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Configurational anatomy of the pancreas: its surgical relevance from ontogenetic and comparative-anatomical viewpoints

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Abstract
The structure of the adult human pancreas retains developmental traits in ontogenesis and comparative anatomy, understanding of which greatly contributes to pancreatic surgical anatomy. The pyramidal process called the "auricle" or "ear" at the inferior margin of the neck suggests the vestige of the ontogenetic twist at the neck, resulting from bursal bulging with rotation of the pancreatic body and tail. This anatomical consideration serves to avoid inadvertent bleeding or pancreatic fistula during dissection of the right gastroepiploic artery and vein at their roots. Recognition of embryonic rotation of the gastrointestinal tract eases detachment of the pancreaticoduodenal and jejunal vessels at their origins, enabling "reversed Kocherization" and complete resection of the mesoduodenum and upper mesojejunum. Embryological knowledge of vascular arcades of the pancreatic head serves as a guide for limited resection of the pancreas. The anterior inferior pancreaticoduodenal artery often runs behind, not in front of, the lower portion ("mentum" or "chin") of the pancreatic head, but still on the anterior leaflet of the embryonic mesoduodenum. The attachment of the adult pancreatic head to the duodenum occurs only at the major papilla of Vater and at the region around the minor papilla, which seems to be rational from ontogenetical and comparative-anatomical aspects. Knowledge of the pancreatic attachment helps when performing duodenum-preserving pancreatectomy and pancreas-sparing duodenectomy. The "lingula" or "small tongue", a pancreatic portion overlapping the common bile duct on the posterior aspect of the pancreas, is a key structure in resection of the extrahepatic bile duct.

Key words Configurational anatomy · Ontogenesis · Comparative anatomy · Pancreas

Introduction

The anatomy of the pancreas has remained a subject of interest to surgeons. This is partly because surgical treatment of pancreatic diseases has generally been considered to be associated with a high incidence of postoperative complications, mainly due to pancreatic fistula. Furthermore, benign or low-grade malignant neoplasms of the pancreas have come to be treated with limited resection, which requires a more accurate knowledge than ever of the vasculature and ductal system of the pancreas.[1–3] For surgeons who aspire to conduct extended resection of the pancreas in cancer or trauma surgery, its topographical anatomy is a prerequisite.

Nevertheless, the configurational anatomy of the pancreas has rarely been discussed in modern literature. Almost all surgeons and anatomists seem to take it for granted that there is nothing new or relevant in the shape of the pancreas besides those features known for centuries. According to the author's experience as a pancreatic surgeon for two decades, unknown or scarcely known features of pancreatic configuration do exist, and knowledge of these should help surgeons to perform pancreatic surgery safely and efficiently.

The structure of the adult human pancreas retains developmental traits in ontogenesis, understanding of which greatly contributes to pancreatic surgical anatomy, as in the well-known example of fusion planes[4] or the fasciae of Toldt and Treitz.[1,5] Comparative anatomy also helps in the understanding of surgically important structures of the pancreas.

Bursal bulging with rotation of the pancreatic body and tail

During the seventh and eighth embryonic week, the dorsal mesentery of the stomach (mesogastrium) bulges

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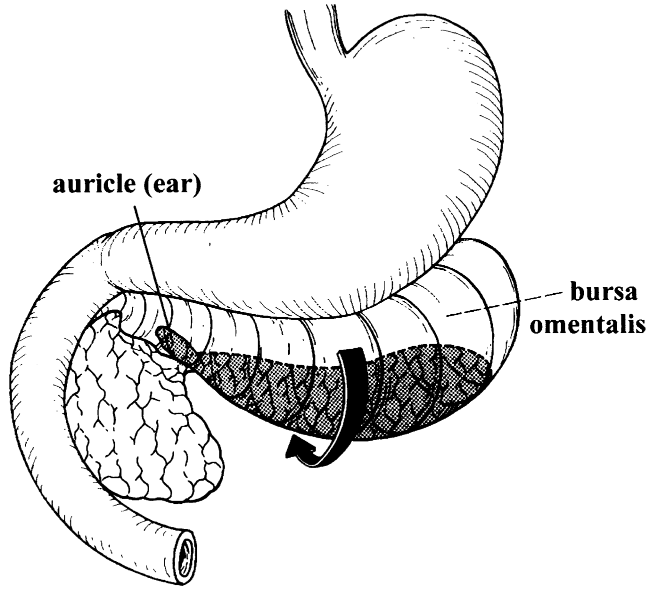

Fig. 1. Formation of the omental bursa and rotation of the pancreatic body and tail. The capsule covering the anterior surface of the pancreatic head derives from the left side of the embryonic mesentery of the duodenum, whereas the anterior capsule of the pancreatic body and tail represents the right side of the original mesoduodenum. On the boundary between both sides of the head and body regions lies the vasculoconnective tissue "wall", including the gastroduodenal artery, as well as the right gastroepiploic artery and vein. The auricle or ear of the pancreas is explained in **Fig. 3.** Reproduced with permission from reference 7

rapidly to the left and caudally, forming the sack of the omental bursa, whereas the ventral mesentery develops slowly.[6] These changes in peritoneal development contribute to the rotation of the stomach on its longitudinal axis by 90°, rendering the original right and left aspects of the stomach the posterior and anterior surfaces, respectively. The pancreatic body and tail also seem to move to the left and rotate on their long axis by 90° (Figs. 1 and 2).[7] Thus, the original right surface of the pancreatic body and tail represents their anterior surfaces after the completion of the omental bursa.

The capsule covering the anterior surface of the pancreatic head derives from the left side of the embryonic mesentery of the duodenum. Contrary to the prevailing notion, therefore, the surface of the human pancreas has an abrupt 180° shift at the neck, from the viewpoint of the primitive common dorsal mesentery.[7] On the boundary between both sides of the head and body regions lies a wall of vasculoconnective tissue, including the gastroduodenal artery, as well as the right gastroepiploic artery and vein.

Even the adult pancreas retains the vestige of the ontogenetic twist at the neck, as described in the next section. After mobilizing the posterior aspect of the pancreatic body and tail along Toldt's fusion fascia, one can turn the distal pancreas cranially to demonstrate a smooth transition from the posterior aspect of the body and tail to the anterior aspect of the head without distortion of the configuration, and without a wall or barrier in between (Fig. 2).

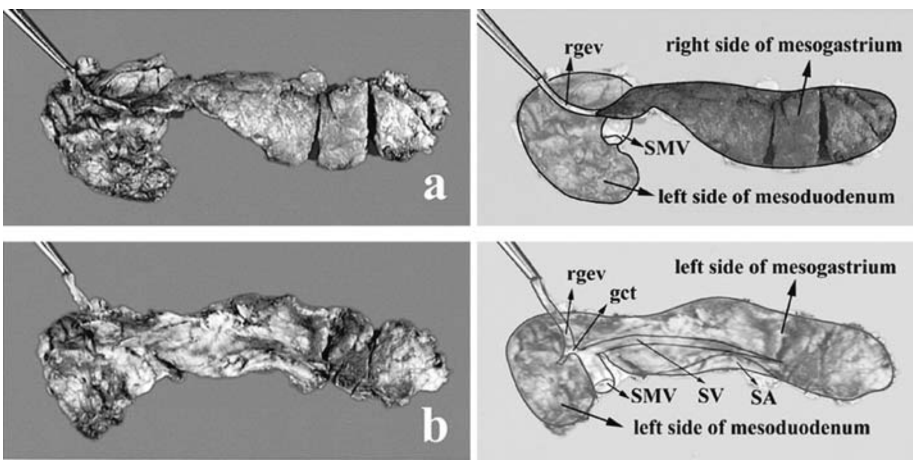

Fig. 2a,b. Demonstration of distal pancreas rotation using autopsy material. **a** In-situ appearance of the pancreas (anterior view). There is an abrupt transition at the neck between the head (*light tone*) and the distal part (*dark tone*) of the pancreas. **b** Assumed prototypic appearance of the pancreas after "corrected" rotation of the distal pancreas. One can see a smooth transition from the anterior surface (left side of the embryonic mesoduodenum) of the pancreatic head to the posterior aspect (left side of the mesogastrium) of the pancreatic body and tail. *gct*, gastrocolic trunk; *SA*, splenic artery; *rgev*, right gastroepiploic vein; *SMV*, superior mesenteric vein; *SV*, splenic vein

During surgery such as side-to-side pancreaticojejunostomy for chronic calcifying pancreatitis, we often have to uncover the entire anterior surface, which ranges from the head to the tail of the pancreas. The anterior surface of the pancreatic body can readily be reached after dividing the gastrocolic ligament and entering the omental bursa. One can also easily expose the anterior surface of the pancreatic head by dissecting the greater omentum, transverse colon, and mesocolon. On the other hand, owing to the above-mentioned ontogenetic transformation, dissection at the neck region of the pancreas requires meticulous division of the vasculoconnective wall.

Auricle (ear) of the pancreas

In approximately half of adults, a pyramidal process called the "auricle" or "ear" of the pancreas exists at the inferior margin of the neck in the transitional zone described above (Fig. 1). In some patients, it protrudes along the root of the right gastroepiploic vessels so prominently that it extends for a distance of 1–1.5 cm towards the greater curvature of the stomach (Fig. 3). In others, the projection embodies only a small hump. In terms of comparative anatomy, the pancreatic "auricle" may be reminiscent of the gastric lobe seen noticeably in the pancreas of rodents (Fig. 4).[8]

Ligation and division of the right gastroepiploic vessels at their roots is one of the fundamentals for radical resection of gastric cancer located in the distal stomach. This procedure can sometimes be tedious, due to fat deposition, which makes it difficult to differentiate fat from the pancreatic parenchyma. Novices tend to go beneath the auricle and injure it, causing sudden bleeding from the pancreatic gland. Pancreatic fistula, to a slight degree, may follow this error.

Intestinal rotation and vasculature of the duodenojejunal mesentery

In the seventh to eleventh weeks, a young embryo undergoes rotation of the gastrointestinal tract around the superior mesenteric artery (SMA) through a total of 270° counterclockwise[6] (Fig. 5). The region involving the lower duodenum and the upper jejunum takes part in the first 180° rotation.

The right side of the embryological mesoduodenum, tightly adherent to the proper retroperitoneum as the fusion fascia of Treitz, makes a spiral roll to emerge on the left side of the SMA as the anterior surface of the uppermost jejunal mesentery (Fig. 6).

Beneath the superior mesenteric vessels lies the rudimentary mesoduodenojejunum, the rotation of which is schematically depicted in Fig. 7. This mesentery contains important arterial branches supplying blood for the duodenum, pancreatic head, and upper jejunum. Along with peritoneal rotation, these arteries leave the proximal part of the superior mesenteric artery from its right side (as the posterior and anterior inferior pancreaticoduodenal arteries; PIPD/AIPD), turning their departure points from behind to its left side (as the first and second jejunal arteries; J1/J2). In 55%–60% of indi-

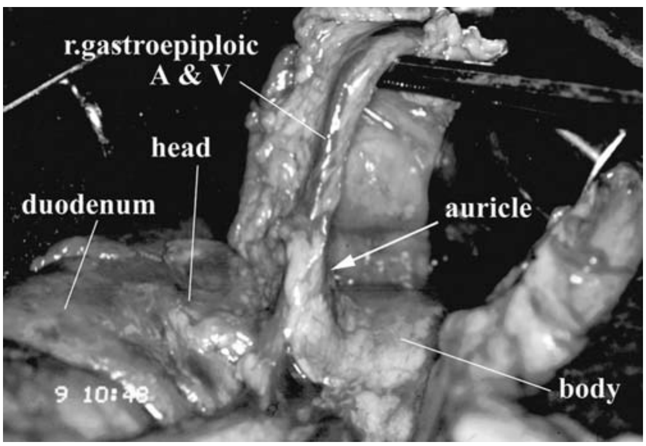

Fig. 3. Auricle or ear of the pancreas. A pyramidal projection of the pancreatic neck is extended upward along the right gastroepiploic artery and vein (*A & V*)

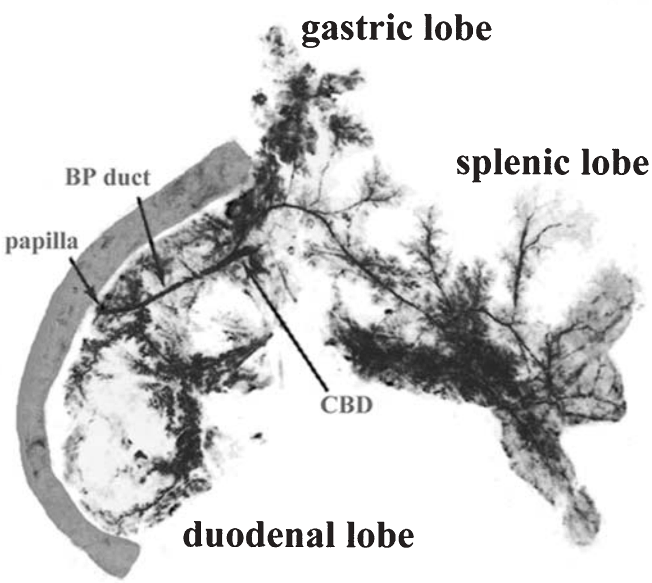

Fig. 4. Pancreatogram of the rat. Note the presence of the gastric lobe of the pancreas. *BP duct*, biliopancreatic duct; *CBD*, common bile duct. Reproduced with permission from reference 8

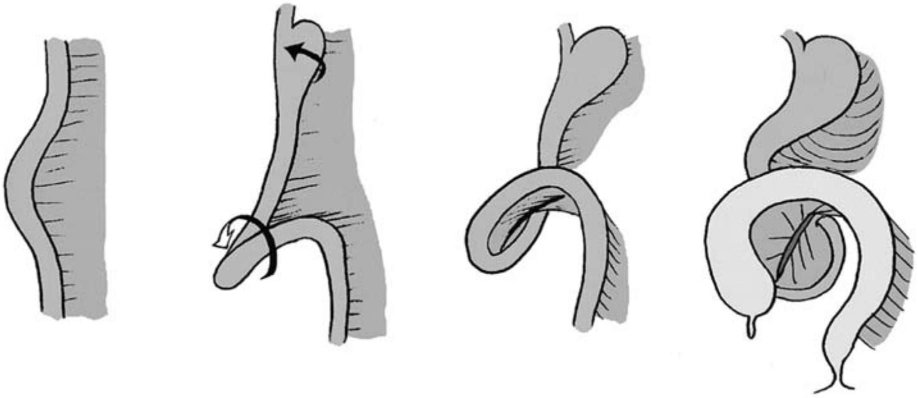

Fig. 5. Schematic drawing of gastrointestinal rotation during the early embryonic period. In the seventh to eleventh embryonic week, rotation of the gastrointestinal tract occurs around the superior mesenteric artery through a total of 270° counterclockwise

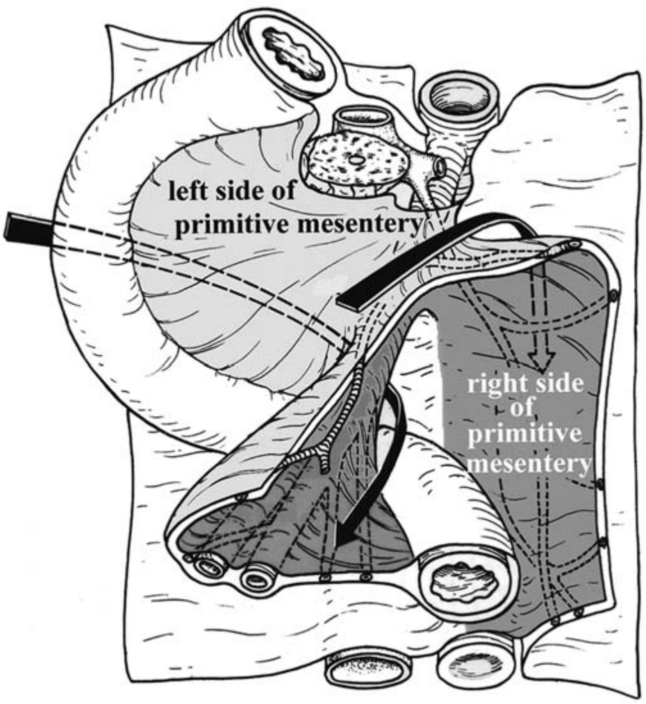

Fig. 6. Relationship among the duodenal and upper jejunal mesenteries. The posterior aspect of the pancreatic head continues anteriorly to the anterior surface of the upper jejunal mesentery, which also coincides with the anterior leaflet of the mesentery of the ascending, transverse, and descending colons. Reproduced with permission from reference 7

viduals,[9] the PIPD and the AIPD form a common stem (inferior pancreaticoduodenal artery; IPD) sharing it also with the J1 (Fig. 8). In such instances, the IPD-J1 has its radix just on the posterior wall of the SMA.

During the early stage of Whipple's pancreatoduodenectomy, the most conventional method uses Kocher's maneuver to mobilize the duodenopancreatic region by dissecting the fusion fascia of Treitz. Devascularization of the pancreatic head has been claimed to be performed easily by dividing the upper jejunum and then "de-rotating" or pulling it back from behind the superior mesenteric vessels toward the right side. This procedure, theoretically, needs to be considered in two ways. Firstly, the conventional "de-rotation" tends to take place after the severing of the left side of the jejunal and lower duodenal mesentery, leaving the right-posterior side of the roots and trunks of the IPD, J1, and J2. As argued regarding mesorectal excision for the surgical treatment of rectal cancer,[10] incomplete excision of the mesoduodenum and upper mesojejunum may cause unfavorable effects on the curability of Whipple's operation for pancreatoduodenal malignancy. Secondly, also from an oncological perspective, manipulation of the duodenopancreatic portion after Kocher's maneuver and "de-rotation" seems to promote peroperative dissemination of tumor cells via venous and/or lymphatic pathways.

Recognition of intestinal and mesenteric rotation around the SMA eases the detachment of the PIPD, AIPD, IPD, J1, and J2 at their origins, leaving the duodenopancreatic portion in situ. This dissection can be performed from the left side of the SMA, in stark contrast to the conventional "de-rotation" method. After devascularization with this new technique, the duodenopancreatic portion is removed from the retroperitoneum by dissecting the fusion fascia of Treitz from the left, not the right, a procedure which the author calls "reversed Kocherization" (Figs. 8–10[11]).

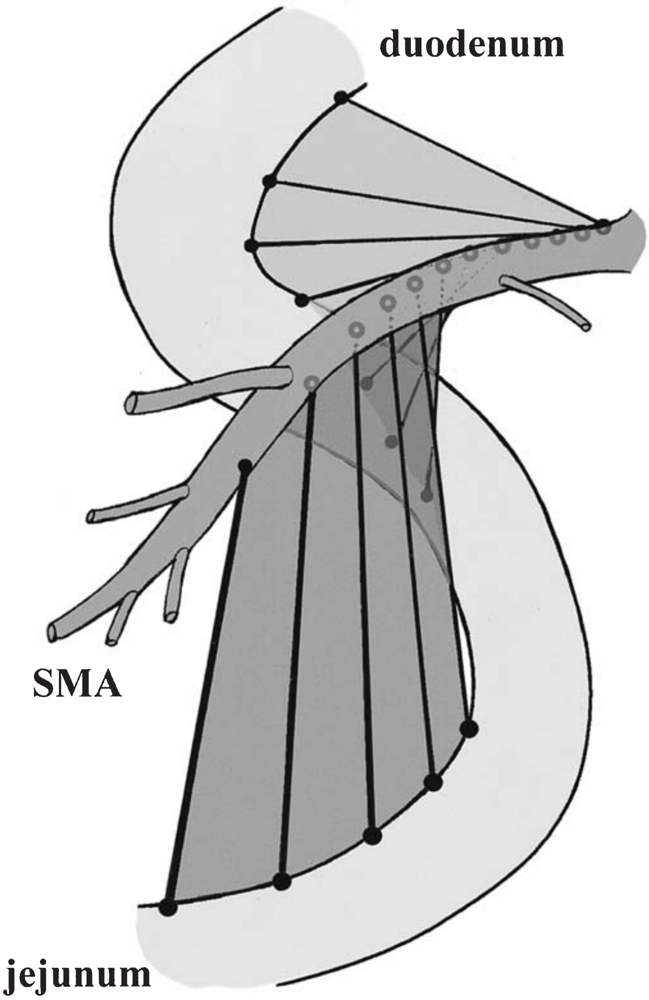

Fig. 7. Schematic depiction of mesenteric rotation of the duodenum and uppermost jejunum. The actual length of the mesentery behind the superior mesenteric vessels is so short that surgeons should be careful when performing dissection and division of the inferior pancreaticoduodenal artery and the first jejunal artery, both of which often form a common stem. The *straight lines* represent the imaginary plicae, not arteries, of the duodenal and jejunal mesentery. *SMA*, Superior mesenteric artery

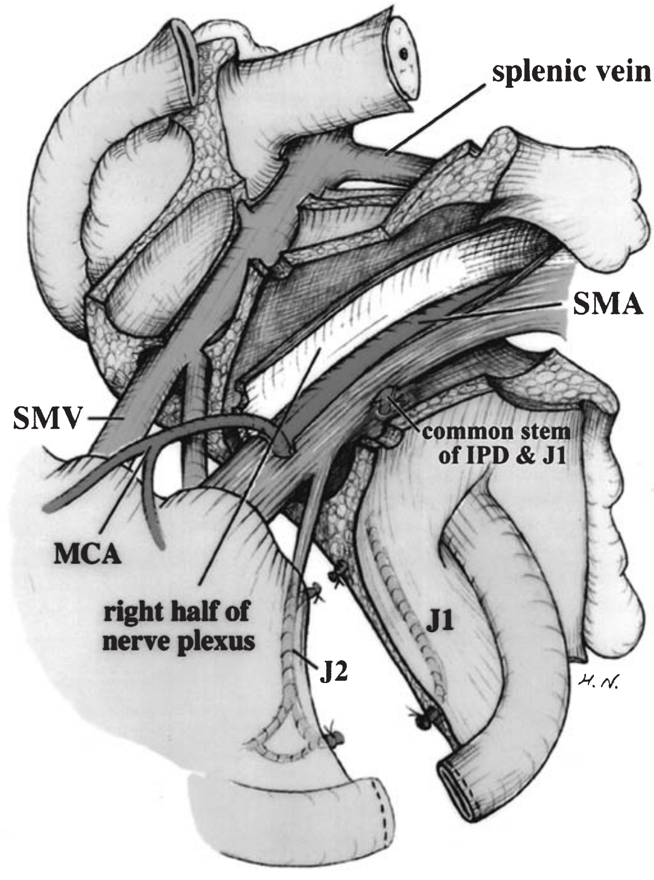

Fig. 8. Dissection of the embryonic mesentery of the duodenum and uppermost jejunum from the left side of the superior mesenteric artery. Note the common stem of the inferior pancreaticoduodenal artery (*IPD*) and the first jejunal artery (*J1*). *J2*, second jejunal artery; *MCA*, middle colic artery; *SMA*, superior mesenteric artery; *SMV*, superior mesenteric vein. Reproduced with permission from reference 11

"Mentum" (chin) of the pancreatic head

Embryologically speaking, the pancreatic head is situated between the right and left peritoneum of the dorsal mesoduodenum, as discussed above. Therefore, the main arterial and venous branches related to the pancreatic head and the duodenum run on the anterior and posterior surfaces of the head of the pancreas as anterior and posterior arcades, respectively, connecting the celiac arterial system and the SMA (Fig. 11).

Detailed anatomical knowledge of these arcades has allowed us to conduct limited resection of the pancreas, including duodenum-preserving pancreatic head resection[12,13] and ventral or dorsal pancreatectomy.[3] In the course of research on the surgical anatomy of the pancreaticoduodenal arteries, the author and his colleague, Kimura, found that, in 70% of adult human pancreata, the AIPD runs not on the anterior surface of, but behind the lower portion of the pancreatic head[13] (Fig. 12). This implies that "AIPD (anterior inferior pancreaticoduodenal artery)" is a misnomer. However, it has become evident that even if the AIPD runs behind the lower portion of the pancreatic head, it never runs on the posterior leaflet of the mesoduodenum, indicating the antero-inferior protrusion of the lower part of the head over the duodenum. The author calls this outgrowth the "mentum" or "chin" of the pancreas.

Although not proven, it seems that the "chin" may derive from the embryological anlage of the dorsal pan-

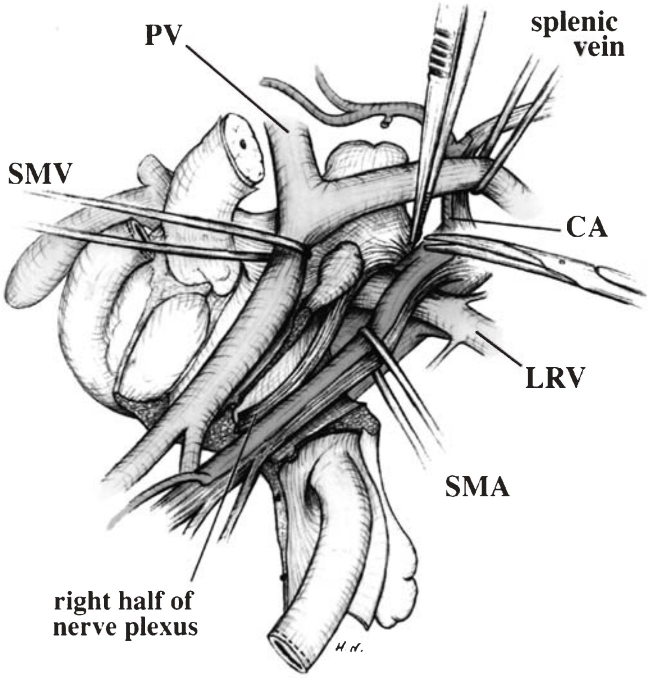

Fig. 9. Final phase of separation of the pancreaticoduodenal region from the superior mesenteric vessels and the nerve plexus around the superior mesenteric and celiac arteries. *CA*, celiac artery; *LRV*, left renal vein; *PV*, portal vein; *SMA*, superior mesenteric artery; *SMV*, superior mesenteric vein. Reproduced with permission from reference 11

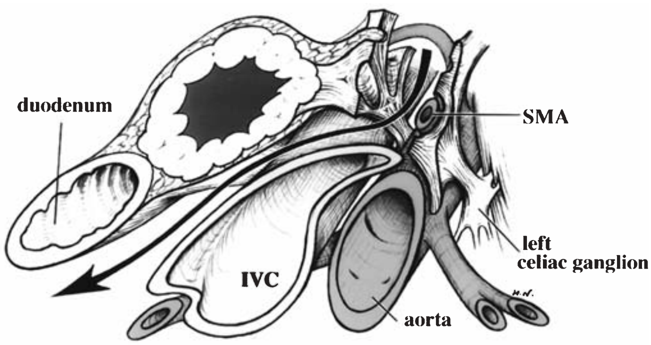

Fig. 10. Reversed Kocherization, showing a "from-medial-to-lateral" dissection of the pancreaticoduodenal region. *IVC*, inferior vena cava; *SMA*, superior mesenteric artery. Reproduced with permission from reference 11

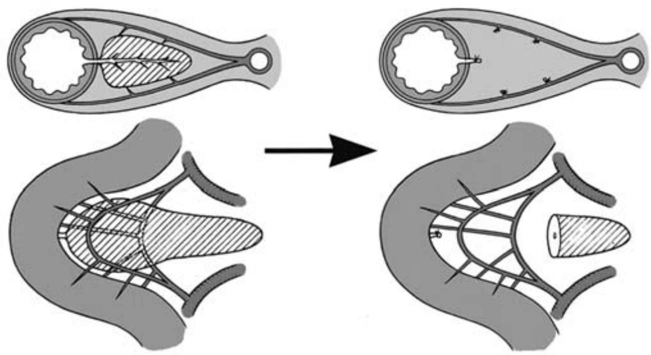

Fig. 11. Illustration of the blood supply to the pancreas and duodenum from the anterior and posterior vascular arcades derived from both the celiac and superior mesenteric arteries. Reproduced with permission from reference 12

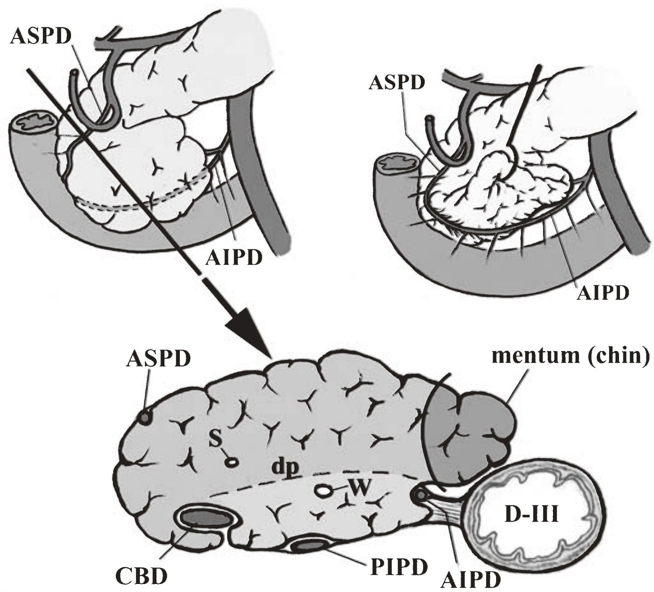

Fig. 12. Course and position of the anterior inferior pancreaticoduodenal artery (*AIPD*) in relation to the pancreatic parenchyma. Seventy percent of adults have the AIPD behind, not in front of, the lower portion (mentum or chin) of the pancreatic head, but still on the anterior leaflet of the embryonic mesoduodenum. *ASPD*, anterior superior pancreaticoduodenal artery; *CBD*, common bile duct; *D-III*, third portion of the duodenum; *dp*, notional plane dividing dorsal and ventral anlagen of the pancreas; *PIPD*, posterior inferior pancreaticoduodenal artery; *S*, Santorini's duct; *W*, Wirsung's duct

creas and that the AIPD may course along the boundary between the dorsal and ventral anlagen (Fig. 12).

Attachment of the pancreatic head to the duodenum

Until recently, the head of the human adult pancreas was thought to be densely attached to the duodenum, especially to its descending part (second portion). Classical textbooks rarely mention precise modes of connection of the pancreas to the duodenal wall. Morris' *Human anatomy*[4] describes the following: "The medial aspect of the descending duodenum is in contact with the head of the pancreas, and some fibers from the muscular tunic are said to become intermingled with the pancreatic lobules."

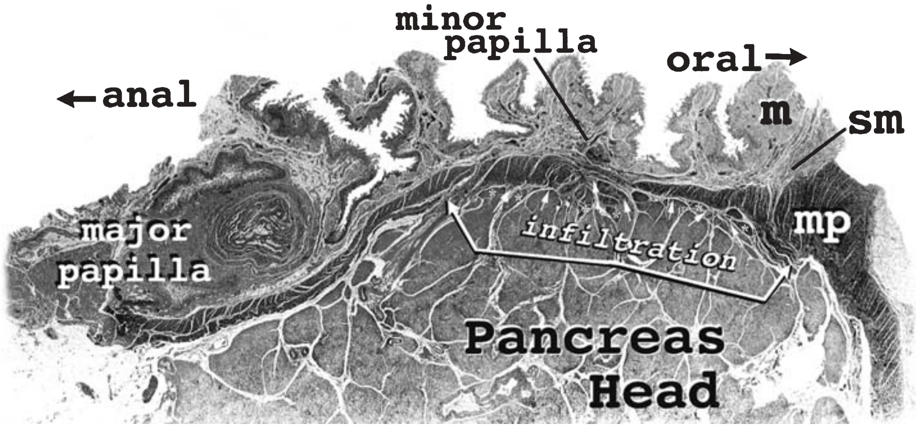

Fig. 13. Protrusion or infiltration (*arrows*) of the pancreatic gland into the proper muscular layer (*mp*) of the duodenum around the minor papilla. Note that the major papilla of Vater does not directly contact the pancreatic parenchyma. *m*, mucosal layer; *sm*, submucosal layer. Reproduced with permission from reference 12

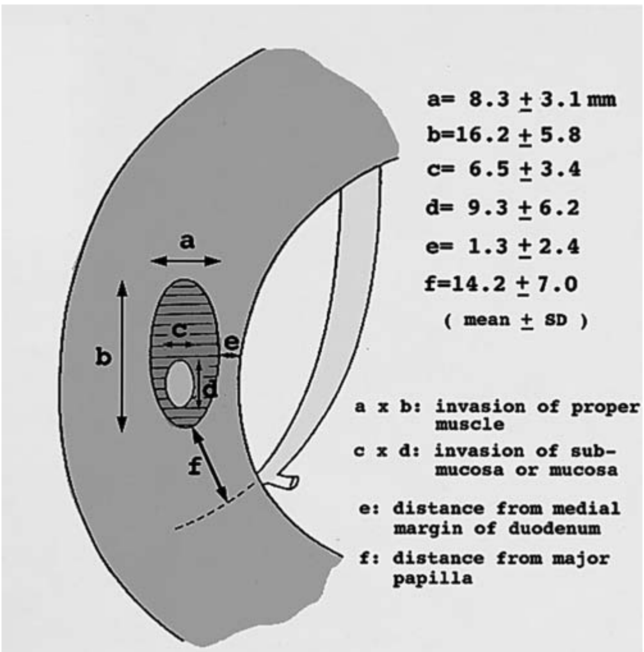

Fig. 14. Duodenal area involved in pancreatic infiltration around the minor papilla. Reproduced with permission from reference 12

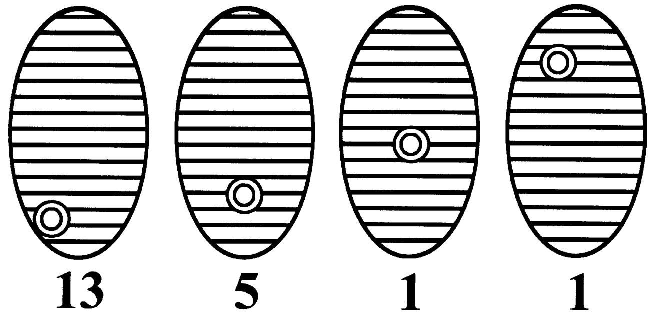

Fig. 15. Location of the minor papilla in relation to pancreatic infiltration of the duodenal wall. The *numbers under each illustration* indicate the numbers of cases. Reproduced with permission from reference 12

The author has revealed that the attachment of the pancreatic head to the duodenum only occurs at the major papilla of Vater and at the region around the minor papilla.[11] Embryologically, the pancreas derives from the dorsal and ventral anlagen, the duodenal orifices of which represent the minor and major papillae, respectively. Anatomy of the pancreata of mammals indicates the apparent separation of the pancreas from the duodenum, except at and around the duodenal papillae. Thus, ontogenetically and in terms of comparative anatomy, the relationship of the pancreas to the duodenum, as described above, seems to be rational.

At the major papilla of Vater, the human adult pancreas appears to be attached to the duodenal wall only via the ductal system, including the common channel of the main pancreatic duct and bile duct along with Oddi's sphincters. No pancreatic parenchymal tissues enter the duodenal wall around the major papilla. On the other hand, some degree of parenchymal "invasion" occurs around the minor papilla. The "invasion," or infiltration forms an oval area, approximately 1 × 2 cm, with intrusion usually into the duodenal muscular layer, but sometimes into the submucosal layer (Figs. 13–15[11]). Interestingly, the orifice of the minor papilla is commonly located eccentrically in the "invasive" area. Knowledge of the pancreatic attachment helps when performing duodenum-preserving pancreatectomy[12–14] and pancreas-sparing duodenectomy.[15]

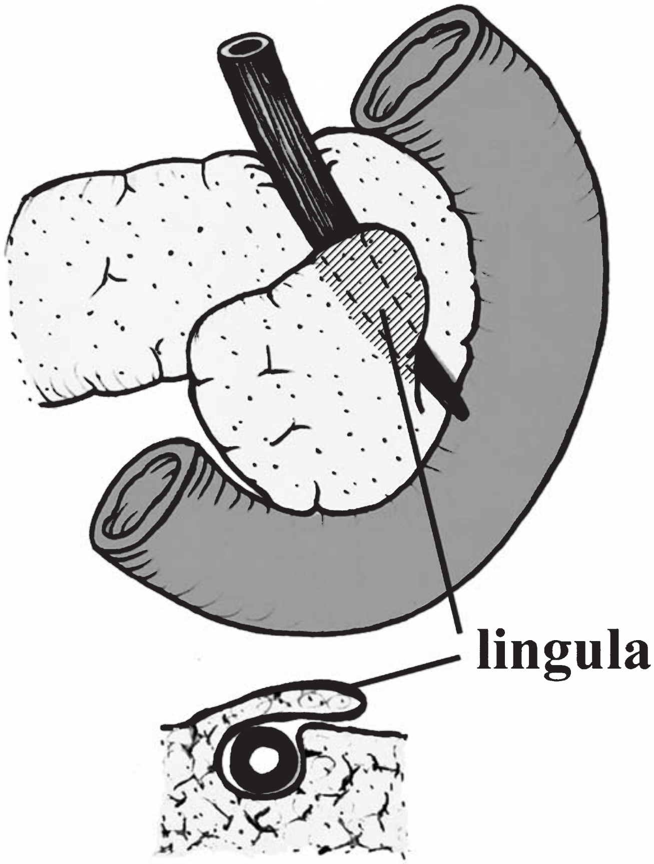

Fig. 16. Lingula or small tongue of the pancreas designated by Smanio.[16] Posterior aspect of the pancreatoduodenal region. Reproduced with permission from reference 17

"Lingula" (small tongue) of the pancreas

The "lingula" or "small tongue" of the pancreas was referred to by Smanio[16] as the pancreatic tissue overlapping the common bile duct on the posterior aspect of the pancreatic head (Fig. 16[17]). Even if the lingula appears to completely cover the bile duct, there is a latent rift to enter in order to reach the entire length of the common bile duct (Fig. 16).

Dissection of the bile duct over its whole course is essential in resection of the extrahepatic bile duct for pancreaticobiliary maljunction and in total choledochectomy for in-situ bile duct cancer with extensive mucosal[18] (Fig. 17). The key to safe exposure is to carefully observe the patterns of pancreatic lobules and to search for a latent fissure between the tip of the lingula and the proper parenchyma. Once identified, the fissure is easily opened without injury to the pancreatic parenchyma.

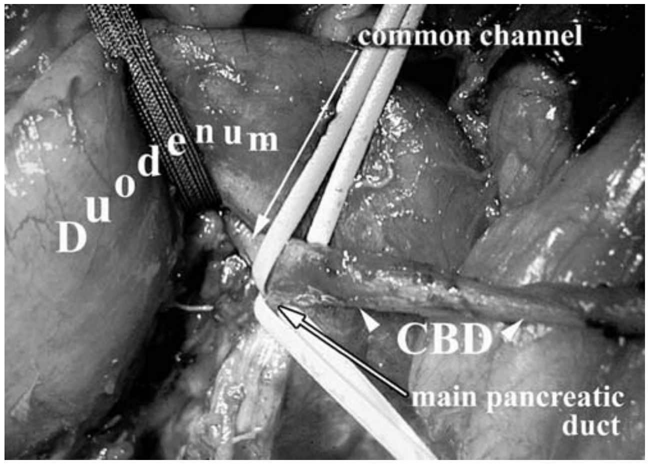

Fig. 17. Biliopancreaticopapillary resection for mucosa-spreading in-situ cancer of the extrahepatic bile duct. The distal main pancreatic duct, bile duct, and common channel of the major papilla are taped after their complete dissection from the pancreatic parenchyma

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