Gordon and Nivatvongs' Principles and Practice of Surgery for the Colon, Rectum, and Anus

Fourth Edition

David E. Beck
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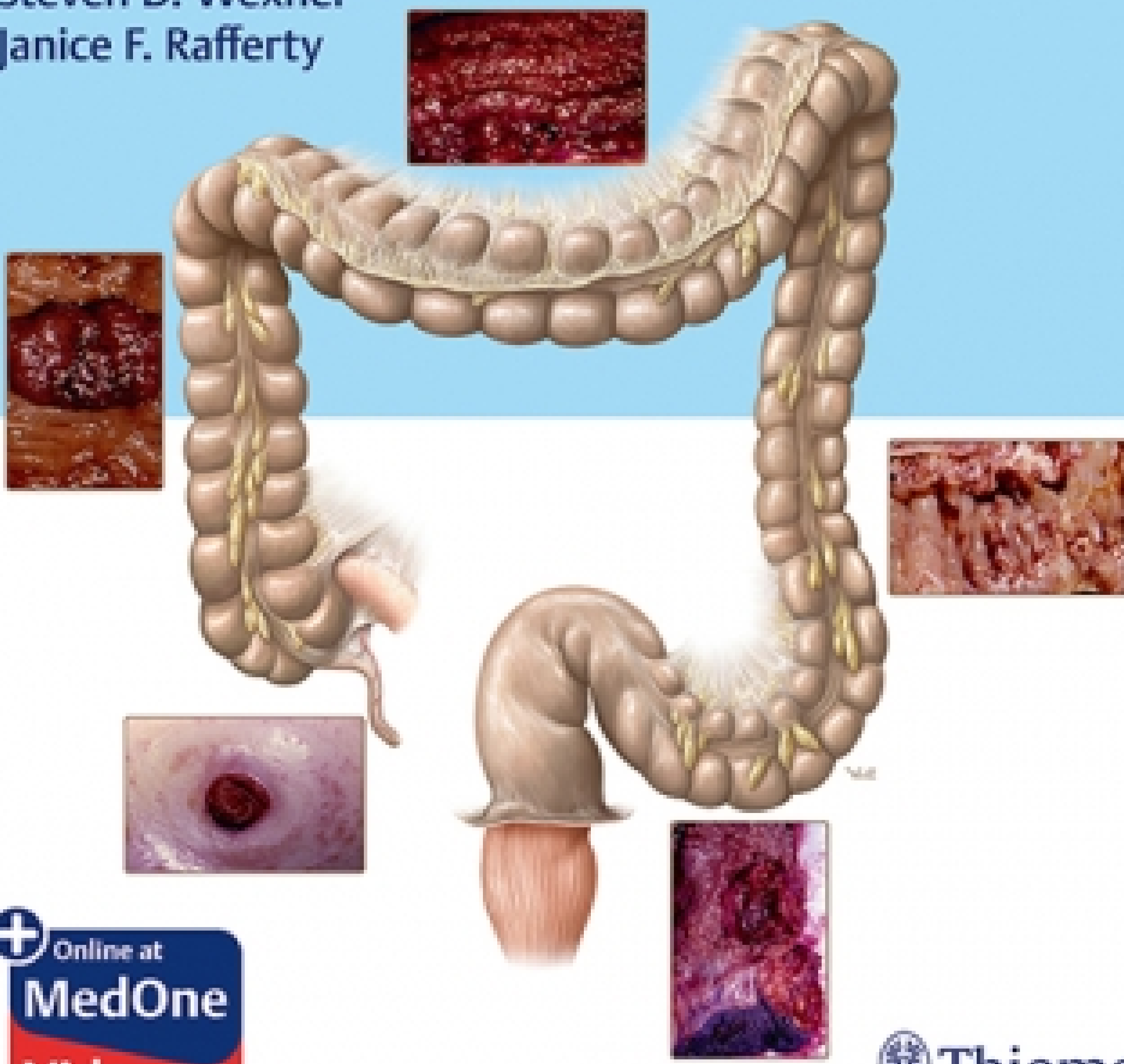

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This fourth edition is dedicated to Philip H. Gordon (13 September 1942 - 11 April 2018) and Santhat Nivatvongs with our utmost respect and affection, and with appreciation for their unmatched contributions to this specialty and their influence on our respective careers.

– DEB, SDW, JFR

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Video Contents

Foreword

The specialty of Colon and Rectal Surgery has a long and distinguished history: we trace our roots to practitioners of proctology and the very beginnings of surgery. Education and teaching has always been a central component of our specialty and textbooks have been central to this activity. Most early textbooks were single authored and described the particular practice of the author. As experience grew and science was brought into Medicine, subsequent textbooks provided evidence and some traditional procedures were abandoned. Unfortunately, most of these texts disappeared with the retirement or death of the author. More recently, multi-authored texts have become the norm. These provide a wider perspective, but often lack unified style or themes. *Principles and Practice of Surgery for the Colon, Rectum, and Anus* was first published in 1992 with the goal to be a comprehensive textbook that would encompass the gamut of colon and anorectal surgery. Authored in the most part by two surgeons, the text emphasized fundamentals of disease, with explanations of etiologies and pathogenesis to guide the reader on why, when and how to institute therapy. The text was a natural extension of their previous text *Essentials of Anorectal Surgery* and was well received by the surgical community; so much so that additional editions were published in 1999 and 2007.

We are pleased that David E. Beck, Steven D. Wexner, and Janice F. Rafferty agreed to continue this legacy and have composed this fully revised fourth edition now entitled *Gordon and Nivatvongs' Principles and Practice of Surgery for the Colon, Rectum, and Anus*. They have produced a new textbook that for the most part retained the organization and style of previous editions. Material that remained current was maintained, but as significant advances have occurred in the last ten years, significant current evidence based material has been added. As this is a textbook written for the busy practicing surgeon, this fourth edition has been streamlined and (with great but careful effort) reduced in bulk.

We hope and expect that our past and future readers (practicing surgeons or those in training) will find this fourth edition as valuable as the previous ones, and we are most grateful that the new authors/editors have continued our commitment to the specialty of Colon and Rectal Surgery.

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Preface

For fifteen years (1992–2007), Dr. Gordon and Dr. Nivatvongs authored the first three editions of *Principles and Practice of Surgery for the Colon, Rectum, and Anus*. They succeeded in producing a comprehensive book that encompassed the gamut of colon and anorectal diseases. The small number of authors and contributors resulted in a uniformity of style rarely seen in the more common multi-authored textbooks. The authors of this fourth edition were honored to be asked by the previous authors to take up the task of producing a new edition.

We are committed to maintaining a small number of authors and specialty contributors and have retained the organization of chapters into 4 main sections. To reflect the significant advances that have occurred in this specialty in the 11 years since the third edition was published, each chapter was reviewed, revised, or rewritten. Some chapters were combined and new ones added, and the text has been condensed by 25% to become easier to handle.

Highlights in this book include an update on the current modalities for anorectal physiology and advances in diagnostic studies such as MRI, CT angiography, and enterography. Perioperative management has seen major changes with adoption of enhanced recovery pathways. The continued migration of outpatient management of anorectal surgery has been highlighted in a new chapter. The limitations of stapled hemorrhoidopexy, and newer options for hemorrhoid treatment, are described. Newer procedures such as ligation of intersphincteric fistula tract (LIFT) have been added to the fistula chapter. The management of sexually transmitted diseases and drug therapies for HIV have been updated. The experience in managing fecal incontinence has been updated, now including the artificial sphincter, hyperbaric oxygen, radiofrequency tissue remodeling, and sacral neuromodulation.

The chapter on the etiology and management of perianal neoplasia and anal carcinoma has been extensively revised reflecting new information, highlighting our current understanding of the role of anal intraepithelial neoplasia (AIN). These additions include new methods of diagnosis and management of high grade AIN of the perianal skin. In the chapter on benign neoplasia, the interest in and better understanding of "serrated" adenoma has been added. Information on uncommon benign polyps has been expanded and the management of malignant polyps of the low rectum has been updated.

New data regarding the incidence, prevalence, and trends in colorectal carcinoma are presented as well as an update on the genetics of colorectal carcinoma with emphasis on heredity non-polyposis colorectal cancer (HNPCC). Indications for and interpretation of genetic testing and the invaluable role of genetic counseling are highlighted. The significant advances in adjuvant therapy have been documented along with updates on the management of recurrent and metastatic colorectal carcinoma. Operative techniques for sphincter sparing operations (pouch, coloplasty, coloanal anastomosis) and expanded transanal procedures are presented. Screening, surveillance, and follow-up for large bowel carcinoma continue to evolve rapidly with better understanding. A new chapter on large bowel obstruction has been added. The expanded role of medical management in inflammatory bowel has been highlighted along with increased experience with surgical management of Crohn's disease and ulcerative colitis.

The changing paradigm regarding the indications for elective operation in diverticular disease has been revisited along with the most recent data on results of the treatment of diverticulitis. Laparoscopy has evolved to be a standard approach for many procedures, and is discussed from a disease perspective rather than singled out for a separate chapter.

We hope we have summarized the enormous amount of published colorectal literature and shared our personal experience and preferences with our readers. We strived for a book that strikes a balance of being authoritative and detailed while minimizing irrelevant material and minutia. We hope our efforts provide the practicing surgeon and surgeon in training the appropriate information to provide a rational and up-to-date course of action to the benefit of their patients.

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Janice F. Rafferty, MD, FACS, FASCRS

Acknowledgments

I am highly appreciative of Phil Gordon's and Sandy Nivatvongs' confidence in selecting my coauthors and me for this fourth edition, and allowing us this unique opportunity to update their highly regarded textbook. Throughout my career, Phil has served as a role model and mentor; it has been an honor to carry on one of his singular accomplishments. I thank our specialty contributors for taking time from work and family to produce superb chapters, and I thank my colleagues Steve Wexner and Janice Rafferty for their efforts in authoring and editing this extensive project. Steve and I are lifelong friends and colleagues; our relationship strengthened by the stresses and challenges of projects like this. Janice has added a new perspective and rose to the challenge of such a major project. I thank Elektra McDermott, who did her usual outstanding job as a developmental editor. I remain indebted to my partners, colleagues, and trainees who continue to support and stimulate my clinical and academic efforts. Finally, I reaffirm my love and appreciation for my wife, Sharon, for her support and encouragement for all the nights and weekends spent in my office working on this project.

– DEB

First and foremost, I thank my late dear mentor Phil Gordon for his phenomenal leadership in our field, his important mentorship in my career, and his cherished friendship in my life. I am indebted to him for entrusting me, David, and Jan with the legacy of his decades-long labor of love. I offer the same appreciation to Santhat Nivatvongs for his wisdom and guidance for many decades, and for his trust with this incredible project. I also give my appreciation to Elektra McDermott for her superlative editorial skills without which this text would not have come to timely fruition. In addition, I thank Dave and Jan for their efforts, expertise, time, talent, and friendship; it has been a pleasure working with them on this project. I am appreciative to our chapter contributors for their time and expertise. Lastly, for their wisdom, love, and support I am eternally grateful to the most important people in my life who patiently waited for me each day that I was engaged in academic endeavors: Trevor, Wesley, Mariana, and my parents. Their love, understanding, encouragement, and patience has given me the energy and ability needed during the conception and completion of many scientific endeavors including this formidable textbook.

– SDW

As a trainee and young colorectal surgeon, the textbook by Dr. Gordon and Dr. Nivatvongs was my favorite reference. My later meeting with these scions of our specialty was a highlight of my career. I am immensely honored by the opportunity to participate in this fourth edition of their classic textbook, and appreciate the confidence that Drs. Beck and Wexner have expressed. Their guidance and friendship has been invaluable; I can only aspire to influence the world of surgery as they have done. I have my husband to thank as well, for the patience and space he provides for me to be everything except a traditional spouse.

– JFR

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Part I

Essential Considerations

I

1 Surgical Anatomy of the Colon, Rectum, and Anus

Santhat Nivatvongs, Philip H. Gordon, and David E. Beck

Abstract
This chapter will review the surgical anatomy of the colon and rectum, including general configuration, course relations, peritoneal coverings, and ileocecal valve in the colon, and peritoneal relations, fascial attachments, fascia propria, Waldeyer's fascia, Denonvilliers' fascia, lateral ligaments of the rectum, histology, muscles of the anorectal region, anorectal spaces, arterial supply, venous drainage, lymphatic drainage, and innervation.

Keywords: surgical anatomy, colon, rectum, histology, muscles, anorectal region, anorectal spaces, arterial supply, venous drainage, lymphatic drainage, innervation

1.1 Introduction

Although often thought of as a single organ, the colon is embryologically divisible into two parts. The transverse and right colon are derived from the midgut and are supplied by the superior mesenteric artery, while the distal half of the colon is derived from the hindgut and receives blood from the inferior mesenteric artery.

The large bowel begins in the right lower quadrant of the abdomen as a blind pouch known as the cecum. The ileum empties into the medial and posterior aspect of the intestine, a point known as the ileocecal junction. The colon proceeds upward and in its course is designated according to location as: ascending (right) colon, hepatic flexure, transverse colon, splenic flexure, descending (left) colon, sigmoid colon, rectum, and anal canal. The colon is approximately 150 cm long, and its diameter gradually diminishes from the cecum to the rectosigmoid junction, where it widens as the rectal ampulla, only to narrow again as the anal canal.

1.2 Colon

1.2.1 General Configuration

The colon differs from the small bowel in that it is characterized by a saccular or haustral appearance, it contains three taenia bands, and it has appendices epiploicae, a series of fatty appendages located adjacent to the tenae on surface of the colon. The taeniae are thickened bands of longitudinal muscle running along the colon from the base of the appendix. They merge in the distal sigmoid colon, where the longitudinal fibers continue through the entire length of the rectum. A study by Fraser et al[1] demonstrated that the longitudinal muscle forms a complete coat around the colon but is much thicker at the taeniae. The three taenia bands are named according to their relation to the transverse colon: taenia mesocolica, which is attached to the mesocolon or mesentery; taenia omentalis, which is attached to the greater omentum; and taenia libera, which has no attachment. These bands are about one-sixth shorter than the intestine and are believed to be responsible for the sacculations.[2] The transition from the sigmoid colon to the rectum is a gradual one. It is characterized by the taeniae coli spreading out from three distinct bands to a uniformly distributed layer of longitudinal smooth muscle that is thicker on the front and back than on each side, the loss of appendices epiploicae, and change in diameter.

1.2.2 Course and Alterations

The general topography of the colon varies from person to person, and such differences should be taken into account while reading the following discussion (▶ Fig. 1.1).

The vermiform appendix projects from the lowermost part of the cecum. From the ileocecal junction, the colon ascends on the right in front of the quadratus lumborum and transversus abdominis muscles to a level overlying the lower pole of the right kidney, a distance of about 20 cm. It is invested by peritoneum on its anterior, lateral, and medial surfaces. Superior to the colon is the undersurface of the right lobe of the liver, lateral to the gallbladder, and here the colon angulates acutely medially, downward, and forward, forming the hepatic flexure. Occasionally, there is a filmy web of adhesions extending from the right abdominal wall to the anterior taenia of the ascending colon, and this has been referred to as Jackson's membrane.

The transverse colon is the longest (40–50 cm) segment of colon, extending from the hepatic to the splenic flexure. It is

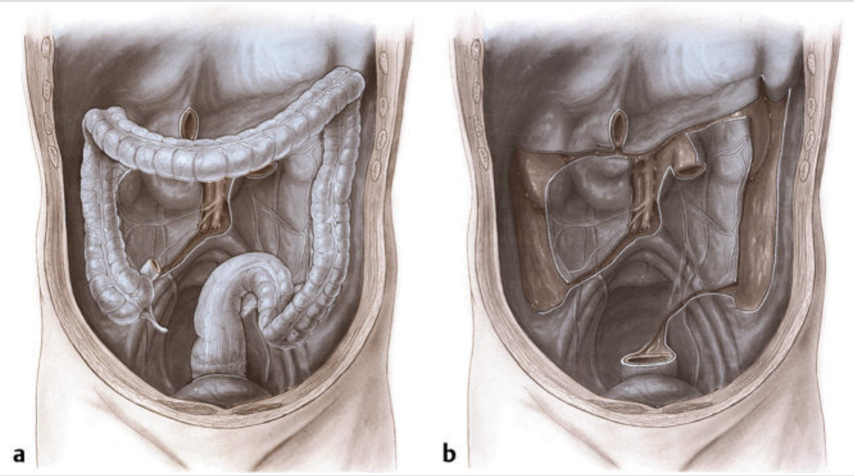


Fig. 1.1 General topography of the large bowel. **(a)** Colon. **(b)** Peritoneum and adjacent structures.

usually mobile and may descend to the level of the iliac crests or even dip into the pelvis. The transverse colon is enveloped between layers of the transverse mesocolon, the root of which overlies the right kidney, the second portion of the duodenum, the pancreas, and the left kidney. It contains the middle colic artery, branches of the right and left colic arteries, and accompanying veins, lymphatic structures, and autonomic nerve plexuses. This posterior relationship is of paramount importance because these structures are subject to injury during a right hemicolectomy if proper care is not exercised. In the left upper quadrant of the abdomen, the colon is attached to the undersurface of the diaphragm at the level of the 10th and 11th ribs by the phrenocolic ligament. The distal transverse colon lies in front of the proximal descending colon. The stomach is immediately above and the spleen is to the left. The greater omentum descends from the greater curvature of the stomach in front of the transverse colon and ascends to the upper surface of the transverse colon. The splenic flexure describes an acute angle, is high in the left upper quadrant, and therefore is less accessible to operative approach. It lies anterior to the midportion of the left kidney.

The descending colon passes along the posterior abdominal wall over the lateral border of the left kidney, turns somewhat medially, and descends in the groove between the psoas and the quadratus lumborum muscles to its junction with the sigmoid at the level of the pelvic brim and the transversus abdominis muscle.[3,4] Its length averages 30 cm. The anterior, medial, and lateral portions of its circumference are covered by peritoneum. The distal portion of the descending colon is usually attached by adhesions to the posterior abdominal wall, and these adhesions require division during mobilization of this portion of the colon.

The sigmoid colon extends from the pelvic brim to the sacral promontory, where it continues as the rectum. Its length varies dramatically from 15 to 50 cm, and it may follow an extremely tortuous and variable course. It often loops to the left but may follow a straight oblique course, loop to the right, or ascend high into the abdomen. It has a generous mesentery and is extremely mobile. The serosal surface has numerous appendices epiploicae. The base of the mesocolon extends from the iliac fossa, along the pelvic brim, and across the sacroiliac joint to the second or third sacral segment; in so doing, it forms an inverted V. Contained within the mesosigmoid are the sigmoidal and superior rectal arteries and accompanying veins, lymphatics, and autonomic nerve plexuses. At the base of the mesosigmoid is a recess, the intersigmoid fossa, which serves as a valuable guide to the left ureter, lying just deep to it. The upper limb runs medially and upward, crossing the left ureter and iliac vessels; this is an extremely important relationship during resection of this part of the colon. The lower limb extends in front of the sacrum and also may be alongside loops of small bowel, the urinary bladder, and the uterus and its adnexa.

1.2.3 Peritoneal Coverings

The antimesenteric border of the distal ileum may be attached to the parietal peritoneum by a membrane (Lane's membrane).[5] The cecum usually is entirely enveloped by peritoneum. The ascending colon is attached to the posterior body wall and is devoid of peritoneum in its posterior surface; thus, it does not have a mesentery. The transverse colon is invested with peritoneum. Its posterosuperior surface, along the taenia band, is attached by the transverse mesocolon to the lower border of the pancreas. The posterior and inferior layers of the greater omentum are fused on the anterosuperior aspect of the transverse colon. To mobilize the greater omentum or to enter the lesser sac, the fusion of the omentum to the transverse colon must be dissected. Because the omental bursa becomes obliterated caudal to the transverse colon and toward the right side, the dissection should be started on the left side of the transverse colon. Topor et al[6] studied 45 cadavers to elucidate surgical aspects of omental mobilization, lengthening, and transposition into the pelvic cavity. They identified that the most important anatomic variables for omental transposition were three variants of arterial blood supply: (1) in 56% of patients, there is one right, one (or two) middle, and one left omental artery; (2) in 26% of patients, the middle omental artery is absent; and (3) in the remaining 18% of patients, the gastroepiploic artery is continued as a left omental artery but with various smaller connections to the right or middle omental artery. The first stage of omental lengthening is detachment of the omentum from the transverse colon mesentery. The second stage is the actual lengthening of the omentum. The third stage is placement of the omental flap into the pelvis. The left colonic flexure is attached to the diaphragm by the phrenocolic ligament, which also forms a shelf for supporting the spleen. The descending colon is devoid of peritoneum posteriorly, where it is in contact with the posterior abdominal wall and thus has no mesentery.

The sigmoid colon begins at about the level of the pelvic brim and is completely covered with peritoneum. The posterior surface is attached by a fan-shaped mesentery. The lateral surface of the sigmoid mesentery is fused to the parietal peritoneum of the lateral abdominal wall and is generally known as the "white line of Toldt." Mobilization of the sigmoid colon requires cutting or incising the lateral peritoneal reflection. The sigmoid colon varies greatly in length and configuration.

1.2.4 Ileocecal Valve

The superior and inferior ileocecal ligaments are fibrous tissue that helps maintain the angulation between the ileum and the cecum. Kumar and Phillips[7] found these structures to be important in the maintenance of competence against reflux at the ileocecal junction. In an autopsy evaluation, the ascending colon was filled with saline solution by retrograde flow, and in 12 of 14 cases the ileocecal junctions were competent to pressures up to 80 mm Hg. Removal of mucosa at the ileocecal junction or a strip of circular muscle did not impair competence to pressures above 40 mm Hg, but division of the superior and inferior ileocecal ligaments rendered the junction incompetent. Operative reconstruction of the ileocecal angle restored competence. It therefore appears that the angulation between the ileum and the cecum determines continence.

1.3 Rectum

Although anatomists traditionally assign the origin of the rectum to the level of the third sacral vertebra, surgeons generally consider the rectum to begin at the level of the sacral promontory. It descends along the curvature of the sacrum and coccyx and ends by passing through the levator ani muscles, at which level it abruptly turns downward and backward to become the anal canal. The rectum differs from the colon in that the outer layer is entirely longitudinal muscle, characterized by the merging of the three taenia bands. It measures 12 to 15 cm in length and lacks a mesentery, sacculations, and appendices epiploicae. These definitions may evolve as magnetic resonance imaging (MRI) is increasingly utilized to define rectal anatomy.

The rectum describes three lateral curves: the upper and lower curves are convex to the right, and the middle is convex to the left. On their inner aspect, these infoldings into the lumen are known as the valves of Houston.[8,9] About 46% of normal persons have three valves, 33% have two valves, 10% have four valves, 2% have none, and the rest have from five to seven valves.[9] The clinical significance of the valves of Houston is that they must be negotiated during successful proctosigmoidoscopic examination and, more importantly, that they are an excellent location for a rectal biopsy, because the inward protrusion makes an easy target. They do not contain all the layers of the bowel wall, and therefore biopsy in this location carries a minimal risk of perforation. The middle fold is the internal landmark corresponding to the anterior peritoneal reflection. Consequently, extra caution must be exercised in removing polyps above this level. Because of its curves, the rectum can gain 5 cm in length when it is straightened (as in performing a low anterior resection); hence, a lesion that initially appears at 7 cm from the anal verge is often found 12 cm from that site after complete mobilization.

In its course, the rectum is related posteriorly to the sacrum, coccyx, levator ani muscles, coccygeal muscles, median sacral vessels, and roots of the sacral nerve plexus. Anteriorly in the male, the extraperitoneal rectum is related to the prostate, seminal vesicles, vasa deferentia, ureters, and urinary bladder; the intraperitoneal rectum may come in contact with loops of the small bowel and sigmoid colon. In the female, the extraperitoneal rectum lies behind the posterior vaginal wall; the intraperitoneal rectum may be related to the upper part of the vagina, uterus, fallopian tubes, ovaries, small bowel, and sigmoid colon. Laterally above the peritoneal reflection, there may be loops of small bowel, adnexa, and sigmoid colon. Below the reflection, the rectum is separated from the sidewall of the pelvis by the ureter and iliac vessels.

1.3.1 Peritoneal Relations

For descriptive purposes, the rectum is divided into upper, middle, and lower thirds. The upper third is covered by peritoneum anteriorly and laterally, the middle third is covered only anteriorly, and the lower third is devoid of peritoneum. The peritoneal reflection shows considerable variation between individuals and between men and women. In men, it is usually 7 to 9 cm from the anal verge, while in women it is 5 to 7.5 cm above the anal verge. The middle valve of Houston roughly corresponds to the anterior peritoneal reflection. The posterior peritoneal reflection is usually 12 to 15 cm from the anal verge (▶ Fig. 1.2).

The location of the peritoneal reflection has not been extensively studied in living patients. Najarian et al[10] investigated the location of the peritoneal reflection in 50 patients undergoing laparotomy. The distance from the anal verge to the peritoneal reflection was measured in each patient via simultaneous intraoperative proctoscopy and intra-abdominal visualization of the peritoneal reflection. The mean lengths of the peritoneal reflection were 9 cm anteriorly, 12.2 cm laterally,

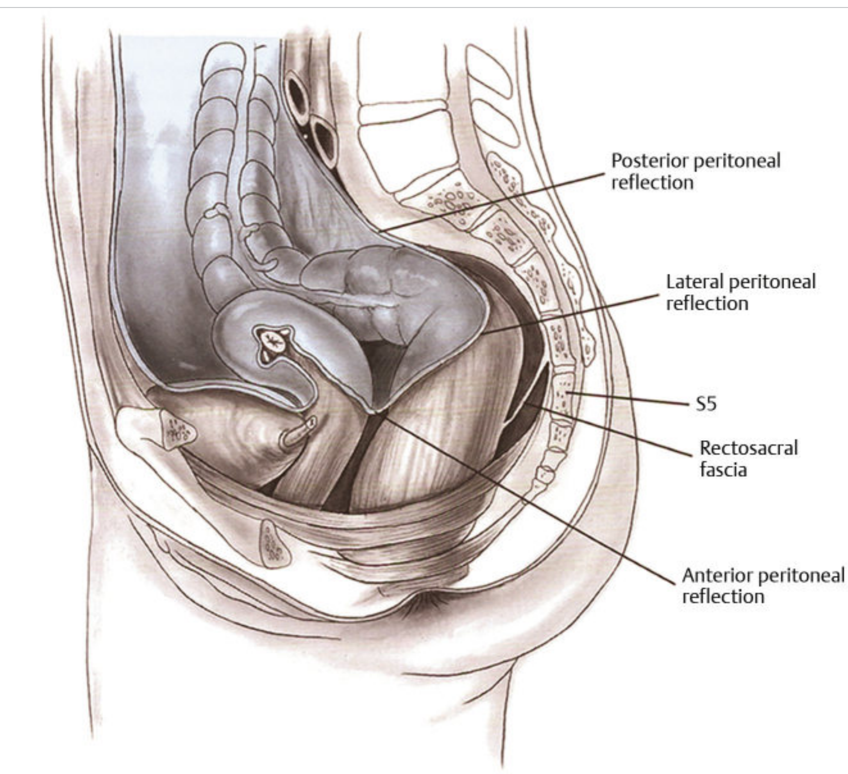


Fig. 1.2 Peritoneal relations of the rectum.

and 14.8 cm posteriorly for females, and 9.7 cm anteriorly, 12.8 cm laterally, and 15.5 cm posteriorly for males. The lengths of the anterior, lateral, and posterior peritoneal measurements were statistically different from one another, regardless of gender. These authors' data indicated that the peritoneal reflection is located higher on the rectum than reported in autopsy studies, and that there is no difference between males and females. Knowledge of the location and position of a rectal carcinoma in relationship to the peritoneal reflection will help the surgeon optimize the use of peranal techniques of resection.

1.3.2 Fascial Attachments

The posterior part of the rectum, the distal lateral two-thirds, and the anterior one-third are devoid of peritoneum, but they are covered with a thin layer of pelvic fascia, called fascia propria or the investing fascia. At the level of the rectal hiatus, the levator ani is covered by an expansion of the pelvic fascia, which on reaching the rectal wall divides into an ascending component, which fuses with the fascia propria of the rectum, and a descending component, which interposes itself between the muscular coats forming the conjoint longitudinal coat.[11] These fibroelastic fibers run downward to reach the dermis of the perianal skin and split the subcutaneous striated sphincter into 8 to 12 discrete muscle bundles.

The sacrum and coccyx are covered with a strong fascia that is part of the parietal pelvic fascia. Known as Waldeyer's fascia, this presacral fascia covers the median sacral vessels. The rectosacral fascia is the Waldeyer's fascia from the periosteum of the fourth sacral segment to the posterior wall of the rectum.[12,13] It is found in 97% of cadaver dissections.[13] Waldeyer's fascia contains branches of sacral splanchnic nerves that arise directly from the sacral sympathetic ganglion and may contain branches of the lateral and median sacral vessels. This fascia should be sharply divided with scissors or electrocautery for full mobilization of the rectum (▶ Fig. 1.3). The posterior space below the rectosacral fascia is the supralevator or retrorectal space (▶ Fig. 1.4).

Anteriorly, the extraperitoneal portion of the rectum is covered with a visceral pelvic fascia, the fascia propria, or investing

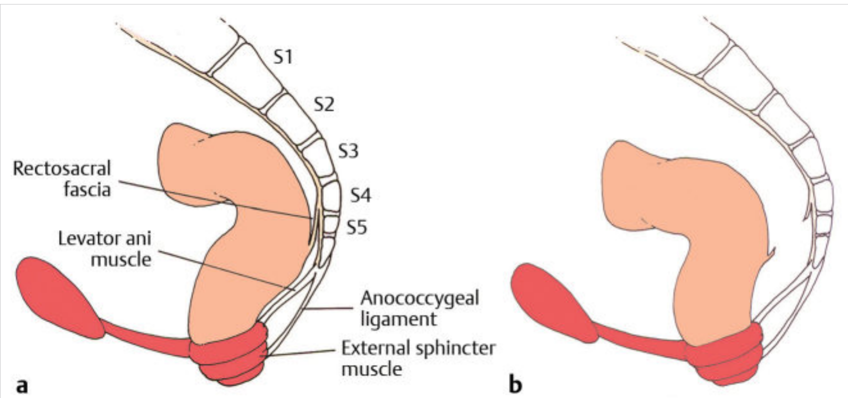


Fig. 1.3 **(a)** Rectosacral fascia. **(b)** Sharp division of the rectosacral fascia for full mobilization of the rectum.

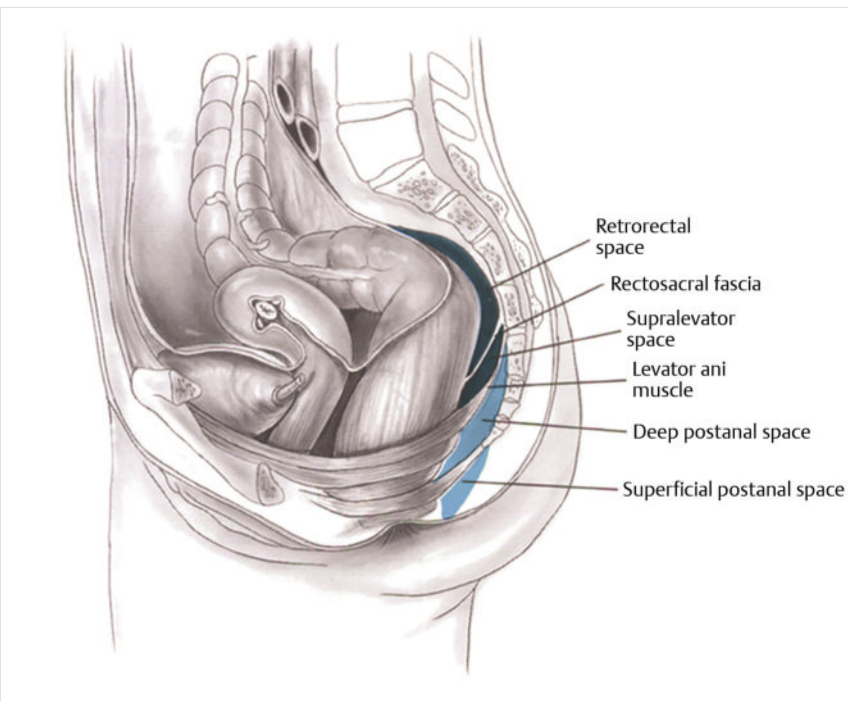


Fig. 1.4 Perianal and perirectal spaces (lateral view).

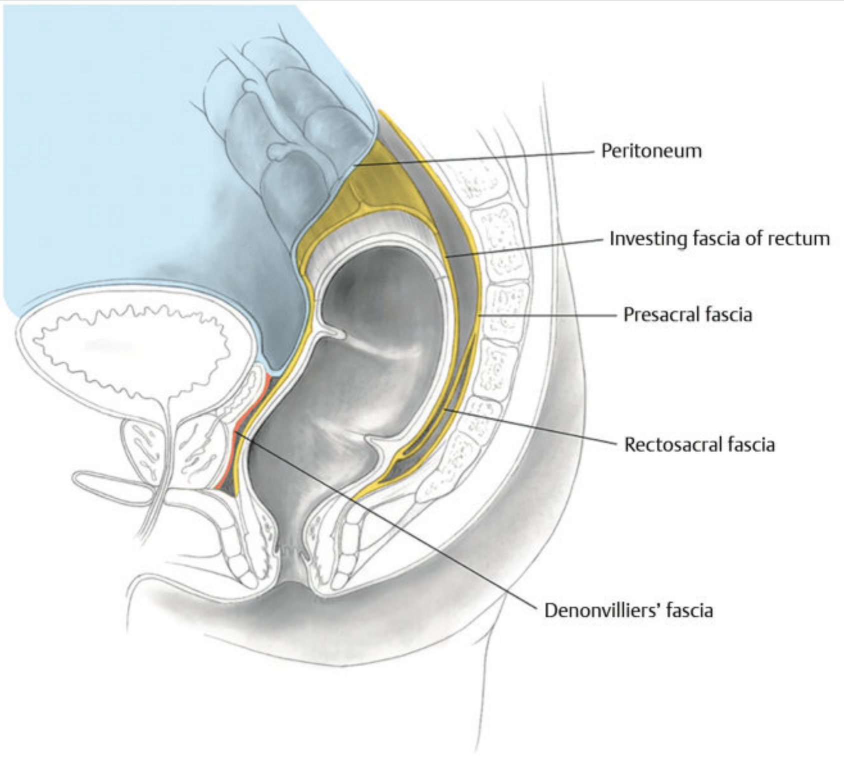


Fig. 1.5 Denonvilliers' fascia.

fascia. Anterior to the fascia propria is a filmy delicate layer of connective tissue known as Denonvilliers' fascia.[14] It separates the rectum from the seminal vesicles and the prostate or vagina (▶ Fig. 1.5). Denonvilliers' fascia has no macroscopically discernible layers. Histologically, it is composed of dense collagen, smooth muscle fibers, and coarse elastic fibers.[15,16] Its attachments have been surrounded by confusion and debates. Some authors believe it is adherent to the rectum,[16,17,18,19] while others note that it is applied to the seminal vesicles and the prostate.[15,20,21,22]

Lindsey et al[23] designed a study to evaluate the anatomic relation of Denonvilliers' fascia: whether it is attached on the anterior fascia propria of the rectum, or on the seminal vesicles and prostate. They prospectively collected 30 specimens from males undergoing total mesorectal excision for mid and low rectal carcinoma, with a deep dissection of the anterior extraperitoneal rectum to the pelvic floor. The anterior aspects of the extraperitoneal rectal sections were examined microscopically for the presence or absence of Denonvilliers' fascia. In patients in whom the carcinoma was anterior, 55% of the specimens had Denonvillier's fascia present. Conversely, when the anterior rectum was not involved with carcinoma 90% of the specimens contained no Denonvilliers' fascia. The authors concluded that "when rectal dissection is conducted on fascia propria in the anatomic plane, Denonvilliers' fascia remains on the posterior aspect of the prostate and seminal vesicles. Denonvilliers' fascia lies anterior to the anatomic fascia propria plane of anterior rectal dissection in total mesorectal excision (TME) and is more closely applied to the prostate than the rectum." This study has put the debates to rest; Denonvilliers' fascia is more closely applied to the seminal vesicles and the prostate than the rectum.

1.3.3 Lateral Ligament

The distal rectum, which is extraperitoneal, is attached to the pelvic sidewall on each side by the pelvic plexus, connective tissues, and middle rectal artery (if present).[24] Histologically, it consists of nerve structures, fatty tissue, and small blood vessels.[25] Recently, the anatomical term *lateral ligament* has been a subject of debate. In dissection of 27 fresh cadavers and 5 embalmed pelves, Nano et al[26] found that lateral ligaments were extension of the mesorectum to the lateral endopelvic fascia. From their experience with anatomic dissection applied to surgery, several conclusions were drawn: lateral ligaments are extensions of the mesorectum and must be cut at their attachment at the endopelvic fascia for TME to take place.

Lateral ligaments contain fatty tissue in communication with mesorectal fat and possibly some vessels and nerve filaments that are of little importance. Insertion of lateral ligaments at the endopelvic fascia is placed under the urogenital bundle. The middle rectal artery courses anteriorly and inferiorly with respect to the lateral ligament. Lateral ligaments can be cut at their insertion on the endopelvic fascia without injuring the urogenital nervous bundle, which, however, should be kept in view during this procedure, because it crosses the middle rectal artery and fans out behind the seminal vesicles. The lateral aspect of the rectum receives the lateral pedicle, which consists of the nervi recti and the middle rectal artery.

A study by Rutegård et al[25] on 10 patients who underwent total mesorectal excision for rectal carcinoma revealed that "the often thin structures, usually referred to as the lateral ligaments, seem to arise from the pelvic plexuses and bridge over into the mesorectum … they can be identified in almost every patient." The authors contend that the lateral ligaments are real anatomical findings. This finding was supported by Sato and Sato[13] in the dissection of 45 cadavers.

Conversely, Jones et al[24] meticulously dissected 28 cadaveric pelves; they found insubstantial thin strands of connective tissues traversing the space between the mesorectum and the pelvic sidewall. These strands of connective tissues were no different from those one would expect to find in any areolar plane. They were often absent altogether. The pelvic plexuses were distinct from the middle rectal artery (if present) and had no association with the connective tissues. Jones et al[24] believed that the lateral ligament was nothing more than a surgical artifact that results from injudicious dissection.

When the rectum is pulled medially, the complex of middle rectal artery and vein, the splanchnic nerves, and their accompanying connective tissues form a bandlike structure extending from the lateral pelvic wall to the rectum.[27] This structure was most likely mistaken as the "lateral ligament" in the past. Whatever one would call the lateral attachment of the low rectum, the tissues need to be divided in full mobilization of the rectum.

1.3.4 Mesorectum

The posterior rectum is devoid of peritoneum and has no mesorectum. The term mesorectum is a misnomer and does not appear in the *Nomina Anatomica*, although it is listed in the *Nomina Embryologica*.[28] The word mesorectum was possibly first used by Maunsell in 1892 and later popularized by Heald of the United Kingdom.[28] In answering the critique of using this word, Heald answered, "… it was a surgical word used by the foremost of my surgical teachers when I was a young registrar. Mr. Rex Lawrice of Guy's Hospital used to describe the process of dividing the mesorectum as was well described in Rob and Smith's textbook of surgery at that time … no other word seems readily available to describe it."[29]

Total mesorectal excision implies the complete excision of all fat enclosed within the fascia propria, which Heald calls the "mesorectum." This dissection is performed in a circumferential manner down to the levator muscles.[28] Bisset et al[30] preferred the term "extrafascial excision of the rectum." The term mesorectum has now been used worldwide and appears well entrenched.

Canessa et al[31] studied the lymph nodes in 20 cadavers using conventional manual dissection. The starting point was at the bifurcation of the superior rectal artery and ending at the anorectal ring. They found an average of 8.4 lymph nodes per rectum; 71% of the lymph nodes were above the peritoneal reflection and 29% were below it. Dissection of seven fresh cadavers on the mesorectum by Topor et al[32] yielded 174 lymph nodes; over 80% of the lymph nodes were smaller than 3 mm. Fifty-six percent of the nodes were located in the posterior mesentery, and most were located in the upper two-thirds of posterior rectal mesentery. The translational importance of this information is attested to by the need to perform a complete or near complete as compared to incomplete total mesorectal excision (TME) when performing a curative protectomy for rectal cancer.

1.4 Histology

Knowledge of the microscopic anatomy of the large intestine is of paramount importance in understanding the various disease processes. This is especially true in the case of neoplasia, where the depth of penetration will dictate the treatment recommendation.

The innermost layer is the mucosa, which is composed of three divisions. The first is a layer of columnar epithelial cells with a series of crevices or crypts characterized by straight tubules that lie parallel and close to one another and do not branch (glands of Lieberkühn). The surface epithelium around the openings of the crypts consists of simple columnar cells with occasional goblet cells. The tubules are lined predominantly by goblet cells, except at the base of the crypts where undifferentiated cells as well as enterochromaffin and amine precursor uptake and decarboxylation (APUD) cells are found. The epithelial layer is separated from the underlying connective tissue by an extracellular membrane composed of glycopolysaccharides and seen as the lamina densa of the basement membrane when viewed by electron microscopy.[33] Abnormalities classified as defects, multilayering, or other structural abnormalities have been reported in many types of neoplasms, including those of the colon and rectum. These abnormalities are more common in malignant than in benign neoplasms. The second division of the mucosa is the lamina propria, composed of a stroma of connective tissue containing capillaries, inflammatory cells, and lymphoid follicles that are more prominent in young persons. The third division is the muscularis mucosa, a fine sheet of smooth muscle fibers that serves as a critical demarcation in the diagnosis of invasive carcinoma and includes a network of lymphatics.[34]

Beneath the muscularis mucosa is the submucosa, a layer of connective tissue and collagen that contains vessels, lymphatics, and Meissner's plexus. It is the strongest layer of the bowel. The next layer is the circular muscle, which is a continuous sheath around the bowel, including both the colon and the rectum. On the external surface of the circular muscle are clusters of ganglion cells and their ramifications; these make up the myenteric plexus of Auerbach. Unmyelinated postganglionic fibers penetrate the muscle to communicate with the submucosal plexus. The outer or longitudinal muscle fibers of the colon are characteristically collected into three bundles, called the taeniae coli; however, in the rectum these fibers are spread out and form a continuous layer. The muscularis propria is pierced at regular intervals by the main arterial blood supply and venous drainage of the mucosa.

The outermost layer, which is absent in the lower portions of the rectum, is the serosa or visceral peritoneum. This layer contains blood vessels and lymphatics.

1.5 Anal Canal

The anal canal is the terminal portion of the intestinal tract. It begins at the anorectal junction (the point passing through the levator ani muscles), is about 4 cm long, and terminates at the anal verge.[35,36] This definition differs from that of the anatomist, who designates the anal canal as the part of the intestinal tract that extends from the dentate line to the anal verge.

The anal canal is surrounded by strong muscles, and because of tonic contraction of these muscles, it is completely collapsed and represents an anteroposterior slit. The musculature of the anorectal region may be regarded as two tubes, one surrounding the other (▶ Fig. 1.6).[37] The inner tube, being visceral, is smooth muscle and is innervated by the autonomic nervous system, while the outer funnel-shaped tube is skeletal muscle and has somatic innervation. This short segment of the intestinal tract is of

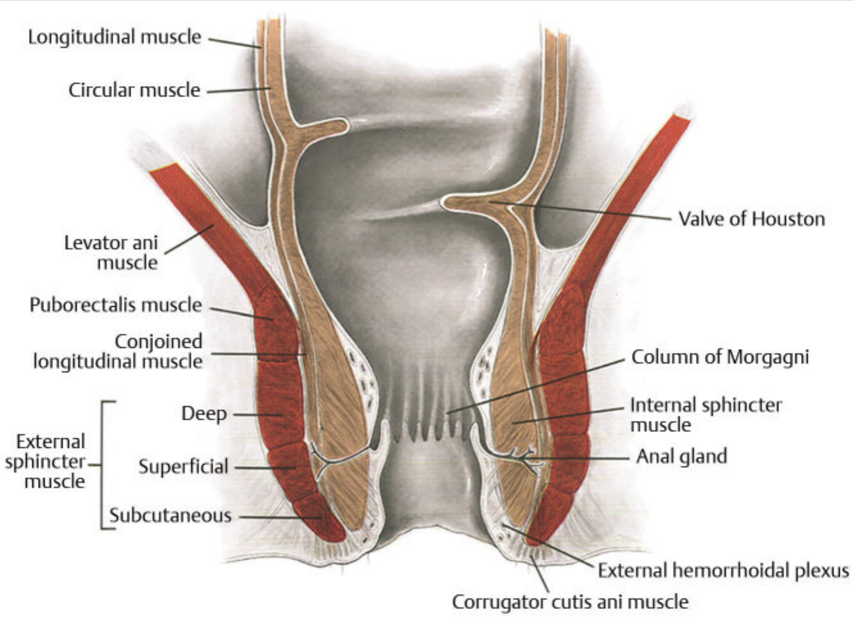


Fig. 1.6 Anal canal.

paramount importance because it is essential to the mechanism of fecal continence and also because it is prone to many diseases.

The anatomy of the anal canal and perianal structures has been imaged using endoluminal magnetic resonance imaging.[38] Investigators found that the lateral canal was significantly longer than its anterior and posterior part. The anterior external anal sphincter was shorter in women than in men and occupied, respectively, 30 and 38% of the anal canal length. The median length and thickness of the female anterior external anal sphincter were 11 and 13 mm, respectively. These small dimensions explain why a relatively small obstetrical tear may have a devastating effect on fecal continence and why it may be difficult to identify the muscle while performing a sphincter repair after an obstetrical injury. The caudal ends of the external anal sphincter formed a double layer. The perineal body was thicker in women than in men and easier to define. The superficial transverse muscles had a lateral and caudal extension to the ischiopubic bones. The bulbospongiosus was thicker in men than in women. The ischiocavernosus and anococcygeal body had the same dimensions in both sexes.

Posteriorly, the anal canal is related to its surrounding muscle and the coccyx. Laterally is the ischioanal fossa with its inferior rectal vessels and nerves. Anteriorly in the male is the urethra, a very important relationship to know during abdominoperineal resection of the rectum. Anteriorly in the female are the perineal body and the lowest part of the posterior vaginal wall.

1.5.1 Lining of Canal

The lining of the anal canal consists of epithelium of different types at different levels (▶ Fig. 1.7). At approximately the midpoint of the anal canal, there is an undulating demarcation referred to as the dentate line. This line is approximately 2 cm from the anal verge. Because the rectum narrows into the anal canal, the tissue above the dentate line takes on a pleated appearance. These longitudinal folds, of which there are 6 to 14, are known as the columns of Morgagni. There is a small pocket or crypt at the lower end of and between adjacent columns of the folds. These crypts are of surgical significance because foreign material may become lodged in them, obstructing the ducts of the anal glands and possibly resulting in sepsis.

The mucosa of the upper anal canal is lined by columnar epithelium. Below the dentate line, the anal canal is lined with a squamous epithelium. The change, however, is not abrupt. For a distance of 6 to 12 mm above the dentate line, there is a gradual transition where columnar, transitional, or squamous epithelium may be found. This area, referred to as the anal transitional or cloacogenic zone, has extremely variable histology.

A color change in the epithelium is also noted. The rectal mucosa is pink, whereas the area just above the dentate line is deep purple or plum color due to the underlying internal hemorrhoidal plexus. Subepithelial tissue is loosely attached to and radially distensible from the internal hemorrhoidal plexus. Subepithelial tissue at the anal margin, which contains the external hemorrhoidal plexus, forms a lining that adheres firmly to the underlying tissue. At the level of the dentate line, the lining is anchored by what Parks[39] called the mucosal suspensory ligament. The perianal space is limited above by this ligament and below by the attachment of the longitudinal muscle to the skin of the anal verge. The area below the dentate line is not true skin because it is devoid of accessory skin structures (e.g., hair, sebaceous glands, and sweat glands). This pale, delicate, smooth, thin, and shiny stretched tissue is referred to as anoderm and runs for approximately 1.5 cm below the dentate line. At the anal verge, the lining becomes thicker and pigmented and acquires hair follicles, glands, and other histologic features of normal skin.[2] In this circumanal area, there is also a well-marked ring of apocrine glands, which may be the source of the clinical condition called hidradenitis suppurativa. Proximal to the dentate line, the epithelium is supplied by the autonomic nervous system, while distally the lining is richly innervated by the somatic nervous system.[40]

1.5.2 Anal Transitional Zone

The anal transitional zone (ATZ) is interposed between uninterrupted colorectal-type mucosa (columnar) above and uninterrupted

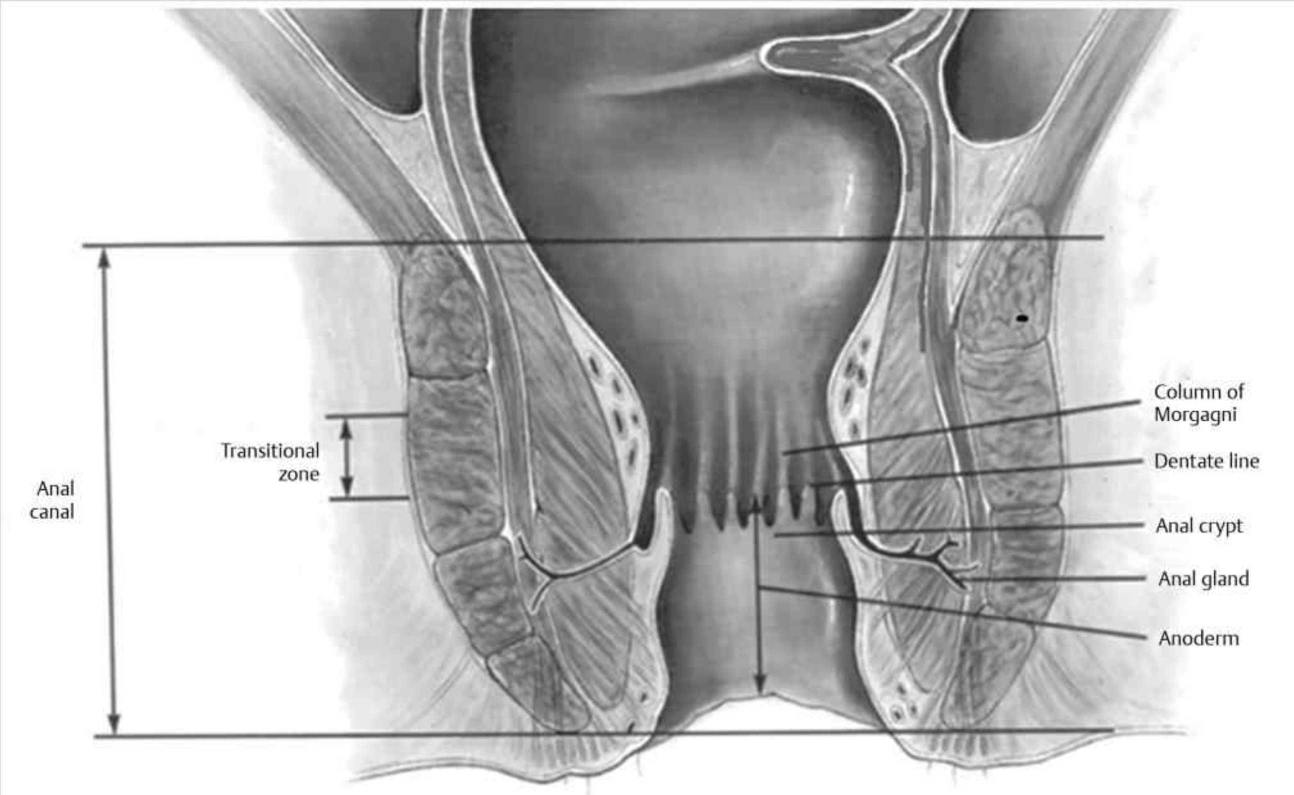


Fig. 1.7 Lining of the anal canal.

squamous epithelium (anoderm) below, irrespective of the type of epithelium present in the zone itself.[41] The ATZ usually commences just above the dentate line. Using computer maps of histology, Thompson-Fawcett et al[42] found that the dentate line was situated at a median of 1.05 cm above the lower border of the internal sphincter. This is much smaller than that reported in the study by Fenger,[41] which portrayed the ATZ extending 0.9 cm above the dentate line. Fenger used the traditional alcian blue stain. This results in overestimation of the length of the ATZ because the pale blue staining is due to staining of superficial nuclei of both squamous anoderm and transitional epithelium rather than staining of mucin-producing cells in the transitional epithelium.[42] The ATZ is much smaller than commonly thought.

The histology of the ATZ is extremely variable. Most of the zone is covered by ATZ epithelium, which appears to be composed of four to nine cell layers—the basal cells, columnar, cuboidal, unkeratinized squamous epithelium, and anal glands. The ATZ epithelium contains a mixture of sulfomucin and sialomucin. The mucin pattern in the columnar variant of the ATZ epithelium and in the anal canal is of the same type and differs from that of colorectal-type epithelium. The findings of a similar mucin pattern in mucoepidermoid carcinoma and in some cases of carcinoma arising in anal fistulas as well as in carcinoma suspected of arising in anal glands might indicate a common origin of the neoplasm in the ATZ epithelium.

Histochemical study shows that endocrine cells have been demonstrated in 87% of specimens. Their function is unknown. Melanin is found in the basal layer of the ATZ epithelium in 14% of specimens. Melanin cannot be demonstrated in the anal gland but is a constant finding in the squamous epithelium below the dentate line, increasing in amount as the perianal skin is approached. The melanin-containing cells in the ATZ seem a reasonable point of origin for melanoma, as do the findings of junctional activity and atypical melanocyte hyperplasia in the ATZ.

The ATZ epithelium has a dominating diploid population, although there was a small hyperdiploid peak representing nuclei with a scattered volume considerably higher than that of the main diploid population. This was present regardless of the histologic variant (columnar or cuboid) of the ATZ epithelium. Tetraploid or octoploid populations are not found.[41]

1.5.3 Anal Glands

The average number of glands in a normal anal canal is six (range, 3–10).[43] Each gland is lined by stratified columnar epithelium with mucus-secreting or goblet cells interspersed within the glandular epithelial lining and has a direct opening into an anal crypt at the dentate line. Occasionally, two glands open into the same crypt, while half the crypts have no communication with the glands. These glands were first described by Chiari in 1878.[44] The importance of their role in the pathogenesis of fistulous abscess was presented by Parks in 1961.[37]

Seow-Choen and Ho[43] found that 80% of the anal glands are submucosal in extent, 8% extend to the internal sphincter, 8% to the conjoined longitudinal muscle, 2% to intersphincteric space, and 1% penetrate the external sphincter. The anal glands are fairly evenly distributed around the anal canal, although the greatest number is found at the anterior quadrant. Mild-to-moderate lymphocytic infiltration is noted around the anal glands and ducts; this is sometimes referred to as "anal tonsil."

In an autopsy study of 62 specimens, Klosterhalfen et al[45] found that nearly 90% of specimens contained anal sinuses. In fetuses and children, more than half of the anal sinuses were accompanied by anal intramuscular glands penetrating the internal anal sphincter, while in adult specimens anal intramuscular glands were rare.

1.6 Muscles of the Anorectal Region and Internal Sphincter Muscle

The downward continuation of the circular, smooth muscle of the rectum becomes thickened and rounded at its lower end and is called the internal sphincter. Its lowest portion is just above the lowest part of the external sphincter and is 1 to 1.5 cm below the dentate line (▶ Fig. 1.6).

1.6.1 Conjoined Longitudinal Muscle

At the level of the anorectal ring, the longitudinal muscle coat of the rectum is joined by fibers of the levator ani and puborectalis muscles. Another contributing source is the pelvic fascia.[11] The conjoined longitudinal muscle so formed descends between the internal and external anal sphincters (▶ Fig. 1.6).[46] Many of these fibers traverse the lower portion of the external sphincter to gain insertion in the perianal skin and are referred to as the corrugator cutis ani.[47] Fine and Lawes[48] described a longitudinal layer of muscle lying on the inner aspect of the internal sphincter and named it the muscularis submucosae ani. These fibers may arise from the conjoined longitudinal muscle. Some fibers that traverse the internal sphincter muscle and become inserted just below the anal valves have been referred to as the mucosal suspensory ligament.[37] Some fibers may traverse the external sphincter to form a transverse septum of the ischioanal fossa (▶ Fig. 1.6). In a review of the anatomy and function of the anal longitudinal muscle, Lunnis and Phillips[49] speculated that this muscle plays a role as a skeleton supporting and binding the internal and external sphincter complex together, as an aid during defecation by everting the anus, as a support to the hemorrhoidal cushions, and as a determining factor in the ramification of sepsis.

1.6.2 External Sphincter Muscle

This elliptical cylinder of skeletal muscle that surrounds the anal canal was originally described as consisting of three distinct divisions: the subcutaneous, superficial, and deep portions.[36] This account was shown to be invalid by Goligher,[50] who demonstrated that a sheet of muscle runs continuously upward with the puborectalis and levator ani muscles. The lowest portion of the external sphincter occupies a position below and slightly lateral to the internal sphincter. A palpable groove at this level has been referred to as the intersphincteric groove. The lowest part (subcutaneous fibers) is traversed by the conjoined longitudinal muscle, with some fibers gaining attachment to the skin. The next portion (superficial) is attached to the coccyx by a posterior extension of muscle fibers that combine with connective tissue, forming the anococcygeal ligament. Above this level, the deep portion of the external sphincter is devoid of posterior attachment and proximally becomes continuous with the puborectalis muscle. Anteriorly, the high fibers of the external sphincter are inserted into the perineal body, where some merge and are continuous with the transverse perineal muscles. The female sphincter has a variable natural defect occurring along its anterior length.[51,52,53,54,55,56] This makes interpretation of the isolated endoanal ultrasound difficult and explains overreporting of obstetric sphincter defects. The external sphincter is supplied by the inferior rectal nerve and a perineal branch of the fourth sacral nerve. From their embryonic study, Levi et al[52] demonstrated that the external sphincter is subdivided into two parts, one superficial and one deep without any connection with the puborectalis.

Shafik[46] has suggested that the anal sphincter mechanism consists of three **U**-shaped loops and that each loop is a separate sphincter and complements the others to help maintain continence (▶ Fig. 1.8). This concept has not been generally accepted. In fact, more recently, Ayoub[56] found that the external sphincter is one muscle mass, not divided into layers or laminae, and that all fibers of the external sphincter muscles retain their skeletal attachment by the anococcygeal ligament to the coccyx. Clinical experience supports Ayoub's concept; we have not been able to identify Shafik's three-part scheme.[46] Indeed, during postanal repairs for anal incontinence, the external sphincter, puborectalis, and levator ani muscles present as one continuous funnel-shaped sheet of skeletal muscle. The currently accepted perception of the arrangement of the external sphincter is that it is one continuous circumferential mass, a

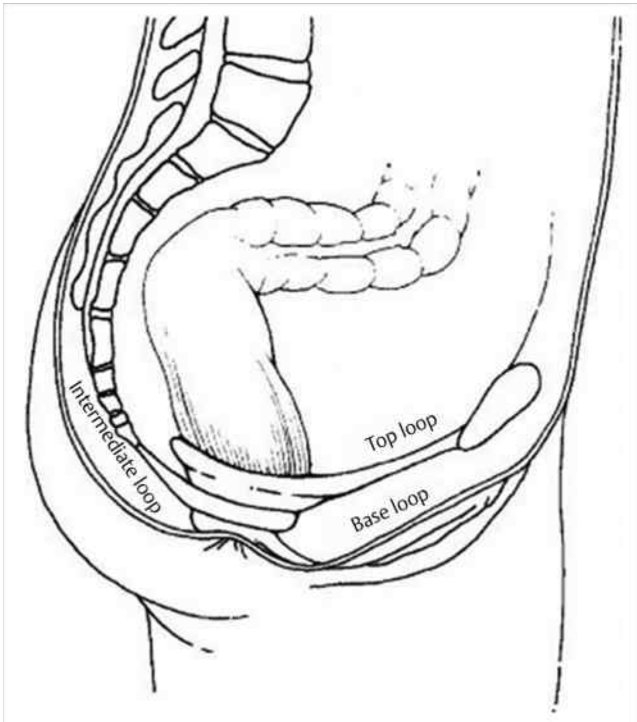


Fig. 1.8 Shafik loops.[46]

concept in accordance with a study in which anal endosonography was used.[53]

1.6.3 Perineal Body

The perineal body is the anatomic location in the central portion of the perineum where the external sphincter, bulbocavernosus, and superficial and deep transverse perineal muscles meet (▶ Fig. 1.9). This tends to be a tendinous intersection and is believed to give support to the perineum and to separate the anus from the vagina. In patients who have sustained a sphincter injury, an effort should be made to rebuild the perineal body as well as to reconstruct the sphincter.

1.6.4 Pelvic Floor Muscles

The levator ani muscle is a broad, thin muscle that forms the greater part of the floor of the pelvic cavity and is innervated by the fourth sacral nerve (▶ Fig. 1.10). This muscle traditionally has been considered to consist of three muscles: the iliococcygeus, the pubococcygeus, and the puborectalis.[3] Oh and Kark[54] and Shafik[55] suggested that it consists only of the iliococcygeus and pubococcygeus muscles and that the puborectalis is part of the deep portion of the external sphincter muscle, since the two are fused and have the same nerve supply, the pudendal nerve.[56] However, the electrophysiologic study by Percy et al[57] concluded that in 19 of 20 patients, stimulation of sacral nerves above the pelvic floor resulted in electromyographic activity in the ipsilateral puborectalis but not in the external sphincter. Results of postmortem innervation studies have favored a perineal nerve supply to the puborectalis, but the weight of evidence in favor of a pudendal nerve supply has been challenged by in vivo studies. Levi et al[52] believe that the puborectalis muscle must be considered part of the levator ani because it is never connected with the external sphincter in different steps of embryonic development.

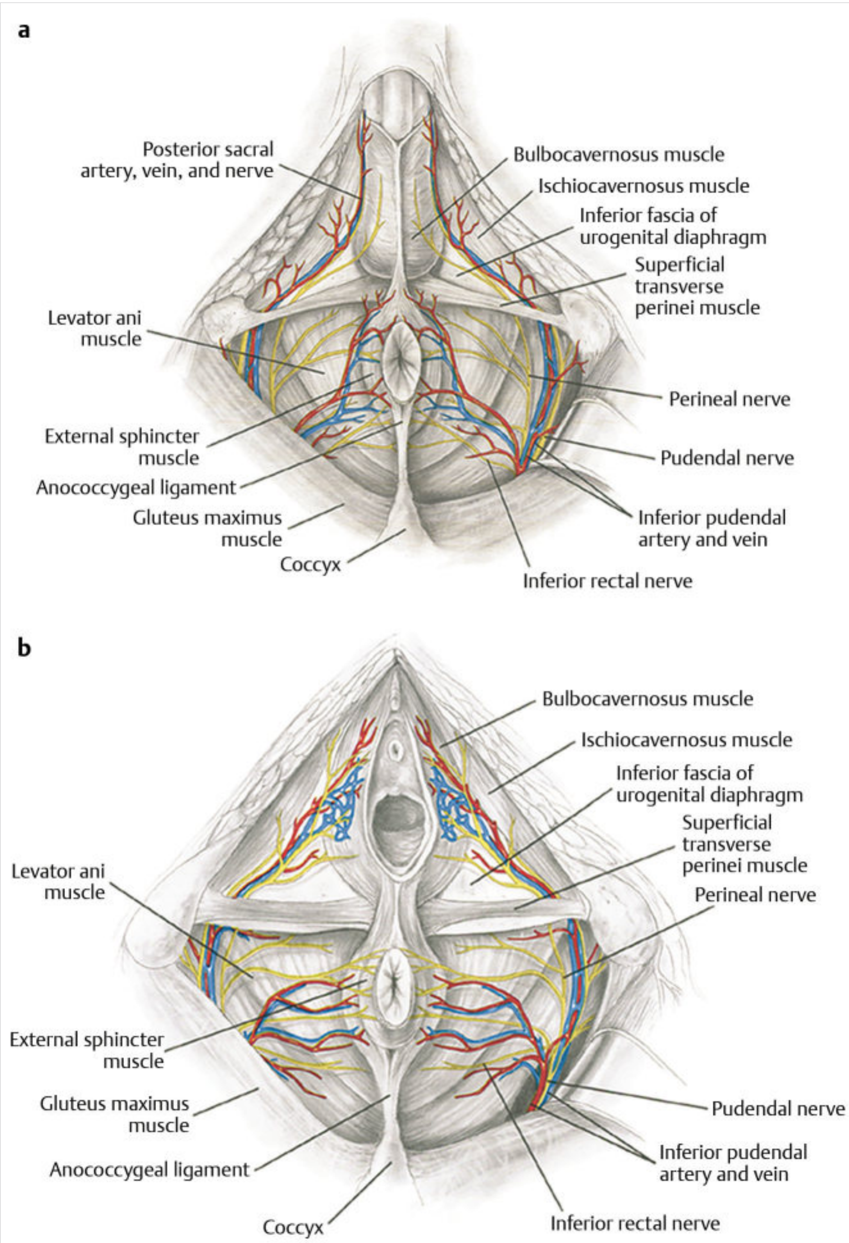


Fig. 1.9 Perineal view. **(a)** Male perineum. **(b)** Female perineum.

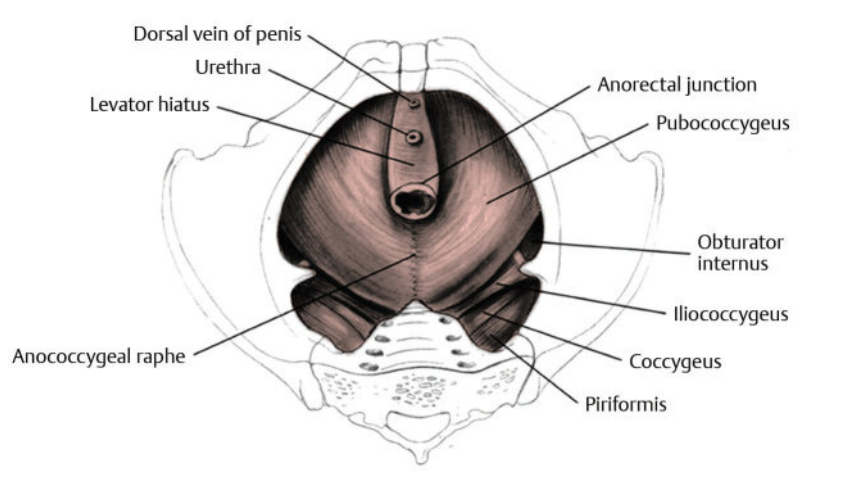


Fig. 1.10 Levator muscles.[46]

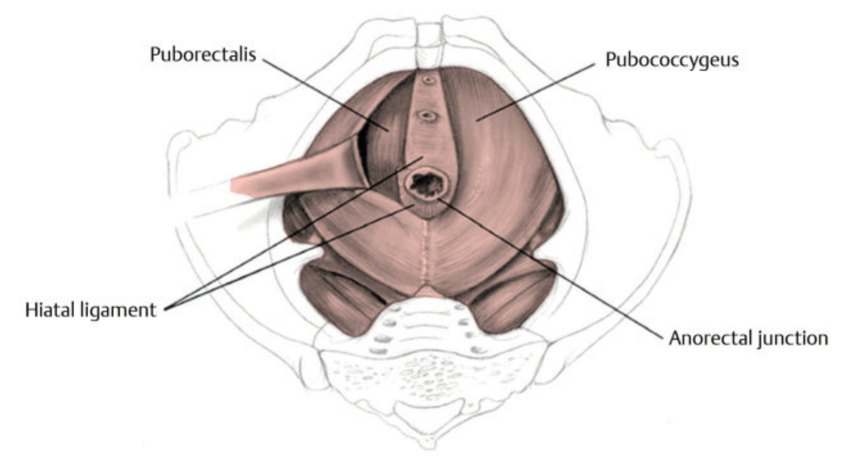


Fig. 1.11 Hiatal ligament.[46]

In a neuroanatomy study, Matzel et al[58] dissected cadavers and traced the sacral nerves from their entrance into the pelvis through the sacral foramina throughout their branching to their final destinations and found that the neural supply of the levator ani was distinct from that of the external anal sphincter. The levator is supplied by branches from the sacral nerves proximal to the sacral plexus and running on the inner surface; the external anal sphincter is supplied by nerve fibers traveling with the pudendal nerve on the levator's undersurface. To document the functional relevance of these anatomic findings, stimulation of the pudendal and sacral nerves was performed. The former increased anal pressure, whereas stimulation of S3 increased anal pressure only slightly but caused an impressive decrease of the rectoanal angle. When S3 was stimulated after bilateral pudendal block, anal pressure did not change, but the decrease in rectoanal angulation persisted. The authors concluded from their anatomic dissection and neurophysiologic study that two different peripheral nerve supplies are responsible for anal continence, that one muscle complex is innervated mainly by the third sacral nerve and another by the pudendal nerve. Further investigation will be required to clarify this point.

Puborectalis Muscle

The puborectalis muscle arises from the back of the symphysis pubis and the superior fascia of the urogenital diaphragm, runs backward alongside the anorectal junction, and joins its fellow muscle of the other side immediately behind the rectum, where they form a **U**-shaped loop that slings the rectum to the pubes (▶ Fig. 1.11).

Iliococcygeus Muscle

The iliococcygeus muscle arises from the ischial spine and posterior part of the obturator fascia, passes downward, backward, and medially, and becomes inserted on the last two segments of the sacrum, the coccyx, and the anococcygeal raphe. There are no connections to the anal canal.[11]

Pubococcygeus Muscle

The pubococcygeus muscle arises from the anterior half of the obturator fascia and the back of the pubis. Its fibers are directed backward, downward, and medially, where they decussate with fibers of the opposite side.[11,56] This line of decussation is called the anococcygeal raphe (▶ Fig. 1.10). Some fibers, which lie more posteriorly, are attached directly to the tip of the coccyx and the last segment of the sacrum. This muscle also sends fibers to share the formation of the conjoined longitudinal muscle (▶ Fig. 1.6). The muscle fibers of the pubococcygeus, while proceeding backward, downward, and medially, form an elliptical space, called the "levator hiatus" (▶ Fig. 1.10), through which pass the lower part of the rectum and either the prostatic urethra and dorsal vein of the penis in men or the vagina and urethra in women. The intrahiatal viscera are bound together by part of the pelvic fascia, which is more condensed at the level of the anorectal junction and has been called the "hiatal ligament" (▶ Fig. 1.11).[56] This ligament is believed to keep the movement of the intrahiatal structures in harmony with the levator ani muscle. The crisscross arrangement of the anococcygeal raphe prevents the constrictor effect on the intrahiatal structures during levator ani contraction and causes a dilator effect.[56] The puborectalis and the levator ani muscles have a reciprocal action. As one contracts, the other relaxes. During defecation, there is puborectalis relaxation accompanied by levator ani contraction, which widens the hiatus and elevates the lower rectum and anal canal. When a person is in an upright position, the levator ani muscle supports the viscera.

1.6.5 Anorectal Ring

"Anorectal ring" is a term coined by Milligan and Morgan[36] to denote the functionally important ring of muscle that surrounds the junction of the rectum and the anal canal. It is composed of the upper borders of the internal sphincter and the puborectalis muscle. It is of paramount importance during the treatment of abscesses and fistulas because division of this ring will inevitably result in anal incontinence.

1.7 Anorectal Spaces

Certain potential spaces in and about the anorectal region are of surgical significance and will be briefly described (▶ Fig. 1.4, ▶ Fig. 1.12, ▶ Fig. 1.13).

1.7.1 Perianal Space

The perianal space is in the immediate area of the anal verge surrounding the anal canal. Laterally, it becomes continuous with the subcutaneous fat of the buttocks or may be confined by the conjoined longitudinal muscle. Medially, it extends into the lower part of the anal canal as far as the dentate line. It is continuous with the intersphincteric space. The perianal space contains the lowest part of the external sphincter, the external

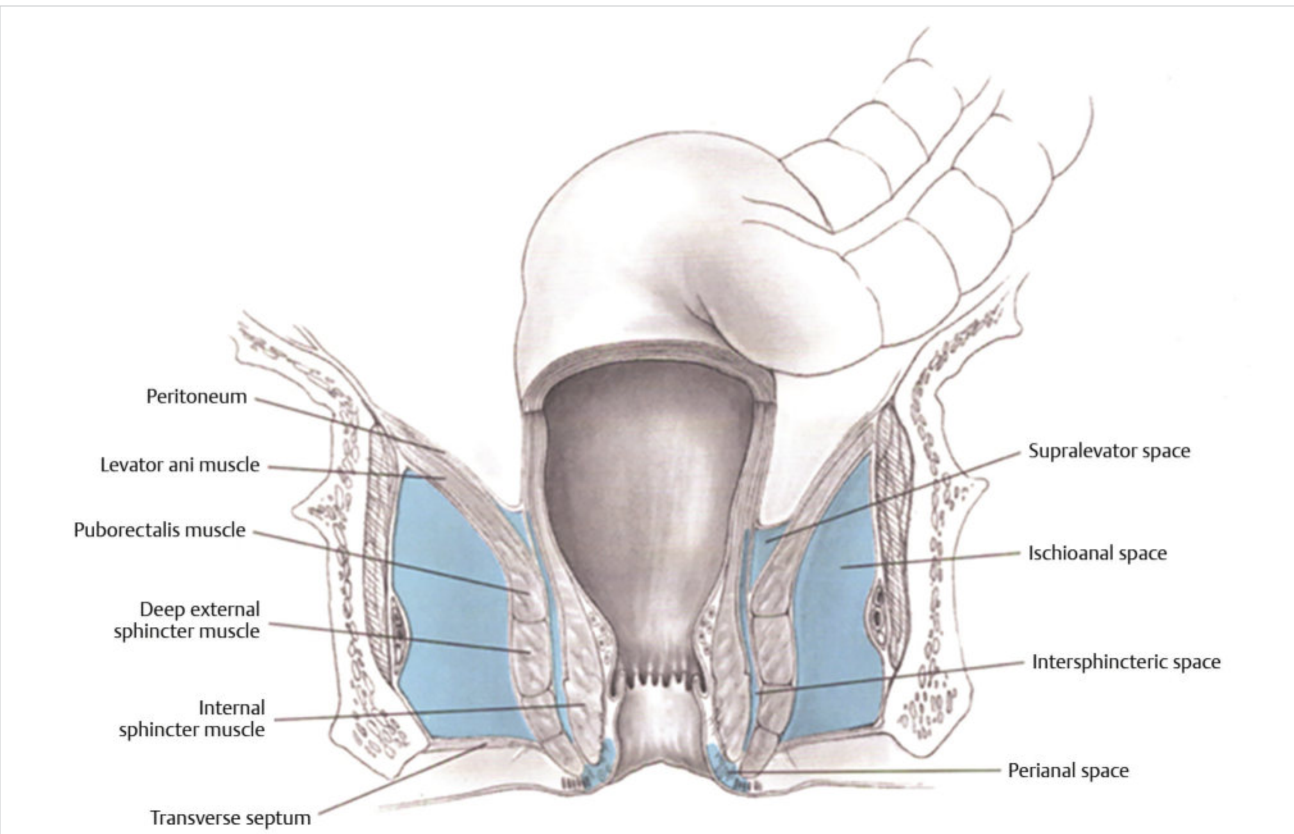


Fig. 1.12 Perianal and perirectal spaces (frontal view).

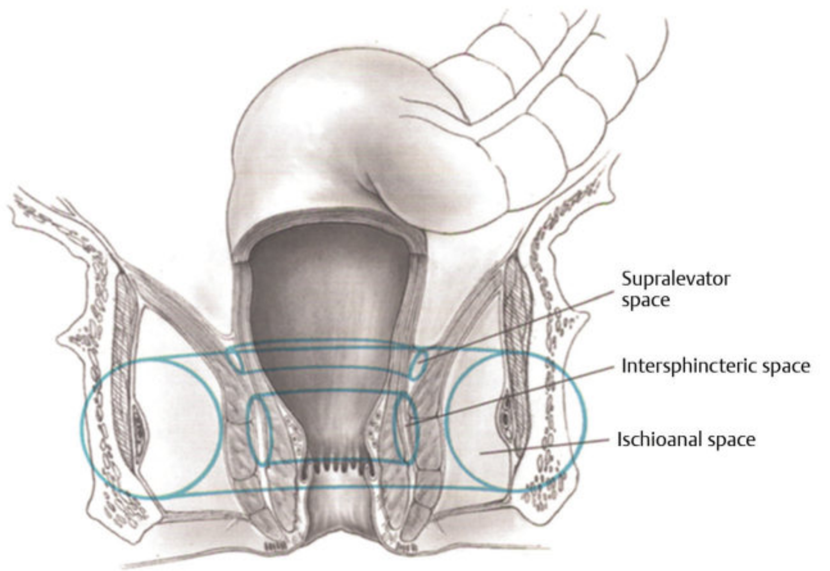


Fig. 1.13 Horseshoe-shaped connections of the anorectal spaces.

hemorrhoidal plexus, branches of the inferior rectal vessels, and lymphatics. The radiating elastic septa divide the space into a compact honeycomb arrangement, which accounts for the severe pain produced by a collection of pus or blood.

1.7.2 Ischioanal Space

The ischioanal fossa is a pyramid-shaped space. The apex is formed at the origin of the levator ani from the obturator fascia, and the inferior boundary is the skin on the perineum. The anterior boundary is formed by the superficial and deep transverse perineal muscles and the posterior boundary of the perineal membrane. The posterior boundary is the gluteal skin. The medial wall is composed of the levator ani and the external sphincter muscles. The lateral wall is nearly vertical and is formed by the obturator internus muscle and the ischium and by the obturator fascia. The base or inferior boundary is the transverse septum, which divides this space from the perianal space.[59] In the obturator fascia, on the lateral wall, is the Alcock canal, which contains the internal pudendal vessels and the pudendal nerve. When the ischioanal and perianal spaces are regarded as a single tissue space, it is called the ischioanal fossa.[60] The contents of the ischioanal fossa consist of a pad of fat, the inferior rectal nerve coursing from the back of the ischioanal fossa forward and medially to the external sphincter, the inferior rectal vessels, portions of the scrotal nerves and vessels in men and the labial nerves and vessels in women, the transverse perineal vessels, and the perineal branch of the fourth sacral nerve running to the external sphincter from the posterior angle of the fossa.[61] Anteriorly, the ischioanal space has an important extension forward, above the urogenital diaphragm, which may become filled with pus in cases of ischioanal abscesses.

1.7.3 Intersphincteric Space

The intersphincteric space lies between the internal and external sphincter muscles, is continuous below with the perianal space, and extends above into the wall of the rectum.

1.7.4 Supralevator Space

Situated on each side of the rectum is the supralevator space, bounded superiorly by the peritoneum, laterally by the pelvic wall, medially by the rectum, and inferiorly by the levator ani muscle. Sepsis in this area may occur because of upward extension of anoglandular origin or from a pelvic origin.

1.7.5 Submucous Space

Between the internal sphincter and the mucosa lies the submucous space. It extends distally to the dentate line and proximally becomes continuous with the submucosa of the rectum. It contains the internal hemorrhoidal plexus. Although abscesses in this space have been described, they are probably of little clinical significance and have been mistaken for what, in fact, were intersphincteric abscesses.

1.7.6 Superficial Postanal Space

The superficial postanal space connects the perianal spaces with each other posteriorly below the anococcygeal ligament.

1.7.7 Deep Postanal Space

The right and left ischioanal spaces are continuous posteriorly above the anococcygeal ligament but below the levator ani muscle these spaces communicate through the deep postanal space (▶ Fig. 1.4), also known as the retrosphincteric space of Courtney.[62] This postanal space is the usual pathway by which purulent infection spreads from one ischioanal space to the other, which results in the so-called horseshoe abscess (▶ Fig. 1.13).

1.7.8 Retrorectal Space

The retrorectal space lies between the upper two-thirds of the rectum and sacrum above the rectosacral fascia. It is limited anteriorly by the fascia propria covering the rectum, posteriorly by the presacral fascia, and laterally by the lateral ligaments (stalks) of the rectum. Superiorly, it communicates with the retroperitoneal space, and inferiorly it is limited by the rectosacral fascia, which passes forward from the S4 vertebra to the rectum, 3 to 5 cm proximal to the anorectal junction.

Below the rectosacral fascia is the supralevator space, a horseshoe-shaped potential space, limited anteriorly by the fascia propria of the rectum and below by the levator ani muscle (▶ Fig. 1.4). The retrorectal space contains loose connective tissue. The presacral fascia protects the presacral vessels that lie deep to it. The presacral veins are part of the extensive vertebral plexus and are responsible for the major bleeding problems encountered in this area during operation. In addition to the usual tissues from which neoplasms can arise, this is an area of embryologic fusion and remodeling; thus, it is the site for persistence of embryologic remnants from which neoplasms also can arise. The perianal, ischioanal, and supralevator spaces on each side connect posteriorly with their counterparts on the opposite side, forming a horseshoe-shaped communication (▶ Fig. 1.13).

1.8 Arterial Supply

Because the arterial supply of the large bowel is variable, the following descriptions are presented with the full recognition that they represent only the most frequently encountered patterns. However, they do serve as a basis on which a host of variations will be observed. In general, the right colon is served by branches of the superior mesenteric artery, while the left colon is served by the inferior mesenteric artery.

1.8.1 Ileocolic Artery

The ileocolic artery is the last branch of the superior mesenteric artery, arising from its right side and running diagonally around the mesentery to the ileocecal junction. It is always present and as a rule has two chief branches. The ascending branch anastomoses with the descending branch of the right colic artery, and the descending branch anastomoses with the ileal artery. Others include anterior and posterior cecal branches and an appendicular branch (▶ Fig. 1.14a).

1.8.2 Right Colic Artery

The origin of the right colic artery varies greatly from person to person. This artery may arise from the superior mesenteric artery, the middle colic artery, or the ileocolic artery (▶ Fig. 1.14a). In the series of Steward and Rankin,[63] the right colic artery was absent in 18% of cases, whereas in the series of Michels et al[64] it was absent in only 2% of cases. In a detailed dissection of 56 human cadavers, Garćia-Ruiz et al[65] found an ileocolic artery in all cases, a middle colic in 55 of 56 cases, and a right colic artery in only 6 (10.7%) cadavers. Conventionally, the right colic artery is described as dividing into a descending branch that anastomoses with colic branches of the ileocolic artery and an ascending branch that anastomoses with the right branch of the middle colic artery.

1.8.3 Middle Colic Artery

The middle colic artery normally arises from the superior mesenteric artery either behind the pancreas or at its lower border (▶ Fig. 1.14a). It frequently shares a common stem with the right colic artery. The artery curves toward the hepatic flexure, and, at a variable distance from the colonic wall, it divides into a right branch that anastomoses with the ascending branch of the right colic artery and a left branch that anastomoses with the ascending branch of the left colic artery. Although Griffiths[66] found the middle colic artery to be absent in 22% using arteriography and dissection, other investigators using cadaver dissection found it to be present in 96 to 98%.[63,67,68]

1.8.4 Inferior Mesenteric Artery

The inferior mesenteric artery arises from the abdominal aorta approximately 3 to 4 cm above the aortic bifurcation, about 10 cm above the sacral promontory, or 3 to 4 cm below the third part of the duodenum.[66] The first branch is the left colic artery, arising 2.5 to 3 cm from its origin (▶ Fig. 1.14a). It bifurcates, and its ascending branch courses directly toward the splenic flexure and anastomoses with the left branch of the middle colic artery. The descending branch anastomoses with sigmoid vessels. According to Griffiths,[66] the sigmoid arteries exhibit two principal modes of origin. In 36% of cases, they arise from the inferior mesenteric artery, and in 30% of cases the first sigmoid artery arises from the left colic artery. The second and third branches of the sigmoid arteries usually come directly from the inferior mesenteric artery. The number of sigmoidal branches may vary up to six.

1.8.5 Superior Rectal Artery

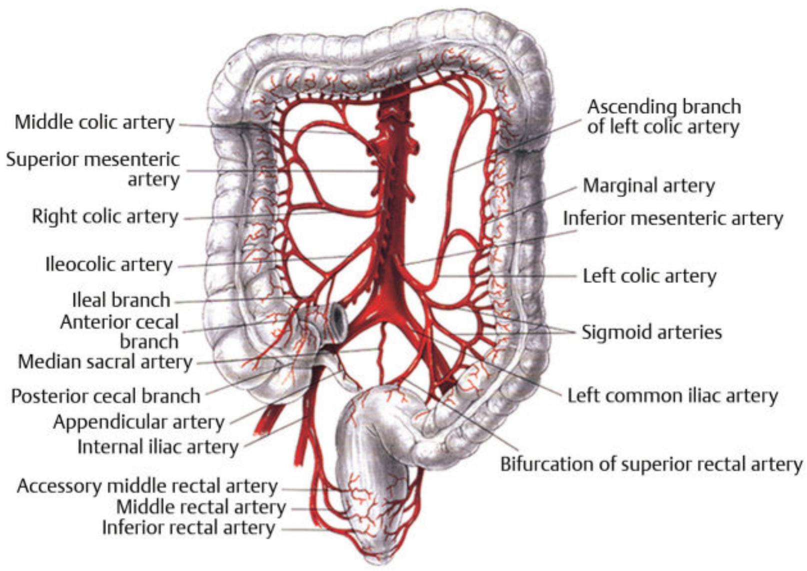
The inferior mesenteric artery proceeds downward, crossing the left common iliac artery and vein to the base of the sigmoid mesocolon to become the superior rectal artery. The superior rectal artery starts at the last branch of the sigmoid artery. It lies posterior to the right of the sigmoid colon, coming in close contact with the posterior aspect of the bowel at the rectosigmoid junction. It forms a rectosigmoid branch, an upper rectal branch, and then divides into left and right terminal branches. The terminal branches extend downward and forward around the lower two-thirds of the rectum to the level of the levator ani muscle. Tortuous small branches ascend subperitoneally to the anterior aspect of the upper third of the rectum and anastomose with the upper rectal branch (▶ Fig. 1.14b).[67]

The rectosigmoid branch arises at the rectosigmoid junction and divides directly into two diverging branches. One ascends to the sigmoid colon and anastomoses with branches of the last sigmoid artery, and the other descends to the rectum and anastomoses with the upper rectal branch. The upper rectal branch arises from the superior rectal artery before its bifurcation. It makes an extramural anastomosis with the lower branch of the rectosigmoid artery and the terminal branch of the superior rectal artery (▶ Fig. 1.14b).[67]

1.8.6 Middle Rectal Arteries

Most middle rectal arteries arise from the internal pudendal arteries (67%). The rest come from inferior gluteal arteries (17%) and internal iliac arteries (17%).[13] A middle rectal artery of appreciable diameter (1–2 mm) is observed on both sides in only 4.8%, on the right side in 4.8%, and on the left side in 2.4%

a



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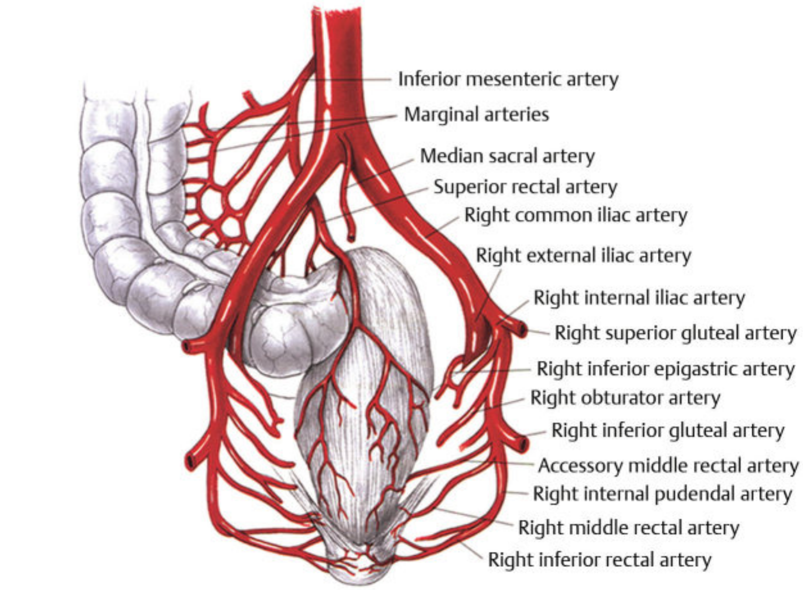

Fig. 1.14 Arterial supply. **(a)** Supply to the colon. **(b)** Supply to the rectum (posterior view).

in the cadaver dissection by Ayoub.[68] Sato and Sato[13] find middle rectal arteries in 22% of the specimens. Their terminal branches pierce the wall of the rectum at variable points but usually in the lower third of the rectum. The presence of the middle rectal artery can be anticipated if the diameter of the terminal branches of the superior rectal artery is smaller than usual. Conversely, when the middle rectal arteries are absent, the superior rectal artery has larger size than usual.[68]

There is considerable controversy in the literature regarding the presence and origin of this vessel. Other series found the middle rectal artery to be present in 47 to 100% of cases.[27,69,70] Sato and Sato[13] believe that discrepancies, for the most part, result from incomplete dissection. The origin and course of several arteries, those from inferior vesical arteries, arteries to the ductus deferens, and uterine or vaginal arteries,[13] are almost indistinguishable from the middle rectal arteries, which enter the rectum via the lateral stalks. In the presence of occlusive vascular disease, Fisher and Fry[71] believe that collateral circulation develops between superior and middle rectal arteries.

1.8.7 Inferior Rectal Arteries

The inferior rectal arteries, which are branches of the inferior iliac arteries, arise from the pudendal artery (in Alcock's canal). They traverse the ischioanal fossa and supply the anal canal and the external sphincter muscles. There is no extramural anastomosis between the inferior rectal arteries and other rectal arteries. However, arteriography demonstrates an abundance of anastomoses among the inferior and superior rectal arteries at deeper planes in the walls of the anal canal and rectum.[68]

The superior rectal artery is the chief blood supply of the rectum. The middle rectal arteries are inconsistent and cannot be relied on after ligation of the superior rectal artery. Although there is no extramural anastomosis among the superior rectal artery, middle rectal arteries, and inferior rectal arteries on cadaver dissection, arteriography shows abundant intramural anastomosis among them, particularly in the lower rectum.[66,67] When a low anterior resection for carcinoma of the rectum is performed in which the superior rectal artery and the middle rectal arteries are ligated, the rectal stump relies on the blood supply from the inferior rectal arteries. It may be safer to perform the anastomosis lower rather than higher, provided there is no tension.

1.8.8 Median Sacral Artery

The median sacral artery arises from the back of the aorta at 1.5 cm above its bifurcation and descends over the last two lumbar vertebrae, the sacrum and the coccyx, and behind the left common iliac vein (▶ Fig. 1.14a). Twigs of arteries form the median sacral artery. The terminal part of the anterior division of the internal iliac artery, the internal pudendal artery, arteries of the levator ani, and the inferior vesical artery in males and the vaginal artery in females are frequently found. These twigs are distributed mainly to pararectal tissues and sparsely to the wall of the rectum. No obvious anastomosis exists between these twigs and other rectal arteries. They are the major source of oozing during mobilization of the rectum.[68] The surgical significance of the median sacral artery is that during rectal excision it is exposed on the front of the sacrum, and when the coccyx is disarticulated, this vessel may demonstrate troublesome bleeding. The presence of this artery is inconsistent (often it is absent), and it probably is insignificant in providing the blood supply to the lower rectum.

1.8.9 Collateral Circulation

The marginal artery, generally known as the marginal artery of Drummond, is a series of arcades of arteries along the mesenteric border of the entire colon. It is the branch that connects the superior and the inferior mesenteric arteries. The arcades begin with the ascending colic branch of the ileocolic artery and continue distally to the sigmoid arteries (▶ Fig. 1.14a). The arcades are constant and rarely incomplete. Ligation of the inferior mesenteric artery in performing a rectosigmoidectomy can keep the left colon viable via the marginal artery.

Slack[72] attributed our current understanding of the distribution of vessels around the colon to the classic paper by Drummond in 1916. That description remains generally accepted today. By using injection studies, Slack determined the exact relationship of the blood vessels supplying the colon to the muscle layers and the position of diverticula. His findings supported those of Drummond. As soon as the vasa recta arise from the marginal artery, they divide into anterior and posterior branches, except in the sigmoid colon, where they may form secondary arcades (▶ Fig. 1.15).[73] They initially run subserosally in the wall, and just prior to the taeniae they penetrate the circular muscle and continue in the submucosa toward the antimesenteric border.[3] The vasa brevia are smaller arteries arising from the vasa recta, and some originate from the marginal artery.[74] They supply the mesocolic two-thirds of the circumference. However, a truly critical point exists at the splenic flexure, where the marginal artery is often small. As noted in 11% of the subjects in a series studied by Sierociński,[74] an area from 1.2 to 2.8 cm in the splenic flexure is devoid of vasa recta. This “weak point” is prone to a compromised blood supply. In the absence of the left colic artery, the marginal artery in this region is larger than usual.[50]

The “arc of Riolan” is found in about 7% of individuals. It is a short loop connecting the left branch of the middle colic artery and the trunk of the inferior mesenteric artery (▶ Fig. 1.16). The term frequently has been misquoted for the marginal anastomosis at the left colic flexure. The arc of Riolan also has been referred to as the “meandering mesenteric artery.” It courses in the left colon mesentery roughly parallel to the mesenteric border of the colon. Its size enlarges when a significant arterial occlusion is present. If the arc of Riolan is present in patients undergoing operations to correct aneurysms, consideration

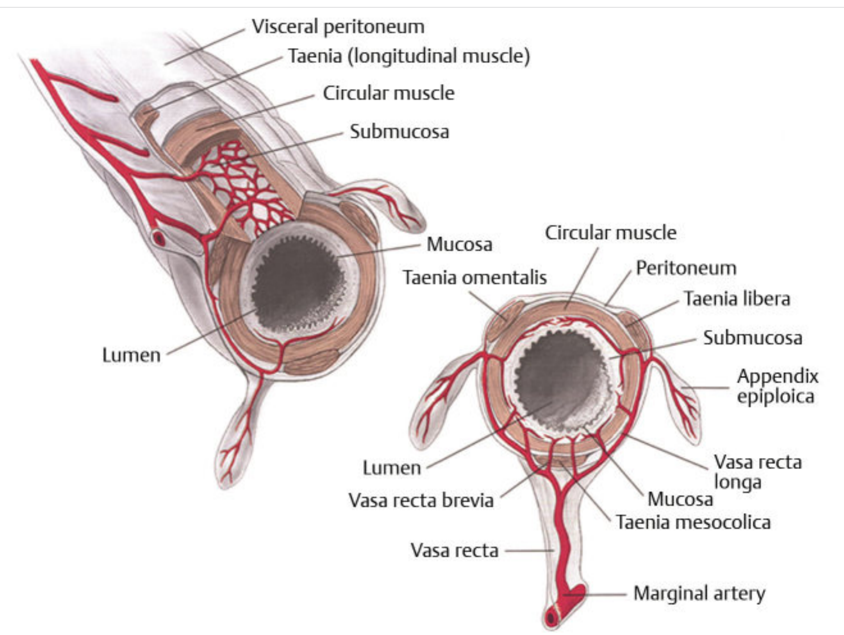

Fig. 1.15 Vasa brevia and vasa recta.

should be given to reimplantation of the inferior mesenteric artery. If the superior mesenteric artery is stenotic, the celiac and inferior mesenteric arteries provide the main collateral flow necessary for viability of the small intestine and the right colon (▶ Fig. 1.17a).[71] If the inferior mesenteric artery is stenotic, the superior mesenteric artery provides the main collateral flow necessary for the viability of the left colon and the rectum (▶ Fig. 1.17b).[71]

The inferior mesenteric artery also can function as an important collateral vessel to the lower extremities.[71] In instances of distal aortic occlusion, the trunk of the inferior mesenteric artery, the internal iliac artery, and the external iliac artery frequently remain patent. In this circumstance, blood flowing antegrade through the meandering mesenteric artery flows into the superior rectal artery, which then forms a collateral network with the middle rectal artery, an anterior division branch of the internal iliac artery. Blood can flow from the middle rectal artery into the internal iliac artery and from there into the external iliac artery. Obviously, incorrect ligation of the inferior mesenteric artery or ligation of the meandering mesenteric artery not only would threaten the viability of the rectum but also may cause acute ischemia of the lower extremity (▶ Fig. 1.17c).

The significance of the meandering mesenteric artery is that, during operation on the aorta, if flow is from the superior mesenteric artery to the inferior mesenteric artery, the inferior mesenteric artery may be ligated at its origin; however, if flow direction is the reverse, the inferior mesenteric artery must be reimplanted to avoid necrosis of the left colon (▶ Fig. 1.17a and b). For operations planned on the left colon, major mesenteric resection must be avoided because, by necessity, the meandering mesenteric artery will be divided. If flow is from the superior mesenteric artery to the inferior mesenteric artery,[75] necrosis of the sigmoid or rectum or even vascular insufficiency of the lower limb may occur. If flow is from the inferior mesenteric artery to the superior mesenteric artery, necrosis of the proximal colon and small bowel may occur.

In 1907, Sudeck[76] described an area in the rectosigmoid colon where the marginal artery between the lowest sigmoid and the superior rectal arteries is absent. Under these circumstances, ligation of the last sigmoid artery was believed to account for the occasional necrosis of part of the sigmoid and rectum during a rectal resection through a perineal or presacral approach. Most recent experiences with transabdominal rectosigmoid resection and dye injection studies have shown that the anastomosis between the superior artery and the last sigmoid artery is always adequate.[66,77] Thus, Sudeck's critical point does not have the surgical importance that was previously emphasized. With the use of an aortogram, Lindstrom[78] found that there is an important anastomosis between the superior and middle rectal vessels that potentially can prevent gangrene of pelvic organs when the distal aorta is occluded.

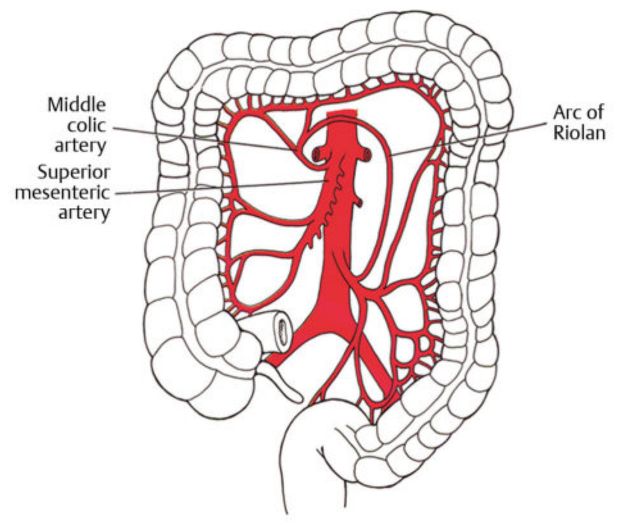

Fig. 1.16 Arc of Riolan.

1.9 Venous Drainage

The veins of the intestine follow their corresponding arteries and bear the same terminology.

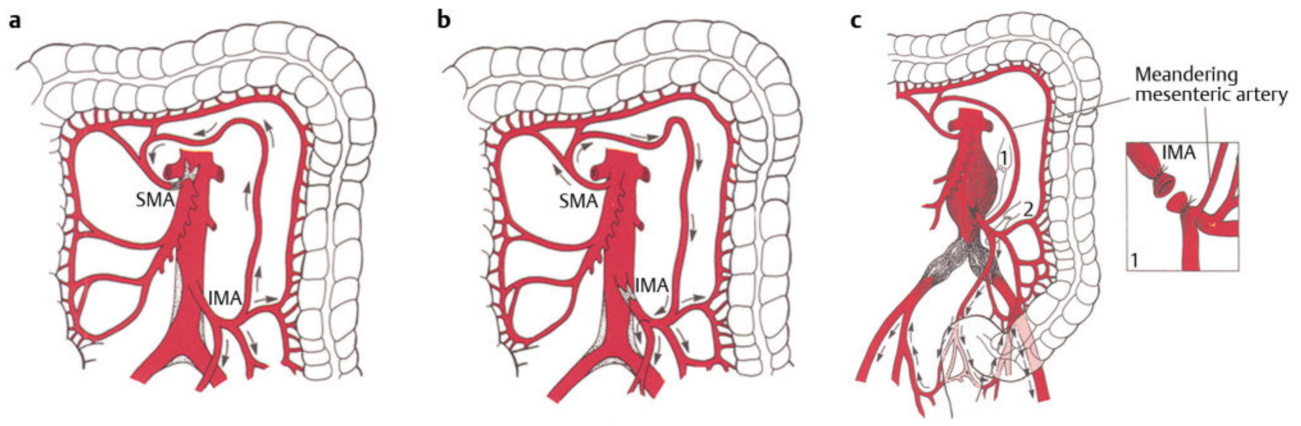

Fig. 1.17 Pathologic anatomy and occlusion of the superior mesenteric artery (SMA) and the inferior mesenteric artery (IMA). **(a)** Occlusion of SMA. **(b)** Occlusion of IMA. **(c)** Location for ligating IMA: (1) correct location of ligation (see inset); (2) incorrect location of ligation.

1.9.1 Superior Mesenteric Vein

The veins from the right colon and transverse colon drain into the superior mesenteric vein. The superior mesenteric vein lies slightly to the right and in front of the superior mesenteric artery. It courses behind the head and neck of the pancreas, where it joins the splenic vein to form the portal vein (▶ Fig. 1.18).

In the cadaver dissection, Yamaguchi et al[79] found highly variable venous anatomy of the right colon: all ileocolic veins drained into the superior mesenteric vein. The right colic vein, if present, joined the superior mesenteric vein in 56% and gastrocolic trunk in 44%. The middle colic vein, which was the most variable, and the right colic vein occasionally formed a common trunk with the right gastroepiploic vein and/or the pancreaticoduodenal vein. This common trunk was defined as the gastrocolic trunk. The middle colic vein drained into the superior mesenteric vein in 85% and the rest drained into the gastrocolic trunk.

1.9.2 Inferior Mesenteric Vein

The inferior mesenteric vein is a continuation of the superior rectal vein. It receives blood from the left colon, the rectum, and the upper part of the anal canal. All the tributaries of the inferior mesenteric vein closely follow the corresponding arteries but are slightly to the left of them. At the level of the left colic artery, the inferior mesenteric vein follows a course of its own and ascends in the extraperitoneal plane over the psoas muscle to the left of the ligament of Treitz. It continues behind the body of the pancreas to enter the splenic vein (▶ Fig. 1.18).

In the conduct of an extended low anterior resection of the rectum or a coloanal anastomosis, division of the inferior mesenteric vein just inferior to the duodenum prior to its union with the splenic vein may be necessary to ensure adequate mobilization of the colon to permit a tension-free anastomosis. Access to the vessel is facilitated by incising the peritoneum at and just to the left of the ligament of Treitz.

Blood return from the rectum and anal canal is via two systems: portal and systemic. The superior rectal vein drains the rectum and upper part of the anal canal, where the internal hemorrhoidal plexus is situated, into the portal system via the inferior mesenteric vein. The middle rectal veins drain the lower part of the rectum and the upper part of the anal canal into the systemic circulation via the internal iliac veins. The inferior rectal veins drain the lower part of the anal canal, where the external hemorrhoidal plexus is located, via the internal pudendal veins, which empty into the internal iliac veins and hence into the systemic circulation (▶ Fig. 1.18). Controversy exists regarding the presence or absence of anastomoses formed by these three venous systems. Current thinking supports the concepts of free communication among the main veins draining the anal canal and that of no association between the occurrence of hemorrhoids and portal hypertension.[80]

1.10 Lymphatic Drainage

Lymphatic drainage of the large intestine starts with a network of lymphatic vessels and lymph follicles in the lower part of the lamina propria, along the muscularis mucosa, but becomes more abundant in the submucosa and muscle wall.[34] These vessels are connected with and drain into the extramural lymphatics. Although some lymphatic channels exist in the lamina propria above the muscularis mucosa, carcinomas that are confined to the lamina propria have not been known to metastasize.[34,81,82] On this basis, the term "invasive carcinoma" is used only when the malignant cells have invaded through the muscularis mucosae.[34] Knowledge of the lymphatic drainage is essential in planning operative treatment for malignancies of the large intestine.

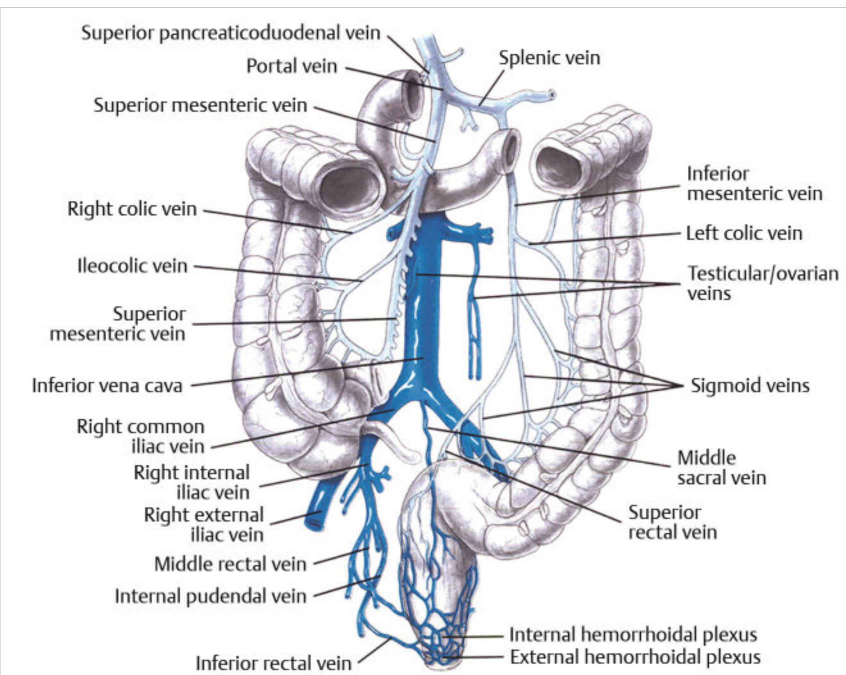

Fig. 1.18 Venous drainage of the colon and rectum. (Dark blue represents systemic venous drainage. Light blue shows portal venous drainage.)

1.10.1 Colon

The extramural lymphatic vessels and lymph nodes follow the regional arteries. Retrograde flow is retarded by numerous semilunar valves. Jamieson and Dobson[83] conveniently classified colonic lymph nodes into four groups: epicolic, paracolic, intermediate, and main (principal) glands (▶ Fig. 1.19).

Epicolic Glands

The epicolic glands lie on the bowel wall under the peritoneum and in the appendices epiploicae. In the rectum, they are situated on the areolar tissue adjacent to the outer longitudinal muscular coat and are known as the "nodules of Gerota." The epicolic glands are very numerous in young subjects, but decrease in number in older patients. Although found on any part of the large intestine, they are especially numerous in the sigmoid colon.

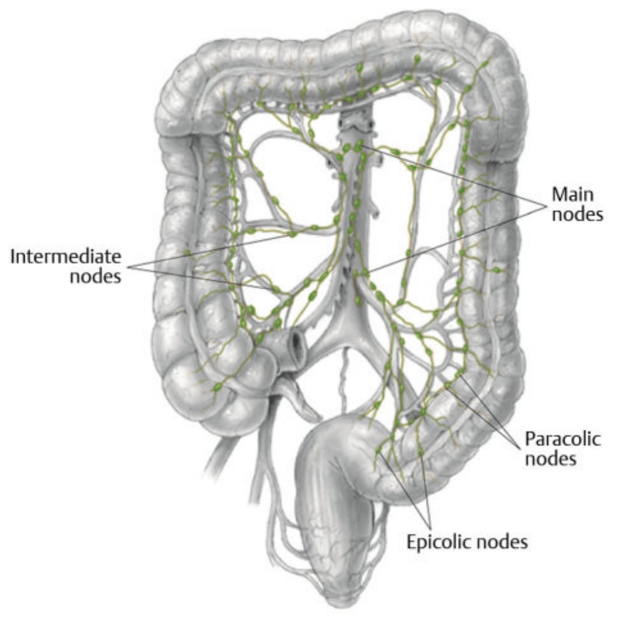

Fig. 1.19 Lymphatic drainage of the colon.

Paracolic Glands

The paracolic glands lie along the inner margin of the bowel from the ileocolic angle to the rectum, mainly between the intestine and the arterial arcades along the marginal artery and on the arcades. The paracolic glands are believed to be the most important colonic lymph glands and to have the most numerous filters.

Intermediate Glands

The intermediate glands lie around the main colic arteries before their point of division.

Main Glands

The main (principal) glands lie along the origins of the superior and inferior mesenteric vessels and their middle and left colic branches. The main glands receive the efferents of the intermediate glands, from efferents of the paracolic glands, and frequently from vessels directly from the bowel.

1.10.2 Rectum and Anal Canal

Lymph from the upper and middle parts of the rectum ascends along the superior rectal artery and subsequently drains to the inferior mesenteric lymph nodes. The lower part of the rectum drains cephalad via the superior rectal lymphatics to the inferior mesenteric nodes and laterally via the middle rectal lymphatics to the internal iliac nodes (▶ Fig. 1.20).

Studies of the lymphatic drainage of the anorectum in women have shown that when dye is injected 5 cm above the anal verge, spread of the dye occurs to the posterior vaginal wall,

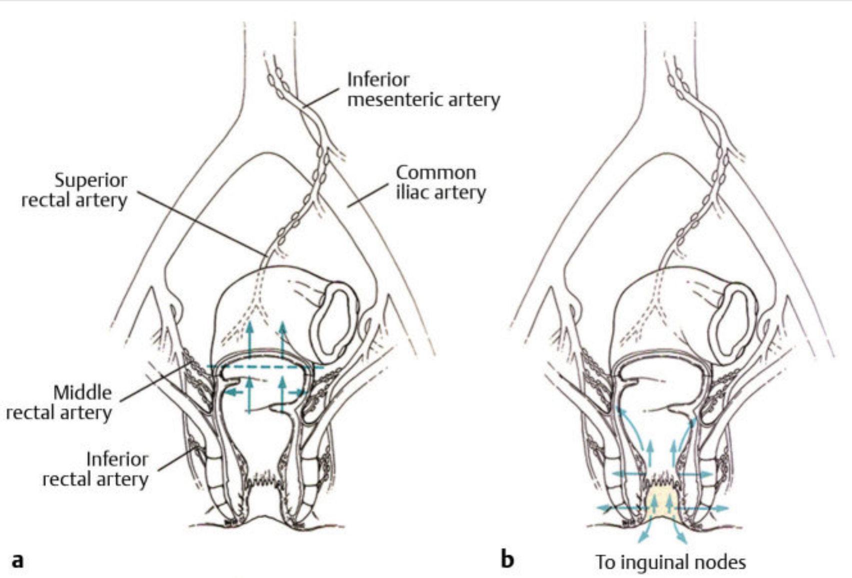

Fig. 1.20 Lymphatic drainage of the rectum **(a)** and anal canal **(b)**.

uterus, cervix, broad ligament, fallopian tubes, ovaries, and cul-de-sac. When the dye is injected at 10 cm above the anal verge, spread occurs only to the broad ligament and cul-de-sac, whereas injection at the 15 cm level shows no spread to the genital organs.[84] It generally has been known that retrograde lymphatic spread in carcinoma of the rectum and anal canal occurs only after there has been extensive involvement of the perirectal structures, serosal surfaces, veins, perineural lymphatics, and proximal lymphatic channels.[85]

The most modern study of lymphatic drainage of the rectum and anal canal has used lymphoscintigraphy. Following injection of a radiocolloid (rhenium sulfide labeled with technetium-99m), lymphatic drainage was detected by means of a computerized gamma camera. The lymphatic drainage of both the intraperitoneal and extraperitoneal rectum occurs along the superior rectal and inferior mesenteric vessels to the lumboaortic nodes. There is no communication between these vessels and the vessels along the internal iliac nodes.[86]

Canessa et al[87] performed a systematic examination of the number and distribution of lateral pelvic lymph nodes using 16 cadaveric dissections.[19] Dissection fields were divided according to the three surgical groups of pelvic wall lymph nodes: presacral, obturator, and hypogastric. A total of 458 lymph nodes were found, with a mean of 28.6 nodes per pelvis (range, 16–46). Lymph node size ranged from 2 to 13 mm. The highest number of lymph nodes was found in the obturator fossa group (mean, 7; range, 2–18). Hypogastric lymph nodes were found lying predominantly above the inferior hypogastric nerve plexus but reaching the deep pelvic veins. Complete excision of hypogastric lymph nodes demands a deep pelvic dissection of neurovascular structures.

Lymphatics from the anal canal above the dentate line drain cephalad via the superior rectal lymphatics to the inferior mesenteric nodes and laterally along both the middle rectal vessels and the inferior rectal vessels through the ischioanal fossa to the internal iliac nodes. Lymph from the anal canal below the dentate line usually drains to the inguinal nodes. It also can drain to the superior rectal lymph nodes or along the inferior rectal lymphatics through the ischioanal fossa if obstruction occurs in the primary drainage (▶ Fig. 1.20).

1.11 Innervation

The large intestine is innervated by the sympathetic and parasympathetic systems, the distribution of which follows the course of the arteries. The peristalsis of the colon and rectum is inhibited by sympathetic nerves and is stimulated by parasympathetic nerves. A third division of the autonomic nervous system is the enteric nervous system, which is described in Chapter 2.

1.11.1 Colon

Sympathetic Innervation

The sympathetic fibers are derived from the lower thoracic and upper lumber segments of the spinal cord. They reach the sympathetic chain via corresponding white rami. The thoracic fibers proceed to the celiac plexus by way of the lesser splanchnic nerves. From here, they proceed to the superior mesenteric plexus. Nerve fibers from the superior mesenteric ganglia supply the right colon including the appendix. The lumbar sympathetic nerves leave the sympathetic chain via the lumbar splanchnic nerves and join the mesenteric nerves. The fibers to the descending colon, the sigmoid colon, and the upper rectum originate in the inferior mesenteric plexus. A lumbar or sacral sympathectomy is often followed by increased tone and contraction of the colon.

Parasympathetic Innervation

Parasympathetic innervation of the colon derives from two levels of the central nervous system: vagus nerve and sacral outflow.[5] The vagus nerves descend to the preaortic plexus and then are distributed along the colic branches of the superior mesenteric artery that supply the cecum, the ascending colon, and most of the transverse colon.[88] These nerves are secretomotor to the glands, motor to the muscular coat of the gut, but inhibitory to the ileocolic sphincter.[88] Administration of parasympathomimetic drugs such as Prostigmin (Valeant Pharmaceuticals North America, Aliso Viejo, CA) usually causes vigorous intestinal contraction and diarrhea. Fibers of the sacral outflow emerge in the anterior roots of the corresponding sacral nerves, as the nervi erigentes, which in turn join the hypogastric plexuses. The uppermost fibers of the sacral outflow are believed to extend as high as the splenic flexure. The preganglionic parasympathetic fibers entering the colon form synapses in ganglia clustered in the myenteric plexus of Auerbach and Meissner's plexus. There are numerous intricate connections between postganglionic fibers of adjacent myenteric and submucosal ganglia. Postganglionic parasympathetic fibers are cholinergic (▶ Fig. 1.21 and ▶ Fig. 1.22).

1.11.2 Rectum

Sympathetic Innervation

The sympathetic fibers to the rectum are derived from the first three lumbar segments of the spinal cord, which pass through

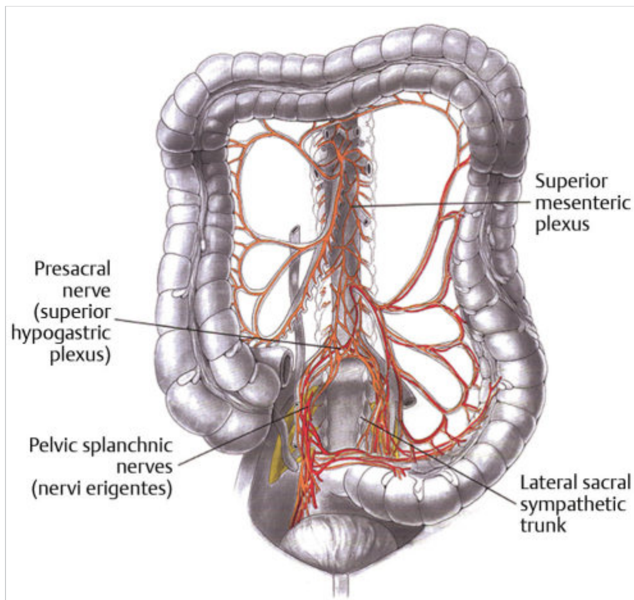

Fig. 1.21 Nerve supply to the rectum (frontal view).

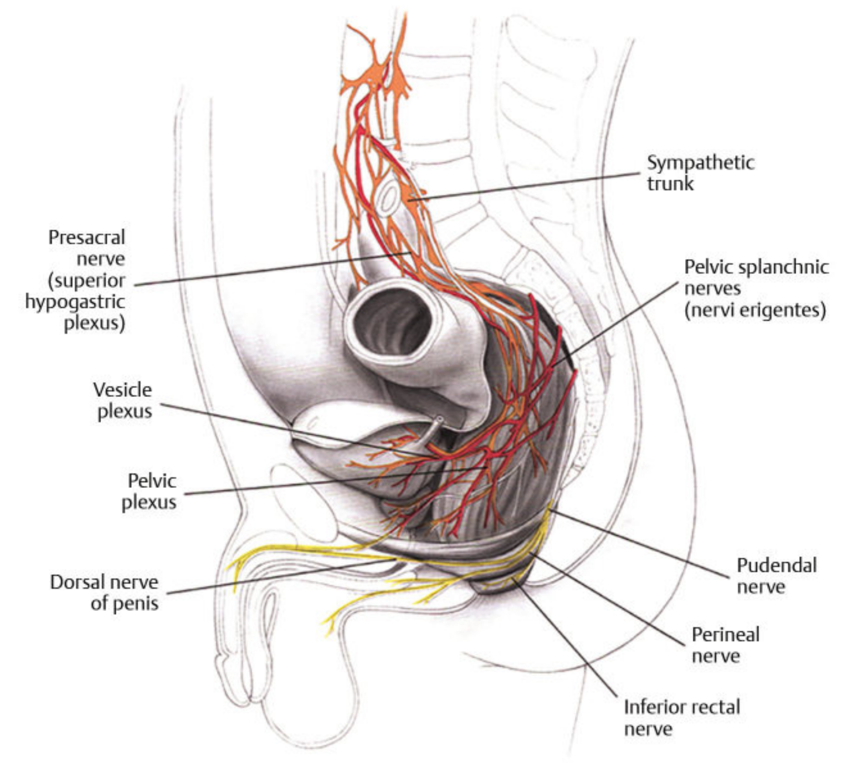

Fig. 1.22 Nerve supply to the rectum (lateral view).

the ganglionated sympathetic chains and leave as a lumbar sympathetic nerve that joins the preaortic plexus. From there, a prolongation extends along the inferior mesenteric artery as the mesenteric plexus and reaches the upper part of the rectum. The presacral nerve or superior hypogastric plexus arises from the aortic plexus and the two lateral lumbar splanchnic nerves (▶ Fig. 1.21 and ▶ Fig. 1.22). The plexus thus formed divides into two hypogastric nerves. The hypogastric nerves are identified at the sacral promontory, approximately 1 cm lateral to the midline and 2 cm medial to each ureter on cadaver dissection.[27] The hypogastric nerve on each side continues caudally and laterally following the course of the ureter and the internal iliac artery along the pelvic wall. It joins the branches of the sacral parasympathetic nerves, or nervi erigentes, to form the pelvic plexus.

During mobilization of the rectum after the peritoneum on each side of the rectum is incised, the hypogastric nerves along with the ureters should be brushed off laterally to avoid injury. The key zones of sympathetic nerve damage are during ligation of the inferior mesenteric artery and high in the pelvis during initial posterior rectal mobilization adjacent to the hypogastric nerves.

Parasympathetic Innervation

The parasympathetic nerve supply is from the nervi erigentes, which originate from the second, third, and fourth sacral nerves on either side of the anterior sacral foramina. The third sacral nerve is the largest of the three and is the major contributor.[27] The fibers pass laterally, forward, and upward to join the sympathetic nerve fibers to form the pelvic plexus on the pelvic side walls (▶ Fig. 1.21 and ▶ Fig. 1.22). From here, the two types of nerve fibers are distributed to the urinary and genital organs and to the rectum. In women, the sympathetic nerve fibers from the presacral nerve pass toward the uterosacral ligament close to the rectum. In men, the nerve fibers from the presacral nerve pass immediately adjacent to the anterolateral wall of the rectum in the retroperitoneal tissue.[89,90]

The pelvic plexus supplies the prostate, seminal vesicles, corpora cavernosa, terminal parts of vasa deferentia, prostatic and membranous urethra, ejaculatory ducts, and bulbourethral glands.[91]

The pelvic plexus also provides visceral branches that innervate the bladder, ureters, seminal vesicles, prostate, rectum, membranous urethra, and corpora cavernosa. In addition, branches that contain somatic motor axons travel through the pelvic plexus to supply the levator ani, coccygeus, and striated urethral musculature. The pelvic plexus on each side is encased in the midportion of the lateral ligament, which is located just above the levator ani muscle. To avoid nerve injury in full mobilization of the rectum, the lateral ligament should be cut close to the rectal sidewall.[90,92]

The branches of the pelvic plexus along with the blood vessels (neurovascular bundle) that supply the male genital organs are located posterolateral to the seminal vesicles (▶ Fig. 1.23).[93]

The nerves innervating the prostate, the membranous urethra, and the corpora cavernosa travel dorsolaterally in the lateral pelvic fascia between the prostate and rectum. The bulk of the pelvic plexus is located lateral and posterior to the seminal vesicles, which can be used as an intraoperative landmark. Near the apex of the prostate, the nerves course slightly anteriorly to travel on the lateral surface of the membranous urethra. After piercing the urogenital diaphragm, they pass behind the dorsal penile artery and dorsal penile nerve before entering the corpora cavernosa.

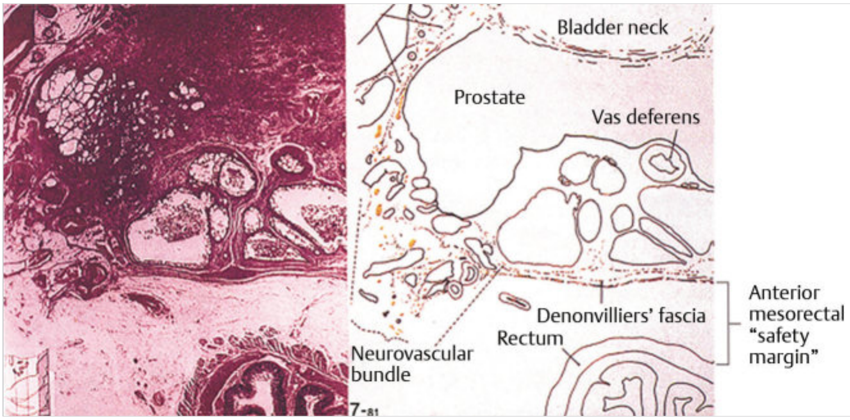

Fig. 1.23 Section shows the avascular areolar space between rectum and seminal vesicles and the location of the neurovascular bundle.[93] (Reproduced with permission from Lepor H, Gregerman M, Crosby R, Mostifi FK, Walsh PC. Precise localization of the autonomic nerves from the pelvic plexus to the corpora cavernosa: A detailed anatomic study of the adult male pelvis. J Urol. 1985;133:207-212.)

Both sympathetic and parasympathetic nervous systems are involved in erection. The nerve impulses from the parasympathetic nerves that lead to erection produce arteriolar vasodilatation and increase blood in the cavernous spaces of the penis. Activity of the sympathetic system inhibits vasoconstriction of the penile vessels, thereby adding to vascular engorgement and sustained erection. Moreover, sympathetic activity causes contraction of the ejaculatory ducts, seminal vesicles, and prostate, with subsequent expulsion of semen into the posterior urethra.[94] Depending on which nerves have been damaged, certain deficiencies may occur, including incomplete erection, lack of ejaculation, retrograde ejaculation, or total impotence. Injury to nervi erigentes may occur during division of the lateral ligaments.

Anterior mobilization should start at the avascular plane between the rectum and the seminal vesicles in the midline. The incision is carried laterally to the lateral border of the seminal vesicle. At this point, the incision should curve downward (posteriorly) to avoid injury to the neurovascular bundles. Injury to the neurovascular bundle (▶ Fig. 1.23) probably causes ejaculation problems. Key zones of risk to parasympathetic nerves are during lateral dissection in the pelvis near the pelvic plexus and during the anterolateral dissection deep in the pelvis while mobilizing the rectum from the seminal vesicles and the prostate.

Pudendal Nerve

The pudendal nerve arises from the sacral plexus (S2–S4). It leaves the pelvis through the greater sciatic foramen, crosses the ischial spine, and continues in the pudendal canal (Alcock's canal) toward the ischial tuberosity in the lateral wall of the ischioanal fossa on each side. Three of its important branches are the inferior rectal, perineal, and dorsal nerves of the penis or clitoris (▶ Fig. 1.22). The main pudendal nerve is anatomically protected from injury during mobilization of the rectum. Sensory stimuli from the penis and clitoris are mediated by the branch of the pudendal nerve and are preserved after proctectomy.

1.11.3 Anal Canal

Motor Innervation

The internal anal sphincter is supplied by both sympathetic and parasympathetic nerves that presumably reach the muscle by the same route as that followed to the lower rectum. The parasympathetic nerves are inhibitory to the internal sphincter. The action of sympathetic nerves to the internal sphincter is conflicting. Shepherd and Wright[95] and Lubowski et al[96] found it to be inhibitory, whereas Carlstedt et al[97] found it to be stimulating.

The external sphincter is supplied by the inferior rectal branch of the internal pudendal nerve and the perineal branch of the fourth sacral nerve. The pudendal nerve passes through the greater sciatic foramen and crosses the sacrospinous ligament accompanied by the internal pudendal artery and vein. The pudendal nerve lies on the lateral wall of the ischioanal fossa, where it gives off the inferior rectal nerve, which crosses the ischioanal fossa with the inferior rectal vessels to reach the external sphincter. Gruber et al[98] studied the topographic relationship of the pudendal nerve to the accompanying pudendal vessels and the ischial spine. In 58 left and 58 right pelves, the course of the pudendal nerve and vessels at the ischial spine were evaluated. Multitrunked pudendal nerves were found in 40.5% with a left-versus-right ratio of 1:1.5. The diameters of the single-trunked nerves ranged from 1.3 to 6.8 mm. In 75.9%, the pudendal nerve was found medial to the accompanying internal pudendal artery. The distance to the artery ranged from 17.2 mm medial to 8 mm lateral. The distance to the tip of the ischial spine ranged from 13.4 mm medial to 7.4 mm lateral. Knowledge of the close spatial relationship between the pudendal nerve and the internal pudendal artery is important for any infiltration technique and even surgical release. In 31% of cases, an additional direct branch from the fourth sacral nerve innervates the external sphincter. This is important because it helps to explain why a bilateral pudendal block produces complete paralysis of the external sphincter in only about half the subjects, despite loss of sensation in the area innervated by the pudendal nerves.[99] The puborectalis muscle is supplied not by the pudendal nerves, but by a direct branch of the third and fourth sacral nerves, which lie above the pelvic floor.[57] The levator ani muscles are supplied on their pelvic surface by twigs from the fourth sacral nerves, and on their perineal aspect by the inferior rectal or perineal branches of the pudendal nerves.

Sensory Innervation

The sensory nerve supply of the anal canal is the inferior rectal nerve, a branch of the pudendal nerve. The epithelium of the anal canal is profusely innervated with sensory nerve endings, especially in the vicinity of the dentate line. Pain sensation in the anal canal can be felt from the anal verge to 1.5 cm proximal to the dentate line.[40] The anal canal can sense touch, cold, and pressure.

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2 Colonic and Anorectal Physiology

W. Ruud Schouten and Philip H. Gordon

Abstract
This chapter will focus on colonic physiology, including function, microflora, and propulsion and storage, and anorectal physiology, including anal continence, investigative techniques, and clinical applications.

Keywords: anorectal physiology, colonic physiology, function, microflora, propulsion, storage, anal continence, investigative techniques, clinical application

2.1 Colonic Physiology

The colon is the final conduit of the digestive tract in which digestive material is stored. Another major function of the large bowel is the absorption of water and salt. The absorption of sodium and chloride is balanced with the secretion of potassium and bicarbonate. This interaction is essential for the maintenance of electrolyte homeostasis. By absorbing most of the water and salt presented to it, the colon responds to body requirements and plays an essential role in protecting the body against dehydration and electrolyte depletion. The absorptive capability enables the colon to reduce the volume of fluid material received from the small bowel and to transform it into a semisolid mass suitable for defecation. The propulsion of feces toward the rectum and the storage of this material between defecations are the result of complex and poorly understood patterns of motility. Other functions of the large bowel include digestion of carbohydrate and protein residues and secretion of mucus.

2.1.1 Functions

Absorption

Physiologic control of intestinal ion transport involves an integrated system of neural, endocrine, and paracrine components.[1] Endogenous mediators, including neurotransmitters and peptides, act on enterocytes through membrane receptors coupled to energy-requiring “pumps” or “channels” through which ions flow passively in response to electrochemical gradients.

In healthy individuals, the colon absorbs water, sodium, and chloride, while secreting potassium and bicarbonate. It receives approximately 1,500 mL of fluid material from the ileum over a 24-hour period. From this input, the large bowel absorbs approximately 1,350 mL of water, 200 mmol of sodium, 150 mmol of chloride, and 60 mmol of bicarbonate.[2] It has been estimated that the colon possesses enough reserve capacity to absorb an additional 3.5 to 4.5 L of ileal effluent, a feature that allows the large bowel to compensate for impaired absorption in the small intestine.[3] Several factors that determine colonic absorption include the volume, composition, and rate of flow of luminal fluid. The success of whole gut irrigation capitalizes on this principle. The absorptive capacity is not homogeneous throughout the large intestine due to significant differences in the colonic segments. It has been shown that more salt and water are absorbed from the right colon than from the distal colon.[3] Thus, a right hemicolectomy is more likely to result in diarrhea than is a left hemicolectomy. Whenever ileocecal flow exceeds the capacity of the colon to absorb fluid and electrolytes, an increase in fecal water excretion (diarrhea) will ensue.

Most electrolytes cannot cross the phospholipid membrane of colonic epithelial cells by simple diffusion. Passing this membrane is only possible using distinct membrane proteins, which act like channels, carriers, and pumps. These proteins are required to facilitate and to speed up the transport across the apical membrane. This transport is passive because it is not energy dependent and because the flow is down the concentration gradient.

Absorption of Salt

The average concentration of sodium in the fluid chyme accepted by the colon from the terminal ileum is 130 to 135 mmol/L and in the stool is approximately 40 mmol/L. When the luminal concentration of sodium is high, more is absorbed; no absorption occurs when the luminal concentration is below 15 to 25 mmol/L.[4] In this way, there is a linear relationship between the luminal concentration of sodium and sodium absorption. The bulk of sodium absorption is electroneutral in exchange for intracellular hydrogen. This electroneutral absorption is facilitated by Na^+/H^+ exchange proteins. To date, three types of Na^+/H^+ exchangers (NHE) have been identified in the colon. NHE3 is the most prominent one. In addition to the electroneutral pathway, the distal colon also exhibits an electrogenic way to enhance the sodium uptake. This electrogenic absorption is facilitated by proteins in the apical membrane, which act like an ion-specific channel, belonging to the family of epithelial Na^+ channels (ENaCs). These ENaC proteins are inhibited by the diuretic amiloride and stimulated by mineralocorticoids. A small proportion of sodium is absorbed with the help of a sodium–glucose linked transporter. This membrane protein acts like a carrier and couples sodium and glucose. The transport of sodium across the apical membrane with the aid of all these distinct proteins is driven by the downhill electrochemical gradient and the negative membrane voltage. The electrochemical gradient is generated by the Na^+, K^+-ATPase at the basolateral membrane, which acts as a pump. This pump is stimulated by mineralocorticoids and has an electrogenic effect, extruding three Na^+ ions in exchange for two K^+ ions, and thereby maintaining relatively low intracellular Na^+ and high intracellular K^+ concentrations compared with concentrations of these electrolytes in the extracellular environment. The Na^+/K^+ pump results in a negative intracellular voltage. Across the colonic mucosa, there is an electrical potential difference of approximately 20 to 60 mV.[2] The basolateral membrane of the mucosal cell is electrically positive, whereas the apical membrane along the luminal border is electrically negative (▶ Fig. 2.1).[5,6] Sodium absorption is also stimulated by short-chain fatty acids (SCFAs) such as acetate, butyrate, and propionate, which are produced by bacterial fermentation.[7,8,9] The absorption of sodium is closely linked to the absorption of chloride. This anion either moves through the paracellular pathway or enters the epithelial cell

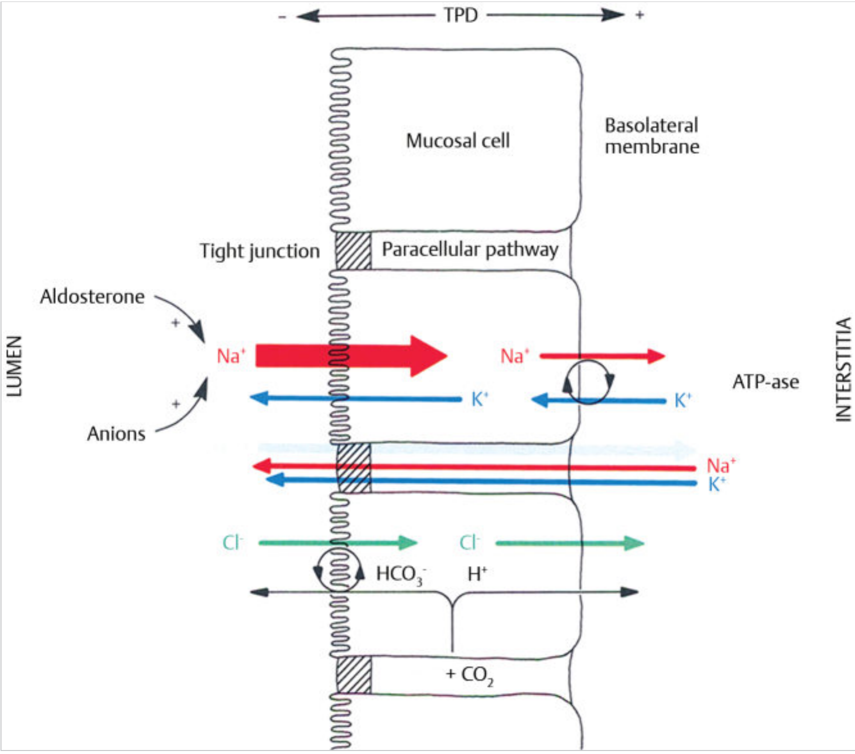

Fig. 2.1 Simplified diagram showing electrolyte transport across colonic epithelium. This diagram does not show the membrane proteins, which are required to facilitate and to speed up this process of electrolyte transport. TPD, transmural potential difference.

through its apical membrane (▶ Fig. 2.1). The transcellular absorption of chloride is electroneutral in exchange for intracellular bicarbonate[10] and is facilitated by Cl^-/HCO_3^- exchange proteins. The absorption of chloride is also driven by a concentration gradient and is increased by a low luminal pH. Chloride concentrations are high in ileal effluent but fall markedly during passage through the large intestine. Although the transport of salt across the colonic mucosal layer is characterized by net absorption, salt can also move backward into the colonic lumen through cellular and paracellular pathways. After basolateral uptake, the cellular pathway ends with apical excretion of chloride through Cl^- channels. The most important one is cystic fibrosis transmembrane conductance regulator. In patients with cystic fibrosis, this apical membrane protein does not function properly, resulting in impaired secretion of both Cl^- and HCO_3^-.[11]

Absorption of Water

Like the small bowel, the colon also absorbs water by simple diffusion. This process does not require membrane proteins and is driven by the osmotic gradient across the colonic mucosa, generated by the absorption of sodium. Water is transported through both paracellular and cellular pathways. Like salt, water also can move backward into the colonic lumen (▶ Fig. 2.1). Water cannot be absorbed if the colonic lumen contains a high concentration of inabsorbable, osmotically active solutes. Any water that remains in the colon will simply be excreted as watery diarrhea. The most common cause of this so-called osmotic diarrhea is lactose intolerance. Lactose must be cleaved into its component monosaccharides by lactase before their absorption. In the absence of lactase, osmotically active lactose cannot be absorbed and remains in the intestinal lumen, thus interfering with water resorption.

Secretion

Bicarbonate

As described earlier, chloride is absorbed in exchange for intracellular bicarbonate. This process is facilitated by Cl^-/HCO_3^- exchange proteins located in the apical membrane. The fact that chloride in the colonic lumen facilitates the secretion of bicarbonate is clinically evident in patients with ureterosigmoidostomy, who may develop hyperchloremia and secrete excessive amounts of bicarbonate.[12] Besides this Cl^--dependent process, there are two other pathways involved in the secretion of bicarbonate. One is through the apical Cl^- channels, mediated by cyclic adenosine monophosphate (cAMP). The other pathway is by exchange with SCFAs. The resulting net secretion of bicarbonate ions into the lumen aids in neutralization of the acids generated by microbial fermentation in the large bowel.[11,13]

Potassium

Potassium may be absorbed or secreted, depending on the luminal concentration. It is absorbed if the concentration exceeds 15 mEq/L, and is secreted if it falls below this value. Since luminal K^+ concentration is usually less than 15 mEq/L, net secretion normally occurs.[5] Potassium moves into the colonic lumen through both cellular and paracellular pathways (▶ Fig. 2.1). In the past, it was thought that this transport was mainly passive, along an electrochemical gradient. At present, it has become clear that colonic epithelial cells also contain membrane proteins, which act as channels to facilitate the uptake and excretion of potassium at their basolateral and apical membrane, respectively.[3,11] Because the distal colon is relatively impermeable to potassium, the luminal concentration may increase by the continued absorption of water. It has been suggested that there may be active secretion of potassium in the human rectum.[8] The presence of potassium in fecal bacteria and colonic mucus, as well as from desquamated cells, also may contribute to the high concentration (50–90 mmol/L) of potassium in human stool.[7,9]

Urea

Urea is another constituent of the fluid secreted into the colonic lumen. Of the urea synthesized by the liver, about 6 to 9 g/day (20%) is metabolized in the digestive tract, mainly in the colon.[2] Because the maximum amount of urea entering the colon from the ileum is about 0.4 g/day,[14] the bulk of urea hydrolyzed in the large bowel by bacterial ureases must be secreted into the lumen. The metabolism of urea in the colon gives rise to 200 to 300 mL of ammonia each day. Since only a small amount of ammonia (1–3 mmol) can be found in the feces, most must be absorbed across the colonic mucosa. Although the production of ammonia in the large bowel can be abolished by neomycin, the absorption of ammonia is not affected by this antibiotic.

Ammonia

Ammonia absorption probably occurs by passive coupled nonionic diffusion in which bicarbonate and ammonium ions form ammonia and carbon dioxide.[2] The nonionized ammonia can freely diffuse across the colonic mucosa. This process is partially influenced by the pH of the luminal contents; as the luminal pH falls, the absorption of ammonia decreases.[2] Although urea is the most important source of ammonia, the ammonia in the colon also may be derived from dietary nitrogen, epithelial cells, and bacterial debris.

Mucus

Mucus is another product secreted into the colonic lumen. Throughout the entire length of the large bowel, the epithelium contains a large number of mucus-secreting cells, and it has been shown that nerve fibers come close to these goblet cells. Stimulation of the pelvic nerves increases mucus secretion from the colonic mucosa, as has been confirmed histologically. There is evidence for such a nerve-mediated secretion of mucus in the large bowel.[15] The colon is able to absorb amino acids and fatty acids, but only by passive mechanisms. Bile acids also can be reabsorbed.

Digestion

A little recognized function of the colon is the role it plays in digestion. Digestion of food begins in the stomach and is almost accomplished when transit to the end of the small intestine is complete. However, a small amount of protein and carbohydrate is not digested during transit through the small bowel. The colon plays a role in salvaging calories from malabsorbed sugars and dietary fiber.[16] In the colon, some of the protein residues are fermented by anaerobic bacteria into products such as indole, skatole (b-methylindole), phenol, cresol, and hydrogen sulfide, which create the characteristic odor of feces. The carbohydrate residues are broken down by anaerobic bacteria into SCFAs such as acetic 60%, propionic 20%, and butyric acid 15%.[17] It has been estimated that 100 mmol of volatile fatty acids are produced for each 20 g of dietary fiber consumed.

Most of these SCFAs, which constitute the major fecal anion in humans,[18] are absorbed in a concentration-dependent way. Their absorption is associated with the appearance of bicarbonate in the lumen, which in turn stimulates the absorption of sodium and water.[1] Other end products of fiber fermentation are hydrogen and methane. About 70% of colonic mucosal energy supply is derived from SCFAs originating in the lumen.[17] The functions of the colonocytes, mainly dependent on the absorption and oxidation of SCFAs, include cellular respiration, cell turnover, absorption, and numerous enzyme activities. Furthermore, SCFAs are used by the colonocytes not only as a source of energy but also as substrates for gluconeogenesis, lipogenesis, protein synthesis, and mucin production.

Propulsion and Storage

The main functions of colonic and anorectal motor activity are to absorb water, to store fecal wastes, and to eliminate them in a socially acceptable manner.[19] The first is achieved by colonic segmentation and motor activity that propels colonic material forward and backward over relatively short distances. The second is facilitated by colonic and rectal compliance and accommodation, whereas the third is regulated by the coordination of anorectal and pelvic floor mechanisms with behavioral and cognitive responses.[19]

Distinct patterns of mechanical activity are required for the normal propulsion and storage of colonic contents. The rate and volume of material moved along a viscus also is related to the pressure differential, the diameter of the tube, and the viscosity of the material. Observation of transit does not necessarily reflect the contractile activity responsible for transit. Although the investigation of colonic motility in vivo has proved to be difficult because of the relative inaccessibility of the colon, new data have been revealed through the use of modern recording techniques. This information provides a better understanding of normal colonic motility in humans.

Assessment and Control of Motility

Radiologic Evaluation

Early efforts to investigate colonic motility involved radiographic studies in which the colon was filled with barium from either above or below. These studies could demonstrate only organized movements of the colon, represented by changes in contour, and were not helpful in the detailed examination of colonic motility. Moreover, the well-known side effects of radiation have limited the possibilities of radiologic observations, even with such sophisticated techniques as time-lapse cinematography.[20]

At the beginning of the 20th century, radiographic studies revealed three types of colonic motility: retrograde movement, segmental nonpropulsive movement, and mass movement. Retrograde movements were identified as contractions originating in the transverse colon and traveling toward the cecum.[21,22] Later, studies with cinematography also demonstrated a retrograde transportation of colonic contents.[23] These retrograde movements are believed to delay the transit in the right colon, resulting in greater exposure of colonic contents to the mucosa to allow sufficient absorption of salt and water.[24]

Segmental nonpropulsive movements are the type more frequently observed during radiologic investigation. These segmental movements are caused by localized, simultaneous contractions of longitudinal and circular muscles, isolating short segments of the colon from one another. Adjacent segments alternately contract, pushing the colonic contents either anterograde or retrograde over a short distance.[20] Although segmental movements occur mainly in the right colon, they also have been observed in the descending colon and the sigmoid colon. Like retrograde movements, segmental contractions also might slow colonic transit.

The third type of colonic motility identified from radiographic observations is mass movement, for the first time described by Hertz.[25] It occurs three or four times a day, primarily in the transverse and descending colon, but it also occurs in the sigmoid colon during defecation. Colonic contents are propelled by mass movement over a long distance at a rate of approximately 0.5–1 cm/s.[26,27] Using a microtransducer placed via a sigmoid colostomy, Garcia et al[28] recorded activity over a 24-hour period. They documented a series of contractions and spiking potentials averaging 5.6 minutes, following which a "big contraction" appeared with mean pressure values of 127 mm Hg and mean electric values of 10.6 mV. The duration of this phenomenon averaged 24.93 seconds and corresponded to an observed intense evacuation via the colostomy. They assumed that this electropressure phenomenon represents the mass movement.

Radiologic assessment can demonstrate only changes in contour. For detailed examination of colonic motility, other techniques must be employed, such as isotope scintigraphy, the measurement of intracolonic pressure, the investigation of colonic and rectal wall contractility with barostat balloons, and the examination of myoelectrical activity of colonic smooth muscle.

Isotope Scintigraphy

Although evacuation proctography and isotope proctography with radiolabeled material inserted into the rectum allow the description of rectal emptying, neither technique provides any information about transport of colonic contents during defecation. Colorectal scintigraphy after oral intake of isotopes is a physiological technique and allows accurate assessment of colorectal transport during defecation. Utilizing this technique, Krogh and co-workers observed an almost complete emptying of the rectosigmoid, the descending colon, and part of the transverse colon after normal defecation.[29]

Measurement of Intracolonic Pressure

Pressure activity of the large bowel has been intensively studied with many different devices, including water- or air-filled balloons, perfused catheters, radiotelemetry capsules, and microtransducers. The measurement of intracolonic pressure presents special problems. First, the colonic contents may interfere with recording by changing the basal physiologic state of the colon or plugging or displacing the recording device. Second, problems of retrograde introduction of recording devices and difficulty in maintaining them at a constant site may be encountered.

Initially, manometric recordings were limited to the rectum and distal sigmoid colon. Most studies were static and manometry was performed with a retrogradely placed assembly in the prepared left hemicolon. To avoid the potential perturbation of motor patterns by colonic cleansing and to permit ambulation, several authors have adopted an antegrade approach via nasocolonic intubation of the unprepared colon. To capture all the relevant activity throughout the entire colon with sufficient spatial resolution, it is necessary to use an assembly with multiple, closely spaced recording sites.[30] Initially, the manometric devices, designed for this purpose, contained a maximum of about 16 recording sites. In order to obtain recordings from the entire length of the colon, the sensors were spaced at intervals of 7 cm or more. Recently, it has been shown that sensor spacing above 2 cm results in misinterpretation of the frequency and polarity of propagating pressure waves.[31] Studies utilizing manometric devices with sensor spacing of 7 cm or more are actually based on low-resolution manometry. This technique has revealed two major pressure wave patterns. The first wave pattern is a very distinctive pattern of high-amplitude propagating sequences (HAPS). Most of these pressure waves with a high amplitude (> 100 mm Hg) arise in the cecum and ascending colon, especially after awaking and after a meal. The other pressure wave pattern, detected by this low-resolution manometry, is difficult to classify and is usually defined as segmental or nonpropagating activity. Recently, Dinning et al introduced high-resolution fiber-optic manometry.[32] The device, utilized in their study, contained 72 sensors spaced at 1-cm intervals. After mechanical bowel preparation, the catheter was introduced with a colonoscope and fastened to the mucosa of the ascending colon with endoclips. An abdominal X-ray was performed to verify the correct placement of the catheter (▶ Fig. 2.2).

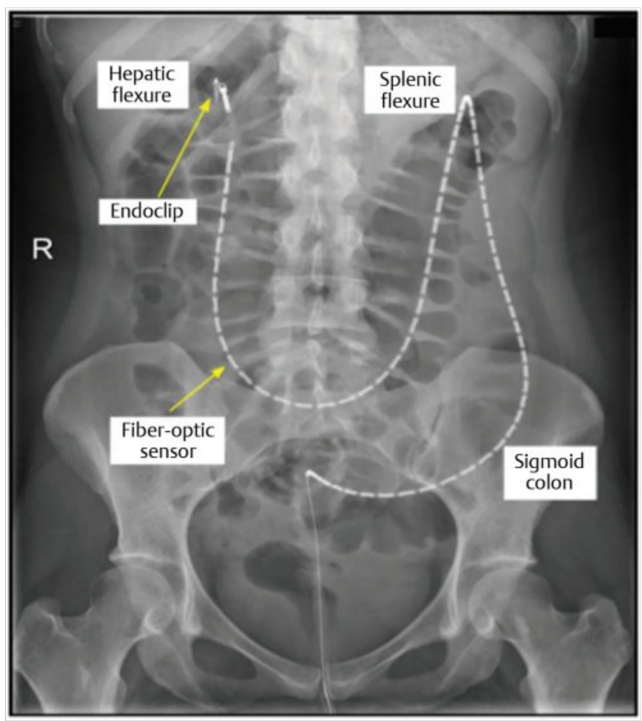

Fig. 2.2 X-ray image of the fiber-optic catheter positioned in the healthy human colon. The tip of the catheter can be seen at the hepatic flexure. The middle of each white segment is the position of each pressure sensor.[32] (With permission © 2004 John Wiley and Sons.)