CHAPTER 1

Anatomy of the Pancreas

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The pancreas, because of its location, has long been a relatively inaccessible organ. Its retroperitoneal position in the upper reaches of the abdominal cavity precludes palpation. Its history has been to remain silent until disease was announced by severe pain or until it caused marked, detectable changes in other viscera (10).

With recent perfection of a number of imaging techniques, the size, location, condition, and associations of the pancreas may be determined with some degree of accuracy. Its ductal system, with that of the related bile duct system, may be visualized by radiography of contrast medium injected by endoscopic retrograde choledoco-pancreatography. The normality of its extensive and complex vascular system may be assessed by angiography, the selectivity of which may be adjusted quite precisely to match the diagnostic point in question (8). Computerized tomography cross-sectional "slices" present clear representations of the relations of the pancreas to related viscera. Similar representations of associations may be derived from the pictures of ultrasonography, presenting the possibility of longitudinal and oblique "slices" through the abdomen, as well as transverse or cross-sectional ones. The size of the pancreas is detected as areas in single images produced by ultrasound or computerized tomography. This may be converted to a volume, either abstractly or diagrammatically, as multiple images are produced and integrated (15).

In order to understand the conclusions and implications of these imaging techniques, used singly or in combination, it is necessary to visualize the three-dimensional conformation of the pancreas as it is situated within the body, and the three-dimensional relationships of the pancreas to surrounding viscera. The relationships with major structures are necessary for location and visualization of the pancreas, in addition to providing information on the effects it may have on the surrounding structures. Size, shape, consistency, and homogeneity are all important to assess. A major purpose of this chapter is to present the pancreas, in relation to major structures, in such a way as to encourage the formation of a three-dimensional concept as a background for appreciating the information available from imaging techniques.

THE PANCREAS PROPER

The pancreas is a pinkish tan organ that appears distinctly lobulated to the unaided eye. The investing connective tissue provides the septation to produce these macroscopic lobules; each is composed of many microscopic lobules, which are the functional units of the exocrine pancreas. The wet organ weighs approximately 100 g in adult males, 85 g in adult females, and 5 g in the newborn. The adult gland is 14 to 18 cm long, 2 to 9 cm wide, and 2 to 3 cm thick. It is divided into four regions: head, neck, body, and tail. The greatest mass is concentrated in the head, which represents a composite structure derived in part from both dorsal and ventral embryonic pancreatic anlagen (see Lee and Lembenthal, this volume). The head remains to some extent divisible structurally and functionally according to these disparate progenitors (3). The neck is thinned front-to-back; the

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splanic and superior mesenteric veins unite posterior to the neck, forming the portal vein. The body continues the substance of the gland toward the left and blends without a distinct boundary into the tapering tail, which terminates bluntly adjacent to the spleen. The pancreas has a firm, rubbery consistency and a specific gravity of 1.04 to 1.05 (16). It is 71% water and 13% (wet weight) protein. Its fatty composition may be quite variable (3–20%). The substance of the gland is penetrated by numerous vascular structures, both those supplying the gland proper and those passing to other locations. The latter may form deep grooves in the surface.

The main channel of drainage of pancreatic exocrine secretions begins in the tail by a confluence of smaller ducts. The main pancreatic duct, thus formed, then runs closer to the posterior surface through the body and neck into the head, receiving in its course the secondary ducts, which join it in regular fashion almost at right angles, forming a so-called herringbone pattern. In the head the main duct inclines distinctly caudally and dorsally, sometimes following an arcuate path, to its exit in the duodenum. The main pancreatic duct comes to lie immediately to the left of the common bile duct in the head, where the common bile duct penetrates the pancreatic substance or lies in a groove on the posterior surface. The two ducts penetrate the duodenal wall obliquely in parallel with each other. They may unite in the duodenal wall to form the hepatopancreatic ampulla (of Vater). The main pancreatic duct (of Wirsung) and the bile duct empty into the duodenal lumen at the major duodenal papilla (of Vater), a prominence located 8 to 10 cm distal to the pylorus (Fig. 1). Additional drainage of the pancreas may be accomplished via the accessory pancreatic duct (of Santorini), which anastomoses with the main pancreatic duct and its branches in the head, penetrates the wall of the duodenum, and opens at the minor duodenal papilla, approximately 2 cm superior to the major duodenal papilla (Fig. 1). The accessory pancreatic duct is not always functional (17).

There is a commonly observed correlation between the presence of gallstones and the occurrence of acute pancreatitis. Opie (14) described a small gallstone impacted in the ampulla of Vater, in a patient who had died with acute pancreatitis, in a manner which maintained communication between the main pancreatic duct and the bile duct. On autopsy, bile was observed in the main pancreatic duct. Furthermore, he showed that injection of bile into the pancreatic duct of dogs produced hemorrhagic, necrotizing pancreatitis. His conclusion that gallstone impaction at the orifice of the ampulla of Vater provided the initial causative event that led to hemorrhagic pancreatitis generated a great deal of interest in the termination of these ducts. The common bile duct and the main pancreatic duct join into a common channel (the ampulla of Vater) approximately 80% of the time, and open into the duodenal lumen separately in 18%; a functional main pancreatic duct is missing in the remainder (9). The ducts become ensheathed in a com-

![FIG. 1. Frontal view of the pancreas to show its relationship with the duodenum and the relationship of pancreatic and bile ducts. The head of the pancreas is tucked into the curvature of the duodenum, overlapping somewhat both in front and behind. The main pancreatic duct (MPD) comes to lie to the left of the common bile duct (CBD) in the head, and they open into the duodenum at the major duodenal papilla (MAJ DP). The right hepatic duct (RHD) and left hepatic duct (LHD) unite after exiting from the liver to form the common hepatic duct (CHD), which in turn unites with the cystic duct (CD) to form the common bile duct, which is transmitted toward the pancreas and duodenum through the lesser omentum. An extension of the head, the uncinate process, is extended behind the emerging superior mesenteric vein and artery (SMV A). APD, Accessory pancreatic duct; MIN DP, minor duodenal papilla.](image-url)
common connective tissue coat and a complex intrinsic muscular coat. The smooth muscle coat surrounds the ducts individually and in common. Additional thickness of the walls is contributed by the increased presence of glands in the mucosa. With an increase in the thickness of these walls, there is a concomitant decrease in the diameters of the lumina. The average diameter of the bile duct is reduced from 5.7 to 3.9 mm at the thickened wall. As it passes through the submucosa, the average diameter of 3.3 mm is reduced to 1.9 mm at the junction with the pancreatic duct. The diameter of the ampulla expands to 2.9 mm, and the orifice averages 2.1 mm (9). Gallstones are found more commonly in the bile duct than in the ampulla. Mann and Giordano (13) have estimated that in only 3.5% of individuals is the structure of the ampulla of Vater of appropriate dimensions to create the common channel described by Opie. Most other studies would indicate a greater proportion than this, but 3.5% is still a high enough figure to be consistent with the small number of patients who develop pancreatitis associated with gallstones. Nevertheless, there are reasons to think that additional factors are important in the etiology of pancreatitis under these conditions. The presence of bile in the pancreatic ducts is not necessarily accompanied by pancreatitis. A stone is usually not impacted in the ampulla of patients with pancreatitis. However, it is interesting that Acosta and Ledesma (1) found gallstones in the feces in 34 of 36 patients who had pancreatitis but in only 3 of 36 patients who had gallstones but no pancreatitis, suggesting that passage through the orifice could also be an etiological factor. For further discussion of the relative roles of the presence of bile constituents in the pancreatic duct and increased pressure due to obstruction, see Chapter 28.

The bile and pancreatic ducts pass through the duodenal wall obliquely. The mucosa of the ampulla is thrown into folds composed mainly of connective tissue and mucous glands to form mucosal valvules (9). The result of these factors is that normally fluid passes into the duodenal lumen under relatively low pressures, but flow in the opposite direction is prevented. Duodenal contents capable of activating pancreatic enzymes are thus excluded from the pancreatic ductal system. It is interesting to consider whether the presence of an impacted stone, or the passage of a stone through the ampulla of Vater, could in some cases compromise the gating capacity of this apparatus.

RELATIONSHIPS

The head of the pancreas is intimately related to the duodenum (Fig. 1). The body and tail angle distinctly superiorly as they approach the spleen. The pancreas and duodenum lie behind the peritoneum anterior to the upper lumbar vertebrae. Here, the vertebral column forms

![FIG. 2. Representation of a cross section through the abdomen in the upper lumbar area. The relative locations of liver, stomach, spleen, kidneys, intestine (INT), and duodenum (DUOD) are shown. The pancreas lies immediately ventral to the aorta (A) and inferior vena cava (IVC). The superior mesenteric artery (SMA) lies between aorta and pancreas. The hepatic portal vein (PV) is represented where it is formed from the joining of the superior mesenteric vein (SMV) and splenic vein (SV). The left renal vein (RV) is shown as it proceeds toward its crossing the aorta posterior to the superior mesenteric artery to join the inferior vena cava. The main pancreatic duct (PD) and common bile duct (CBD) are shown in the head of the pancreas as they progress toward the major duodenal papilla. Compare with Figs. 1 and 3.]


AS THE TRANSVERSE COLON CURVES FROM RIGHT COLOIC FLEXURE TO LEFT COLOIC (SPLENIC) FLEXURE, IT CROSSES ANTERIOR TO THE DESCENDING PORTION OF THE DUODENUM AND THE HEAD OF THE PANCREAS. IN ITS COURSE IT IS RELATED IN TURN TO LIVER, GREATER CURVATURE OF THE STOMACH, AND SPLEEN ALONG ITS SUPERIOR SURFACE. PERITONEUM REFLECTS OFF THE POSTERIOR BODY WALL, INCLUDING ANTERIOR SURFACES OF DUODENUM AND PANCREAS, TO FORM THE TRANSVERSE MesoCOLON. COILS OF SMALL INTESTINE ALSO COME INTO RELATIONSHIP WITH THE PANCREAS AND DUODENUM, AS WELL AS WITH THE OTHER DESCRIBED VISCERA.

COMPARISON OF FRONTAL (FIG. 1), CROSS-SECTIONAL (FIG. 2), AND LONGITUDINAL (FIG. 3) REPRESENTATIONS OF THE PANCREAS AND ITS MAJOR RELATED STRUCTURES WILL ALLOW A THREE-DIMENSIONAL IMAGE OF THE DISPOSITION OF THE PANCREAS TO BE DEVELOPED (12). THE IMAGE THUS DEVELOPED MAY SERVE AS A VALUABLE BACKGROUND TO WHICH VARIOUS IMAGING TECHNIQUES MAY BE RELATED. THE READER IS REFERRED TO SUCCESSING CHAPTERS ON SPECIFIC IMAGING TECHNIQUES FOR FURTHER ANATOMICAL DETAILS.

ARTERIAL SUPPLY

THE PANCREAS IS CHARACTERIZED BY ITS ASSOCIATION WITH A PLETHORA OF VASCULAR STRUCTURES. ITS SUBSTANCE IS PЕRMEATED BY BLOOD VESSELS SUPPLYING THE GLAND ITSELF. IN ADDITION, MAJOR BLOOD VESSELS MAY BE TRANSMITTED TO OTHER STRUCTURES THROUGH ITS SUBSTANCE OR THROUGH DEEP GROOVES THAT PROVIDE AN INTIMATE RELATIONSHIP.

LIKE THE REST OF THE GASTROINTESTINAL TRACT, THE ARTERIAL SUPPLY OF THE PANCREAS IS MARKED BY NUMEROUS ANASTOMOSSES. ARTERIAL ARCADES ARE FORMED BY BRANCHES FROM DIFFERENT MAIN SUPPLYING ARTERIES, AND BETWEEN BRANCHES FROM EACH MAIN ARTERY.


FIG. 3. REPRESENTATION OF A PARASAGITTAL SECTION THROUGH THE UPPER ABDOMINAL REGION, SLIGHTLY TO THE LEFT OF THE MID-LINE. THE AORTA IS SHOWN AS IT RUNS VENTRAL TO THE VERTEBRAL COLUMN, GIVING OFF THE CELIAC TRUNK (CT) OR CELIAC ARTERY, AND THE SUPERIOR MESENTERIC ARTERY (SMA) IN THE IMMEDIATE AREA OF THE PANCREAS. THE SPLENIC VEIN (SV) IS REPRESENTED GROOVING THE DORSAL ASPECT OF THE PANCREAS AS IT PROCEEDS TO ITS JUNCTION WITH THE SUPERIOR MESENTERIC VEIN TO FORM THE PORTAL VEIN. THE LEFT RENAL VEIN (LRV) IS SHOWN BETWEEN SUPERIOR MESENTERIC ARTERY AND AORTA AS IT PROGRESSES TO JOIN THE INFERIOR VENA CAVA. THE RELATIVE LOCATIONS OF LIVER, STOMACH, HORIZONTAL DUODENUM (DUOD), AND TRANSVERSE COLON (TC) ARE REPRESENTED. COMPARE WITH FIGS. 1 AND 2.
hepatic portal vein from the splenic and superior mesenteric veins (Fig. 5). The splenic vein begins by the confluence of veins from the spleen and is joined by the short gastric and left gastroepiploic veins. The splenic vein runs to the right in a groove in the dorsal portion of the pancreas, caudal to the splenic artery. In its course it receives numerous small tributaries draining the pancreas. Behind the neck of the pancreas, it unites with the superior mesenteric vein to form the hepatic portal vein. The superior mesenteric vein approaches the lower margin of the pancreas by passing ventral to the horizontal (third) portion of the duodenum, after receiving blood draining from much of the small and large intestines. The superior mesenteric vein, in parallel with the superior mesenteric artery, passes ventral to the uncinate process toward its junction with the splenic vein. The portal vein thus formed passes through the lesser omentum to the porta hepatitis. The pancreaticoduodenal veins drain into the superior mesenteric and portal veins, as do smaller tributaries draining the pancreas. The pattern for anastomosis and drainage of the venous system is even more irregular than that for the arterial system.

VENOUS DRAINAGE

Venous drainage from the pancreas flows into the hepatic portal system about the region of formation of the corresponding anastomosing arteries from the superior mesenteric are the anterior inferior pancreaticoduodenal and the posterior inferior pancreaticoduodenal. The superior mesenteric artery contributes other branches that supply the body and tail of the pancreas, including contribution to the transverse pancreatic artery, which may also receive contributions from the splenic artery. The pancreaticoduodenal arteries tend to run in the interval between the head of the pancreas and the duodenum, providing branches to both organs. The superior mesenteric artery has a special relationship with the pancreas. It arises from the aorta posterior to the pancreas, immediately passing ventrally, so that a portion of the head of the pancreas, the uncinate process, is prolonged to the left to lie anterior to the aorta and posterior to the superior mesenteric artery (Fig. 3).
LYMPHATIC SYSTEM

The pancreas has an extensive lymphatic drainage, although the lymphatics are not particularly prominent under physiological conditions. The great potential for fluid and particulate drainage via lymphatics is evident, however, when edema, hemorrhage, and cellular breakdown are present during pancreatitis (6). The deep lymphatic plexuses of the pancreas originate in the perilobular connective tissue. They gain access to the surface by paralleling the blood vessels running through connective tissue septa. Lymph nodes may be found embedded in pancreatic tissue, but they usually lie adjacent to the organ in close association with the major arteries of supply. A chain of lymph nodes stretching along the splenic artery, the pancreaticosplenic nodes, serve as the primary nodes of drainage for a great deal of the body and tail. Their efferents then drain into the celiac nodes, the upper group of preaortic nodes clustered about the celiac trunk. Other chains of nodes, called pancreaticoduodenal, are grouped in the intervals, anteriorly and posteriorly, where the duodenum is overlapped by the head of the pancreas. Drainage from pancreaticoduodenal nodes may be inferiorly to the superior mesenteric nodes (a second division of preaortic nodes) or superiorly to the hepatic nodes dispersed along the hepatic artery, and thence to the celiac nodes. Drainage from part of the head may be through subpyloric nodes and hepatic nodes to the celiac nodes. The celiac and superior mesenteric nodes drain via the intestinal lymphatic trunk into the cisterna chyli ventral to the second lumbar vertebra, thence via the thoracic duct through the aortic hiatus into the thoracic cavity, eventually to open into the left subclavian vein.

NERVOUS SYSTEM

The pancreas is supplied by branches from both parasympathetic and sympathetic divisions of the autonomic nervous system. In addition, visceral afferent fibers that run with each of these divisions supply the organ.

Parasympathetic innervation provides part of the secretory stimulus for the pancreas and is supplied by the vagus nerves. Nerve cell bodies are located in the dorsal nucleus of cranial nerve X. Fibers in the right vagus are conducted along the posterior vagal trunk to the celiac plexus about the celiac trunk, thence along supplying blood vessels to the substance of the pancreas, where synapse is made on small ganglia that are collections of the postganglionic neurons that have nerve endings dispersed diffusely in the connective tissue. Fibers in the left vagus are conducted to the celiac plexus via the anterior vagal trunk, make their way to the descending portion of the duodenum, and supply the adjacent head of the pancreas through ganglia similar to those described above.

Sympathetic innervation originates in the intermediate-lateral cell column in segments 5 to 10 of the thoracic spinal cord. Sympathetic fibers are conducted to the celiac ganglia via the greater splanchnic nerves. After synapse in the celiac ganglia, the postganglionic fibers are conducted along the hepatic artery and its branches (hepatic plexus), along the splenic artery and its branches (splenic plexus), and along the superior mesenteric artery (superior mesenteric plexus) to supply innervation for the pancreatic vasculature.

A greater portion of the pancreatic fibers in the vagus nerve are visceral afferent than are parasympathetic. Visceral afferent fibers also accompany the supply from the sympathetic system, entering the spinal cord at levels corresponding to efferent origin. The fibers that mediate pain in the pancreas are thought to be those that accompany sympathetic fibers.

Pain is an important factor in pancreatic disease. Although the mechanisms are not fully understood, there are morphological changes that reasonably may be correlated with the induction of pain. It has been shown recently (5) that the perineurium, which normally forms a barrier within which the nerve fibers exist in a special microenvironment, is damaged in chronic pancreatitis. Inflammatory cells, mainly lymphocytes, but also granulocytes and macrophages, frequently are concentrated around nerves and ganglia in the pancreas of patients with chronic pancreatitis. The multilayered epithelioid cells of the perineurium, and the accompanying basal laminae, are disrupted, allowing biologically active materials to penetrate into the endoneurium and therefore to gain direct access to the nerve fibers (Fig. 6). It is likely

FIG. 6. Representation of alterations in a pancreatic nerve as occurs in chronic pancreatitis. The multilayered perineurium (P), which normally forms a continuous barrier providing a specialized microenvironment for the nerve fibers contained in the center, is disrupted. Inflammatory cells (lymphocytes, granulocytes, macrophages) are found in close approximation. Biologically active material from these cells, from the blood, and from pancreatic cells may therefore enter and stimulate the nerve fibers.
that both sensory and motor fibers would be stimulated under these conditions. The fact that nerves were found to be more numerous and their mean diameter was found to be greater than in normal pancreas argues against constriction, due to fibrosis, being a stimulus for pain.

A likely cause for pain in pancreatic cancer is the penetration of nerves by the tumor. Drapiewski (7) reported that out of 83 cases of pancreatic carcinoma studied, 84% showed invasion of nerves by the tumor. Nerve fibers could be stimulated in this situation either by the direct effect of invading tissue or by damaging the perineurial barrier, allowing biologically active substances to enter the endoneurial compartment.

It must be assumed that there are multiple ways in which pancreatic pain may be generated. In addition to the mechanisms discussed above, distention of pancreatic ducts, edema, spasm of smooth muscle, and ischemia may cause pain singly or in concert. Pain does not always occur with invasion of nerves by carcinoma, or with distention of pancreatic ducts. Conversely, pain may occur without evidence of either of these conditions. Much remains to be done on the origin and management of pancreatic pain.

**ORGANIZATION OF THE EXOCRINE PANCREAS**

Each microscopic pancreatic lobule is composed of a large proportion of cells that synthesize digestive enzymes and store them as zymogen granules (acinar cells) and a much smaller proportion of cells that comprise the ductal system (intralobular and intercalated ducts). Endocrine tissue, in the form of islets of Langerhans, occupies part of the lobules. Lobular arterioles supply a large proportion of blood to the islets and a smaller proportion directly to exocrine tissue. All the blood draining from the islets, however, passes through capillaries supplying exocrine tissue before exiting from the lobules via lobular venules. Thus the exocrine tissue immediately surrounding islets normally is subjected to very high concentrations of islet hormones (see Steer and Saluja, this volume).

The organization of ducts and acini within the lobule may be quite complex, as recently demonstrated by reconstruction studies using light microscopic analysis of serial sections and retrograde injections of silicone rubber into the duct system (2,4). It cannot be assumed that each acinus is a spheroidal accumulation of cells at the termination of an intercalated duct. Acini may be spheroidal, tubular, or irregularly shaped. Many acini may be formed on the sides of a duct as it courses through a lobule. A duct may lead to an acinus, and another duct may continue on the opposite side of the acinus. Thus an intercalated duct may be intercalated between acini as well as between an acinus and an intralobular duct. Furthermore, anastomoses may exist, so that a lumen, surrounded by acinar cells and/or ductal cells, may form a continuous loop (Figs. 7 and 8).

The primary significance in understanding this three-dimensional organization of the exocrine pancreas lies in the basis it provides for understanding the changes that take place during pancreatic disease. In conditions including cystic fibrosis, chronic pancreatitis, and pancreatic adenocarcinoma, it frequently is possible to see ac-

![FIG. 7. Scanning electron micrograph of a cast of human exocrine pancreas prepared by retrograde injection of silicone rubber and subsequent removal of tissue. Continuity and branching are evident, as is an anastomotic loop. (From ref. 4, with permission.)](image-url)
cumulations of ductule-like structures, which have been referred to as ductular proliferation or reduplication. It is now evident that these accumulations, which may be termed tubular complexes, are the result of loss of zymogen granules from acinar cells, decreased acinar cell height, and concomitantly increased luminal diameter. Thus the tubular complexes represent complexes of ductular cells that were originally in the lobule plus acinar cells that have undergone regressive changes. The precise causes of these changes, or the mechanisms of the changes, are not understood. In addition, anastomotic ductules may provide alternative routes for drainage of secretory products under conditions of obstruction due to protein precipitations in acinar luminae (11).

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