mesenteric artery and bulges out through the umbilical cord (Fig. 1.13). These contents move in a counterclockwise fashion, turning 90° from the sagittal to the horizontal plane (Fig. 1.14).

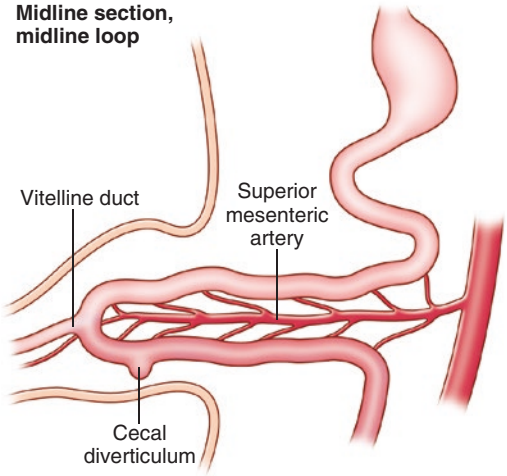


Fig. 1.13 Elongation of the midgut loop

- During the second stage, the midgut loops return to the peritoneal cavity and simultaneously rotate an additional 180° in the counterclockwise direction (Fig. 1.15). The pre-arterial portion of the duodenum returns to the abdomen first, followed by the counterclockwise rotation around the superior mesenteric vessels, resulting in the duodenum lying behind them. The colon returns after the rotation, resulting in their anterior location.
- The third stage (fixation of the midgut) begins once the intestines have returned to the peritoneal cavity and ends at birth. The cecum migrates to the right lower quadrant from its initial position in the upper abdomen (Fig. 1.16). After the completion of this 270° counterclockwise rotation, fusion begins, typically at weeks 12–13. This results in fusion of the duodenum as well as the ascending and descending colon (Fig. 1.17).

Major Anomalies of Rotation

Non-rotation

- The midgut returns to the peritoneum without any of the normal rotation. This results in the small intestine being on the right side of the abdomen and the colon on the left side

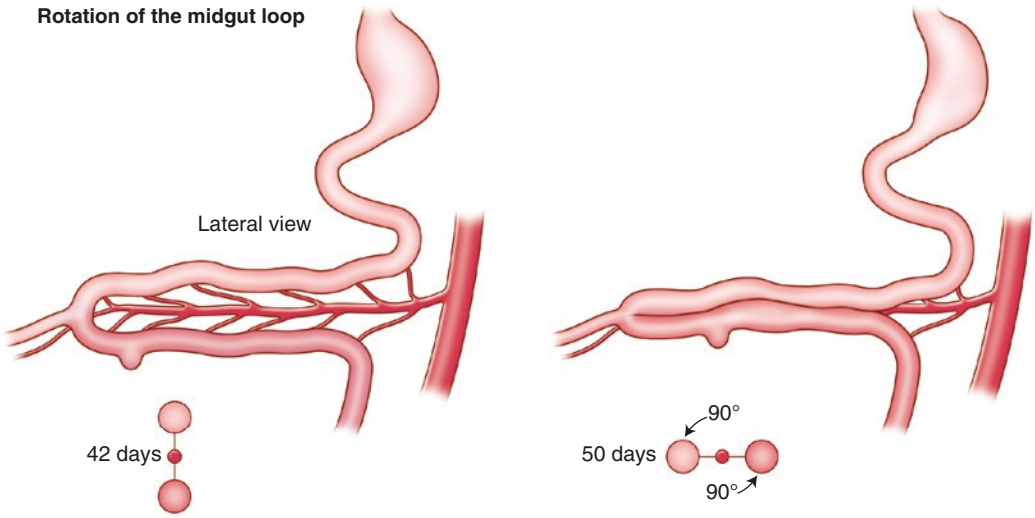


Fig. 1.14 Rotation of the midgut loop

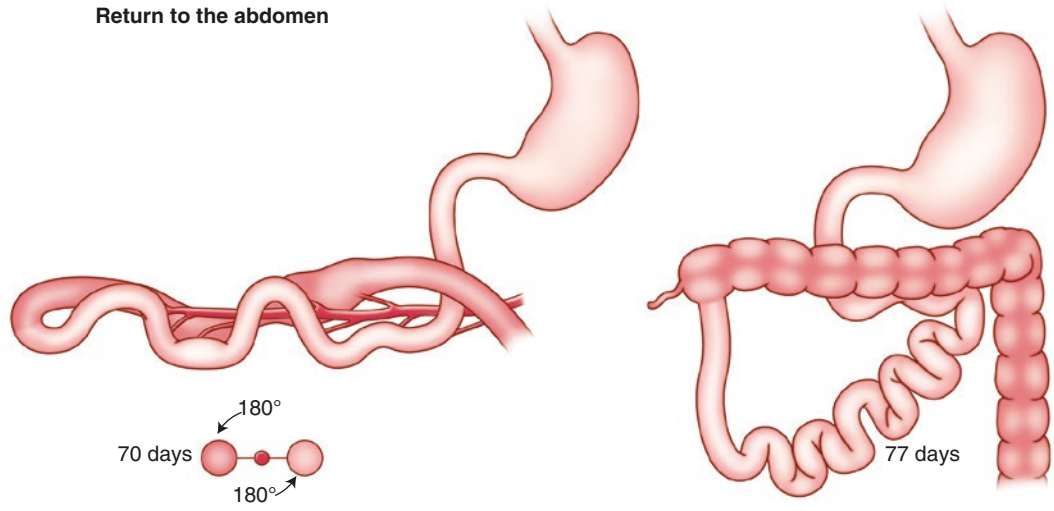
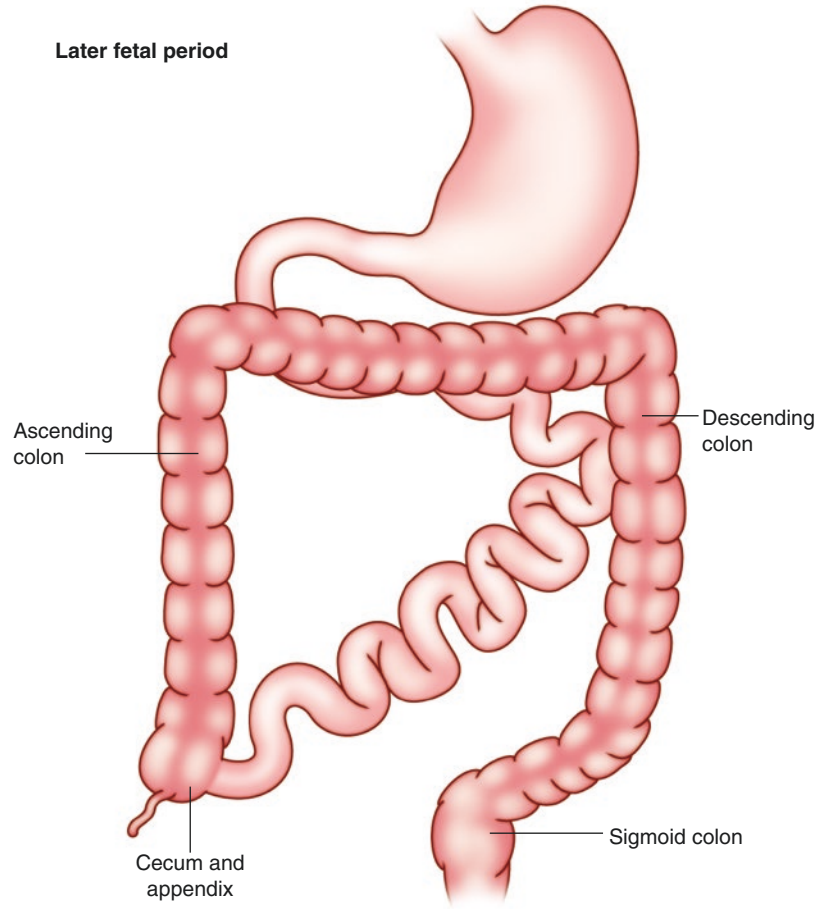


Fig. 1.15 Return of the intestinal loop to the abdomen

Fig. 1.16 Later fetal development



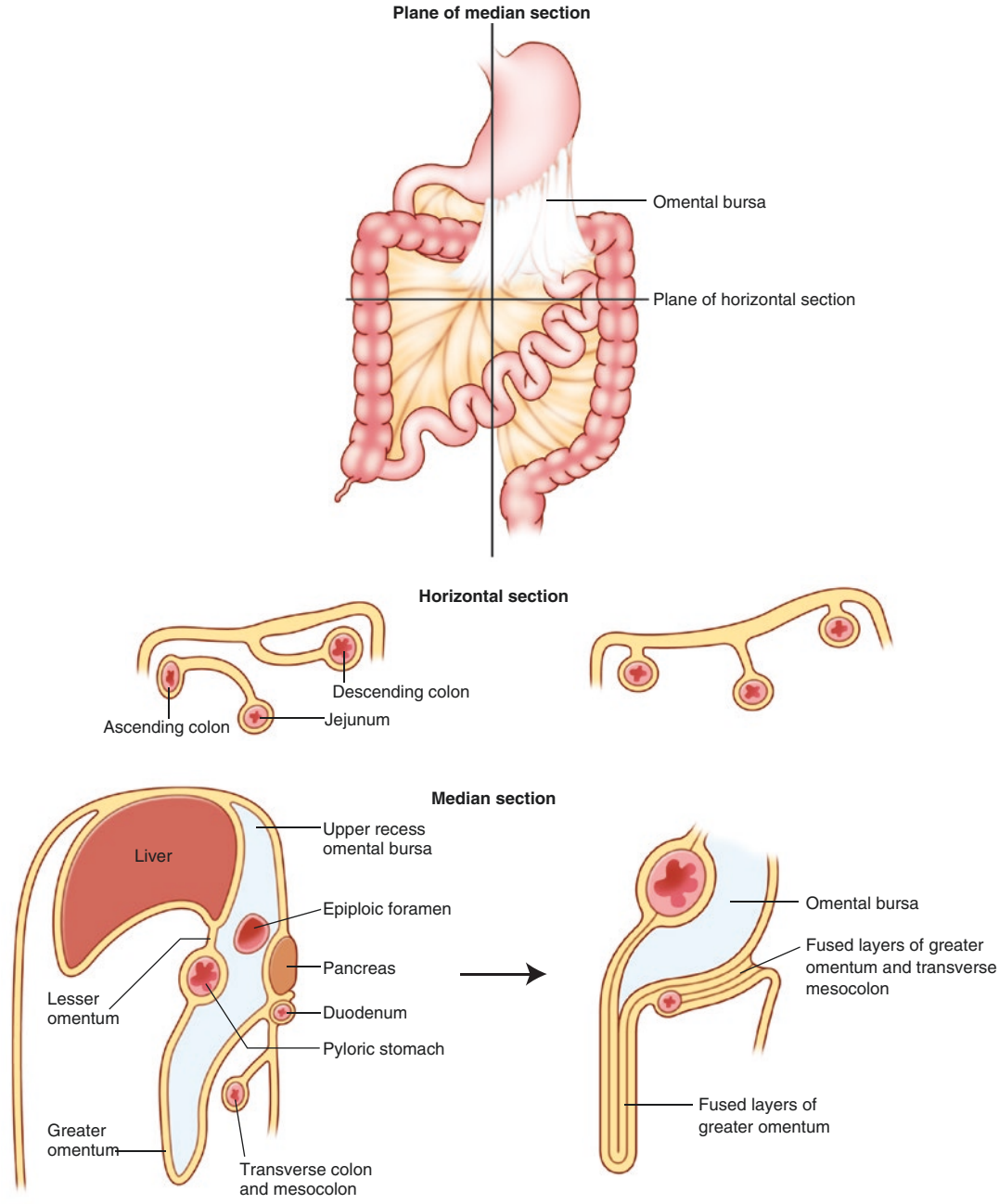


Fig. 1.17 Development of the mesentery and omental fusion

(Fig. 1.18). This condition can remain asymptomatic (a finding noted at laparoscopy or laparotomy) or result in volvulus affecting the entirety of the small intestine. The twist generally occurs at the duodenojejunal junction as well as the midtransverse colon.

Malrotation

- There is normal initial rotation, but the cecum fails to complete the normal 270° rotation around the mesentery. This results in the cecum being located in the mid-upper abdomen with lateral bands (Ladd's bands)

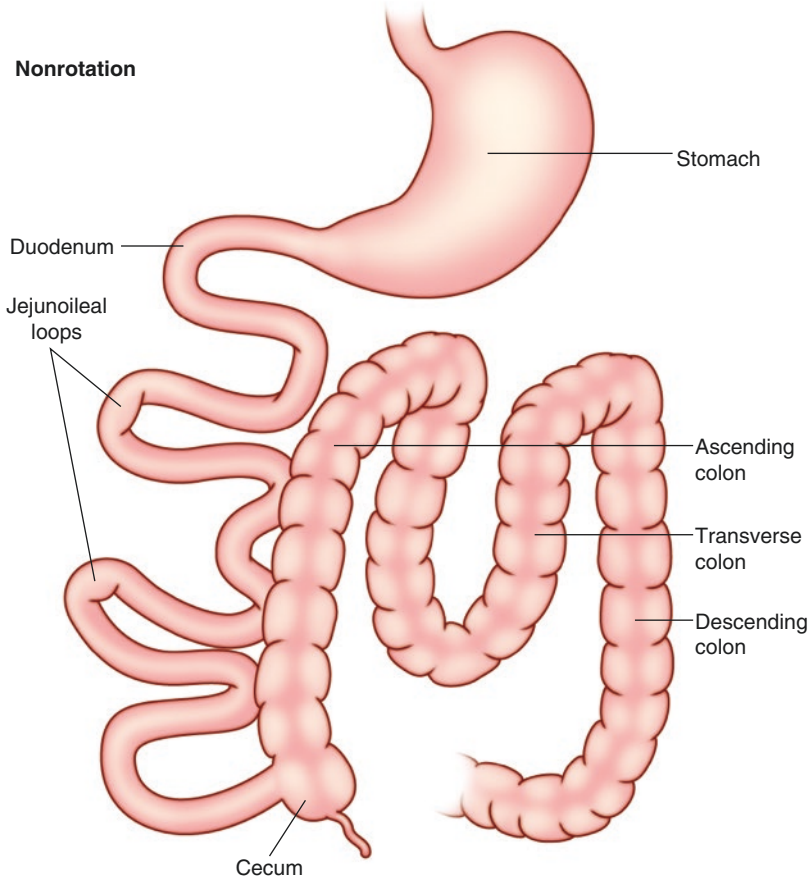


Fig. 1.18 Intestinal non-rotation

fixating it to the right abdominal wall (Fig. 1.19). These bands can result in extrinsic compression of the duodenum.

Reversed Rotation

- Clockwise (rather than counterclockwise) rotation of the midgut results in the transverse colon being posterior to the superior mesenteric artery, while the duodenum lies anterior to it.

Omphalocele

- An omphalocele is, basically, the retention of the midgut within the umbilical sac and its failure to return to the peritoneal cavity.

Internal Hernias

- Internal hernias, as well as congenital obstructive bands, can cause congenital bowel obstructions. These are considered failures of the

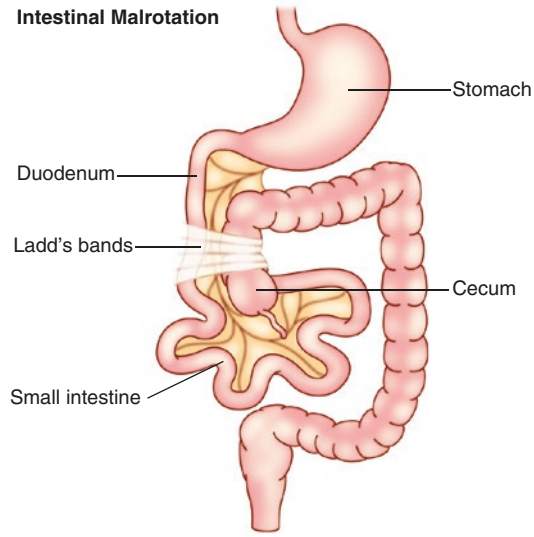


Fig. 1.19 Intestinal malrotation

process of fixation (the third stage of rotation). This can be the result of an incomplete fusion of the mesothelium or when structures are abnormally rotated. Retroperitoneal hernias can occur in various positions, most notably paraduodenal, paracecal, and intersigmoid.

Other Congenital Malformations of the Colon and Small Intestine

Proximal Colon Duplication

- There are three general types of colonic duplication: mesenteric cysts, diverticula, and long colon duplication. Mesenteric cysts are lined with intestinal epithelium and variable amounts of smooth muscle. They are found within the colonic mesentery or posterior to the rectum (within the mesorectum). They generally present as a mass or with intestinal obstruction as they enlarge.
- Diverticula can be found on the mesenteric or antimesenteric sides of the colon and are outpouchings of the bowel wall. They often contain heterotopic gastric or pancreatic tissue.
- Long colonic duplications of the colon are the rarest form of duplication. They usually run the entire length of the colon and rectum, and there is an association with other genitourinary abnormalities.

Meckel's Diverticulum

- A Meckel's diverticulum is the remnant of the vitelline or omphalomesenteric duct (Fig. 1.13). It arises from the antimesenteric aspect of the terminal ileum, most commonly within 50 cm of the ileocecal valve.
- They can be associated with a fibrous band connecting the diverticulum to the umbilicus (leading to obstruction), or it may contain ectopic gastric mucosa or pancreatic tissue (leading to bleeding or perforation) (Fig. 1.20).
- An indirect hernia containing a Meckel's diverticulum is termed a Littre's hernia.
- Meckel's diverticulum is generally asymptomatic and, per autopsy series, is found in up to 3% of the population.
- Surgical complications are more common in children than adults and include hemorrhage, obstruction, diverticulitis, perforation, and umbilical discharge.

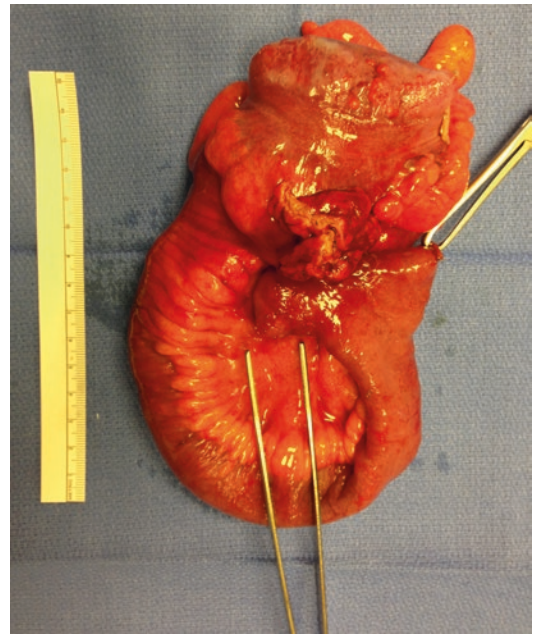


Fig. 1.20 Perforated Meckel's diverticulum with fistula to the ileum

Atresia of the Colon

- Colonic atresia, representing only 5% of all gastrointestinal atresias, is a rare cause of congenital obstruction. They are likely the result of vascular compromise during development. They vary in severity from a membranous diaphragm blocking the lumen to a fibrous cord-like remnant, on to a complete absence of a segment.

Hirschsprung's Disease

- This nonlethal anomaly, which is more common in males, results from the absence of ganglion cells within the myenteric plexus of the colon.
- It is caused by interruption of the normal migration of the neuroenteric cells from the neural crest before they reach the rectum. This results in dilation and hypertonicity of the proximal colon.
- The extent of the aganglionosis is variable, though the internal sphincter is always involved. Its severity is dependent upon the length of the involved segment.

Anorectal Malformations

- Abnormalities in the normal development of the anorectum can be attributed to "developmental arrest" at various stages of normal development. Skeletal and urinary anomalies are associated in up to 70%, while digestive tract anomalies (e.g., tracheoesophageal fistula or esophageal stenosis) and cardiac and abdominal wall abnormalities are also noted in patients with anorectal anomalies.

Anal Stenosis

- Twenty-five to twenty-nine percent of infants are born with anal stenosis, but only about 25% of these are symptomatic. The majority of these children undergo spontaneous dilation by 6 months of age.

Membranous Atresia

- This very rare condition is characterized by the presence of a thin membrane of the skin between the blind end of the anal canal and the surface. It is also termed the covered anus. It is more common in males.

Anal Agenesis

- The rectum develops below the puborectalis where it either ends in an ectopic opening (fistula) in the perineum, vulva, or urethra or it ends blindly (less commonly). The sphincter is present at its normal site.

Anorectal Agenesis

- Anorectal agenesis is the most common type of "imperforate anus." More common in males, the rectum ends well caudal to the surface, and the anus is represented by a dimple with the anal sphincter usually being normal in location. In most cases, there is a fistula to the urethra or vagina. High fistulae (to the vagina or urethra) with anorectal agenesis develop as early as the sixth or seventh week of gestation, while the low fistulae (perineal) or anal ectopia develop later, in the eighth or ninth week of development.

Rectal Atresia or "High Atresia"

- In rectal atresia, the rectum and the anal canal are separated from one another by an atretic portion. It is embryologically the distal-most type of colon atresia but is still considered an anorectal disorder clinically.

Persistent Cloaca

This rare condition, which only occurs in female infants, is the result of total failure of descent of the urorectal septum. It occurs at a very early stage of development.