RadioGraphics

Collateral Pathways in Patients with Celiac Axis Stenosis: Angiographic–Spiral CT Correlation[1]

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LEARNING OBJECTIVES

After reading this article and taking the test, the reader will be able to:

- Discuss the causes and clinical significance of celiac axis stenosis.
- Describe various collateral pathways from the superior mesenteric artery.
- Describe the anatomic environment of these collateral pathways at spiral CT.

Although celiac axis stenosis is a frequently encountered occlusive vascular disease, clinically significant ischemic bowel disease caused by celiac axis stenosis is rarely reported due to rich collateral circulation from the superior mesenteric artery (SMA). The most important and frequently encountered collateral vessels from the SMA in patients with celiac axis stenosis are the pancreaticoduodenal arcades and the dorsal pancreatic artery. Subtypes of collateral pathways via the dorsal pancreatic artery include a longitudinal pathway between the celiac branches and the SMA or its branches and a transverse pathway to either the splenic or gastroduodenal artery. A communicating channel between the right hepatic artery and the SMA can be a route for collateral circulation. Hepatic artery variants cause the development of unique collateral pathways that have different characteristics depending on the type of variant. These collateral pathways include intrahepatic interlobar collateral vessels, right gastric to left gastric arterial anastomoses, left hepatic to left gastric arterial anastomoses, and peribiliary arterial plexuses. Major collateral pathways in patients with celiac axis stenosis can be identified with spiral CT, and knowledge concerning this collateral circulation may be important for certain medical procedures such as interventional procedures for the management of hepatic tumors, pancreaticobiliary surgery, and liver transplantation.

Abbreviation: SMA = superior mesenteric artery

Index terms: Angiography, 95.12 • Arteries, celiac, 951.721 • Arteries, CT, 95.12915 • Arteries, pancreatic, 959.721 • Arteries, stenosis or obstruction, 9*.721 • Arteries, superior mesenteric, 955.721 • Hepatic arteries, 952.13, 952.721

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Relative Prevalence of Various Collateral Routes from the SMA Supplying Celiac Branches in 94 Patients with Celiac Axis Stenosis or Occlusion

Collateral Pathway	Patients with Normal Hepatic Artery Anatomy (n = 81)	Patients with Hepatic Artery Variation (n = 13)	All Patients (n = 94)
Pancreaticoduodenal arcades	77(95)	12(92)	89(95)
Dorsal pancreatic arteries	61(75)	10(77)	71(76)
Longitudinal pathway*	19/39	5/8	24/47
Transverse pathway to splenic artery*	21/39	4/8	25/47
Transverse pathway to gastroduodenal artery*	14/39	5/8	19/47
Communicating channel between the right hepatic artery and the SMA	6(6)	0(0)	6(6)
Intrahepatic interlobar collateral vessels	0(0)	11(12)	11(12)
Right gastric to left gastric arterial anastomosis	0(0)	2(2)	2(2)
Left hepatic to left gastric arterial anastomosis	0(0)	2(2)	1(1)
Peribiliary arterial plexuses	0(0)	1(1)	1(1)

Note.—Numbers in parentheses are percentages.
*Subtype of collateral circulation via the dorsal pancreatic artery, which demonstrated dominant or codominant contribution in 47 patients. Eight of these 47 patients had hepatic artery variation.

Introduction

The suggested causes of celiac axis stenosis are atherosclerosis, acute and chronic dissection, and compression of the celiac axis by the median arcuate ligament (1–4), the latter having been described as the principal cause of celiac axis stenosis, particularly in the Asian population (5). In a series of 110 unselected cadavers by Derrick et al (6), the lumen of the celiac artery was narrowed by over 50% in 21% of cases. A high prevalence of significant stenosis of the celiac artery has also been reported in asymptomatic patients (1,7). However, clinically significant ischemic bowel disease secondary to celiac axis stenosis is rarely encountered (3,4), mainly owing to the development of rich collateral vessels from the superior mesenteric artery (SMA).

Knowledge concerning these collateral vessels from the SMA in a patient with celiac axis stenosis may be important for regional interventional procedures, surgical management of periampullary lesions, or liver transplantation (8). In hepatic chemoembolization, celiac axis stenosis increases the risk of inadvertent splenic infarction due to reverse blood flow in the common hepatic or left hepatic artery. When the celiac axis is completely occluded, selective catheterization of collateral vessels may be required. Collateral pathways can be the only routes for chemoembolization of hepatic tumors. If visualization of celiac axis stenosis or of related collateral vessels at axial computed tomographic (CT) is possible, it may be helpful in preoperative planning or interventional procedures.

With the introduction of and recent technologic advances in spiral CT, precise preoperative evaluation of small visceral vessels of the abdomen and visualization of celiac axis stenosis is possible (9–12).

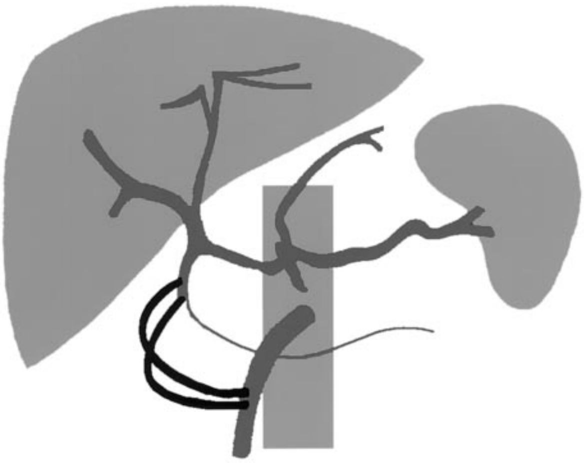
In this article, we discuss and illustrate the conventional angiographic anatomy of various collateral pathways from the SMA in patients with celiac axis stenosis. We correlate these findings with available arterial-phase spiral CT findings to demonstrate the cross-sectional anatomic environment of these collateral pathways.

Types of Collateral Pathways

We classified collateral pathways from the SMA with a retrospective analysis of conventional angiographic findings in 94 patients with celiac axis stenosis (Table). The most commonly noted collateral vessels were the pancreaticoduodenal arcades and the dorsal pancreatic artery. Other types of collateral vessels were found in 19 patients. All 13 of the patients with a variant hepatic artery that arises from the SMA had unique collateral vessels.

Pancreaticoduodenal Arcades

The pancreaticoduodenal arcades supply the head of the pancreas and the C loop of the duodenum, at least one being anterior and at least one posterior to the head of the pancreas (13–15).



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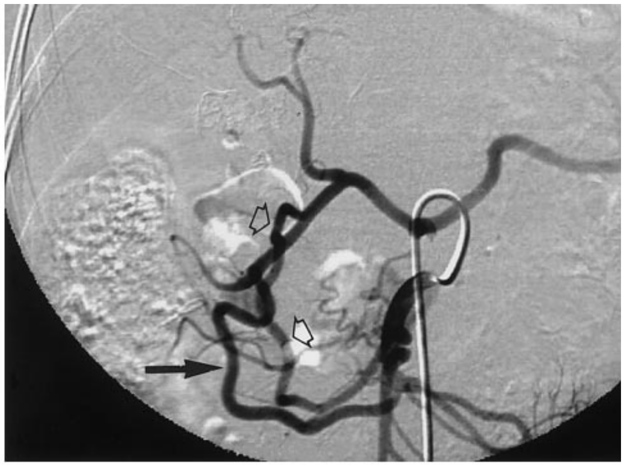

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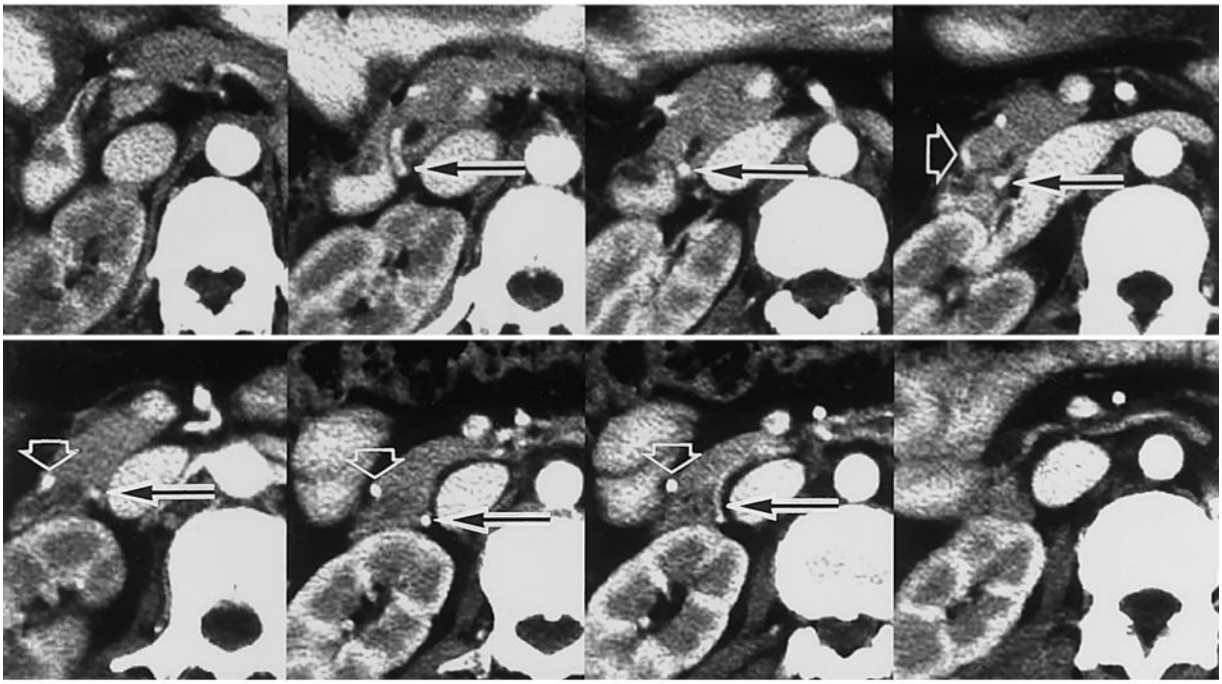

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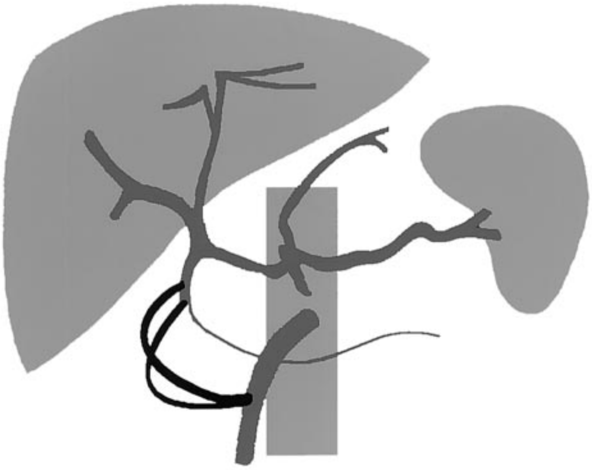
Figure 1. Typical pancreaticoduodenal arcade anatomy. **(a)** Drawing illustrates typical pancreaticoduodenal arcade anatomy with separate inferior pancreaticoduodenal arteries. **(b)** Superior mesenteric arteriogram shows retrograde contrast material filling of the celiac branches via the anterior (solid arrow) and posterior (open arrows) pancreaticoduodenal arcades, which arise separately from the SMA. **(c)** Serial spiral CT scans clearly depict the anatomic course of both the anterior (open arrows) and posterior (solid arrows) pancreaticoduodenal arcades. The anterior arcade runs along the groove between the head of the pancreas and the C loop of the duodenum. The posterior arcade arises from the gastroduodenal artery and wraps around the distal common bile duct posteriorly.

The anterior pancreaticoduodenal arcade is formed by the anterior superior pancreaticoduodenal artery, the smaller of the two end branches of the gastroduodenal artery. The posterior pancreaticoduodenal arcade is formed by the retroduodenal artery (posterior superior pancreaticoduodenal artery), usually the first branch of the gastroduodenal artery before or immediately after it passes behind the duodenum. The two arcades either unite with the SMA via separate inferior pancreaticoduodenal arteries given off by the SMA—one for each arcade (Fig 1)—or end in a common inferior pancreaticoduodenal artery



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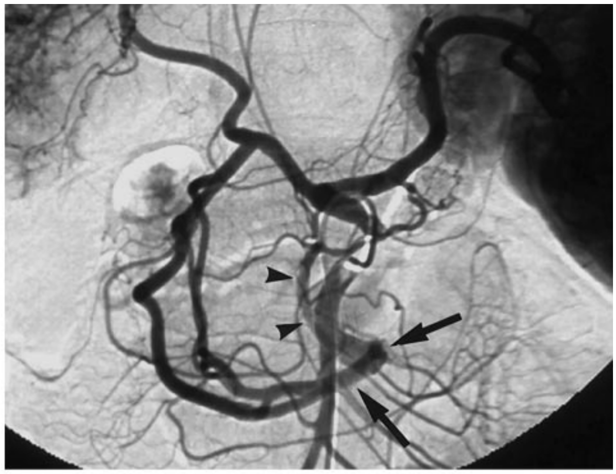

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Figure 2. Pancreaticoduodenal arcade variant in which both the anterior and posterior arcades unite with the SMA via a common inferior pancreaticoduodenal artery. **(a)** Drawing illustrates the pancreaticoduodenal arcades with a common inferior pancreaticoduodenal artery. **(b)** Superior mesenteric arteriogram shows a common inferior pancreaticoduodenal artery (arrows), from which the dorsal pancreatic artery arises (arrowheads).

(Fig 2). There may be anywhere from one to four anterior and one to four posterior arcades. The posterior arcades are more cephalad than the anterior arcades.

The pancreaticoduodenal arcades are the most common collateral pathways from the SMA to the celiac branches. Although in most cases both the anterior and posterior arcades developed as collateral pathways between the SMA and the common hepatic artery, occasionally one or both arcades developed as a single channel (Fig 3).

Spiral CT demonstrates the anatomic environment of the pancreaticoduodenal arcades. In Figure 1c, the anterior arcade is continuous with the gastroduodenal artery, which is located at the right anterior aspect of the head of the pancreas, and courses along the groove between the head of the pancreas and the C loop of the duodenum. After arising from the gastroduodenal artery, the posterior pancreaticoduodenal arcade wraps around the distal common bile duct posteriorly and is positioned at the posterior aspect of the head of the pancreas. In some cases, the pancreaticoduodenal arcade passes through the parenchyma of the pancreas (Fig 4).

Dorsal Pancreatic Artery

The dorsal pancreatic artery is the first large pancreatic branch of the splenic artery. In an anatomic study of 200 cadavers by Michels (13), the dorsal pancreatic artery was seen to arise from the splenic artery in 39% of cases. However, in 61% of cases it arose from other sources, such as the right hepatic artery (12%), SMA (14%), or celiac artery (22%). A dorsal pancreatic artery of SMA origin has numerous anastomotic connections with the celiac branches (Fig 5) and therefore has an important role in the collateral circulation in patients with celiac axis stenosis. The dorsal pancreatic artery typically divides into two right branches and one left branch (13,15). One of the right branches joins the pancreaticoduodenal arcade, whereas the other becomes the artery to the uncinate process of the pancreas. The left branch becomes the transverse pancreatic artery. The pancreatica magna or caudal pancreatic arteries of the splenic artery anastomose with the transverse pancreatic artery. The fourth branch of the dorsal pancreatic artery often descends below the

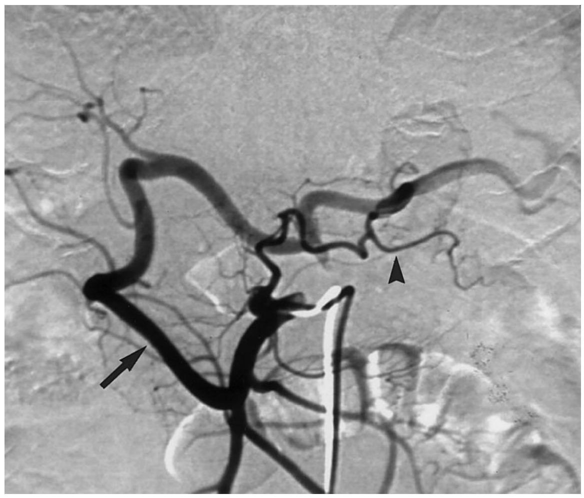

Figure 3. Collateral pathway via a pancreaticoduodenal arcade that developed as a single channel. Superior mesenteric arteriogram shows a large single pancreaticoduodenal arcade (arrow). Arrowhead indicates the transverse pancreatic artery.

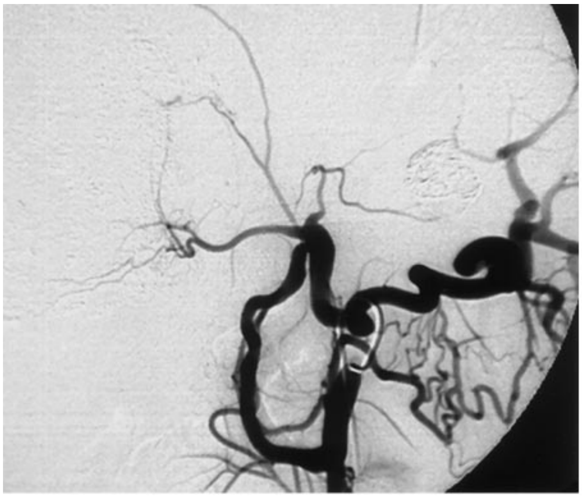

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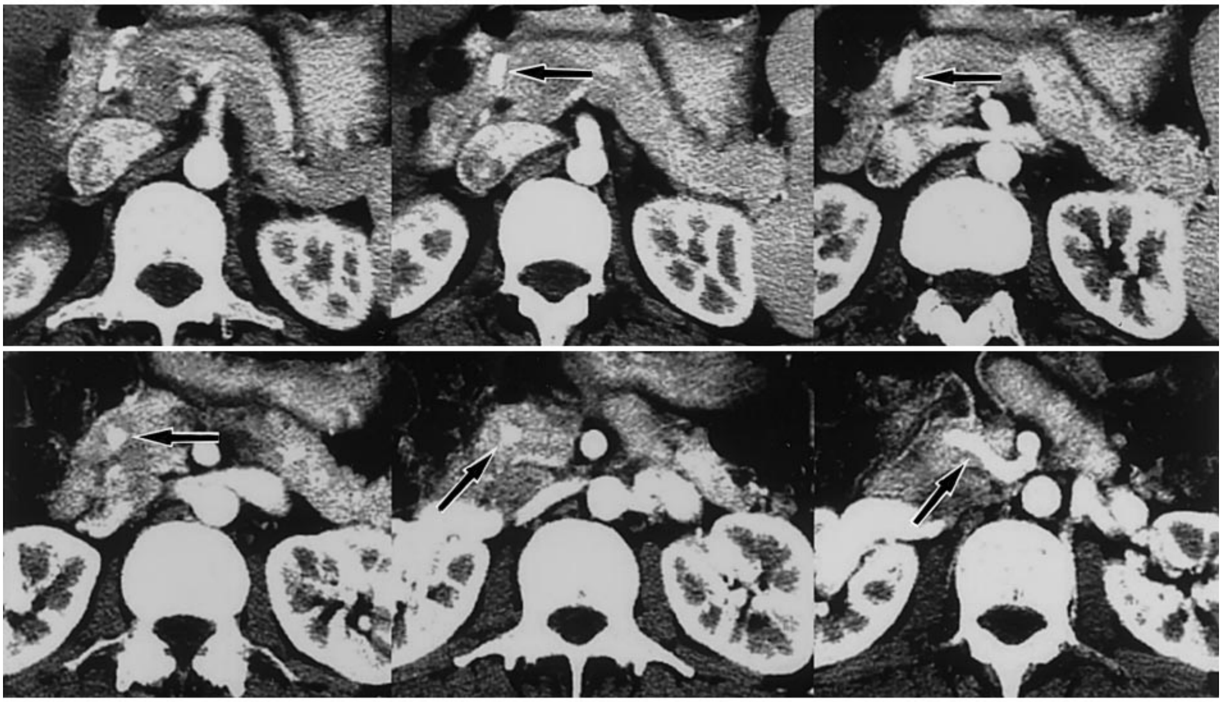
Figure 4. Pancreaticoduodenal arcade with a transpancreatic course. **(a)** Superior mesenteric arteriogram shows retrograde filling of the celiac branches mainly via a large anterior pancreaticoduodenal arcade. **(b)** Serial spiral CT scans show the transpancreatic course of the pancreaticoduodenal arcade (arrows), which is buried in the parenchyma of the uncinate process of the pancreas.



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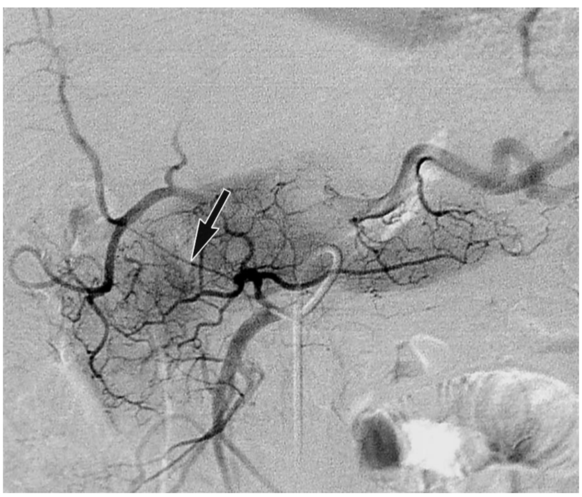
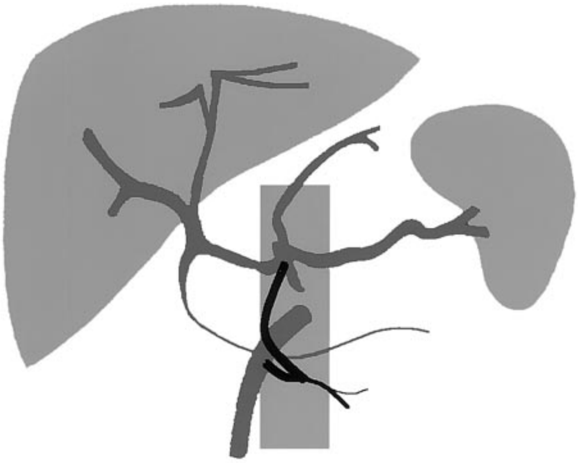


Figure 5. Dorsal pancreatic artery with anastomoses. Arteriogram obtained during accidental catheterization of the dorsal pancreatic artery, which arises from the SMA, shows the artery with the typical two right branches and one left branch. There are fine anastomotic channels to the gastroduodenal and splenic arteries via the branches of the artery. A fine communicating channel between the dorsal pancreatic artery and the hepatic artery is also noted (arrow).



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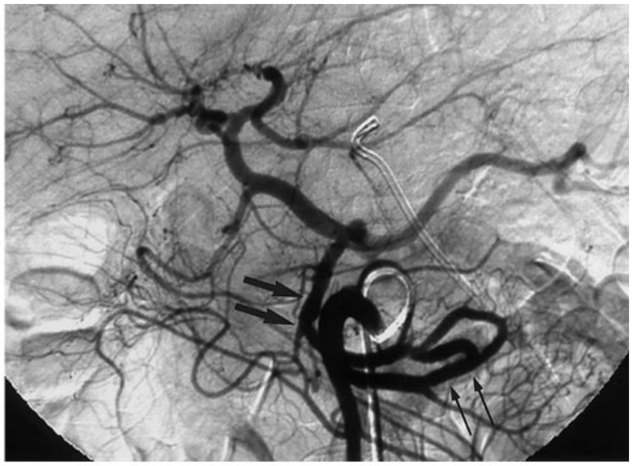

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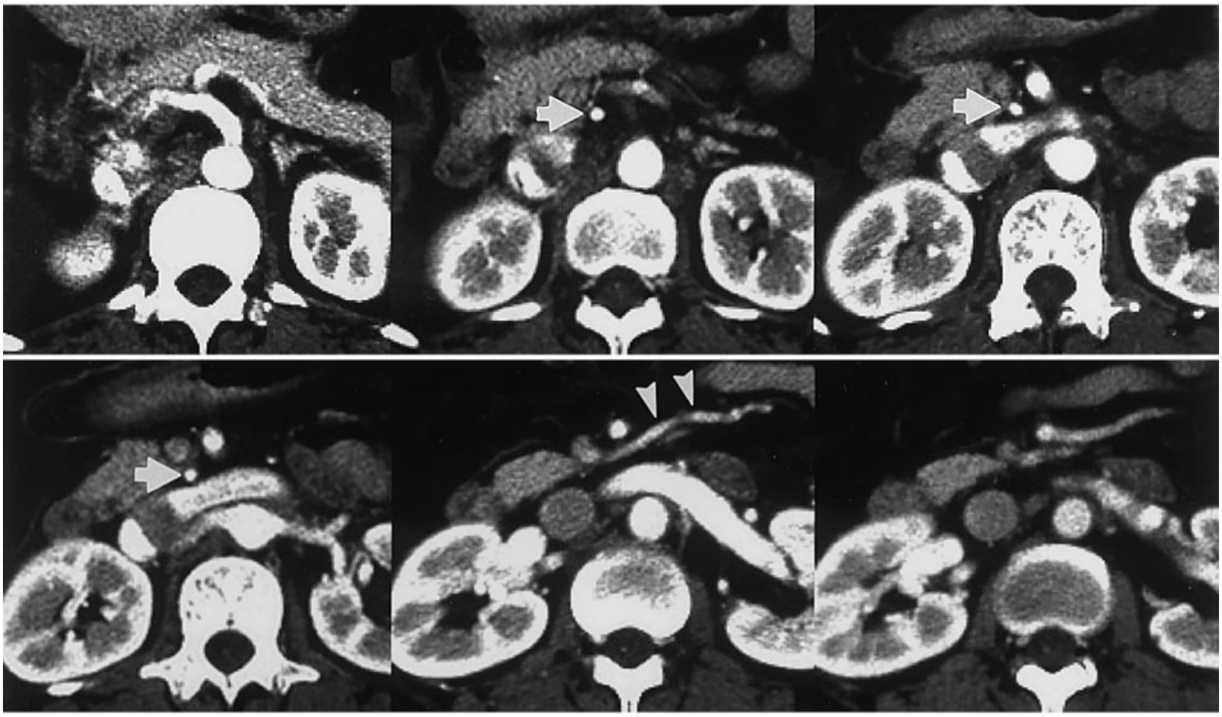

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Figure 6. Longitudinal pathway via the dorsal pancreatic artery. **(a)** Drawing illustrates a longitudinal pathway between the celiac axis and a branch of the SMA. **(b)** Superior mesenteric arteriogram shows a large vascular channel (thick arrows) directly connecting the celiac axis and a jejunal branch of the SMA (thin arrows). **(c)** Serial arterial-phase spiral CT scans clearly show the anatomic environment of the dorsal pancreatic artery (arrows), which is posteromedial to the superior mesenteric vein. Anastomosis between the dorsal pancreatic and jejunal arteries is well delineated (arrowheads).

inferior border of the pancreas behind the splenic vein to communicate with the SMA or one of its branches (the jejunal, middle colic, or accessory middle colic artery), thereby constituting an important longitudinal collateral pathway between the celiac artery and the SMA.

The pathways via the dorsal pancreatic artery have the second most important role in collateral circulation. We found three subtypes of collateral pathways via the dorsal pancreatic artery: (*a*) a longitudinal pathway between the celiac branches and the SMA or its branches (Figs 6, 7), (*b*) a transverse pathway to the splenic artery via a

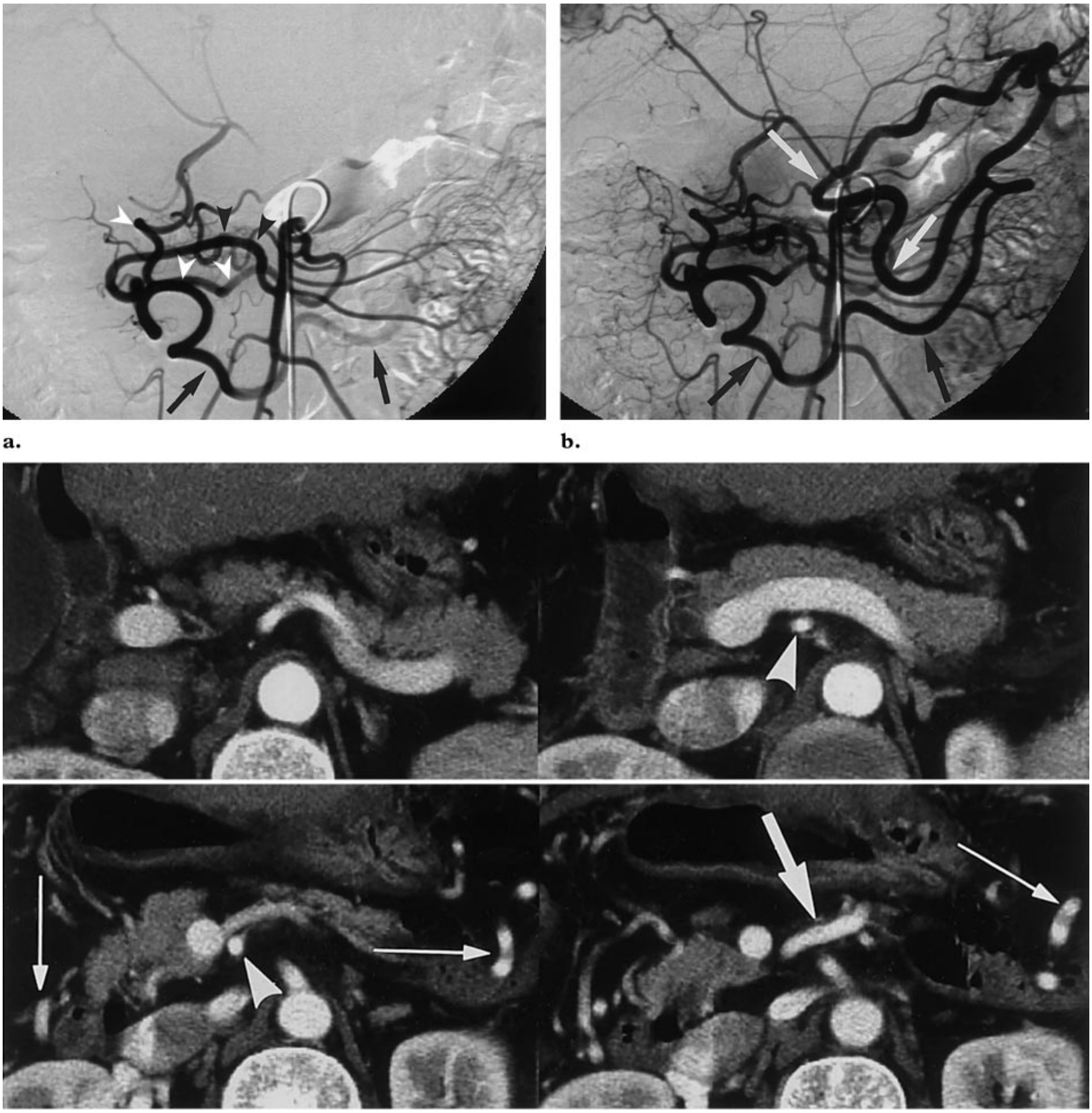

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Figure 7. Longitudinal pathway via the dorsal pancreatic artery. **(a)** Early arterial-phase superior mesenteric arteriogram shows a large, hypertrophic marginal artery of the colon (arrows) that arises from the right colic artery (black arrowheads). Retrograde contrast material filling of the hepatic artery via a pancreaticoduodenal arcade (white arrowheads) is also noted. **(b)** Later arterial-phase arteriogram reveals that the hypertrophic marginal artery (black arrows) is continuous with the middle colic artery (white arrows), which arises from a dorsal pancreatic artery of splenic artery origin. **(c)** Serial spiral CT scans show a large middle colic artery (thick arrow) that arises from the dorsal pancreatic artery (arrowheads). Note the hypertrophic marginal arteries of the colon (thin arrows).

transverse pancreatic artery (Fig 8), and (*c*) a transverse pathway to the gastroduodenal artery (Fig 9).

A longitudinal pathway is identical to the fourth branch of the dorsal pancreatic artery as described in textbooks. It appears as a direct anastomotic channel between the celiac branches and the SMA or connects with a branch of the

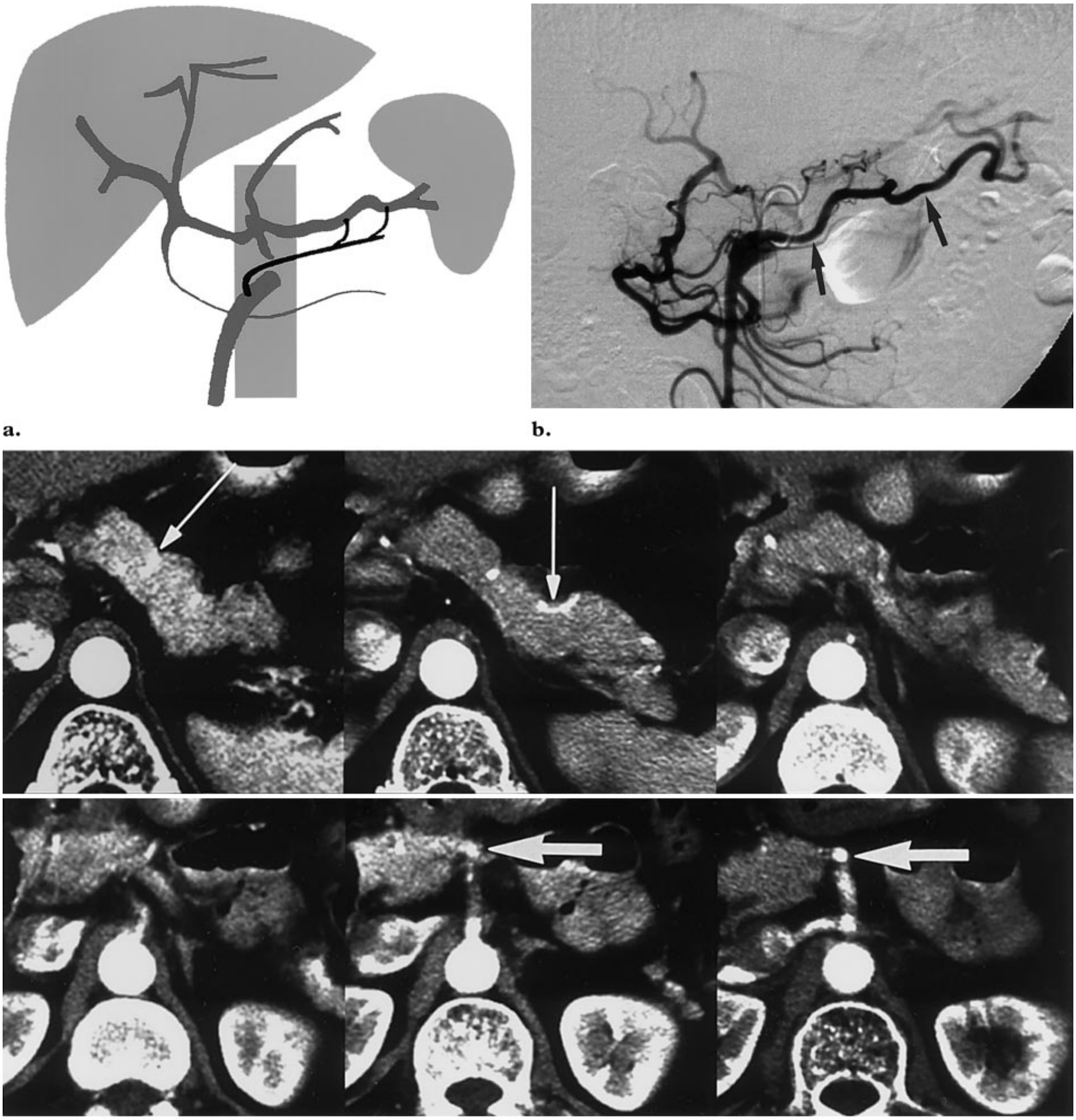

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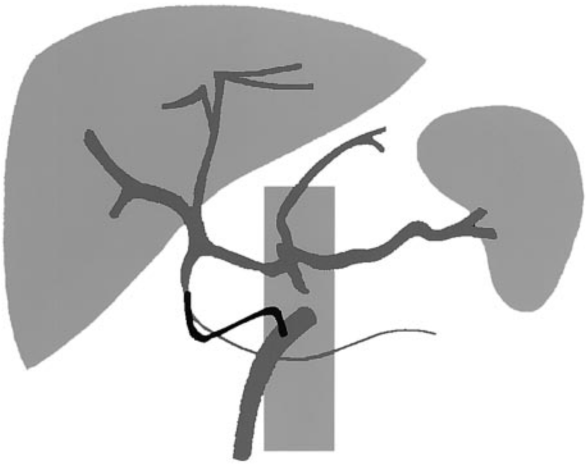
Figure 8. Transverse pathway to the splenic artery via the dorsal pancreatic artery. **(a)** Drawing illustrates a transverse pathway via a transverse pancreatic artery that arises from a dorsal pancreatic artery of SMA origin. **(b)** Superior mesenteric arteriogram shows retrograde filling of the splenic artery via a large transverse pancreatic artery (arrows) that arises from the dorsal pancreatic artery. The transverse pancreatic artery anastomoses with multiple pancreatic branches of the splenic artery. Hypertrophic pancreaticoduodenal arcades are also noted. **(c)** Serial spiral CT scans show unusually hypertrophic arteries (thin arrows) within the parenchyma of the body and tail of the pancreas, which anastomose with the dorsal pancreatic artery (thick arrows).

SMA such as the jejunal artery (Fig 6), the inferior pancreaticoduodenal artery, the middle colic artery, an aberrant right hepatic artery that arises from the SMA, or a common trunk of the jejunal and inferior pancreaticoduodenal arteries. In two of our patients, a longitudinal pathway via the middle colic artery plays a major role in collateral circulation (Fig 7). In two transverse pathways,



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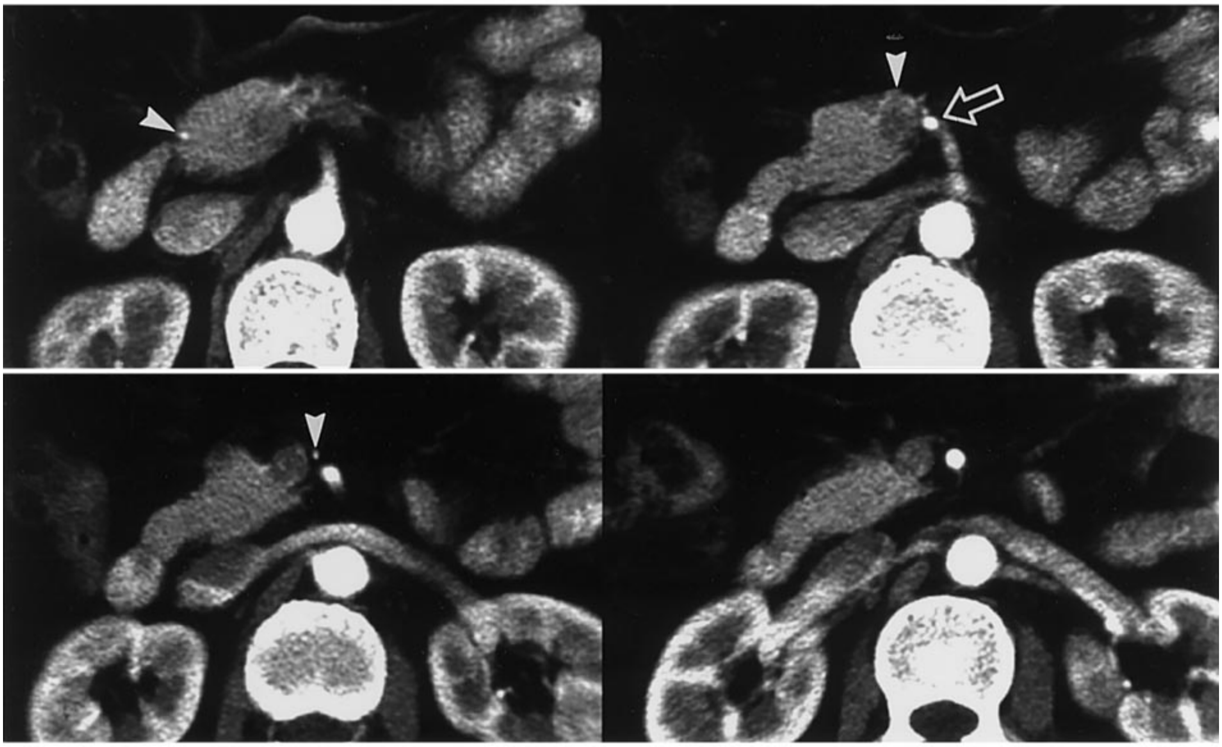

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Figure 9. Transverse pathway to the gastroduodenal artery via the dorsal pancreatic artery. **(a)** Drawing illustrates a transverse pathway between the dorsal pancreatic artery and gastroduodenal artery. **(b)** Superior mesenteric arteriogram shows retrograde filling of the celiac branches via a collateral vessel between the gastroduodenal artery and a large dorsal pancreatic artery of SMA origin (thick arrows). Another collateral pathway via a transverse pancreatic artery (thin arrows) is also seen. **(c)** Serial spiral CT scans show the anterior pancreaticoduodenal artery (arrowheads), which anastomoses with the dorsal pancreatic artery (arrow).

the dorsal pancreatic artery that arises from the SMA contributes collateral circulation through the right branch to the gastroduodenal artery (Fig 8) or through the left branch (transverse pancreatic artery) to the splenic artery (Fig 9).

At spiral CT, the dorsal pancreatic artery is seen to ascend vertically from the SMA or descend from the splenic, celiac, or common hepatic artery and is posteromedial or medial to the superior mesenteric vein. Sometimes, spiral CT demonstrates in detail its pathway via the branches of the SMA (Figs 6–9).

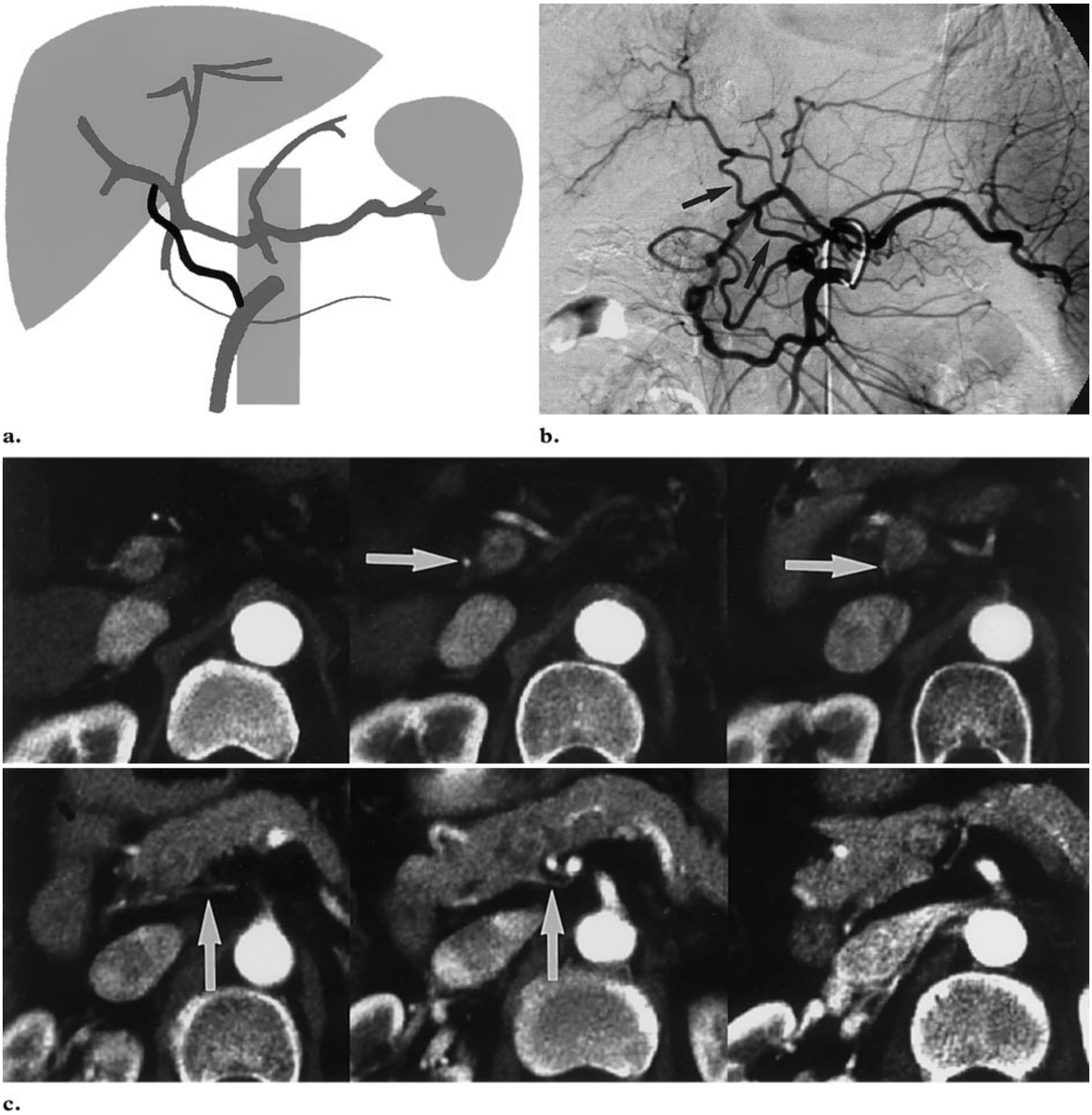


Figure 10. Communicating channel between the right hepatic artery and the SMA. **(a)** Drawing illustrates a communicating channel between the SMA and the right hepatic artery. **(b)** Superior mesenteric arteriogram shows a tortuous artery (arrows) that arises from a dorsal pancreatic artery of SMA origin, which supplies most of the right hepatic artery. Other collateral vessels via a pancreaticoduodenal artery and transverse pancreatic artery are also noted. **(c)** Serial spiral CT scans show the anatomic environment of the communicating channel (arrows), which arises from the dorsal pancreatic artery and then passes through the portocaval space.

Communicating Channel between the Right Hepatic Artery and the SMA

In six patients, we saw a direct communicating channel between the right hepatic artery and the SMA ($n = 4$) or a dorsal pancreatic artery of SMA origin ($n = 2$). At spiral CT, this communicating channel was located in the portocaval space and had an anatomic course identical to that of a variant right hepatic artery that arises from the SMA (16). Consequently, we view it as a remnant of the embryonic channel that forms this aberrant right hepatic artery (Fig 10). Occasionally, this channel can be visualized at conventional angiography in a patient without celiac axis stenosis (Fig 5).

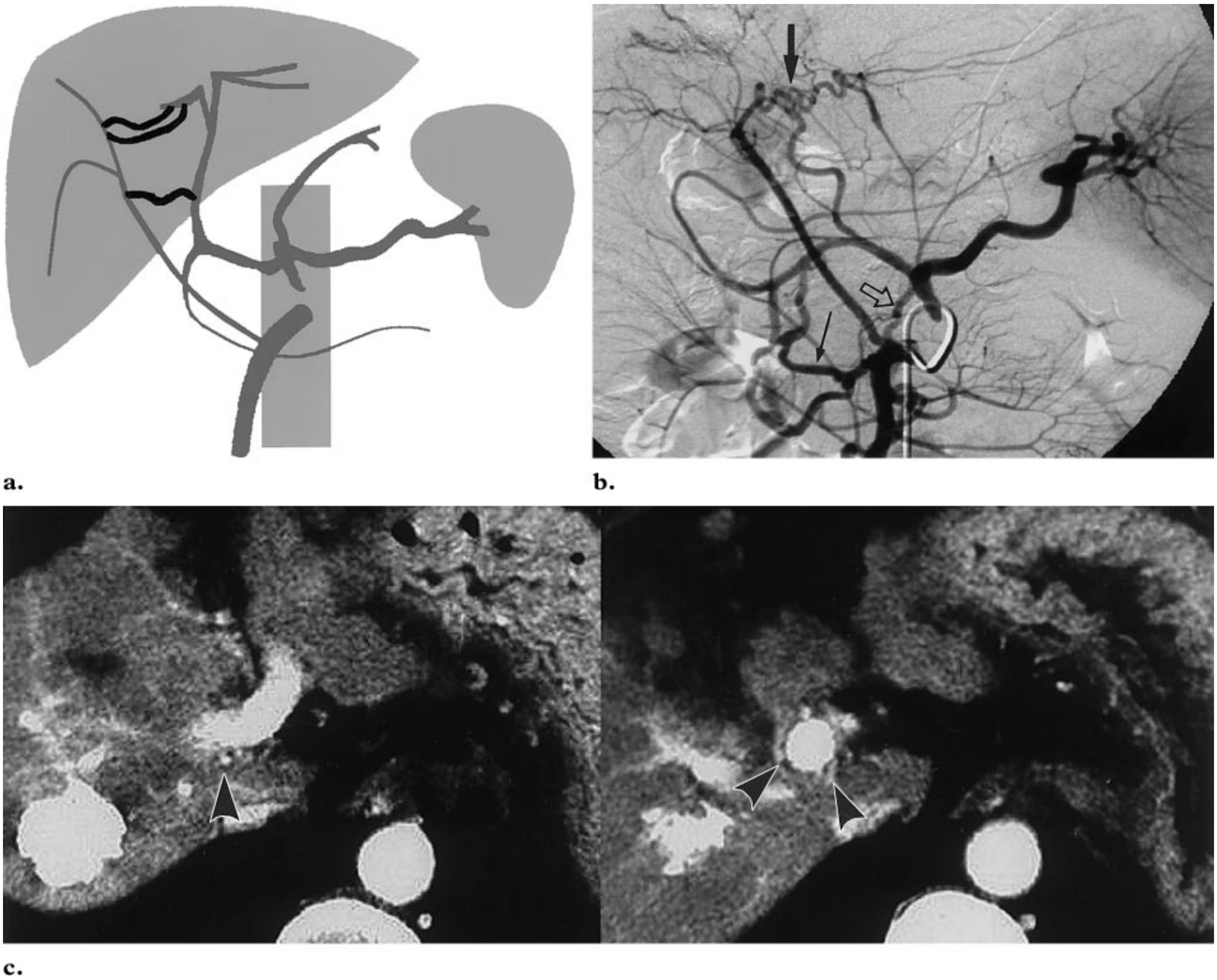


Figure 11. Intrahepatic interlobar collateral vessels in a patient with an aberrant right hepatic artery that arises from the SMA. **(a)** Drawing illustrates interlobar collateral vessels between the left hepatic artery and a right hepatic artery that arises from the SMA. **(b)** Superior mesenteric arteriogram reveals tortuous interlobar collateral vessels (thick solid arrow) between a right hepatic artery of SMA origin and a left hepatic artery of celiac origin. Other collateral vessels via a pancreaticoduodenal arcade (thin solid arrow) and the dorsal pancreatic artery (open arrow) are also seen. **(c)** Serial spiral CT scans show fine collateral vessels around the portal vein (arrowheads).

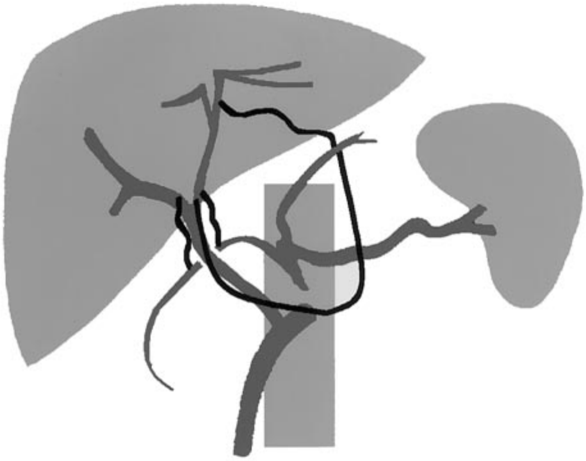
Collateral Pathways in Patients with Hepatic Artery Variation

Anatomic variation in the site of origin of the hepatic artery is the main cause for the development of unusual collateral routes (17). Charnsangavej et al (18) described the development of interlobar or intersegmental intrahepatic collateral vessels in patients who underwent coil embolization of an aberrant hepatic artery from the SMA or left gastric artery for intraarterial chemotherapy. In patients with a variant right hepatic artery that arises from the SMA, celiac axis stenosis causes hepatic arterial flow that is hemodynamically similar to that seen in patients who have undergone embolization of an aberrant hepatic artery.

The 13 patients in our retrospective analysis with a variant hepatic artery that arises from the SMA had unique collateral pathways that were not found in patients with normal hepatic artery anatomy. The pathways of collateral circulation vary depending on the type of hepatic artery variation.

Interlobar collateral vessels develop between a variant right hepatic artery that originates from the SMA and the left hepatic artery. At spiral CT, these collateral vessels appear as multiple small arterial structures around the portal vein (Fig 11).

In cases of variant proper and common hepatic arteries that originate from the SMA, there are three possible collateral pathways to the branches of the gastrosplenic trunk. The peribiliary arterial plexuses in the hepatoduodenal ligament are hypertrophic and connect the central hepatic and gastroduodenal arteries in the case of a variant proper hepatic artery that arises from the SMA



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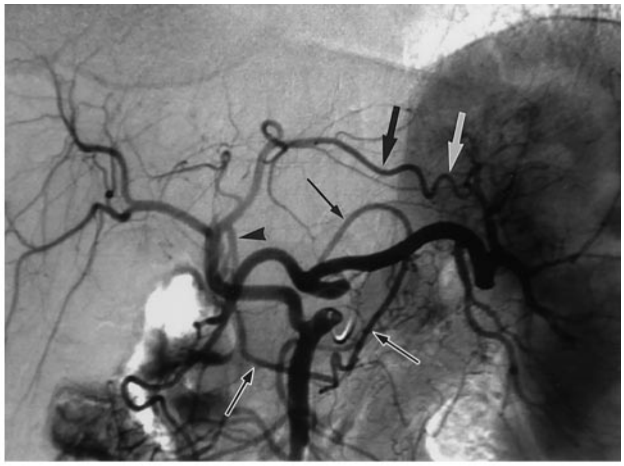

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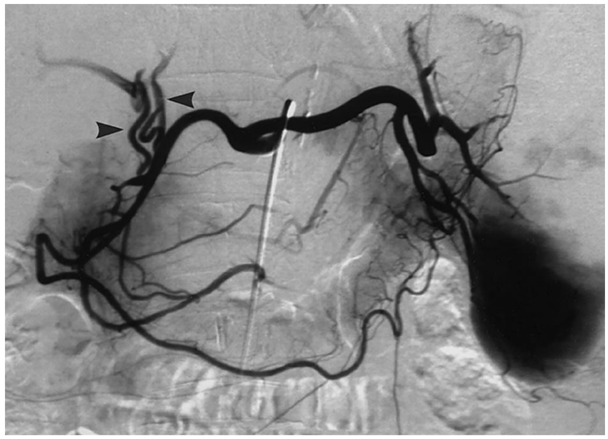

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Figure 12. Collateral circulation in a patient with a variant proper hepatic artery that arises from the SMA. **(a)** Drawing illustrates the collateral routes produced by such a variant. **(b)** Superior mesenteric arteriogram shows collateral vessels through the peribiliary arterial plexuses (arrowhead), a left hepatic to left gastric arterial anastomosis (thick arrows), and a right gastric to left gastric arterial anastomosis (thin arrows). **(c)** Celiac arteriogram obtained after partial splenic embolization clearly shows contrast material filling of the proximal right and left hepatic arteries via hypertrophic peribiliary plexuses (arrowheads) from the gastroduodenal artery.

(Fig 12). In both variant proper hepatic arteries and variant common hepatic arteries, a hypertrophic arcade between the right and left gastric arteries is noted. These patients also have anastomoses and collateral circulation between the left hepatic and left gastric arteries (Figs 12, 13). About 2%–14% of the general population have an accessory left gastric artery that arises from the left hepatic artery (19,20). An aberrant left hepatic artery is seen to arise from the left gastric artery in 11%–17% of the general population (21,22). All of these anastomoses between the left hepatic and left gastric arteries occur via the lesser omentum.

Conclusions

The most common and important collateral vessels from the SMA in patients with celiac axis stenosis are the pancreaticoduodenal arcades and the dorsal pancreatic artery. A communicating channel between the right hepatic artery and the SMA can be a route for collateral circulation. Hepatic artery variations induce unique collateral vessels that are related to the pattern of variation. Major collateral pathways in patients with celiac axis stenosis can be identified with spiral CT, and this imaging modality may provide important information prior to surgical or interventional procedures.

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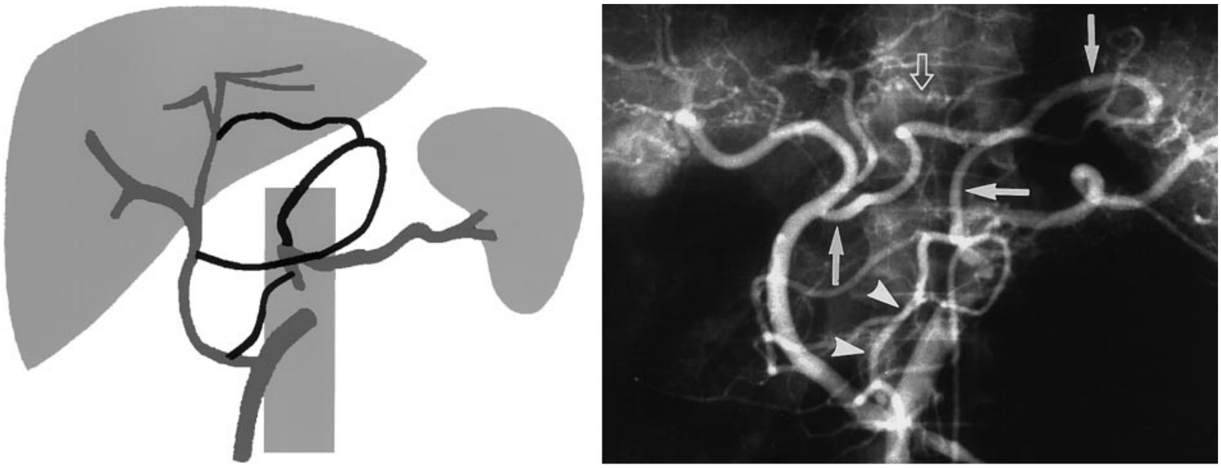

a. b.

Figure 13. Collateral circulation in a patient with a variant common hepatic artery that arises from the SMA. **(a)** Drawing illustrates the collateral routes produced by such a variant. **(b)** Superior mesenteric arteriogram shows right gastric to left gastric (solid arrows) and left hepatic to left gastric (open arrow) arterial anastomoses. Another collateral vessel is seen that arises from the dorsal pancreatic artery (arrowheads).

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