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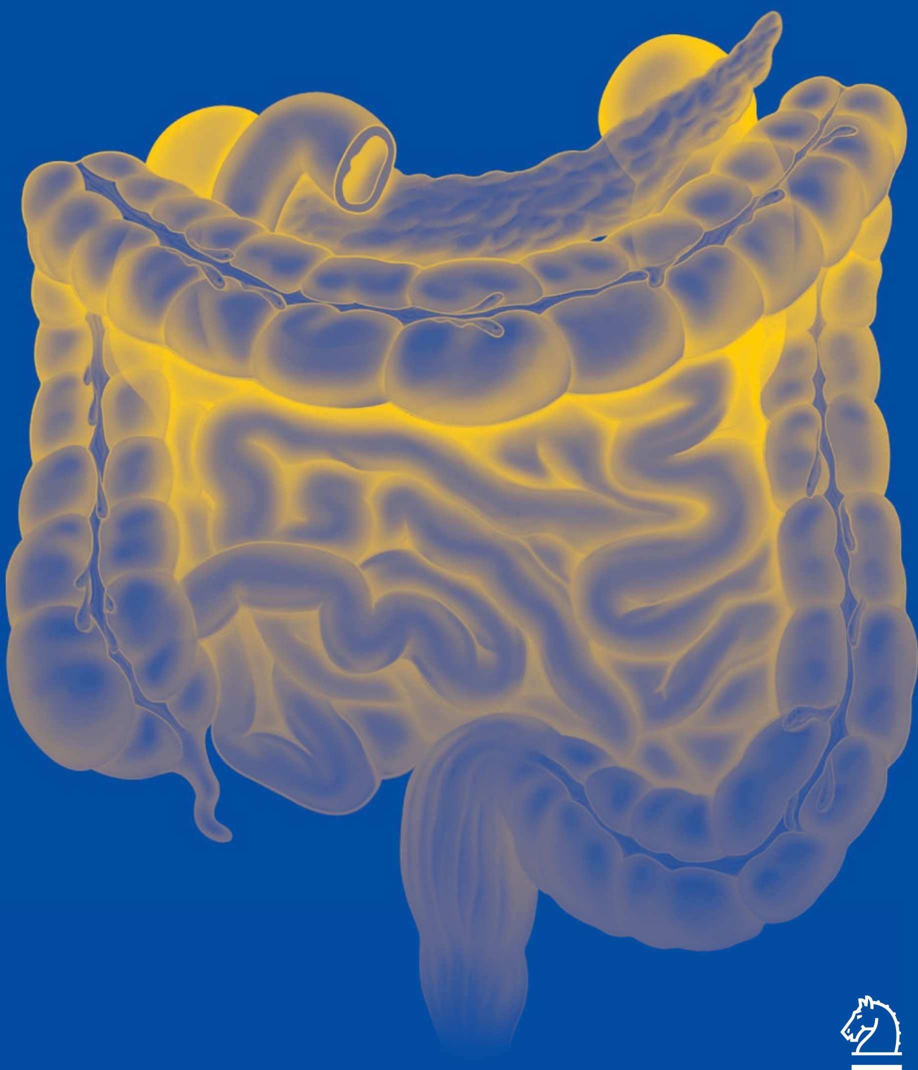
Lower Gastrointestinal Tract Surgery: Vol.1, Laparoscopic procedures



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This Atlas is dedicated to my wife, Carol, whose love, understanding, patience and support are boundless, to all my children and grandchildren of whom I have seen too little over the years, to all my colleagues and students who taught me more than they will ever know, to all those who became and remain friends whose loyalty and friendship I have cherished and to Professor Hans Troidl who first taught me the art of laparoscopic surgery in Cologne 30 years ago.

Michael Parker

Foreword

It is a great pleasure for me to write the foreword for this new book which is the first of the two volumes on lower gastrointestinal tract surgery. This first volume concerns laparoscopic surgical techniques, and the second will comprise open operations. The Atlas has been coedited by two senior colorectal surgeons, namely, Professor Mike Parker and Professor Werner Hohenberger. Both of these surgeons have spent a lifetime seeking to perfect the concept of surgery in the correct anatomical plane so as to produce perfect resectional surgery and virtually bloodless operations. Both volumes of the Atlas have been written with the intention of providing surgeons around the world with a road map of open and laparoscopic techniques for the vast majority of colorectal operations performed currently.

When I was a junior—nearly 40 years ago—there was very little focus on surgical anatomy, and usually a more senior junior rather than a consultant taught the youngest trainee in the majority of procedures.

At that time, a right hemicolectomy for a cancer was believed just to be an extended appendicectomy, and within colorectal surgery, only rectal cancer was taught by the consultants, who performed their magical movements blindly in the pelvic cavity.

Bill Heald was the first surgeon who was able to precisely teach open rectal cancer surgery at an international level based on embryological principles of the development of the rectum. His concept of total mesorectal excision has provided the platform for all modern surgery for rectal cancer, and similar principles have recently been described and popularised by Werner Hohenberger as complete mesocolic excision for colon cancer.

During the same period, there have been tremendous technical achievements including the use of electric knives and staplers, but a new area has come with the introduction of minimally invasive surgery (laparoscopic or robotic surgery).

Mike Parker has been a pioneer in the development of laparoscopic colorectal surgery. He is not only a very skilled surgeon, but in my opinion, he is second to none in teaching laparoscopic surgery to both young and experienced surgeons. It is due to him that we in Denmark have had a fast and safe transformation from open to laparoscopic colorectal surgery.

However, to make laparoscopic surgery safe and oncologically effective, it is imperative that the surgeon has detailed knowledge of surgical anatomy and the most common anatomical variations. This first volume of the Atlas has been compiled by multiple, internationally renowned authors, all of whom have a reputation for teaching operative surgery. They have all written individual chapters supplemented by high-quality operative photographs to illustrate the correct anatomical planes in which to operate. These photographs have been complemented with high-quality artistic illustrations to demonstrate the anatomy clearly. This approach will allow the reader to interpret the photographs more easily and hence understand the steps of the operations.

I am certain that this book has the potential to improve the quality and outcome of colorectal surgery to the benefits of all our patients.

Clinical Professor of Surgery
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Søren Laurberg

Preface

The art of surgery is based upon a consummate knowledge of anatomy, meticulous technique and a thorough understanding of the pathology requiring surgery. Inherent in the knowledge of anatomy is the cognisance of embryology which defines the tissue planes so important in optimal surgery. It is the recognition of the tissue planes which allows the expert surgeon to operate with minimal blood loss and completeness of resection margins when dealing with tumours, both benign and malignant.

Both editors have spent a lifetime perfecting the techniques of both open and laparoscopic abdominal and pelvic surgery and have combined forces in order to produce a *Lower Gastrointestinal Surgery* atlas in two volumes. The first volume is concerned with laparoscopic and the second with open surgery. Both volumes contain chapters written by recognised world-class authorities in lower gastrointestinal surgery with specific interest in the subject matter of the particular subject designated to their authorship. Each chapter is illustrated with operative photographs accompanied where appropriate with artistic illustrations to clarify the anatomy and orientation which can be especially difficult to comprehend in the laparoscopic approach. To our knowledge, this is the first time that an atlas of colorectal surgery has been illustrated primarily with operative photographs. Previously, all published colorectal atlases have been illustrated with line drawings only.

The editors both feel that this will provide the reader with a clear understanding of what to expect in all aspects of both styles of surgery. After all, it is of little value to understand a line drawing of an operation if when faced by the real thing the anatomy becomes unintelligible. Each author has been tasked to provide a text, easily understandable to a colleague whether senior or junior, complemented by photographs of the operation described. By reading each chapter, the reader should then be in a position to understand the steps necessary to complete individual operations.

We sincerely hope that this Atlas will provide the next generation of surgeons with an easily comprehensible road map such that safe colorectal surgery, both open and laparoscopic, will be easy to learn and to perform throughout the careers of those aspiring professionals.

Dartford, UK — Michael Parker
Erlangen, Germany — Werner Hohenberger

Acknowledgements

The editors would like to acknowledge the enthusiasm and support of John Lumley without whose encouragement this Atlas would not have materialised. We would also like to acknowledge the relentless support of Lee Klein of Springer who has provided immense help in the editing process with the design and multiple redesigns of the artistic material to such a high standard. We would also like to thank the multiple authors whose patience has been supreme in waiting for the final excellent versions of their chapters to mature into those contained in this Atlas. Finally we would like to thank Professor Søren Laurberg for his support and experience in writing the foreword to this Atlas.

Michael Parker
Werner Hohenberger

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The Anatomy of the Small Intestine

1

Susan Standring

The small intestine extends from the distal end of the pyloric canal to the ileocaecal junction and consists of the duodenum, jejunum, and ileum (Fig. 1.1) [1]. The jejunum and ileum (collectively often termed the *small bowel*) are attached to the posterior abdominal wall by a mesentery and their loops are mobile. The mesentery of the small intestine begins at the duodenojejunal flexure to the left of the lower border of the first lumbar vertebra and passes obliquely downwards to the right sacroiliac joint. It contains the superior mesenteric vessels, the lymph nodes draining the small bowel and autonomic nerve fibres. Its surface projection is an oblique line from a point just to the left of the lower border of the first lumbar vertebra (in the transpyloric plane) towards the right iliac fossa. (*See* Mirjalili et al. [2] for a full discussion of evidence-based surface anatomy of the abdomen.)

Intraoperatively, the adult small bowel has a mean length from the ligament of Treitz to the ileocaecal valve of 5 m (range 3–8.5 m) [3]. The longer mean lengths cited in earlier post mortem studies reflect the absence of muscular tone in the longitudinal muscle of the post mortem bowel. The duodenum lies in the upper part of the abdominal cavity, entirely above the umbilicus and the jejunum tends to lie in the umbilical region; in the supine position, the ileum lies mainly in the hypogastrium and right iliac fossa, dipping into the pelvis anterior to the rectum in the erect position.

An isolated loop of small intestine can be identified with absolute certainty only by following it in one direction to the duodenal junction, or in the other direction to the ileocaecal junction [4]. There is no sharp boundary between the jejunum and ileum. On inspection, changes can be seen and felt as the bowel is traced distally. The jejunum is wider than the ileum and has a thicker wall because the plicae circulares (valvulae conniventes; Kerckring folds) are large and thick: they decrease in size distally in the ileum and disappear in the distal ileal bowel loops. The jejunum is supplied by simple arterial arcades that typically contain one to three tiers, whereas the ileum is supplied by more complex arterial arcades that often contain two to six arcades (Fig. 1.2). The mesentery becomes progressively more fat laden distally and abuts somewhat more of the circumference of the ileal wall than it does of the jejunal wall.

The arterial blood supply of the duodenum as far as the entry of the bile duct is derived from the coeliac trunk (reflecting its foregut origin); the remainder of the duodenum and all of the small bowel are supplied by branches of the superior mesenteric artery (reflecting their mid-gut origin). The venous drainage is via tributaries of the portal vein accompanying the arterial branches. Solitary lymphoid follicles are scattered throughout the small intestinal mucosa but are most numerous in the distal ileum; lymph drains via numerous small nodes that lie near or on the bowel wall to larger nodes along the mesentery and then to coeliac and superior mesenteric nodes, from which efferent vessels drain to the cisterna chyli. The pattern of lymphatic drainage corresponds reasonably accurately with that of the blood supply of each segment of gut wall.

Innervation is both intrinsic (enteric nervous system, ENS) and extrinsic (parasympathetic, sympathetic and visceral sensory systems). The reflex circuitry of the ENS in the small and large intestines controls numerous functions, including muscle activity, transmucosal fluid fluxes and local blood flow (Fig. 1.3). (For details of the ENS, *see* Furness et al. [5].) Parasympathetic drive is via branches of the vagus nerve, which synapse with postganglionic enteric neurones in the myenteric (Auerbach's) and submucosal (Meissner's) plexuses in the wall of the gut. Sympathetic drive is via the thoracic splanchnic nerves (preganglionic neurones in spinal cord segments T5–T10, although this is variable), which synapse with postganglionic neurones in the coeliac and superior mesenteric ganglia. Some neurones in sympathetic prevertebral ganglia receive both CNS and ENS inputs. In general,

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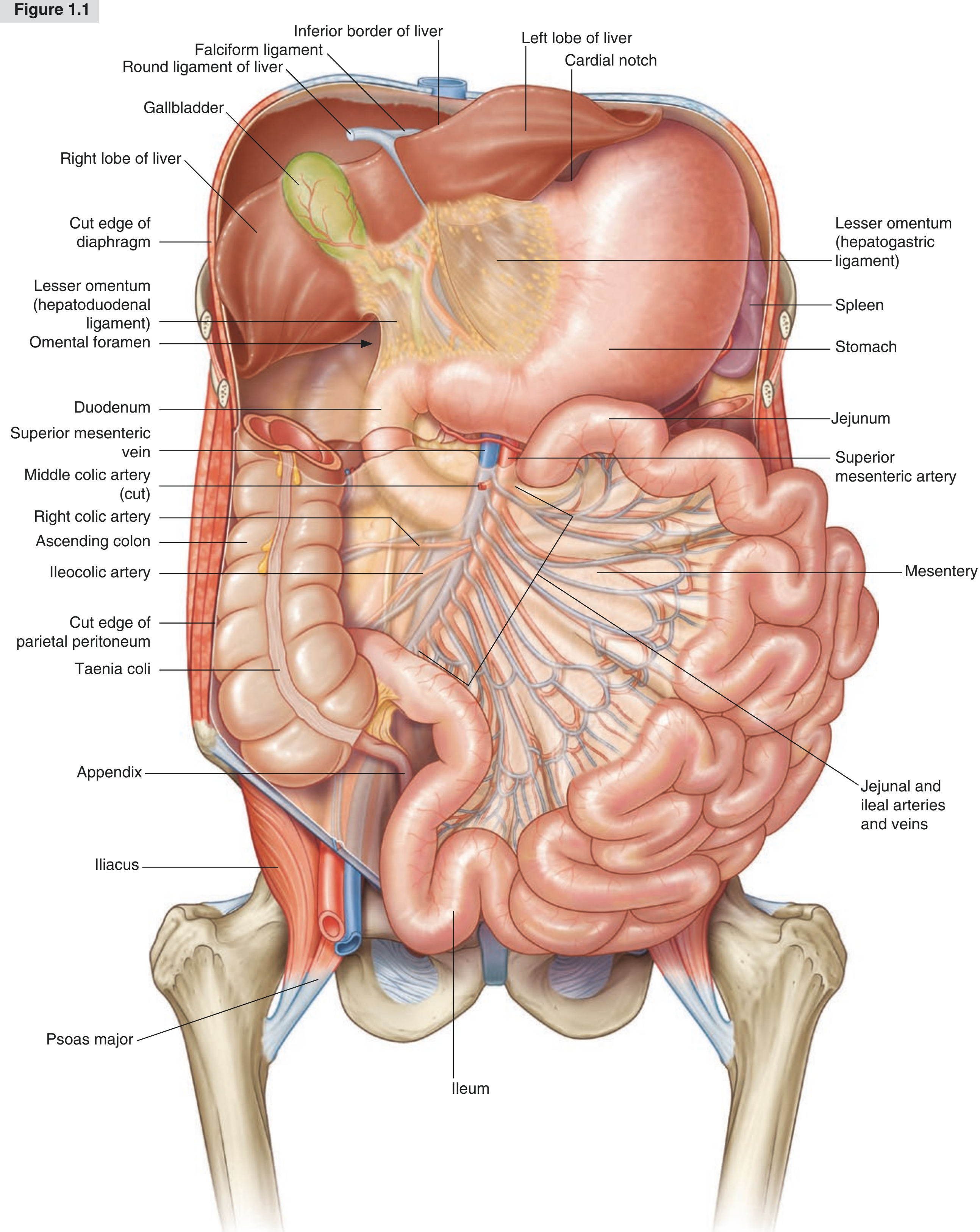
Figure 1.1

Overview diagram of the small intestine, in which the small intestine has been displaced in order to display the superior mesenteric vessels. (Reproduced with *permission from* Drake RL, Vogl AW, Mitchell AWM, Tibbitts RM, Richardson PE, editors. Gray's atlas of anatomy. 2nd ed. Philadelphia: Elsevier; 2014)

Figure 1.1



Inferior border of liver
Falciform ligament
Round ligament of liver
Gallbladder
Right lobe of liver
Cut edge of diaphragm
Lesser omentum (hepatoduodenal ligament)
Omental foramen
Duodenum
Superior mesenteric vein
Middle colic artery (cut)
Right colic artery
Ascending colon
Ileocolic artery
Cut edge of parietal peritoneum
Taenia coli
Appendix
Iliacus
Psoas major
Ileum
Left lobe of liver
Cardial notch
Lesser omentum (hepatogastric ligament)
Spleen
Stomach
Jejunum
Superior mesenteric artery
Mesentery
Jejunal and ileal arteries and veins

Figure 1.2

Cadaveric specimens of jejunum (**a**) and ileum (**b**) in which the superior mesenteric artery was injected with red-coloured gelatin before embalming. The specimens were then dehydrated, cleared in benzene, and immersed in methyl salicylate. The largest vessels present are the jejunal and ileal branches of the superior mesenteric artery. These are succeeded by anastomotic arterial arcades, which are relatively few in number (1–3) in the jejunum, and become more numerous (2–6) in the ileum. Straight arteries (arteriae recta) pass towards the gut wall from the arcades; successive straight arteries are frequently distributed to opposite sides of the gut. (Reproduced with *permission from Gabe* [1])

Figure 1.3

Schematic diagram showing the organisation of the enteric nervous system in the small intestine. SMP—submucosal plexus. (*Redrawn in* Gabe [1], *with permission from* Furness JB. The enteric nervous system and neurogastroenterology. Nat Rev. Gastroenterol Hepatol. 2012;9:286–94. *Reprinted with permission from* Nature Publishing Group)

Figure 1.2

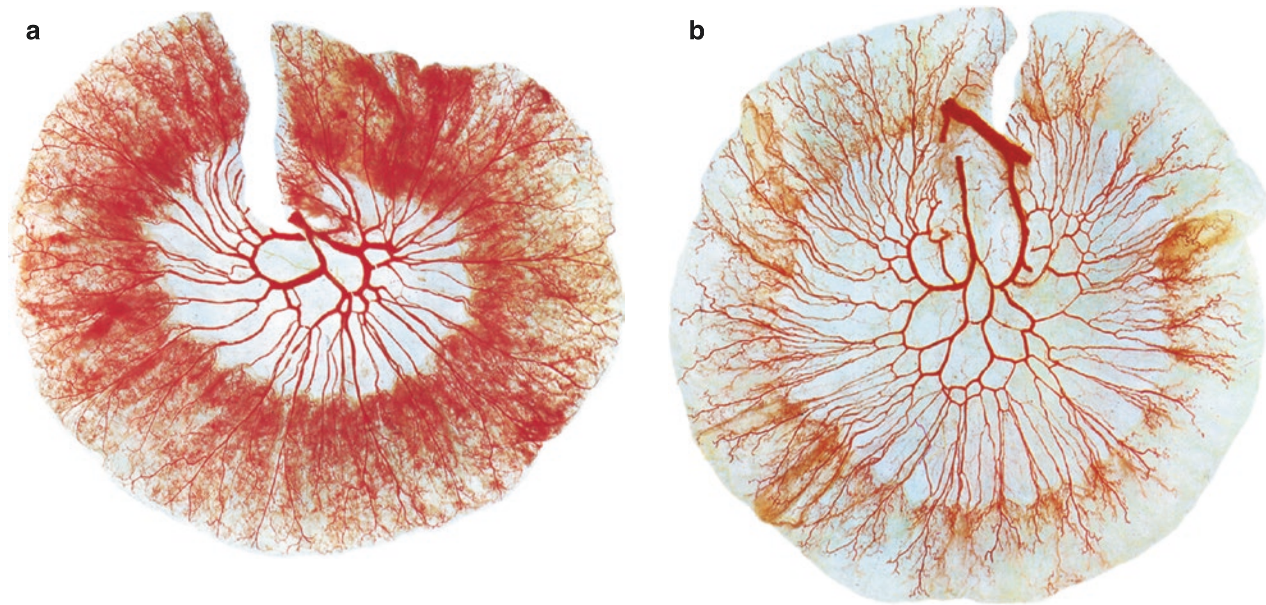
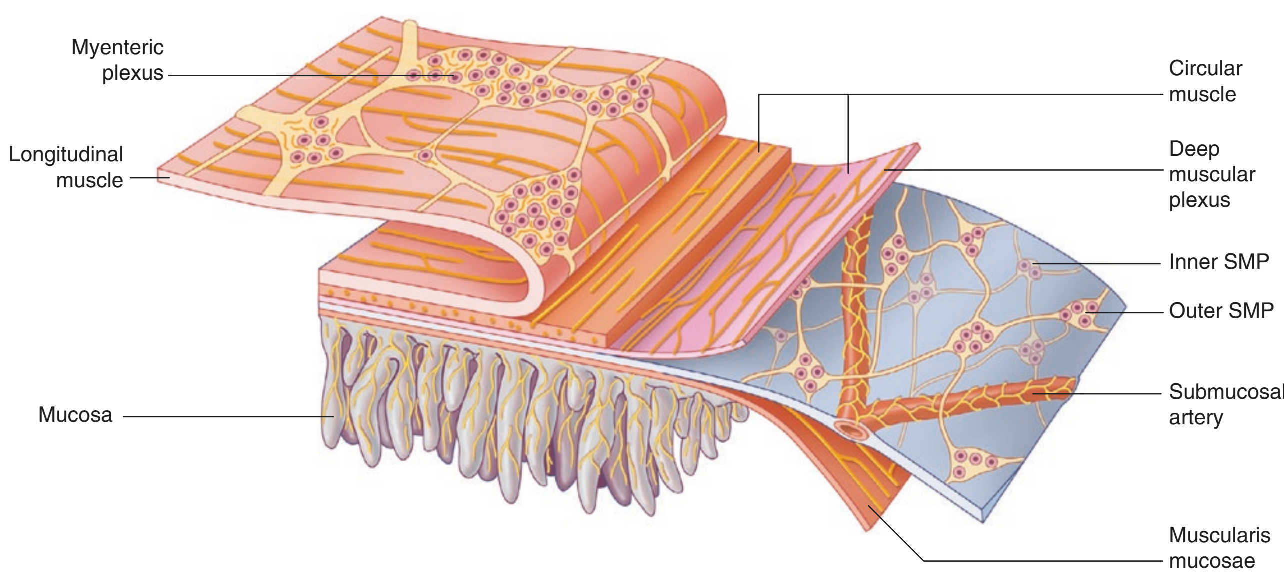


Figure 1.3



sympathetic drive inhibits visceral smooth muscle motility and glandular secretions and induces sphincter contraction and vasoconstriction.

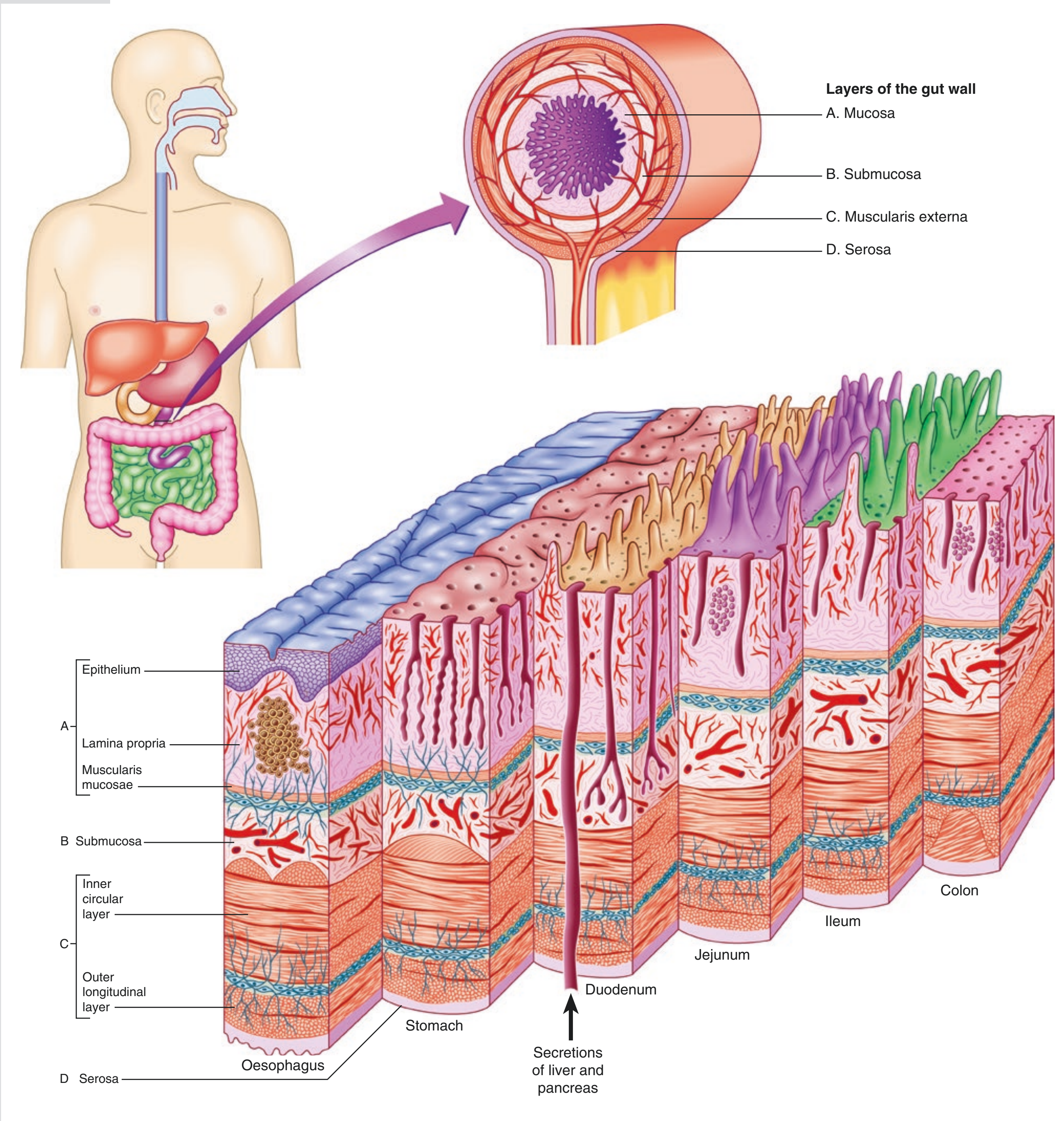
From the lumen outwards, the wall of the small intestine is composed of four main layers: mucosa, submucosa, muscularis externa and serosa (Fig. 1.4). The mucosa (mucous membrane) consists of a lining epithelium, an underlying lamina propria (reticular connective tissue containing elastin, reticulin and collagen fibres, lymphocytes, plasma cells, eosinophilic granulocytes, lymphatic vessels and capillaries)

Figure 1.4

Schematic diagram showing the layers of the gut wall at the levels indicated. (Reproduced with *permission from* Standring S, editor. Gray's anatomy: the anatomical basis of clinical practice. 41st ed. Philadelphia: Elsevier; 2016) and the muscularis mucosae (thin layer of smooth muscle). The submucosa is a highly vascularised layer of connective tissue that extends into the plicae circulares (but not the villi). The muscularis externa consists of inner circular and outer longitudinal layers of smooth muscle. Aggregates of lymphoid follicles are scattered throughout the small intestine: they are found in highest concentration within the ileum (Peyer's patches).

For a description of the development of the small intestine, *see* Collins [6].

Figure 1.4



1.1 Duodenum

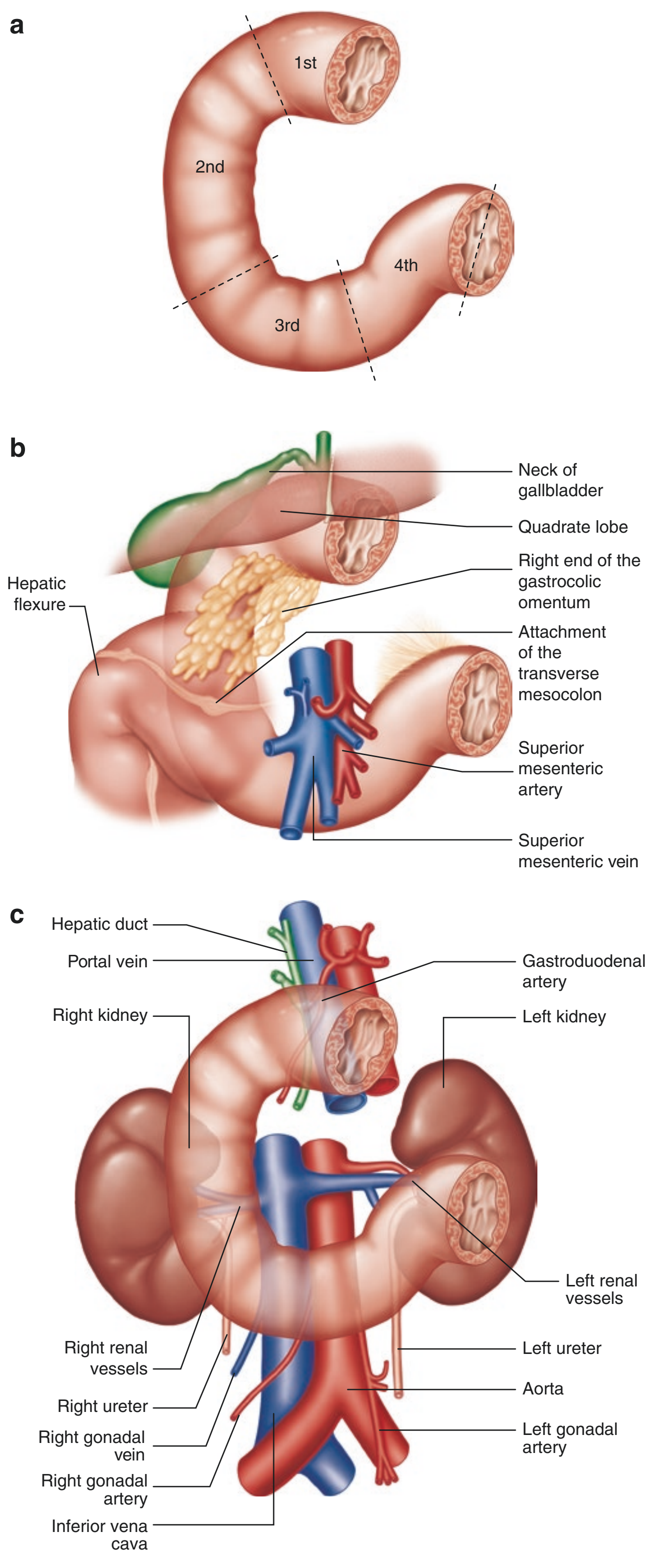
The duodenum was first named by the Greek physician Herophilus (c. 353–280 B.C.E.); the modern word reflects a medieval translation of *dodekadaktylon*, literally ‘twelve fingers long’. The adult duodenum is approximately 25 cm long and lies at the level of L1–L3, predominantly on the righthand side of the vertebral column. It extends from the stomach to the duodenojejunal flexure and is the shortest and widest part of the small intestine. The proximal 2.5 cm

Figure 1.5

(**a**) The four parts of the duodenum. (**b**) Anterior relations. (**c**) Posterior relations. (Reproduced with *permission from* Gabe et al. [1])

is intraperitoneal, and the remainder is retroperitoneal. Curved around the head and uncinate process of the pancreas like an elongated letter 'C', the duodenum has four named parts (D1–D4): superior, descending, horizontal (transverse or inferior), and ascending (Fig. 1.5). In paediatric surgery, the duodenojejunal flexure is an important surgical landmark in establishing whether normal intestinal rotation has occurred [7].

Figure 1.5



The first (superior) part of the duodenum is approximately 5 cm long. Its proximal half is mobile and intraperitoneal, whereas its distal half is fixed and covered by peritoneum on its superior and anterior surfaces, forming the inferior boundary of the epiploic foramen. The lesser omentum is attached to its upper border, and the greater omentum is attached to its lower border. It ascends from the duodenal bulb posteriorly and laterally and then makes a sharp curve inferiorly at the superior duodenal flexure. The duodenal 'cap' is the most proximal segment of the first part and readily distends on insufflation during endoscopy (Fig. 1.6). The first part of the duodenum is related to the gallbladder and liver anteriorly; the common bile duct, portal vein and gastroduodenal artery posteriorly; the epiploic foramen superiorly; and the pancreatic head inferiorly. A penetrating peptic ulcer on the posterior wall may erode into the gastroduodenal artery or one its branches, producing a haemorrhage, whereas a similar ulcer on its anterior wall may perforate into the peritoneal cavity. The common hepatic and hepatoduodenal lymph nodes lie close to the first part of the duodenum and may be visualised using endoscopic ultrasound. The junction between the first and second parts of the duodenum is posterior to the neck of the gallbladder.

The second (descending) part of the duodenum is approximately 8 cm long. It begins at the superior duodenal flexure and passes downwards, typically reaching a point level with the lower border of the body of the third lumbar vertebra, before making a sharp turn medially into the inferior duodenal flexure. Its upper anterior surface is covered with peritoneum. It lies posterior to the gallbladder and the right lobe of the liver superiorly and is crossed anteriorly by the right end of the gastrocolic omentum and by the transverse colon and mesocolon, which are both attached to its anterior surface by loose connective tissue. The mesentery of the upper part of the ascending colon and the hepatic flexure are also loosely attached to its anterior surface below the attachment of the transverse mesocolon. This part of the duodenum may be injured during mobilisation of the ascending colon and hepatic flexure. It is anterior to the hilum of the right kidney, right renal vessels, right ureter, lateral edge of the inferior vena cava, and right psoas major. Loops of jejunum lie inferiorly. Laterally, it is related to the ascending colon, hepatic flexure, and right kidney, and medially, to the head of the pancreas and the common bile duct. The latter unites with the pancreatic duct to form a common pancreaticobiliary

Figure 1.6

Contrast radiographic appearance of the duodenum shows a distended duodenal cap. (Reproduced with *permission from* Gabe et al. [1])

tract or channel, often containing a dilated segment, the hepatopancreatic ampulla (of Vater), which opens on the summit of the major duodenal papilla on the posteromedial wall of the second part of the duodenum, 8–10 cm distal to the pylorus [8]. (This point marks the approximate junction between the caudal part of the foregut and the cranial part of the midgut.) When present, an accessory pancreatic duct (of Santorini) enters the gut lumen about 2 cm proximal to the major duodenal papilla. Adequate visualisation of the ampulla of Vater is important for the early detection of periampullary or pancreaticobiliary diseases and may be complicated by the anatomy of the second part of the duodenum, particularly the tangential angle or the presence of a periampullary diverticulum [9].

The third (horizontal, transverse, or inferior) part of the duodenum is approximately 10 cm long. It passes transversely and to the left from the inferior duodenal flexure, which lies approximately at the lower border of the third lumbar vertebra. The third part of the duodenum usually crosses the midline at the level of the third lumbar vertebra. In its path it lies anterior to the root of the mesentery of the small bowel, the right ureter, right psoas major, right gonadal vessels, inferior vena cava and abdominal aorta (typically at the origin of the inferior mesenteric artery), before becoming continuous with the fourth, ascending part. Anteroinferiorly, loops of jejunum lie in the right and left infracolic compartments. The mid portion of the third part of the duodenum lies in the angle between the superior mesenteric artery anteriorly and the abdominal aorta posteriorly.

The fourth (ascending) part of the duodenum is the shortest portion, approximately 2.5 cm long. It passes superiorly, to the left of the abdominal aorta, until it reaches the inferior border of the body of the pancreas at approximately the level of the upper border of the body of the second lumbar vertebra and then curves anteriorly to become continuous with the jejunum at the duodenojejunal flexure. The latter is usually suspended from the retroperitoneum by a double fold of peritoneum, the suspensory ligament of the duodenum (ligament of Treitz). The upper part of this ligament, running from the right crus of the diaphragm at the oesophageal hiatus to connective tissue around the coeliac trunk, may contain striated muscle (Hilfsmuskel); the subsequent part, running from this connective tissue to the duodenum, and passing behind the pancreas anterior to the left renal vein, may contain smooth muscle. The

Figure 1.6

ligament exhibits considerable anatomical variation and may be absent [10]. Abdominal CT scans taken in the supine position at end tidal inspiration have shown that the duodenojejunal flexure commonly sits at L1 (range, lower T11 to upper L3) and is significantly more caudal in women [2]. The abdominal aorta, left sympathetic trunk, left psoas major, left renal and left gonadal vessels are posterior relations of the fourth part of the duodenum; the left kidney and left ureter are posterolateral, and the transverse colon and mesocolon are anterior, separating it from the stomach. The peritoneum of the root of the mesentery of the small bowel descends over its anterior surface.

Pathological processes involving the pancreatic head, duodenum, distal pancreaticobiliary tract, duodenal papilla or retroperitoneum converge around the pancreaticoduodenal groove [11]. This is a potential space bordered anteriorly by the first part of the duodenum and occasionally by the gastric antrum; bordered posteriorly by the third part of the duodenum or the bile duct (either in or adjacent to the posterior aspect of the pancreatic head); laterally, by the serosal surface of the second part of the duodenum; and medially, by the pancreatic head. Small lymph nodes in the groove are usually not seen on imaging. The superior pancreaticoduodenal artery anastomoses with the inferior pancreaticoduodenal artery in the pancreaticoduodenal groove.

1.1.1 Vascular Supply, Lymphatic Drainage and Innervation of the Duodenum

1.1.1.1 Arteries

An extensive literature attests to the variability of the blood supply of the duodenum, particularly of the first

Figure 1.7

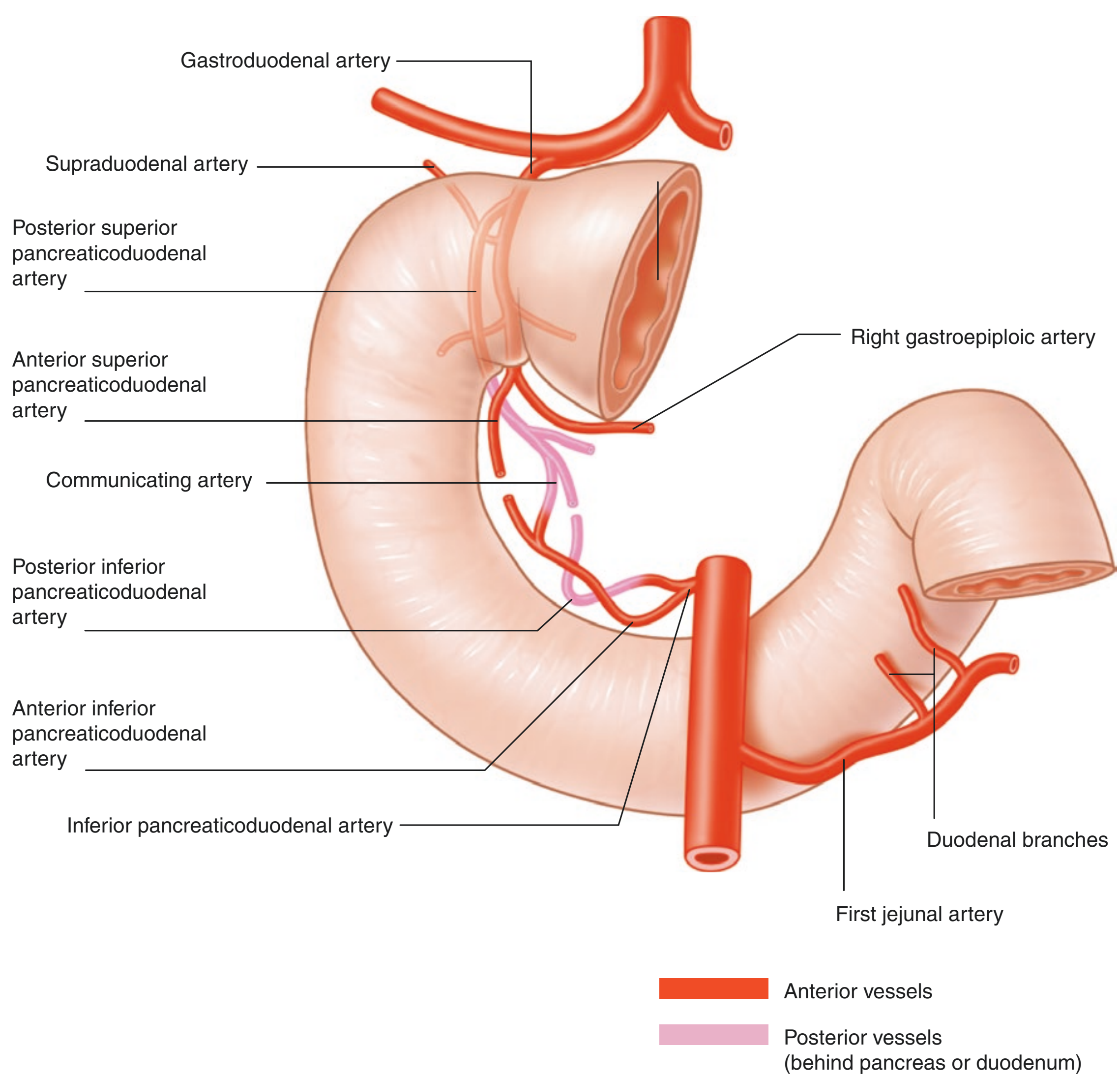
The arterial supply of the duodenum. (Only representative branches of the small vessels are shown.) (Reproduced with *permission from* Gabe et al. [1])

part [8]. The main supply is derived from the superior and inferior pancreaticoduodenal arteries, which are branches of the gastroduodenal artery. The latter usually arises from the common hepatic artery, posterior or superior to the first part of the duodenum, but may arise as either a trifurcation with the right and left hepatic arteries, or from the coeliac trunk, the superior mesenteric artery (SMA) or branches of the hepatic artery. The gastroduodenal artery descends posterior to the retroperitoneal portion of the first part of the duodenum, lying to the left of the common bile duct and gives off the posterior superior pancreaticoduodenal artery, retroduodenal arteries and a supraduodenal artery [12]. Emerging below the first part of the duodenum, the gastroduodenal artery usually gives off the right gastroepiploic artery and several pyloric branches [13]. It then descends further on the anterior surface of the pancreas, where it divides into the anterior superior pancreaticoduodenal artery and pancreatic branches (Fig. 1.7). The second, third and fourth parts of the duodenum are supplied by an arterial arcade that receives contributions from the anterior and posterior superior pancreaticoduodenal arteries (from the gastroduodenal artery) and from the anterior and posterior inferior pancreaticoduodenal arteries (from the SMA or its first jejunal branch). A communicating artery between the anterior and posterior pancreaticoduodenal arterial arcades may be important in the blood supply of the papilla of Vater [14].

1.1.1.2 Veins

The venous anatomy of the duodenum is not well characterised. The first part of the duodenum and the pylorus

Figure 1.7



are drained by subpyloric veins, which typically open into the right gastroepiploic vein and by suprapyloric veins, which open into either the portal vein or the posterior superior pancreaticoduodenal vein. Anastomoses between suprapyloric and subpyloric veins pass around the first part of the duodenum. The venous arcades draining the rest of the duodenum follow the arterial arcades, lying superficial to them. The inferior pancreaticoduodenal vein runs inferiorly and drains into either the superior mesenteric vein or its first jejunal tributary. Numerous small anastomoses occur between veins draining the second and third parts of the duodenum and retroperitoneal veins [15].

1.1.1.3 Lymphatic Drainage

Lymph drains from plexuses within the wall of the duodenum to superior and inferior pancreaticoduodenal lymph nodes in the pancreaticoduodenal groove and thence to suprapyloric, infrapyloric, hepatoduodenal, common hepatic, coeliac and superior mesenteric nodes.

1.1.1.4 Innervation

The duodenum is innervated by both parasympathetic and sympathetic neurones.

The cell bodies of preganglionic parasympathetic neurones are in the dorsal motor nucleus of the vagus nerve. Their axons are carried via the vagus through the coeliac plexus to synapse on postganglionic neurones in the duodenal wall. The parasympathetic supply is secretomotor to the duodenal mucosa and motor to the smooth muscle of the duodenum.

The cell bodies of preganglionic sympathetic neurones usually lie in the intermediolateral columns of the grey matter in the fifth to the 12th thoracic spinal segments. Their axons travel via the greater and lesser thoracic splanchnic nerves to the coeliac plexus and synapse in the coeliac and superior mesenteric ganglia. The greater splanchnic nerve is invariably present and is most frequently derived from T5–T9, although it may arise from T4. After passing through the diaphragm, it bends anteriorly at nearly 90° to enter the posterolateral edge of the coeliac ganglion [16]. Axons of postganglionic neurones are distributed to the duodenal wall via periarterial plexuses on the branches of the coeliac trunk and SMA; they are vasoconstrictor to the duodenal vasculature and inhibitory to the smooth muscle of the duodenum. Clinically, the thoracic splanchnic nerves and coeliac ganglia play a major role in pain management for upper abdominal disorders, particularly chronic pancreatitis and pancreatic cancer. It is therefore wise to remember that the thoracic splanchnic nerves have anatomical variation as diverse as any structure in the body [17].

1.2 Jejunum

The jejunum has an external diameter of approximately 4 cm and an internal diameter of approximately 3 cm. Its wall is thicker than that of the ileum, particularly proximally, where the plicae circulares are more numerous and deeper than elsewhere in the small bowel. Their arrangement produces a characteristic appearance during single-contrast radiography or CT or MR enterography (Fig. 1.8).

1.3 Ileum

The ileum has a median external diameter of approximately 3 cm and an internal diameter of approximately 2.5 cm. Its wall tends to be thinner than that of the jejunum and the plicae circulares become progressively less obvious in the distal ileum. The mucosa of the terminal ileum immediately proximal to the ileocaecal junction may appear almost flat at endoscopy. The terminal ileum frequently lies in the pelvis, from where it ascends over the right psoas major and right iliac vessels, to end by opening at the ileocaecal junction in the right iliac fossa.

1.4 Vascular Supply, Lymphatic Drainage and Innervation of the Small Bowel

1.4.1 Arterial Supply

The jejunum and ileum are supplied by branches from the superior mesenteric artery (Fig. 1.9). This artery forms the central axis around which the intestines rotate during embryogenesis. It arises at an acute angle from the abdominal aorta approximately 1 cm below the coeliac trunk, usually at the level of the lower border of the first lumbar vertebra in the transpyloric plane [18]. Compression of a normally situated left renal vein by the aorta and the superior mesenteric artery (SMA) may produce anterior nutcracker syndrome [19]. The SMA emerges from under the lower border of the pancreas, passes forward anteriorly over the upper border of the third part of the duodenum and descends anteriorly into the mesentery of the small intestine. It is therefore possible for the third part of the duodenum to be compressed between the angle of the aorta posteriorly and the SMA anteriorly [20, 21] (Fig. 1.10). Within the mesentery, the SMA crosses anterior to the inferior vena cava, right ureter and right psoas major; its calibre decreases progressively as successive branches are given off to the small bowel. Its major branches include the inferior pancreaticoduodenal, middle colic, right colic and ileocolic branches from its right side and four to six jejunal branches and 9–13 ileal branches from its left side, anterior aspect [22, 23]. A few centimetres from the border of the intestine, the jejunal and ileal branches form a series of arterial arcades within the mesentery. The final arcade forms an irregular and incomplete 'marginal artery' of the small intestine. Straight arteries (vasa recta) are given off from the most distal arcades and pass directly and without cross-communication through the gut wall, so the blood supply of the antimesenteric border is relatively poor. Branches of the vasa recta form a submucosal arterial plexus of small-calibre vessels that supply the mucosa. Occlusion or division of several consecutive vasa recta may produce segmental ischaemia of the bowel, whereas collateral flow through vascular arcades may prevent ischaemia after division of more proximal vessels in the mesentery. (For further reading about the origin and branching patterns of the SMA, *see* Horton and Fishman [24].) Small twigs from the jejunal arteries supply regional mesenteric lymph nodes. Ileal branches are shorter and thinner than their jejunal counterparts, particularly in the distal ileum, and do not form such distinct parallel 'leaves' of vessels. The terminal ileal arcades are supplied by the ileal branch of the ileocolic artery and the last ileal branch of the SMA. Few other vessels connect the territories of the ileocolic artery and SMA. The ileocolic artery is described in detail in Chap. 2.

1.4.2 Venous Drainage

The superior mesenteric vein joins the splenic vein behind the neck of the pancreas in the transpyloric plane (lower border of the first lumbar vertebra) to form the portal vein. It is formed in the mesentery of the small bowel by the union of tributaries that drain the small intestine, vermiform appendix, caecum, ascending and transverse parts of the colon, and parts of the stomach and greater omentum, via jejunal, ileal, ileocolic, right colic middle colic, right gastroepiploic and inferior pancreaticoduodenal veins. (For further details, *see* Kim et al. [25].) A single trunk may be replaced by large right and left mesenteric branches, both of which join the splenic vein to form the portal vein [26]. In the mesentery of the small intestine, the superior mesenteric vein usually lies to the right of and anterior to the SMA but this relationship is variable, especially in patients with malrotation or nonrotation of the gut. The superior mesenteric vein passes anterior to the right ureter, the inferior vena cava, the third part of the duodenum and the uncinate process of the pancreas. The confluence of the right superior colic vein and the right gastroepiploic vein (the gastrocolic trunk of Henle) may be joined by the anterior inferior pancreaticoduodenal vein before draining into the superior mesenteric vein at the inferior border of the neck of the pancreas [27]. Significant differences in the frequency of a true (i.e., 'bipod') gastrocolic trunk have been reported, but regardless of these differences, the outcomes of studies using different protocols (e.g., preoperative three-dimensional CT, dissection, corrosion casting) all reinforce the view that the variations in venous anatomy at the inferior border of the neck of the pancreas must be considered during surgical or radiological procedures involving the pancreas [28].

1.4.3 Lymphatic Drainage

The intestinal lymphatic system regulates tissue fluid homeostasis, promotes immune surveillance and transports dietary fat and fat-soluble vitamins from the gut lumen. From lumen to serosal surface, the intestinal wall contains three layers of lymphatics: lacteals in the villi and networks in the submucosa and in the smooth muscle layer. The submucosal and muscular networks share few if any connections, but both communicate freely with larger, valved collecting lymphatics at the mesenteric border of the small intestine. Mesenteric lymphatics pass between the layers of the mesentery, draining via lymph nodes concentrated around the regional mesenteric vessels into superior mesenteric nodes around the root of the SMA. (For further reading about the microanatomy of the intestinal lymphatic system, see Miller et al. [29].) Lymph nodes draining the small intestine and colon have been shown to be anatomically separate and immunologically distinct in transgenic mice, suggesting that immune responses in the small intestine and the colon are controlled independently [30].

1.4.4 Innervation

The jejunum and ileum are innervated by parasympathetic and sympathetic fibres via the superior mesenteric plexus. Preganglionic sympathetic axons originate from neurones in the intermediolateral grey matter of the mid-thoracic spinal segments and travel in the greater and lesser thoracic splanchnic nerves to the coeliac and superior mesenteric ganglia, where they synapse [17] (Fig. 1.11). Postganglionic axons accompany the superior mesenteric artery into the mesentery and are distributed along the branches of the artery: they are vasoconstrictor to the vasculature and inhibitory to the smooth muscle of the jejunum and ileum.

The cell bodies of preganglionic parasympathetic neurones are in the dorsal motor nucleus of the vagus. Their axons travel via the vagus nerve through the coeliac and superior mesenteric plexuses to synapse on postganglionic neurones in the wall of the small bowel. The parasympathetic supply is secretomotor to the mucosa and motor to the smooth muscle of the jejunum and ileum (Fig. 1.12).

Figure 1.8

Barium studies of the jejunum and ileum. (**a**) Barium follow-through. Note the feathery appearance of the small intestine caused by the plicae circulares. The constrictions (*arrows*) are produced by peristalsis. (**b**) Small bowel enema (enteroclysis), demonstrating plicae circulares. C—caecum; I—ileum; J—jejunum; PC—plicae circulares; TI—terminal part of ileum. (Reproduced with *permission from* Gabe et al. [1])

Figure 1.8

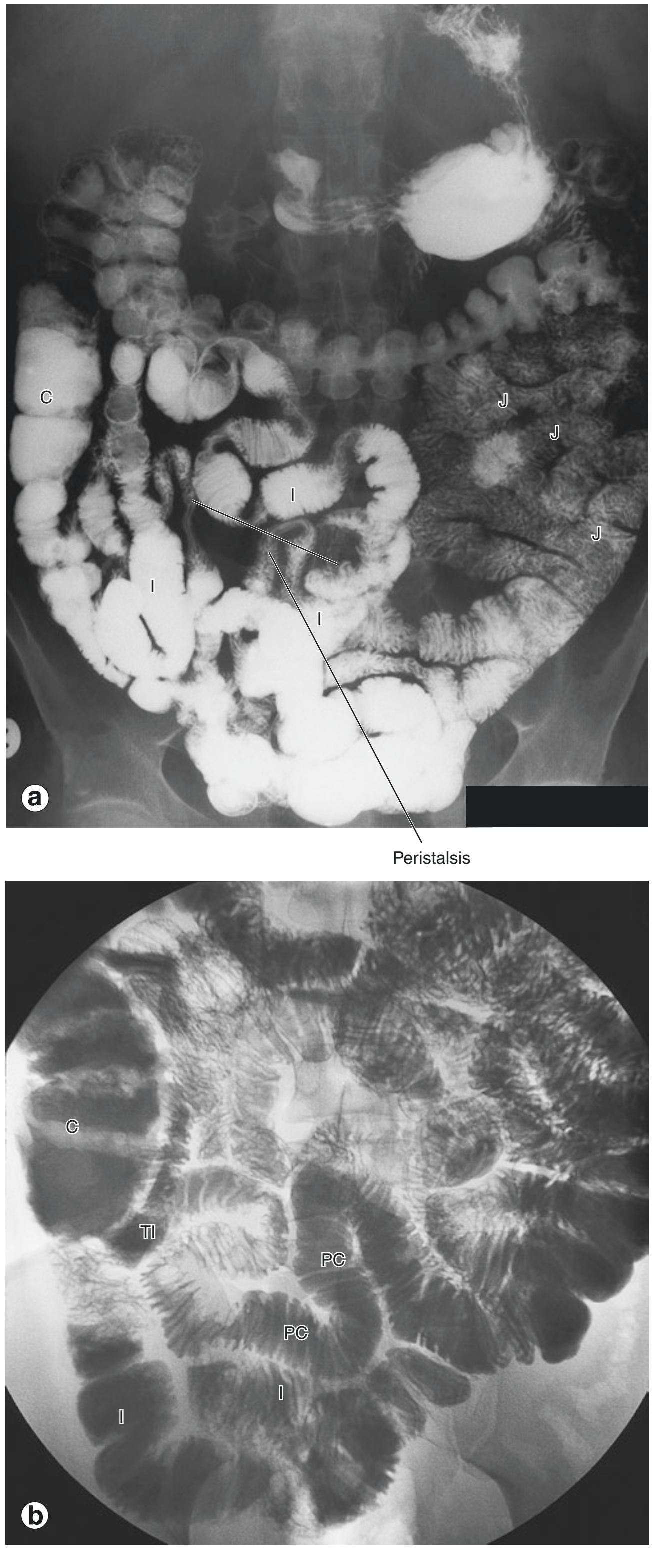


Figure 1.9

(**a**) CT enterography. This coronal slice shows superior mesenteric vessels and loops of small intestine. (**b**) MR enterography. This coronal slice shows small intestine and transverse colon. (Reproduced with *permission from* Gabe et al. [1])

Figure 1.9

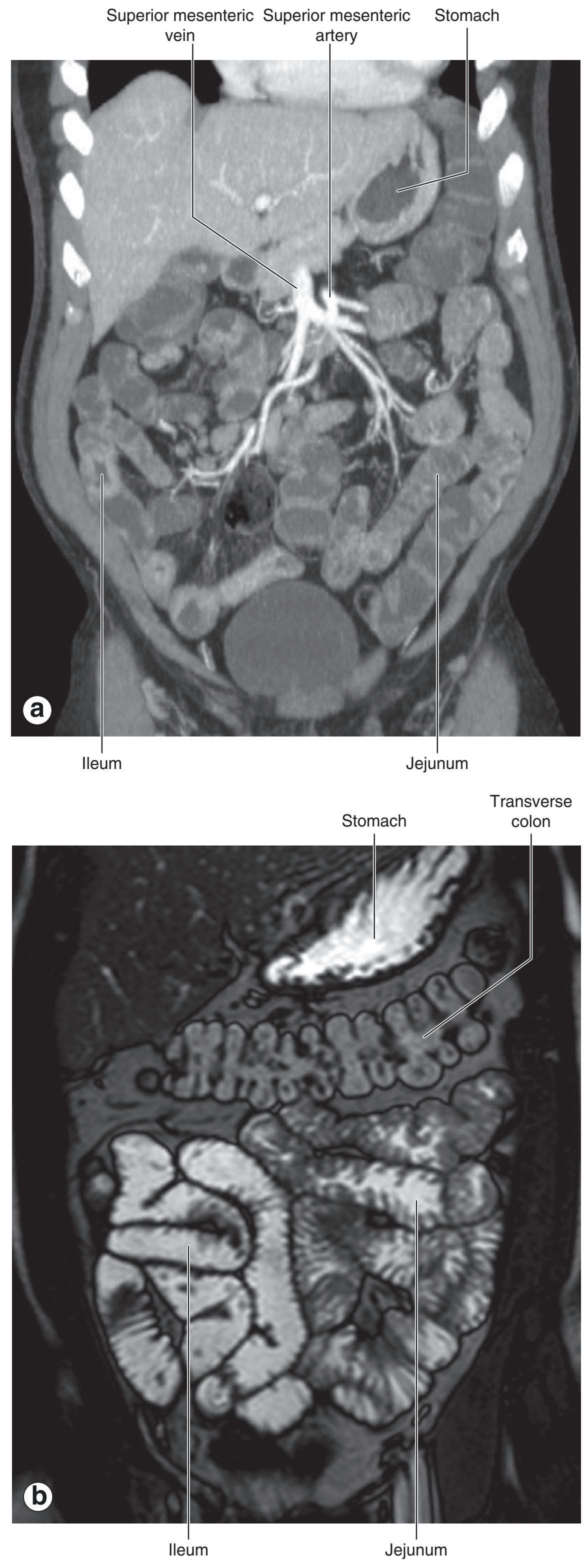

Superior mesenteric vein
Superior mesenteric artery
Stomach
a
Ileum
Jejunum
Stomach
Transverse colon
b
Ileum
Jejunum

Figure 1.10

Schematic diagram showing the origin of the superior mesenteric artery (SMA) from the aorta. Note the wide SMA-aortic angle and the patent lumen of the duodenum in normal patients (*left*) compared with the narrow SMA-aortic angle and the smashed duodenal lumen (*right*) in SMA syndrome. (Reprinted from Mathenge et al. [21] with permission of Wiley Publishing)

Figure 1.10

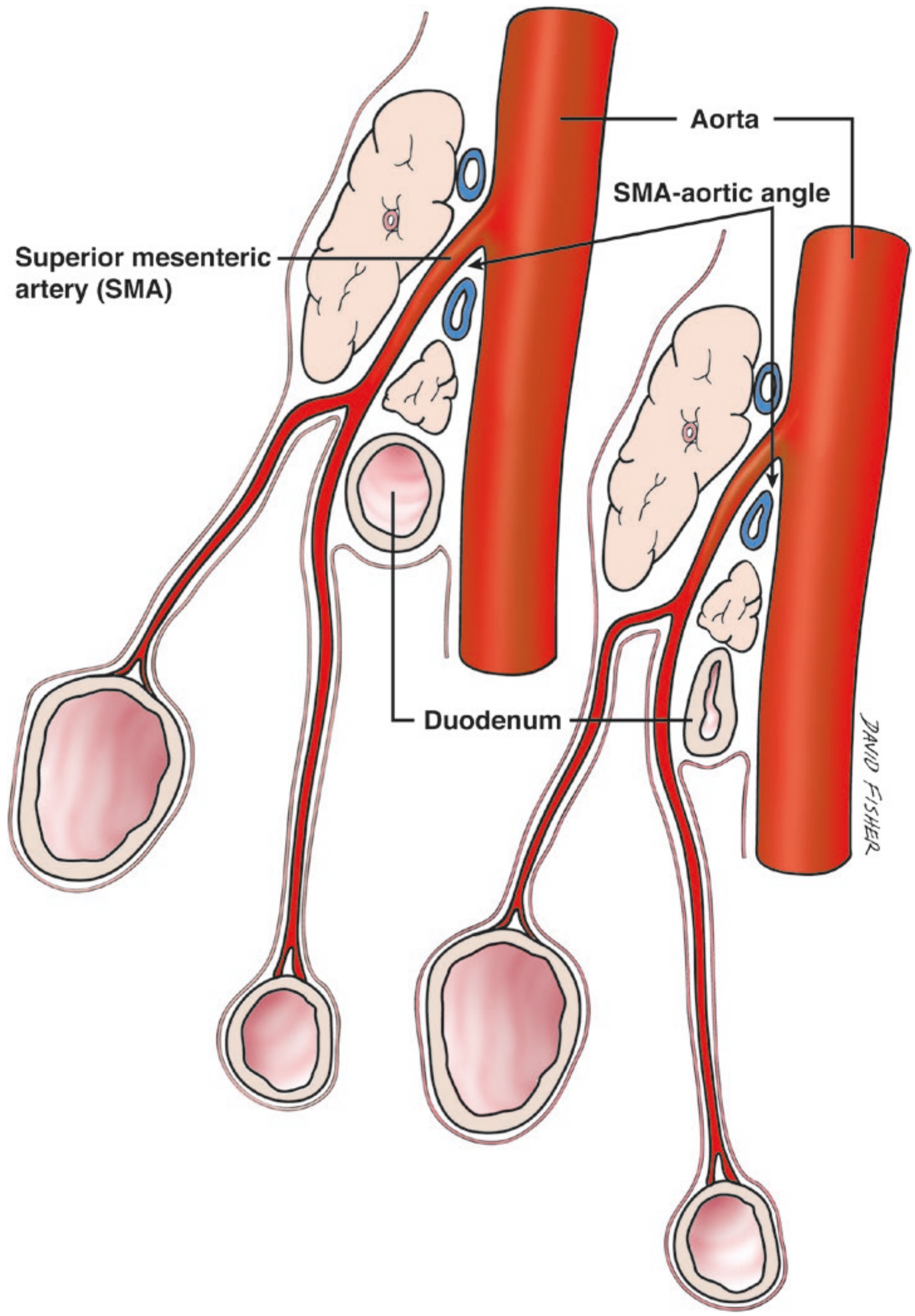

Aorta
SMA-aortic angle
Superior mesenteric
artery (SMA)
Duodenum
DAVID FISHER

Figure 1.11

(**a**) The right hemidiaphragm is visible with the greater splanchnic nerve (GSN) receiving contributions from T6, T7, and T8. (**b**) The left side of the posterior mediastinum is visible, with the GSN receiving contributions from T7 and T8. The diaphragm and liver have been removed. The lesser splanchnic nerve is shown also from T11 (broken) and T12. (Reproduced from Loukas et al. [17], with permission of Wiley Publishing)

Figure 1.11