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

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Anatomy

Anus and Rectum

Anal Canal Structure, Anus, and Anal Verge

- The anus or anal orifice is an anteroposterior cutaneous slit, that along with the anal canal remains virtually closed at rest, as a result of tonic circumferential contraction of the sphincters and the presence of anal cushions.
- The edge of the anal orifice, the anal verge or margin (anocutaneous line of Hilton), marks the lowermost edge of the anal canal and is sometimes the level of reference for measurements taken during sigmoidoscopy.
- Others favor the dentate line as a landmark because it is more precise. The difference between the anal verge and the dentate line is usually 1–2 cm.
- The epithelium distal to the anal verge acquires hair follicles, glands, including apocrine glands, and other features of normal skin and is the source of perianal hidradenitis suppurativa, inflammation of the apocrine glands.

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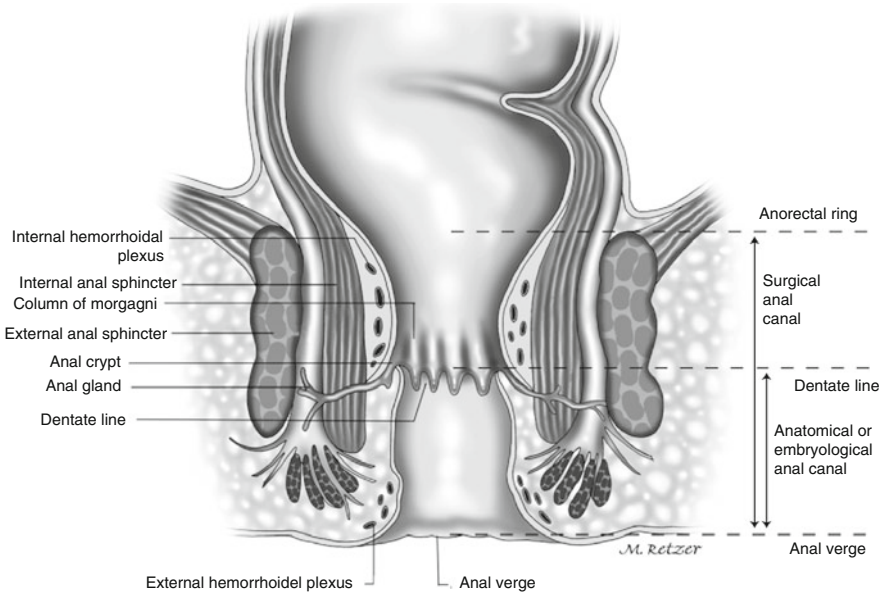

Fig. 1.1 Anal canal

Anatomic Versus Surgical Anal Canal

- Two definitions are found describing the anal canal (Fig. 1.1).
- The "anatomic" or "embryologic" anal canal is only 2.0 cm long, extending from the anal verge to the dentate line, the level that corresponds to the proctodeal membrane. The "surgical" or "functional" anal canal is longer, extending for approximately 4.0 cm (in men) from the anal verge to the anorectal ring (levator ani).
- The anorectal ring is at the level of the distal end of the ampullary part of the rectum and forms the anorectal angle and the beginning of a region of higher intraluminal pressure. Therefore, this definition correlates with digital, manometric, and sonographic examinations.

Anatomic Relations of the Anal Canal

- Posteriorly, the anal canal is related to the coccyx and anteriorly to the perineal body and the lowest part of the posterior vaginal wall in the female and to the urethra in the male. The ischium and the ischiorectal fossa are situated on either side. The fossa ischiorectal contains fat and the inferior rectal vessels and nerves, which cross it to enter the wall of the anal canal.

Muscles of the Anal Canal

- The muscular component of the mechanism of continence can be stratified into three functional groups: lateral compression from the pubococcygeus, circumferential closure from the internal and external anal sphincter, and angulation from the puborectalis (Fig. 1.2).

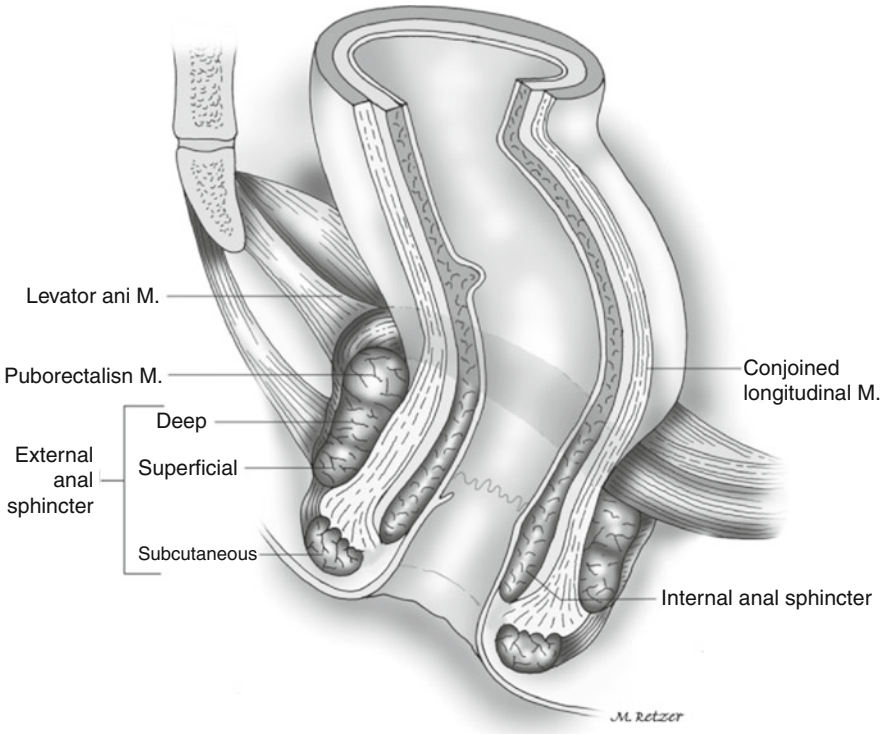

Fig. 1.2 Muscles of the anal canal

Internal Anal Sphincter

- The internal anal sphincter represents the distal 2.5- to 4.0-cm condensation of the circular muscle layer of the rectum. As a consequence of both intrinsic myogenic and extrinsic autonomic neurogenic properties, the internal anal sphincter is a smooth muscle in a state of continuous maximal contraction and represents a natural barrier to the involuntary loss of stool and gas.
- The lower rounded edge of the internal anal sphincter can be felt on physical examination, about 1.2 cm distal to the dentate line. The groove between the internal and external anal sphincter, the intersphincteric sulcus, can be visualized or easily palpated.
- Endosonographically, the internal anal sphincter is a 2- to 3-mm-thick circular band and shows a uniform hypoechogenicity.

External Anal Sphincter

- The external anal sphincter is the elliptical cylinder of striated muscle that envelops the entire length of the inner tube of smooth muscle, but it ends slightly more distal than the internal anal sphincter.
- The deepest part of the external anal sphincter is intimately related to the puborectalis muscle, which can actually be considered a component of both the levator ani and the external anal sphincter muscle complexes.

- In the male, the upper half of the external anal sphincter is enveloped anteriorly by the conjoined longitudinal muscle, whereas the lower half is crossed by it.
- In the female, the entire external anal sphincter is encapsulated by a mixture of fibers derived from both longitudinal and internal anal sphincter muscles.
- The automatic continence mechanism is formed by the resting tone, maintained by the internal anal sphincter, and magnified by voluntary, reflex, and resting external anal sphincter contractile activities.
- In response to conditions of threatened incontinence, such as increased intra-abdominal pressure and rectal distension, the external anal sphincter and puborectalis reflexively and voluntarily contract further to prevent fecal leakage.
- The external anal sphincter and the pelvic floor muscles, unlike other skeletal muscles, which are usually inactive at rest, maintain unconscious resting electrical tone through a reflex arc at the cauda equina level.

Conjoined Longitudinal Muscle

- Whereas the inner circular layer of the rectum gives rise to the internal anal sphincter, the outer longitudinal layer, at the level of the anorectal ring, mixes with fibers of the levator ani muscle to form the conjoined longitudinal muscle. This muscle descends between the internal and external anal sphincter, and ultimately some of its fibers, referred to as the *corrugator cutis ani muscle*, traverse the lowermost part of the external anal sphincter to insert into the perianal skin.
- 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.

Epithelium of the Anal Canal

- The lining of the anal canal consists of an upper mucosal (endoderm) and a lower cutaneous (ectoderm) segment (Fig. 1.1).
- The dentate (pectinate) line is the "saw-toothed" junction between these two distinct origins of venous and lymphatic drainage, nerve supply, and epithelial lining. Above this level, the intestine is innervated by the sympathetic and parasympathetic systems, with venous, arterial, and lymphatic drainage to and from the hypogastric vessels. Distal to the dentate line, the anal canal is innervated by the somatic nervous system, with blood supply and drainage from the inferior hemorrhoidal system. These differences are important when the classification and treatment of hemorrhoids are considered.
- The pectinate or dentate line corresponds to a line of anal valves that represent remnants of the proctodeal membrane. Above each valve, there is a little pocket known as an anal sinus or crypt. These crypts are connected to a variable number of glands, in average 6 (range, 3–12).

- More than one gland may open into the same crypt, whereas half the crypts have no communication.
- The anal gland ducts, in an outward and downward route, enter the submucosa; two-thirds enter the internal anal sphincter, and half of them terminate in the intersphincteric plane. Obstruction of these ducts, presumably by accumulation of foreign material in the crypts, may lead to perianal abscesses and fistulas.
- Cephalad to the dentate line, 8–14 longitudinal folds, known as the rectal columns (columns of Morgagni), have their bases connected in pairs to each valve at the dentate line.
- At the lower end of the columns are the anal papillae. The mucosa in the area of the columns consists of several layers of cuboidal cells and has a deep purple color because of the underlying internal hemorrhoidal plexus. This 0.5- to 1.0-cm strip of mucosa above the dentate line is known as the anal transition or cloacogenic zone. Cephalad to this area, the epithelium changes to a single layer of columnar cells and macroscopically acquires the characteristic pink color of the rectal mucosa.
- The cutaneous part of the anal canal consists of modified squamous epithelium that is thin, smooth, pale, stretched, and devoid of hair and glands.

Rectum

- Both proximal and distal limits of the rectum are controversial: the rectosigmoid junction is considered to be at the level of the third sacral vertebra by anatomists but at the sacral promontory by surgeons, and likewise the distal limit is regarded to be the muscular anorectal ring by surgeons and the dentate line by anatomists.
- The rectum measures 12–15 cm in length and has three lateral curves: the upper and lower are convex to the right and the middle is convex to the left. These curves correspond intraluminally to the folds or valves of Houston. The two left-sided folds are usually noted at 7–8 cm and at 12–13 cm, respectively, and the one on the right is generally at 9–11 cm. The middle valve (Kohlrausch's plica) is the most consistent in presence and location and corresponds to the level of the anterior peritoneal reflection.
- Although the rectal valves do not contain all muscle wall layers from a clinical point of view, they are a good location for performing rectal biopsies, because they are readily accessible with minimal risk for perforation.
- The rectum is characterized by its wide, easily distensible lumen and the absence of taeniae, epiploic appendices, haustra, or a well-defined mesentery.
- The word "mesorectum" has gained widespread popularity among surgeons to address the perirectal areolar tissue, which is thicker posteriorly, containing terminal branches of the inferior mesenteric artery and enclosed by the fascia propria.

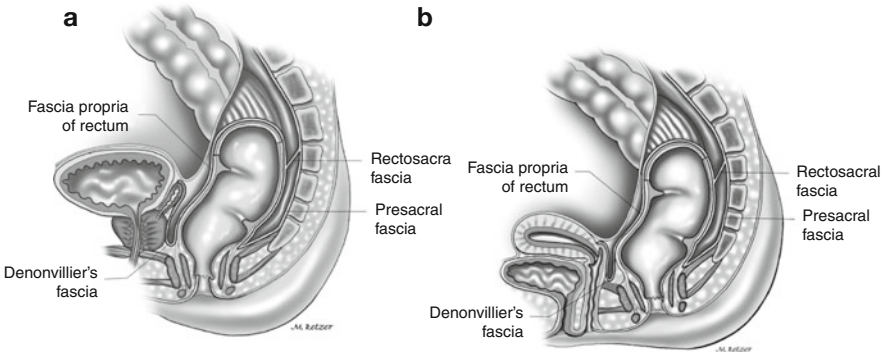

Fig. 1.3 Fascial relationships of the rectum: (**a**) male, (**b**) female

- The "mesorectum" may be a metastatic site for a rectal cancer and is removed during surgery for rectal cancer without neurologic sequelae because no functionally significant nerves pass through it.
- The upper third of the rectum is anteriorly and laterally invested by peritoneum; the middle third is covered by peritoneum on its anterior aspect only. Finally, the lower third of the rectum is entirely extraperitoneal, because the anterior peritoneal reflection occurs at 9.0–7.0 cm from the anal verge in men and at 7.5–5.0 cm from the anal verge in women.

Anatomic Relations of the Rectum

- The rectum occupies the sacral concavity and ends 2–3 cm anteroinferiorly from the tip of the coccyx. At this point, it angulates backward sharply to pass through the levators and becomes the anal canal. Anteriorly, in women, the rectum is closely related to the uterine cervix and posterior vaginal wall; in men, it lies behind the bladder, vas deferens, seminal vesicles, and prostate. Posterior to the rectum lie the median sacral vessels and the roots of the sacral nerve plexus.

Fascial Relationships of the Rectum

- The parietal endopelvic fascia lines the walls and floor of the pelvis and continues on the internal organs as a visceral pelvic fascia (Fig. 1.3a, b).
- The lateral ligaments or stalks of the rectum are distal condensations of the pelvic fascia that form a roughly triangular structure with a base on the lateral pelvic wall and an apex attached to the lateral aspect of the rectum.
- The lateral stalks are comprised essentially of connective tissue and nerves, and the middle rectal artery does not traverse them. Branches, however, course through in approximately 25 % of cases. Consequently, division of the lateral stalks during rectal mobilization is associated with a 25 % risk for bleeding.

- One theoretical concern in ligation of the stalks is leaving behind the lateral mesorectal tissue, which may limit adequate lateral or mesorectal margins during cancer surgery.
- The presacral fascia is a thickened part of the parietal endopelvic fascia that covers the concavity of the sacrum and coccyx, nerves, the middle sacral artery, and presacral veins. Operative dissection deep to the presacral fascia may cause troublesome bleeding from the underlying presacral veins.
- Presacral hemorrhage occurs as frequently as 4.6–7.0 % of resections for rectal neoplasms, and despite its venous nature, can be life threatening. This is a consequence of two factors: the difficulty in securing control because of retraction of the vascular stump into the sacral foramen and the high hydrostatic pressure of the presacral venous system.
- The rectosacral fascia is an anteroinferiorly directed thick fascial reflection from the presacral fascia at the S4 level to the fascia propria of the rectum just above the anorectal ring. The rectosacral fascia, classically known as the fascia of Waldeyer, is an important landmark during posterior rectal dissection.
- The visceral pelvic fascia of Denonvilliers is a tough fascial investment that separates the extraperitoneal rectum anteriorly from the prostate and seminal vesicles or vagina.

Urogenital Considerations

- Identification of the ureters is advisable to avoid injury to their abdominal or pelvic portions during colorectal operations. On both sides, the ureters rest on the psoas muscle in their inferomedial course; they are crossed obliquely by the spermatic vessels anteriorly and the genitofemoral nerve posteriorly. In its pelvic portion, the ureter crosses the pelvic brim in front of or a little lateral to the bifurcation of the common iliac artery and descends abruptly between the peritoneum and the internal iliac artery.
- In the female, as the ureter traverses the posterior layer of the broad ligament and the parametrium close to the side of the neck of the uterus and upper part of the vagina, it is enveloped by the vesical and vaginal venous plexuses and is crossed above and lateromedially by the uterine artery.

Arterial Supply of the Rectum and Anal Canal

- The superior hemorrhoidal artery is the continuation of the inferior mesenteric artery, once it crosses the left iliac vessels. The artery descends in the sigmoid mesocolon to the level of S3 and then to the posterior aspect of the rectum. In 80 % of cases, it bifurcates into right, usually wider, and left terminal branches; multiple branches are present in 17 %. These divisions, once within the submucosa of the rectum, run straight downward to supply the lower rectum and the anal canal.

- The superior and inferior hemorrhoidal arteries represent the major blood supply to the anorectum. In addition, it is also supplied by the internal iliac arteries.
- The contribution of the middle hemorrhoidal artery varies with the size of the superior hemorrhoidal artery; this may explain its controversial anatomy. Some authors report absence of the middle hemorrhoidal artery in 40–88 %, whereas others identify it in 94–100 % of specimens.
- The middle hemorrhoidal artery is more prone to be injured during low anterior resection, when anterolateral dissection of the rectum is performed close to the pelvic floor and the prostate and seminal vesicles or upper part of the vagina are being separated.
- The anorectum has a profuse intramural anastomotic network, which probably accounts for the fact that division of both superior and middle hemorrhoidal arteries does not result in necrosis of the rectum.
- The paired inferior hemorrhoidal arteries are branches of the internal pudendal artery, which in turn is a branch of the internal iliac artery.

Venous Drainage and Lymphatic Drainage of the Rectum and Anal Canal

- The anorectum also drains, via middle and inferior hemorrhoidal veins, to the internal iliac vein and then to the inferior vena cava.
- The external hemorrhoidal plexus, situated subcutaneously around the anal canal below the dentate line, constitutes when dilated the external hemorrhoids.
- The internal hemorrhoidal plexus is situated submucosally, around the upper anal canal and above the dentate line. The internal hemorrhoids originate from this plexus.
- Lymph from the upper two-thirds of the rectum drains exclusively upward to the inferior mesenteric nodes and then to the para-aortic nodes.
- Lymphatic drainage from the lower third of the rectum occurs not only cephalad, along the superior hemorrhoidal and inferior mesentery arteries, but also laterally, along the middle hemorrhoidal vessels to the internal iliac nodes.
- In the anal canal, the dentate line is the landmark for two different systems of lymphatic drainage: above, to the inferior mesenteric and internal iliac nodes, and below, along the inferior rectal lymphatics to the superficial inguinal nodes, or less frequently along the inferior hemorrhoidal artery.
- In the female, drainage at 5 cm above the anal verge in the lymphatic may also spread to the posterior vaginal wall, uterus, cervix, broad ligament, fallopian tubes, ovaries, and cul-de-sac, and at 10 cm above the anal verge, spread seems to occur only to the broad ligament and cul-de-sac.

Innervation of the Rectum and Anal Canal

Innervation of the Rectum

- The sympathetic supply of the rectum and the left colon arises from L1, L2, and L3 (Fig. 1.4a, b).
- Two main hypogastric nerves, on either side of the rectum, carry sympathetic innervation from the hypogastric plexus to the pelvic plexus.
- The parasympathetic fibers to the rectum and anal canal emerge through the sacral foramen and are called the nervi erigentes (S2, S3, and S4).
- The periprostatic plexus, a subdivision of the pelvic plexus situated on Denonvilliers' fascia, supplies the prostate, seminal vesicles, corpora cavernosa, vas deferens, urethra, ejaculatory ducts, and bulbourethral glands.
- Sexual function is regulated by cerebrospinal, sympathetic, and parasympathetic components. Erection of the penis is mediated by both

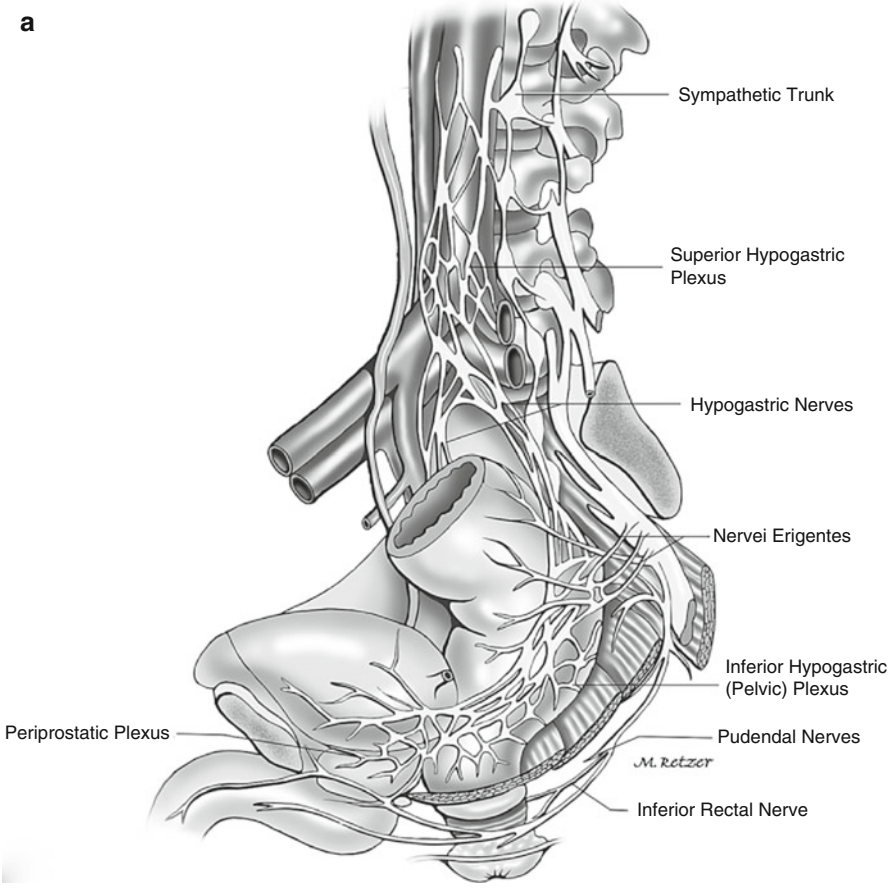

Fig. 1.4 (**a**, **b**) Innervation of the colon, rectum, and anal canal

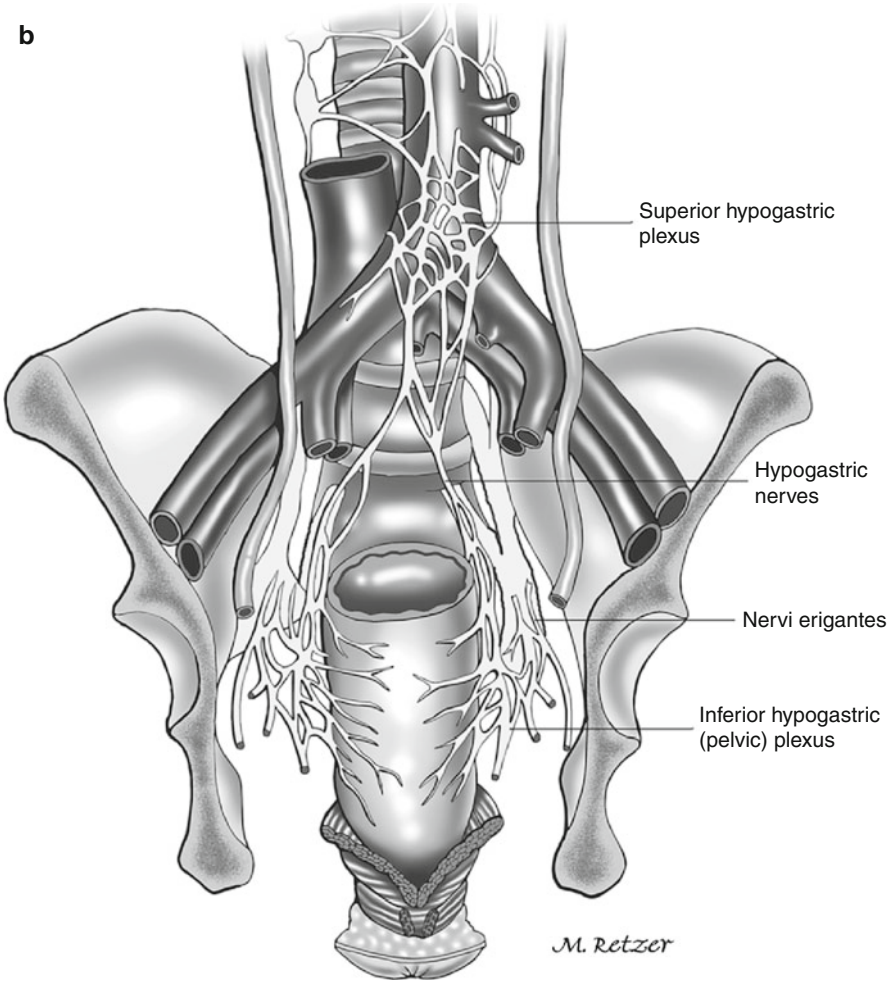

Fig. 1.4 (continued)

parasympathetic (arteriolar vasodilatation) and sympathetic inflow (inhibition of vasoconstriction).

- All pelvic nerves lie in the plane between the peritoneum and the endopelvic fascia and are in danger of injury during rectal dissection. Permanent bladder paresis occurs in 7–59 % of patients after abdominoperineal resection of the rectum; the incidence of impotence is reported to range from 15to 45 % and that of ejaculatory dysfunction from 32 to 42 %. The overall incidence of sexual dysfunction after proctectomy has been reported to reach 100 % when wide dissection is performed for malignant disease.
- Dissections performed for benign conditions are undertaken closer to the bowel wall, thus reducing the possibility of nerve injury.

- Trauma to the autonomic nerves may occur at several points. During high ligation of the inferior mesenteric artery, close to the aorta, the sympathetic preaortic nerves may be injured.
- Division of both superior hypogastric plexus and hypogastric nerves may occur also during dissection at the level of the sacral promontory or in the presacral region. In such circumstances, sympathetic denervation with intact nervi erigentes results in retrograde ejaculation and bladder dysfunction.
- The nervi erigentes are located in the posterolateral aspect of the pelvis and at the point of fusion with the sympathetic nerves are closely related to the middle hemorrhoidal artery. Injury to these nerves will completely abolish erectile function.
- The pelvic plexus may be damaged either by excessive traction on the rectum, particularly laterally, or during division of the lateral stalks when this is performed close to the lateral pelvic wall.
- Finally, dissection near the seminal vesicles and prostate may damage the periprostatic plexus, leading to a mixed parasympathetic and sympathetic injury. This can result in erectile impotence as well as a flaccid, neurogenic bladder.
- Sexual complications after rectal surgery are readily evident in men but are probably underdiagnosed in women.

Anal Canal

- The internal anal sphincter is supplied by sympathetic (L5) and parasympathetic nerves (S2, S3, and S4) following the same route as the nerves to the rectum.
- 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. Despite the fact that the puborectalis and external anal sphincter have somewhat different innervations, these muscles seem to act as an indivisible unit.
- After unilateral transection of a pudendal nerve, external anal sphincter function is still preserved because of the crossover of the fibers at the spinal cord level.
- Anal sensation is carried in the inferior rectal branch of the pudendal nerve and is thought to have a role in maintenance of anal continence.

Anorectal Spaces

- The potential spaces of clinical significance in close relation to the anal canal and rectum include ischiorectal, perianal, intersphincteric, submucosal, superficial postanal, deep postanal, supralevator, and retrorectal spaces (Fig. 1.5a, b).
- The ischiorectal fossa is subdivided by a thin horizontal fascia into two spaces: the perianal and ischiorectal.

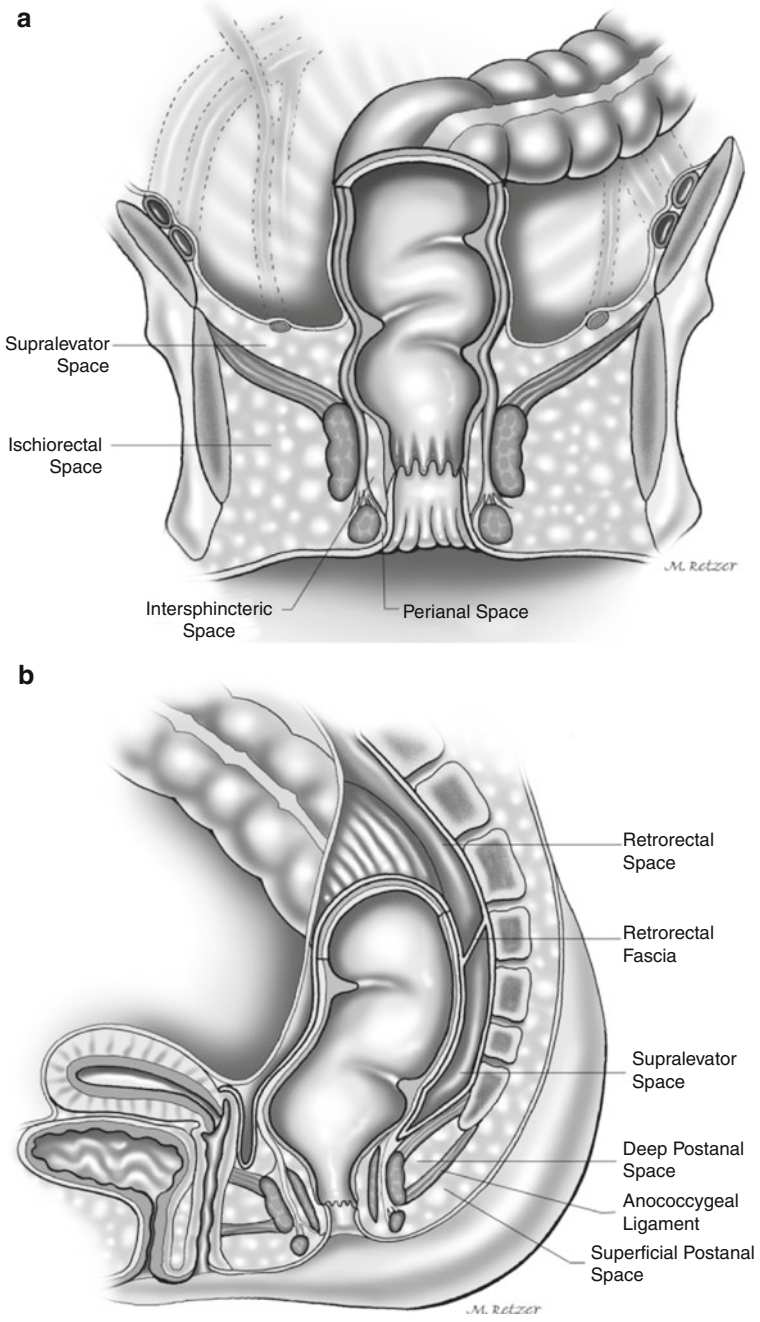

Fig. 1.5 Para-anal and pararectal spaces. (**a**) Frontal view. (**b**) Lateral view

- The perianal space surrounds the lower part of the anal canal and contains the external hemorrhoidal plexus, the subcutaneous part of the external anal sphincter, the lowest part of the internal anal sphincter, and fibers of the longitudinal muscle. This space is the typical site of anal hematomas, perianal abscesses, and anal fistula tracts.
- The intersphincteric space is a potential space between the internal and external anal sphincters. It is important in the genesis of perianal abscess, because most of the anal glands end in this space.
- The submucous space is situated between the internal anal sphincter and the mucocutaneous lining of the anal canal. This space contains the internal hemorrhoidal plexus and the muscularis submucosae ani. It is continuous with the submucous layer of the rectum, and, inferiorly, it ends at the level of the dentate line.
- The superficial postanal space is interposed between the anococcygeal ligament and the skin. The deep postanal space, also known as the retrosphincteric space of Courtney, is situated between the anococcygeal ligament and the anococcygeal raphe. Both postanal spaces communicate posteriorly with the ischiorectal fossa and are the sites of horseshoe abscesses.
- The supralevator spaces are situated between the peritoneum superiorly and the levator ani inferiorly.
- Supralevator abscesses may occur as a result of upward extension of a cryptoglandular infection or develop from a pelvic origin.
- The retrorectal space is located between the fascia propria of the rectum anteriorly and the presacral fascia posteriorly. The retrorectal space is a site for embryologic remnants and rare presacral tumors.

Pelvic Floor Musculature

- The muscles within the pelvis can be divided into three categories: (1) the anal sphincter complex, (2) pelvic floor muscles, and (3) muscles that line the sidewalls of the osseous pelvis.

Levator Ani

- The levator ani muscle, or pelvic diaphragm, is the major component of the pelvic floor. It is a pair of broad, symmetric sheets composed of three striated muscles: ileococcygeus, pubococcygeus, and puborectalis (Fig. 1.6a, b).
- The pelvic floor is “incomplete” in the midline where the lower rectum, urethra, and either the dorsal vein of the penis in men or the vagina in women passes through it. This defect is called the levator hiatus and consists of an elliptic space situated between the two pubococcygeus muscles.
- The puborectalis muscle is a strong, U-shaped loop of striated muscle that slings the anorectal junction to the posterior aspect of the pubis (Fig. 1.7).

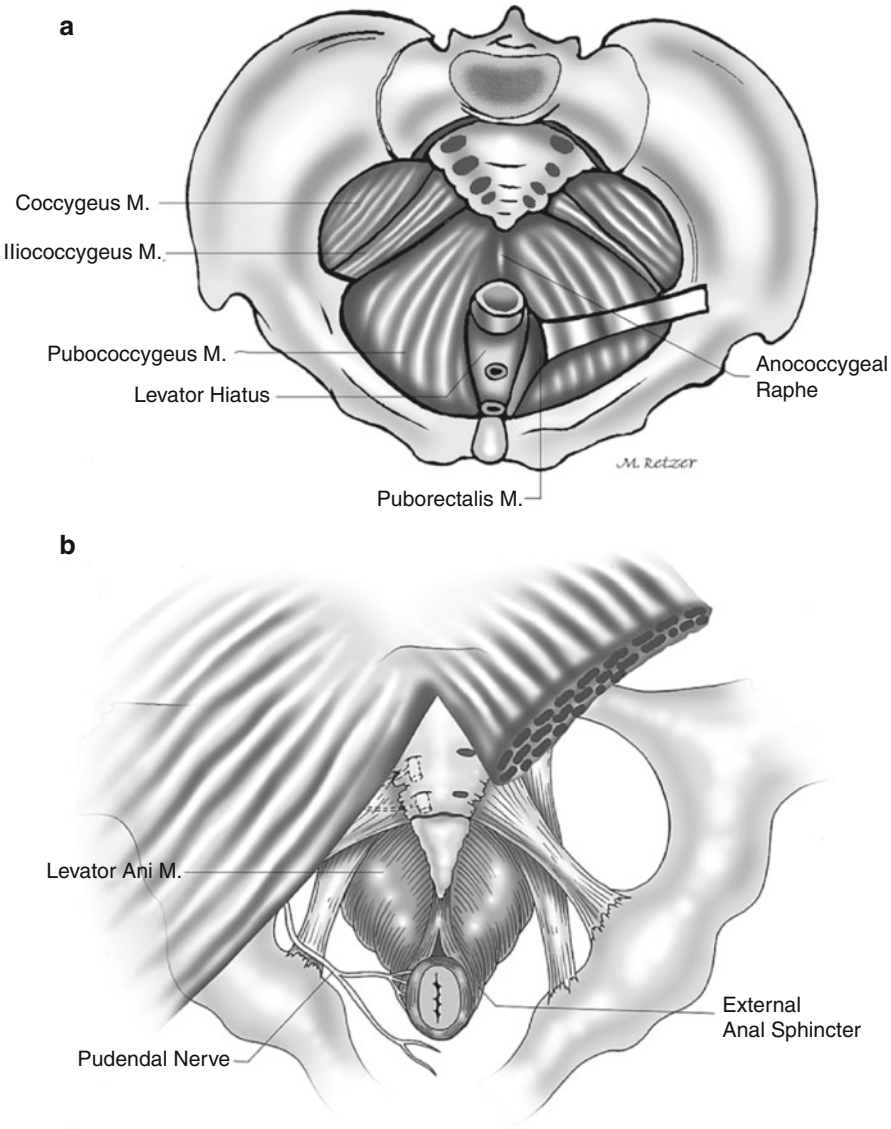

Fig. 1.6 Levator ani muscle. (**a**) Superior. (**b**) Inferior surface

The Anorectal Ring and the Anorectal Angle

- Two anatomic structures of the junction of the rectum and anal canal are related to the puborectalis muscle: the anorectal ring and the anorectal angle. The anorectal ring, a term coined by Milligan and Morgan, is a strong muscular ring that represents the upper end of the sphincter, more precisely the puborectalis, and the upper border of the internal anal sphincter, around the anorectal junction.

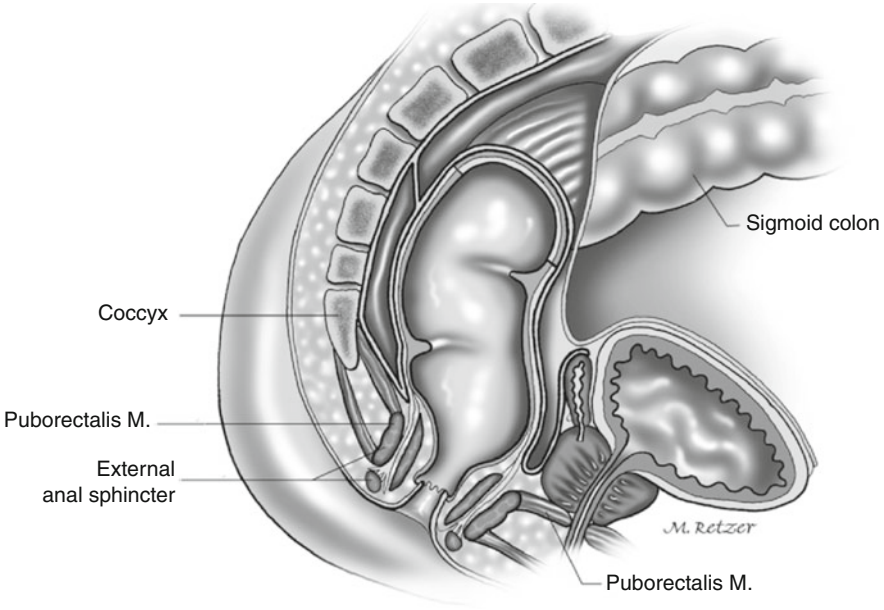

Fig. 1.7 The anteriorly directed pull of the puborectalis contributes to the angulation between the rectum and anal canal, the anorectal angle

- It is of clinical relevance because division of this structure during surgery for abscesses or fistula inevitably results in fecal incontinence.
- The anorectal angle is thought to be the result of the anatomic configuration of the U-shaped sling of the puborectalis muscle around the anorectal junction. Whereas the anal sphincters are responsible for closure of the anal canal to retain gas and liquid stool, the puborectalis muscle and the anorectal angle are designed to maintain gross fecal continence.

Colon

General Considerations

- Named from the Greek *koluein* ("to retard"), the colon is variable in length, averaging approximately 150 cm, which corresponds to one-quarter the length of the small intestine.
- Its diameter can be substantially augmented by distension, it gradually decreases from 7.5 cm at the cecum to 2.5 cm at the sigmoid.
- Anatomic differences between the small and large intestines include position, caliber, degree of fixation, and, in the colon, the presence of three distinct characteristics: the taeniae coli, the haustra, and the appendices epiploicae.
- The three taeniae coli, anterior (taenia libera), posteromedial (taenia mesocolica), and posterolateral (taenia omentalis), represent bands of the

outer longitudinal coat of muscle that traverse the colon from the base of the appendix to the rectosigmoid junction, where they merge.

- The haustra or haustral sacculations are outpouchings of bowel wall between the taeniae; they are caused by the relative shortness of the taeniae, about one-sixth shorter than the length of the bowel wall. The haustra are separated by the plicae semilunares or crescentic folds of the bowel wall, which give the colon its characteristic radiographic appearance when filled with air or barium.
- The appendices epiploicae are small appendages of fat that protrude from the serosal aspect of the colon.

Cecum

- The cecum is the sacculated segment (Latin *caecus*, "blind") of the large bowel that projects downward as a 6- to 8-cm blind pouch below the entrance of the ileum.
- Usually situated in the right iliac fossa, the cecum is almost entirely, or at least in its lower half, invested with peritoneum.
- The ileum terminates in the posteromedial aspect of the cecum.
- A circular sphincter, the ileocecal sphincter, originates from a slight thickening of the muscular layer of the terminal ileum. A competent ileocecal valve is related to the critical closed-loop type of colonic obstruction. However, ileocecal competence is not always demonstrated on barium enema studies. Instead of preventing reflux of colonic contents into the ileum, the ileocecal valve regulates ileal emptying. The ileocecal sphincter seems to relax in response to the entrance of food into the stomach. As in the gastroesophageal junction, extrasphincteric factors such as the ileocecal angulation apparently have a role in the prevention of reflux from the colon to the ileum.

Appendix

- The vermiform appendix is an elongated diverticulum that arises from the posteromedial aspect of the cecum about 3.0 cm below the ileocecal junction. Its length varies from 2 to 20 cm (mean, 8–10 cm), and it is approximately 5 mm in diameter.
- The appendix, because of its great mobility, may occupy a variety of positions, possibly at different times in the same individual. It has been estimated that in 85–95 % of cases, the appendix lies posteromedial on the cecum toward the ileum, but other positions include retrocecal, pelvic, subcecal, pre-ileal, and retroileal.
- The confluence of the three taeniae is a useful guide in locating the base of the appendix.

Ascending Colon

- The ascending colon is approximately 15 cm long. It ascends, from the level of the ileocecal junction to the right colic or hepatic flexure, laterally

to the psoas muscle and anteriorly to the iliacus, the quadratus lumborum, and the lower pole of the right kidney.

- The ascending colon is covered with peritoneum anteriorly and on both sides.
- Like the descending colon on its posterior surface, the ascending colon is devoid of peritoneum, which is instead replaced by an areolar tissue (fascia of Toldt). In the lateral peritoneal reflection, this process is represented by the white line of Toldt, which is more evident at the descending-sigmoid junction. This line serves as a guide for the surgeon when the ascending, descending, or sigmoid colon is mobilized.
- At the visceral surface of the right lobe of the liver and lateral to the gallbladder, the ascending colon turns sharply medially and slightly caudad and ventrally to form the right colic (hepatic) flexure.

Transverse Colon

- The transverse colon is approximately 45 cm long, the longest segment of the large bowel. It crosses the abdomen, with an inferior curve immediately caudad to the greater curvature of the stomach. The transverse colon is relatively fixed at each flexure, and, in between, it is suspended by a 10- to 15-cm-wide area which provides variable mobility; the nadir of the transverse colon may reach the hypogastrium.
- The transverse colon is completely invested with peritoneum, but the greater omentum is fused on its anterosuperior aspect. The left colic or splenic flexure is situated beneath the lower angle of the spleen and firmly attached to the diaphragm by the phrenocolic ligament, which also forms a shelf to support the spleen. Because of the risk for hemorrhage, mobilization of the splenic flexure should be approached with great care, preceded by dissection upward along the descending colon and medially to laterally along the transverse colon toward the splenic flexure. This flexure, when compared with the hepatic flexure, is more acute, higher, and more deeply situated.

Descending Colon

- The descending colon courses downward from the splenic flexure to the brim of the true pelvis, a distance of approximately 25 cm.
- The descending colon is narrower and more dorsally situated than the ascending colon.

Sigmoid Colon

- The sigmoid colon is commonly a 35- to 40 cm long, mobile, omega-shaped loop completely invested by peritoneum; however, it varies greatly in length and configuration.
- The rectosigmoid junction has been frequently regarded by surgeons as an indistinct zone, a region comprising the last 5–8 cm of sigmoid and the uppermost 5 cm of the rectum.

Blood Supply

- The superior and inferior mesenteric arteries nourish the entire large intestine, and the limit between the two territories is the junction between the proximal two-thirds and the distal third of the transverse colon. This represents the embryologic division between the midgut and the hindgut.
- The superior mesenteric artery originates from the aorta behind the superior border of the pancreas at L1 and supplies the cecum, appendix, ascending colon, and most of the transverse colon.
- From its right side arises the colic branches: middle, right, and ileocolic arteries. The ileocolic, the most constant of these vessels, bifurcates into a superior or ascending branch, which communicates with the descending branch of the right colic artery, and an inferior or descending branch, which gives off the anterior cecal, posterior cecal, and appendicular and ileal divisions.
- The right colic artery may also arise from the ileocolic or middle colic arteries and is absent in 2–18 % of specimens. It supplies the ascending colon and hepatic flexure through its ascending and descending branches, both of them joining with neighboring vessels to contribute to the marginal artery.
- The middle colic artery is the highest of the three colic branches of the superior mesenteric artery, arising close to the inferior border of the pancreas. Its right branch supplies the right transverse colon and hepatic flexure, anastomosing with the ascending branch of the right colic artery. Its left branch supplies the distal half of the transverse colon.
  - Anatomic variations of this artery include absence in 4–20 % of cases and the presence of an accessory middle colic artery in 10 %; the middle colic artery can be the main supply to the splenic flexure in about 33 % of cases.
- The inferior mesenteric artery originates from the left anterior surface of the aorta, 3–4 cm above its bifurcation at the level of L2–L3, and runs downward and to the left to enter the pelvis. Within the abdomen, the inferior mesenteric artery branches into the left colic artery and two to six sigmoidal arteries.
  - The left colic artery, the highest branch of the inferior mesenteric artery, bifurcates into an ascending branch, which runs upward to the splenic flexure to contribute to the arcade of Riolan, and a descending branch, which supplies most of the descending colon.
  - The marginal artery terminates within the arcade of sigmoidal arteries. The superior hemorrhoidal artery is the continuation of the inferior mesenteric artery, once it crosses the left iliac vessels.
- The venous drainage of the large intestine basically follows its arterial supply. Blood from the right colon, via the superior mesenteric vein, and from the left colon and rectum, via the inferior mesenteric vein, reaches the intrahepatic capillary bed through the portal vein.

Collateral Circulation

- The central anastomotic artery connecting all colonic mesenteric branches, is also known as the marginal artery of Drummond. Discontinuity of the marginal artery has been shown at the lower ascending colon and especially at the left colic flexure and the sigmoid colon. This potential hypovascularity is a source of concern during colonic resection.
- The splenic flexure comprises the watershed between midgut and hindgut supplies (Griffiths' critical point); this anastomosis is of variable magnitude, and it may be absent in about 50 % of cases. For this reason, ischemic colitis usually affects or is most severe near the splenic flexure.
- The meandering mesenteric artery is a thick and tortuous vessel that makes a crucial communication between the middle colic artery and the ascending branch of the left colic artery, especially in advanced atherosclerotic disease. The presence of the meandering mesenteric artery indicates severe stenosis of either the superior mesenteric artery (retrograde flow) or inferior mesenteric artery (antegrade flow).

Lymphatic Drainage

- The submucous and subserous layers of the colon and rectum have a rich network of lymphatic plexuses, which drain into an extramural system of lymph channels and follow their vascular supply.
- Colorectal lymph nodes are classically divided into four groups: epiploic, paracolic, intermediate, and principal. The epiploic group lies on the bowel wall under the peritoneum and in the appendices epiploicae; they are more numerous in the sigmoid and are known in the rectum as the nodules of Gerota. The lymphatic drainage from all parts of the colon follows its vascular supply. The paracolic nodes are situated along the marginal artery and on the arcades; they are considered to have the most numerous filters. The intermediate nodes are situated on the primary colic vessels and the main or principal nodes on the superior and inferior mesenteric vessels.
- The lymph then drains to the cisterna chyli via the para-aortic chain of nodes. Colorectal carcinoma staging systems are based on the neoplastic involvement of these various lymph node groups.

Innervation

- The sympathetic and parasympathetic components of the autonomic innervation of the large intestine closely follow the blood supply.
- The sympathetic supply of the right colon originates from the lower six thoracic segments. These thoracic splanchnic nerves reach the celiac, preaortic, and superior mesenteric ganglia, where they synapse.
- The parasympathetic supply comes from the right (posterior) vagus nerve and celiac plexus. The fibers travel along the superior mesenteric artery and finally synapse with cells in the autonomic plexuses within the bowel wall.

Embryology

Anus and Rectum

- The distal colon, rectum, and the anal canal above the dentate line are all derived from the hindgut. Therefore, this segment is supplied by the hindgut (inferior mesenteric) artery, with corresponding venous and lymphatic drainage. Its parasympathetic outflow comes from S2, S3, and S4 via splanchnic nerves.
- The dentate line marks the fusion between endodermal and ectodermal tubes, where 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, whereas the hindgut originates above it.
- The cloacal part of the anal canal, which has both endodermal and ectodermal elements, forms the anal transitional zone after breakdown of the anal membrane.
- The sphincters apparently migrate during their development; the external sphincter grows cephalad and the internal sphincter moves caudally. Concomitantly, the longitudinal muscle descends into the intersphincteric plane.

Anorectal Malformations

- The anorectal malformations can be traced to developmental arrest at various stages of normal maturation.
- Associated anomalies, most frequently skeleton and urinary defects, may occur in up to 70 %.
- There is evidence for familial occurrence of anorectal defects; the estimated risk in a family of a second occurrence of some form of imperforate anus is up to 50 times the normal chance.
- The proposed classification systems for the congenital malformations of the anorectal region are usually either incomplete or complex. The most comprehensive system has been proposed by Gough and Santulli and takes into consideration whether the rectum terminates above (anorectal defects) or below (anal defects) the puborectalis sling (Table 1.1).

Anal Defects

Anal Stenosis

- Some degree of stricture of the rectum is present in 25–39 % of infants, and only about 25 % of these will show some degree of disordered evacuation.

Table 1.1 Classification of anorectal malformations

A. Anal defects ("low" defects)
1. Anal stenosis
2. Membranous atresia (rare)
3. Anal agenesis
(a) Without fistula
(b) With fistula (ectopic anus)
B. Anorectal defects ("high" defects)
1. Anorectal agenesis
(a) Without fistula
(b) With fistula
2. Rectal atresia ("high" atresia)
C. Persistent cloaca
1. Rectal duplication
2. Developmental cysts

Membranous Atresia

- This defect, also known as "covered anus," is very rare. It is characterized by presence of a thin membrane of skin between the blind end of the anal canal and the surface.

Anal Agenesis

- The rectum extends below the puborectalis and ends, either blindly or, more often, in an ectopic opening or fistula to the perineum anteriorly, to the vulva, or to the urethra.

Anorectal Defects

Anorectal Agenesis

- Anorectal agenesis more often affects males and represents the most common type of "imperforate anus." The rectum ends well above the surface, the anus is represented by a dimple, and the anal sphincter is usually normal.
- In most cases, there is a fistula or fibrous remnant connecting the rectal ending to the urethra or vagina.

Rectal Atresia or "High Atresia"

- Although considered clinically as an anorectal defect, embryologically this is the most caudal type of atresia of the large intestine. The rectum and anal canal are separated from each other by an atretic portion.

Persistent Cloaca

- This is a rare condition that occurs only in female infants.

Colon and Small Bowel

The normal embryologic process of rotation of the intestinal tract includes three stages:

First Stage: Physiologic Herniation of the Primitive Digestive Tube

- The first stage of rotation begins between the sixth and eighth weeks of intrauterine life, when the primitive intestinal tube elongates on its mesenteric around the superior mesenteric artery and bulges through the umbilical cord as a temporary physiologic herniation.
- The anomalies of this stage are rare and include situs inversus, inverted duodenum, and extroversion of the cloaca.

Second Stage: Return of the Midgut to the Abdomen

- During this stage, the midgut loop returns to the peritoneal cavity from the umbilical herniation and simultaneously rotates 180° counterclockwise around the pedicle formed by the mesenteric root.
- Anomalies of the second stage are relatively more common than the ones originated from the first stage and include nonrotation, malrotation, reversed rotation, internal hernia, and omphalocele.

Third Stage: Fixation of the Midgut

- The third stage of gut rotation starts after return of the gut to the peritoneal cavity and ends at birth. The cecum, initially in the upper abdomen, descends, migrating to the right lower quadrant, as counterclockwise rotation continues to 270°.
- After completion of the sequential rotation of the gastrointestinal tract, in the latter weeks of the first trimester, the process of fixation initiates.
- Anomalies of this stage are common and include mobile cecum, subhepatic or undescended cecum, hyperdescent of the cecum, and persistent colonic mesentery.
- The midgut progresses below the major pancreatic papilla to form the small intestine, the ascending colon, and the proximal two-thirds of the transverse colon. This segment is supplied by the midgut (superior mesenteric) artery, with corresponding venous and lymphatic drainage.
- The distal colon (distal third of the transverse colon), the rectum, and the anal canal above the dentate line are all derived from the hindgut. Therefore, this segment is supplied by the hindgut (inferior mesenteric) artery, with corresponding venous and lymphatic drainage. Its parasympathetic outflow comes from S2, S3, and S4 via splanchnic nerves.

Abnormalities of Rotation

Nonrotation

- In this condition, the midgut loop returns to the peritoneal cavity without the process of rotation, and, consequently, the entire small bowel locates on the right side of the abdomen, and the left colon is on the left side.
- This condition may be entirely asymptomatic and constitute a finding at laparotomies. However, it may complicate with volvulus affecting the entire small bowel. The twist of the entire midgut loop on its pedicle can occur, usually at the level of the duodenojejunal junction and the midtransverse colon, because of the defective fixation of the mesenteric root.

Malrotation

- In malrotation, the cecum fails to complete the 360° rotation around the superior mesenteric and does not complete the migration process. As a result of this failure in the migration process, the malrotated cecum locates in the right upper quadrant and is fixed by lateral bands or adhesions. These bands can overlie the distal part of the duodenum and cause extrinsic compression.

Reversed Rotation

- In this condition, the midgut rotates clockwise instead of counterclockwise; consequently, the transverse colon locates posteriorly and the duodenum anteriorly, in relation to the mesenteric artery.

Omphalocele

- Omphalocele is the retention of the midgut in the umbilical sac as a result of failure of the gut to return to the peritoneal cavity.

Incomplete Attachment of Cecum and Mesentery

- In normal conditions, the cecum is almost entirely, or at least in its lower half, invested with peritoneum. However, its mobility is usually limited by a small mesocecum. In approximately 5 % of individuals, the peritoneal covering is absent posteriorly; it then rests directly on the iliacus and psoas major muscles.
- Alternatively, an abnormally mobile cecum-ascending colon, resulting from an anomaly of fixation, can be found in 10–22 % of individuals. In this case, a long mesentery is present, and the cecum may assume varied positions. This lack of fixation may predispose to the development of volvulus.

Internal Hernias Around Ligament of Treitz

- Both internal hernias and congenital obstructive bands or adhesions are causes of congenital bowel obstruction and result from an anomaly during the process of fixation.
- Retroperitoneal hernias can occur in any intraperitoneal fossae, particularly paraduodenal, paracecal, and intersigmoid. The most common internal hernias resulting from abnormal fixation of the colon are right and left paraduodenal hernias.

Other Congenital Malformations of the Colon and Small Intestine

Proximal Colon Duplications

- Duplication of the colon comprises three general groups of congenital abnormalities: mesenteric cysts, diverticula, and long colon duplication.
  - Mesenteric cysts lie in the mesentery of the colon or behind the rectum, may be separable or inseparable from the bowel wall, and usually present, as the size increases, either as a palpable mass or intestinal obstruction.
  - Diverticula are blind-ending pouches of variable lengths and arise either from the mesenteric or the antimesenteric border of the bowel. They may have heterotopic gastric mucosa or pancreatic-type tissue.
  - Long colon duplication or tubular duplication of the colon is the rarest form of duplication. Frequently it involves the entire colon and rectum. Often, there is an association of pelvic genitourinary anomalies.

Meckel's Diverticulum

- Meckel's diverticulum is a remnant of the vitelline or omphalomesenteric duct, arising from the antimesenteric border of the terminal ileum, usually within 50 cm of the ileocecal valve.
- Associated abnormalities include persistence of a fibrous band connecting the diverticulum to the umbilicus or a patent omphalomesenteric duct, presence of ectopic mucosa or aberrant pancreatic tissue (in more than half of asymptomatic diverticula), and herniation of the diverticulum in an indirect inguinal hernia (Littré's hernia).
- In most people, Meckel's diverticulum is asymptomatic, and according to autopsy series, it exists in 1–3 % of the general population.
- Surgical complications are more frequent in infants and children and include hemorrhage from ectopic gastric mucosa, intestinal obstruction

resulting from associated congenital bands or ileocolic intussusception, diverticulitis, perforation, and umbilical discharge from a patent omphalomesenteric duct.

Atresia of the Colon

- Colonic atresia is a rare cause of intestinal obstruction; it represents only 5 % of all forms of gastrointestinal atresia. It is probably caused by a vascular accident occurring during intrauterine life.

Hirschsprung's Disease

- This disease results from the absence of ganglion cells in the myenteric plexus of the colon caused by interruption of migration of neuroenteric cells from the neural crest before they reach the rectum.
- The physiologic obstruction, more insidious than an anatomic atresia, results in proximal dilation and hypertrophy of the colon above.
- The extent of the aganglionosis is variable. The internal anal sphincter is involved in all cases and the entire rectum in most cases.
- The disease is more common in males, and its severity is related to the length of the aganglionic segment. Although most patients reach surgery before they are a year old, many are older and a few reach adulthood.