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REVIEW ARTICLE

The vascular anatomy of the ligaments of the liver: gross anatomy, imaging and clinical applications

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ABSTRACT

The vessels that communicate between the liver and adjacent structures require bridges between them. The bridges comprise the ligaments of the liver as follows: the falciform ligament, right and left coronary ligaments, lesser omentum including the hepatogastric ligament and hepatoduodenal ligament. Each ligament has specific communications between the intrahepatic and extrahapetic vessels. The venous communications called as the portosystemic shunt would become apparent in patients with portal hypertension, intrahepatic portal vein thrombosis and superior vena cava syndrome. The location of the venous communication is related to the pseudolesion or focal enhancement of the liver demonstrated on the CT scan. The arterial communications called collateral vascularization would become apparent in patients with hepatic artery occlusion, especially post-transhepatic arterial embolization, or in patients with the hepatic tumour abutting diaphragm. The knowledge of these collateral arteries is necessary to accomplish the effective transarterial embolization for the hepatic tumours. We reviewed the vessels in these ligaments using contrast-enhanced CT scans and angiography and discussed the clinical applications. Cadaver dissection photos were included as supplementary images for readers to recognize the actual spatial anatomy of the vessel in each ligament.

INTRODUCTION

The various extrahepatic vessels, such as the aberrant hepatic arteries and paraumbilical vein (PUV), have been reported in terms of anatomical and radiological findings. The vessels that communicate between the liver and adjacent structures require bridges between them. The "bridges" comprise the various ligaments of the liver, including the falciform ligament (FL), the coronary ligament and the lesser omentum. Charnsangavej et al[1] indicated that it was likely that extrahepatic collaterals developed through these ligaments and entered the liver in patients with occluded hepatic arteries.

We review and demonstrate the vessels that run through these ligaments (Table 1) using radiological images obtained *via* contrast-enhanced CT (CECT) scans and angiography, as well as discuss the clinical applications, such as extrahepatic artery embolization. The development of the microcatheter and embolic materials enables infusion or embolization through the collateral pathways to the liver; thus, anatomical information regarding the various ligaments may be crucial for the treatment of liver tumours. Cadaver dissection photos were also included as supplementary images for readers to recognize the actual spatial anatomy of the extrahepatic vessel and adjacent structures in the various ligaments.

FALCIFORM LIGAMENT

The liver arises in the fourth week as a diverticulum from the ventral surface of the foregut[2] and subsequently grows ventrally and cranially into the septum transversum. As the ventral mesentery encloses the liver, it gives rise to its fibrous capsule and mesenterial supports (ligaments). The mesenterial attachment of the liver to the anterior abdominal wall is referred to as the FL because it extends caudal, from the diaphragm to the umbilicus, in a sickle-shaped fold.[3]

Superior group

Vein: superior falciform ligament vein

Vascular anatomy Sappey[4] described two distinct groups of veins in the FL, including the superior and inferior veins. According to his description, the superior group is composed of the veins that run down into the median part of the diaphragm towards the convex surface of the liver

Table 1. The list of the vessels related to the ligaments around the liver. Each vessel communicated with the liver parenchyma or the intrahepatic vessels such as the hepatic artery, portal vein and hepatic vein through the hepatic ligaments

Ligaments	Subgroup	Vein	Artery
Falciform ligament	Superior	ITV	ITA
		IPV	IPA
	Inferior	UV, PUV	HFLA
Coronary ligament	Left	LIPV, LPCPV	LIPA
		LICV	
	Right	RIPV	RIPA
		RICV	RICA
Lesser omentum	Hepatogastric ligament	Ab-LGV	Ac-LGA
			Ab-LHA
			Ac-LIPA
	Hepatoduodenal ligament	Ab-RGV	RGA
		Cavernous transformation	Pericholedochal plexus

Ab-LGV, aberrant left gastric vein; Ab-LHA, aberrant left hepatic artery; Ab-RGV, aberrant right gastric vein; Ac-LGA, accessory left gastric artery; Ac-LIPA, accessory left inferior phrenic artery; HFLA, hepatic falciform ligament artery; IPA, inferior phrenic artery; IPV, inferior phrenic vein; ITA, internal thoracic artery; ITV, internal thoracic vein; LICV, left intercostal vein; LIPA, left inferior phrenic artery; LIPV, left inferior phrenic vein; LPCPV, left pericardiacophrenic vein; PUV, paraumbilical vein; RGA, right gastric artery; RICA, right intercostal artery; RICV, right intercostal vein; RIPA, right inferior phrenic artery; RIPV, right inferior phrenic vein; UV, umbilical vein.

and are subsequently distributed into the lobules to which the FL adheres (Figure 1). However, the radiological reports of the veins of Sappey have been limited,[5] possibly because of the lack of recognition of these veins.

Clinical imaging and application

Portosystemic shunt in patients with portal hypertension Compared with the inferior group of veins, such as the PUV, the prevalence of the superior group of veins demonstrated *via* CECT was substantially less (Figure 2). CT during arterial portography (CTAP) may demonstrate these veins better than CECT because the branches of the portal vein can be selectively opacified. The peripheral branch of the left portal vein penetrates the superior surface of the liver, runs in the superior portion of the FL and subsequently drains into the internal thoracic vein.

Focal enhancement of the liver in patients with superior vena cava syndrome The localized area of increased uptake (hotspot) on ^{99m}Tc sulfur colloid liver scans was reported in the 1970s, especially in patients with superior vena cava obstruction. The hotspot was typically located anteriorly and medially to the gall bladder fossa.[6] However, an unusual hotspot location was also reported in the anterior superior margin of the liver.[7] The similar phenomenon of "liver hot spot" on nuclear medicine studies has been reported as "focal enhancement" of the liver on the CECT (Figure 3).[8]

Artery: superior falciform ligament artery

Vascular anatomy According to our anatomical research,[5] the terminal branches of the internal thoracic artery other than the epigastric and musculophrenic branches consisted of (1) the branch to the superior portion of the FL, the superior FL arteries (Figure 1), and (2) the xiphoid branch (ensiform vessels[9]) extending into the properitoneal fat. The superior FL arteries spread along the superior surface of the liver and communicate with the intrahepatic arteries.

Clinical imaging and application

Extrahepatic collateral supply of hepatocellular carcinoma at the superior aspect of the liver Although some researchers[10] have stated that hepatocellular carcinoma (HCC) at the superior aspect of the right lobe of the liver was supplied by the diaphragmatic branch of the internal thoracic artery, the superior aspect of the liver is not directly attached to the diaphragm; instead, it is covered with the superior portion of the FL. Therefore, we assume that the diaphragmatic branch does not directly supply the HCC; instead, the internal thoracic artery specifically supplies the HCC *via* the superior FL arteries.

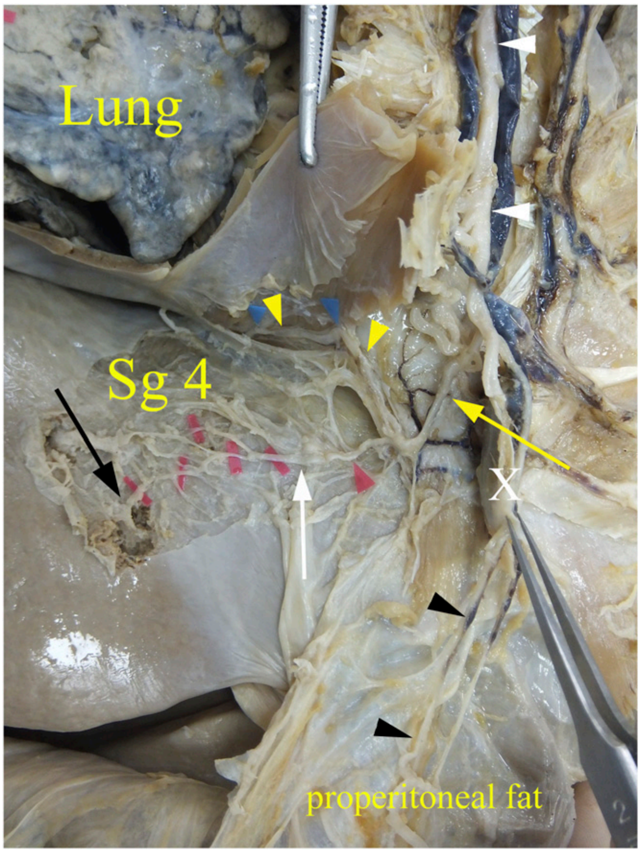
Although the prevalence of the extrahepatic collateral supply of the HCC by the left inferior phrenic artery (LIPA) is low,[11] the LIPA also supplies the tumour located at the superior aspect of the right lobe of the liver (Figure 4).

Inferior group

Vein: umbilical vein and paraumbilical vein

Vascular anatomy The inferior group is composed of a series of veins that originate from the subumbilical part of the front abdominal wall towards the hepatic fissure. The latter, which are included in the part of the FL that encloses the umbilical vein (UV) cord, communicate from their origin with the epigastric veins and cutaneous veins of the abdomen.[4] Lin et al[12] investigated the UVs and PUVs using 22 post-mortem specimens of the liver *via* a silicon rubber technique with Microfil

Figure 1. The falciform ligament (FL) in a cadaver: the anterior thoracic and abdominal walls were removed to show the anterior surface of the left lobe of the liver and FL. Then, the superior portion of the FL was dissected to reveal the vessels in it. The vessels (white arrow) in the superior portion of the FL anastomosed with the internal thoracic artery and vein (yellow arrow) and the inferior phrenic artery and vein (yellow arrowheads). These vessels also anastomosed with the vessel (black arrow) of the liver. The xiphoid branches (black arrowheads) were also demonstrated in the properitoneal fat. These branches anastomosed with the inferior group of vessels such as the hepatic FL artery and the paraumbilical vein. X, xiphoid process. For colour image see online.



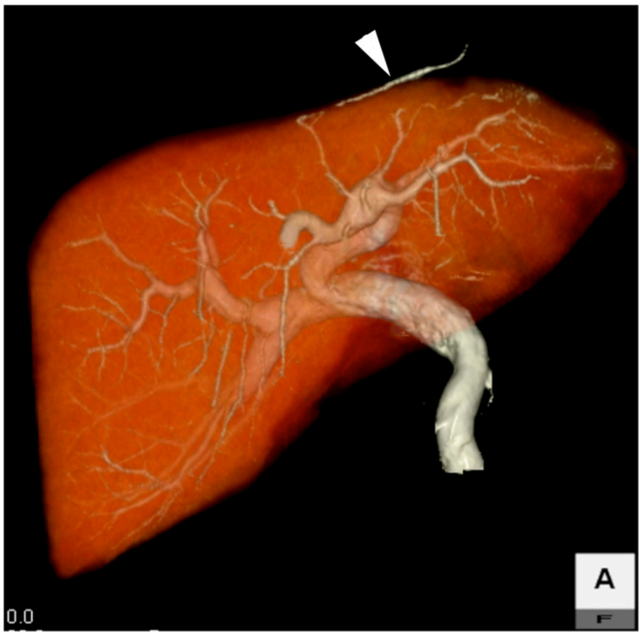
(Flow Tech Inc., Carver, MA). According to their findings, the UV was filled with Microfil in 7 (31.8%) of 22 cases.

Clinical imaging and application

Recanalized umbilical vein and paraumbilical vein in patients with portal hypertension The obstructed UV is typically exhibited as a small round-shaped structure that arises from the bifurcation (the umbilical portion) of P3 and P4 of the left portal vein on an axial CT scan, which is typically not enhanced by the contrast material. However, when the UV was recanalized, this round-shaped structure was enhanced on CECT (Figure 5) in patients with portal hypertension.

In contrast, the PUVs are recognized as the dilated veins that emerge from the liver surface adjacent to the attachment of the FL, which is connected to the intrahepatic left portal vein. The recanalized UV runs towards the umbilicus, but the PUVs can run freely in the FL; thus, the direction of the PUVs varies.

Figure 2. A portosystemic shunt through the superior group of vein in a patient with portal hypertension: the volume-rendered image obtained by CT during arterial portography—the vessel (arrowhead) derived from the left portal vein ran towards the internal thoracic vein in the superior portion of the falciform ligament (FL). Although this portosystemic shunt is rare, the vessel is morphologically identical to the vessel in the superior portion of the FL demonstrated in Figure 1.



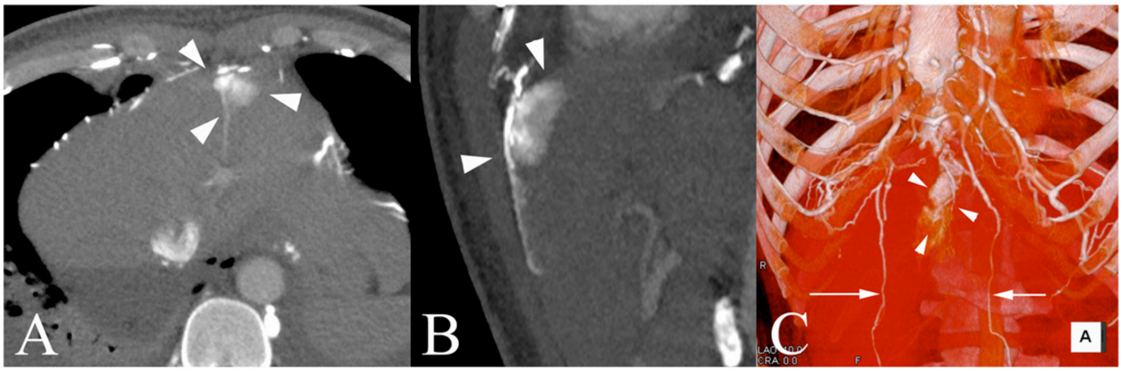
Hepatic pseudolesion adjacent to the falciform ligament on contrast-enhanced CT Hypoattenuating hepatic pseudolesions around the FL have been demonstrated, especially in the portal-dominant phase, in approximately 20% of cases who underwent CECT, and the inferior veins of Sappey that supply these lesions were depicted in 27% of cases.[13]

Focal enhancement of the liver in patients with superior vena cava syndrome As mentioned above, the typical hotspot was located anteriorly and medially to the gall bladder fossa (Figure 6).[6] The volume-rendered image based on the multidetector raw CT can demonstrate the exact pathway of the collateral vessels to the liver.

Artery: hepatic falciform ligament artery

Vascular anatomy As previously described, one of the terminal branches of the internal thoracic artery is the xiphoid branch that extends into the properitoneal fat. This artery has also been reported as the ensiform artery as a direct medial branch of the internal thoracic artery by Nordenson.[14] There is an anastomosis between the xiphoid artery and the hepatic falciform ligament artery (HFLA) in the FL, which has been demonstrated by angiography.[15] According to Michel's

Figure 3. The focal enhancement of the liver through the superior group of veins in a patient with superior vena cava (SVC) syndrome. (a) The axial image of contrast-enhanced CT (CECT): the focal enhancement of the anterior aspect (arrowheads) of the left lobe of the liver was noted. The SVC was obstructed by the mediastinal invasion of lymphoma; thus, the contrast material injected through the left arm ran through the bilateral internal thoracic veins and drained into the liver *via* the veins of the superior portion of the falciform ligament. (b) The sagittal image of CECT: the focal enhancement was located at the superior and anterior aspect (arrowheads) of the liver. (c) The volume-rendered image: the dilated collateral vessels, such as the internal thoracic veins, intercostal veins and superior epigastric veins (arrows), were demonstrated. Focal enhancement (arrowheads) was noted at the superior and anterior aspect of the liver. Compared with Figure 6c, the xiphoid veins in the properitoneal fat were not demonstrated.



description,[16] the HFLA was recognized in 38 (69%) of 55 cadavers. However, the HFLA was recognized in 2–52%[17–19] who underwent celiac or hepatic angiography.

Clinical imaging and application

Dermatitis caused by hepatic falciform ligament artery infusion Since William et al[20] reported three cases with supraumbilical skin rashes during hepatic artery infusion chemotherapy, the HFLA has drawn attention from interventional radiologists. The HFLA may supply the skin around the navel (Figure 7); thus, accidental infusion of the chemotherapy agent during arterial chemoinfusion therapy or transarterial chemoembolization may cause a skin rash or necrosis. Therefore, prophylactic coil embolization has been recommended prior to hepatic artery chemoinfusion or chemoembolization.[17]

The schema of the vascular anastomosis around the FL is provided (Figure 8).

CORONARY LIGAMENT

The peritoneum reflects from the diaphragm to the liver surface and leaves a "bare area" on the liver and diaphragm. The attachment of the liver to the diaphragm has the outline of a crown, which is referred to as the coronary ligament.[21]

Left triangular ligament

The left lobe of the liver is held against the diaphragm largely by the left triangular ligament; the free edge of the left triangular ligament is referred to as the appendix fibrosa hepatis.

Vascular anatomy

Gao et al[22] reported that the appendix fibrosa hepatis included the aberrant bile ducts in 80–89% cadavers, the rudimentary liver cells in 62–65% cadavers and blood vessels in all of the cadavers.

The LIPA and vein run behind the attachment of the left lobe of the liver, which has been referred to as the left bare area.

Figure 4. The pathway of the superior falciform arteries from the left inferior phrenic artery (LIPA). (a) Digital subtraction angiography of the celiac artery in a patient with the tumour located at the superior aspect of the right lobe of the liver: the dilated LIPA (arrow) ran towards the right and supplied the tumour through the superior falciform ligament (FL) arteries (arrowheads). (b) The lateral segment of the left lobe was removed and the stomach was pulled down towards the inferior to reveal the LIPA in the cadaver. The LIPA (arrows) anastomoses the superior FL arteries (arrowheads) at the superior aspect of the FL. It can be noted that this pathway is identical to the vessel demonstrated in the case of (a). D, diaphragm.

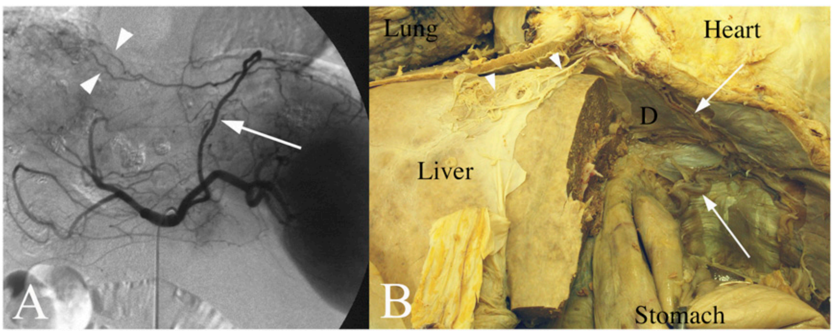
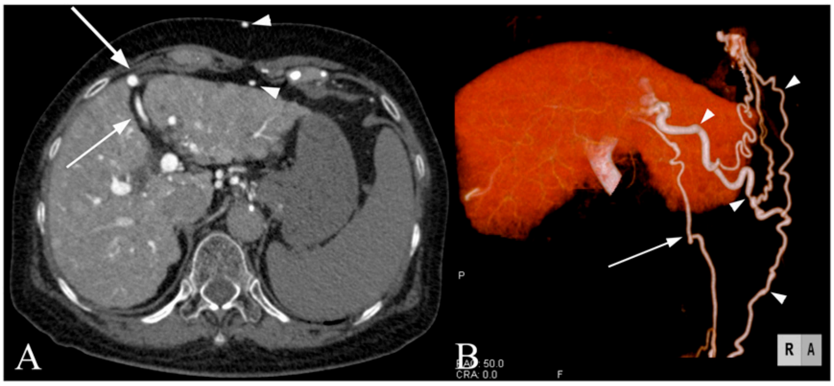


Figure 5. The recanalized umbilical vein (UV) and dilated paraumbilical veins (PUVs) in a patient with portal hypertension. (a) The axial image of CT during arterial portography: the cord-like structure (arrow) in the fissure for the falciform ligament (FL) is the recanalized UV. The dilated vein in front of this vein is the PUV (large arrowhead); its peripheral branches (arrowheads) in the properitoneal fat and subcutaneous tissue are also demonstrated in the anterior abdominal wall. (b) The volume-rendered image of the UVs and PUVs: there are two veins that run towards the anterior and inferior aspect of the abdominal wall. The PUV (arrowheads) ran anteriorly and branched off the ascending and descending veins. The xiphoid veins in the properitoneal fat drained into the internal thoracic vein. The superficial epigastric veins in the subcutaneous tissue are also demonstrated. In contrast, the recanalized UV (arrow) ran towards the umbilicus at the lower edge of the FL.



The actual anastomosis between the inferior phrenic vessels and the liver parenchyma can be observed in some cases (Figure 9).

Clinical imaging and application

Portosystemic shunt at the left bare area in patients with portal hypertension As the peripheral portal vein of superior lateral segment (Sg 2) extends to the liver surface, it can subsequently anastomose the inferior phrenic vein at the left bare area (Figure 10). CTAP can selectively demonstrate the portal veins; thus, it is easy to recognize the extrahepatic vessels that extend from the intrahepatic portal veins as the portosystemic shunt.

Unusual focal enhancement of the liver in patients with superior vena cava syndrome When the superior vena cava or brachiocephalic vein is obstructed, the contrast material injected through the left upper arm may primarily drain into the left pericardiacophrenic vein, which connects the inferior phrenic vein at the same portion where the left phrenic nerve penetrates the left hemidiaphragm. The left inferior phrenic vein typically drains into the left hepatic vein or the left renal vein. However, it drains into the liver *via* the left bare area through the left hepatic vein or the liver parenchyma in some cases (Figure 11).

Collateral artery for liver tumour abutting left diaphragm In some cases, the HCC located at the superior aspect of the left lobe of the liver has been supplied by the LIPA through the left bare area.[11,23]

Spontaneous bile leak in patients with obstructive jaundice Champetier et al[24] demonstrated the bile duct in the appendix fibrosa hepatis *via* the injection of latex into the bile duct. Waldschmidt et al[25] reported spontaneous

Figure 6. Focal enhancement of the liver through the inferior group of veins in a patient with left brachiocephalic vein occlusion. (a) The axial image of contrast-enhanced CT (CECT): the focal enhancement (arrowheads) was noted at the anterior aspect of the medial segment of the left lobe of the liver. The dilated xiphoid vein (arrow) in the properitoneal fat and the superficial epigastric vein (*) in the subcutaneous tissue were also demonstrated. (b) The sagittal image of CECT: the focal enhancement was located at the inferior and anterior aspect (arrowheads) of the liver. It can be noted that this was located caudal to the enhancement demonstrated in Figure 3b. (c) The volume-rendered image: the contrast material injected *via* the left upper arm ran into the internal thoracic vein, the xiphoid vein (arrow) in the properitoneal fat and the inferior falciform ligament vein and subsequently drained into the inferior aspect of the medial segment (arrowheads) of the left lobe of the liver.

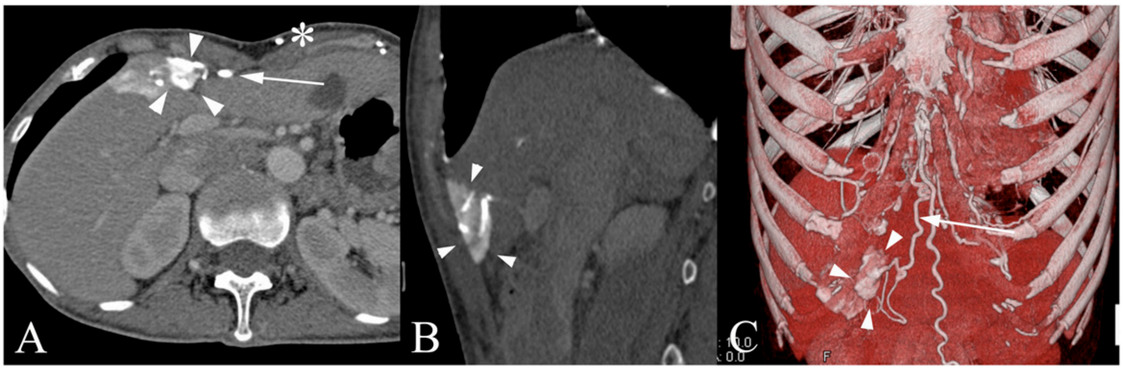
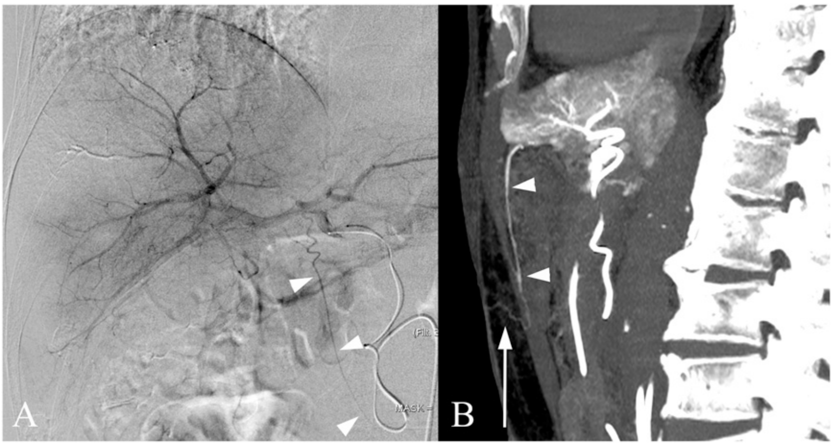


Figure 7. The hepatic falciform ligament artery (HFLA) supplying the subcutaneous tissue in a patient with hepatocellular carcinoma. (a) Common hepatic artery angiography: the HFLA (arrowheads) derived from the left hepatic artery was identified. The characteristics of the HFLA were the downward direction from the hepatic vein towards the umbilicus and the tortuosity. (b) The sagittal image of CT hepatic arteriography: the proximal portion (arrowheads) of the HFLA runs downward behind the linea alba and branches off (arrow) distally in the subcutaneous tissue. When the chemotherapy agent was infused into the HFLA, chemical dermatitis may occur in this particular patient.

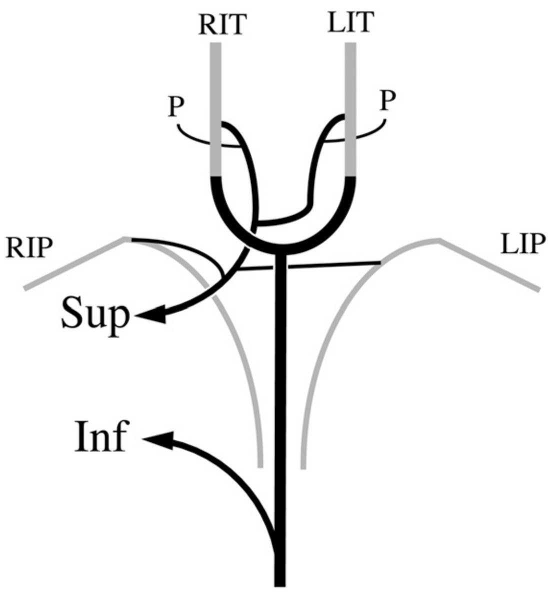


biliary peritonitis caused by the rupture of an aberrant bile duct of the appendix fibrosa hepatis.

Right coronary ligament

The right coronary ligament consists of the superior and inferior layers. The superior layer extends to the right and backwards, and it unites with the inferior layer to form the right triangular ligament.[26] The non-peritonealized surface, which is largely confined to the upper and posterior surface of the right lobe, is referred to as the right bare area.

Figure 8. The schema of the vascular communication at the falciform ligament (FL). The superior group of the FL (Sup) artery and vein communicated with the internal thoracic artery and vein and the inferior phrenic artery and vein. The inferior group of FL (Inf) artery and vein such as the hepatic FL artery and the paraumbilical vein communicated with the xiphoid branch of the internal thoracic artery and vein. LIP, left inferior phrenic; LIT, left internal thoracic vessels; P, pericardial fat; RIP: right inferior phrenic arteries; RIT: right internal thoracic vessels.



Vein

Clinical imaging and application

Portosystemic shunt at the right bare area in patients with portal hypertension Mori et al[27] reported an intrahepatic portosystemic shunt in four cases including three cases which were located in the posterior aspect of the right lobe of the liver, and the extrahepatic part of the shunt represented the inferior phrenic vein (Figure 12).

Artery

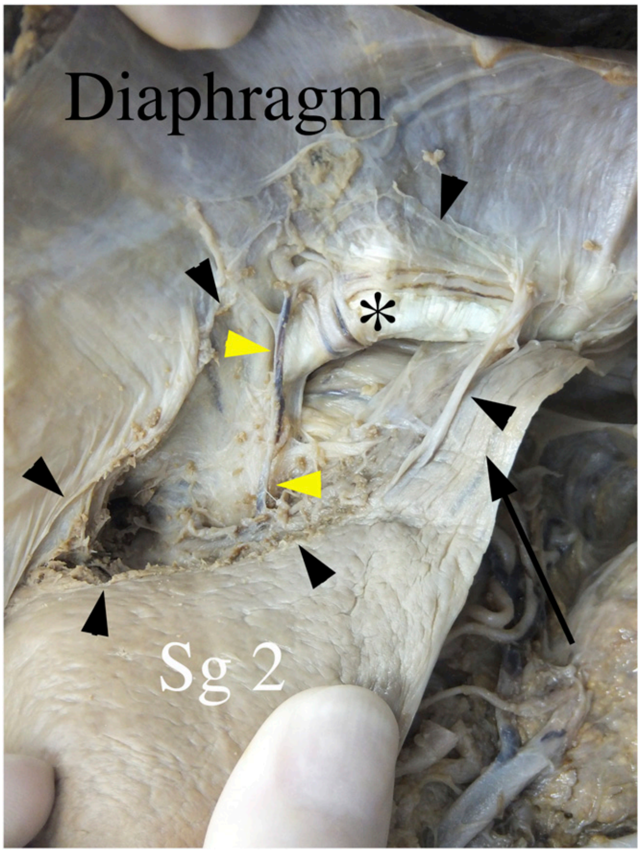
Vascular anatomy Reimann et al[28] demonstrated the anastomosis between the inferior phrenic artery and the hepatic arteries based on a cast anatomical study, and the largest part of the phrenicohepatic anastomoses was derived from the right inferior phrenic artery (RIPA). Segall[29] also demonstrated that the phrenic vessels were invariably more or less completely filled with emulsion in all cases in which the hepatic artery was injected.

Clinical imaging and application

Anastomosis between the inferior phrenic and hepatic arteries Takeuchi et al[30] reported that the liver was supplied by the RIPA (Figure 13a) in 85% and the LIPA in 83% of the patients who underwent temporary balloon occlusion of the proper hepatic artery. However, hepatic artery embolization for post-operative arterial haemorrhage following hepatobiliary pancreatic surgery may carry a substantial risk of ischaemic liver injury if a patient has no aberrant hepatic artery.[31]

Parasitic arterial supply for the hepatocellular carcinoma located at the posterior aspect of the liver When the HCC abuts the posterior surface of the right lobe of the liver (*e.g.* Sg 7), the RIPA may supply this tumour (Figure 13b). There is an

Figure 9. The left triangular ligament and appendix fibrosa hepatis in a cadaver. The abdominal wall was removed and the left triangular ligament (black arrowheads) and the appendix fibrosa hepatis (arrow) were dissected. The left inferior phrenic artery and vein (*) run behind the ligament at the abdominal surface of the diaphragm and there is a small branch (yellow arrowheads) between the liver parenchyma and the left inferior phrenic vein. It can be noted that some vessels that extend from the liver can be seen in the appendix fibrosa hepatis. For colour image see online.



anastomosis between the intercostal artery and the inferior phrenic artery[32] similar to the corresponding vein demonstrated in Figure 12. Therefore, the intercostal artery can also supply the HCC through this anastomosis.

LESSER OMENTUM

The portion of the mesentery that extends from the stomach and duodenum to the liver is the lesser omentum.[3] The hepatoduodenal ligament, which forms the border of the opening into the bursa (foramen of Winslow), contains the common bile duct (CBD), the hepatic artery and the portal vein.[26] The remainder is referred to as the hepatogastric ligament (Figure 14).

Hepatogastric ligament

Vein

Vascular anatomy The left gastric vein typically ends in the portal vein at the upper border of the proximal portion of the duodenum. Hochstetter[33] described a case with a left gastric vein that ran from the lesser curvature of the stomach to the lateral segment of the left lobe of the liver, which was subsequently referred to as an aberrant left gastric vein (ab-LGV). According to Miyaki et al,[34] the prevalence of the ab-LGV was 0.8% in his anatomical study.

Figure 10. A portosystemic shunt through the left bare area in a patient with portal hypertension. In this axial image of CT during arterial portography, the superior lateral branch of the left portal vein (thin arrow) extends to the left hemidiaphragm, anastomoses with the left inferior phrenic veins (arrowheads) and subsequently drains into the left intercostal vein (thick arrow). The web-like structure is one of the features of the inferior phrenic vessels.

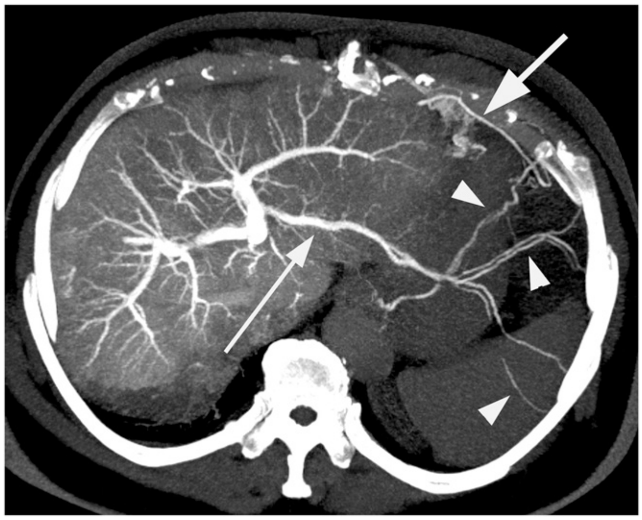


Figure 11. Focal enhancement of the liver through the left bare area in a patient with superior vena cava syndrome. In this axial CT image of contrast-enhanced CT, the contrast material injected *via* the upper arm ran into the left pericardiacophrenic vein and then the left inferior phrenic vein. The focal enhancement (arrowheads) of the posterior aspect of the left lobe of the liver was demonstrated, which was indicated by the anastomosis of the inferior phrenic vein and the intrahepatic portal vein through the left bare area.

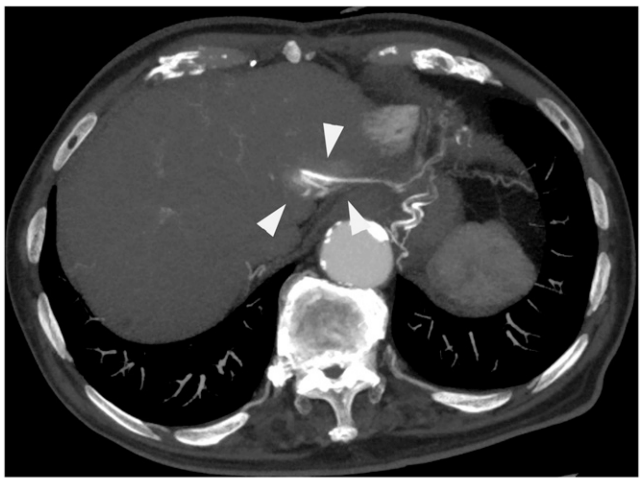
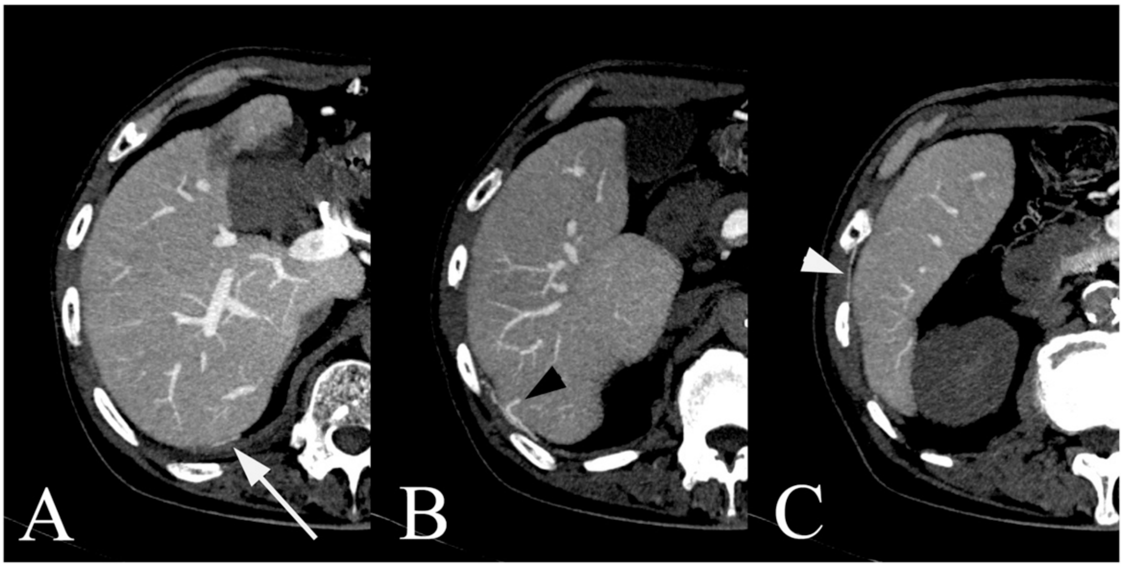


Figure 12. A portosystemic shunt between the intrahepatic peripheral portal vein and the inferior phrenic and intercostal veins through the right bare area in a patient with portal hypertension. (a)–(c) The axial images of CT during arterial portography: the peripheral branch of the right posterior portal vein (black arrowhead) reached the posterior surface of the liver and connected with the right inferior phrenic vein (arrow) and subsequently the right intercostal vein (white arrowhead).



Clinical imaging and application

Pseudolesion or portosystemic shunt through the ab-LGV Reichardt et al[35] reported the ab-LGV demonstrated by percutaneous transhepatic portography in four cases (Figure 15). Tajima et al[36] also reported a case with ab-LGV *via* left gastric artery (LGA) angiography. A pseudolesion in Sg 2 of the liver observed on CTAP owing to the hepatopetal flow of the ab-LGV was also reported.[37]

Artery

Vascular anatomy Michels[38] reported that the accessory left gastric artery (ac-LGA) [ac-LGA: the gastric artery derived from the left hepatic artery (LHA)] was typically smaller (3 mm) than its counterpart, the aberrant left hepatic artery (ab-LHA) (the LHA from the LGA) (3–5 mm). The prevalence of the ac-LGA and ab-LHA was 3% and 23%, respectively. The recognition of these vessels is crucial to avoid the gastric complications owing to the migration of the embolic materials, when the transarterial chemoembolization is planned.

Clinical imaging and application

Accessory left gastric artery that derives from the left hepatic artery Nakamura et al[39] reported that the ac-LGA was distributed on the gastric wall *via* angiography and it was

Figure 13. Arterial anastomosis between the intrahepatic artery and the inferior phrenic artery through the right bare area. (a) Celiac artery angiography in a patient with hepatic artery occlusion: as a hepatic artery aneurysm was embolized by the metallic coils, the proper and common hepatic arteries were occluded in this particular patient. The intrahepatic arteries (arrowheads) through the right inferior phrenic artery (RIPA) (arrow) were demonstrated. It can be noted that the RIPA and the left gastric artery make a common trunk. (b) RIPA angiography in a patient with hepatocellular carcinoma at the posterior (P) aspect of the right lobe of the liver: the tumour stain (arrowheads) was demonstrated between the P and superior (S) branches of the right inferior phrenic arteries.

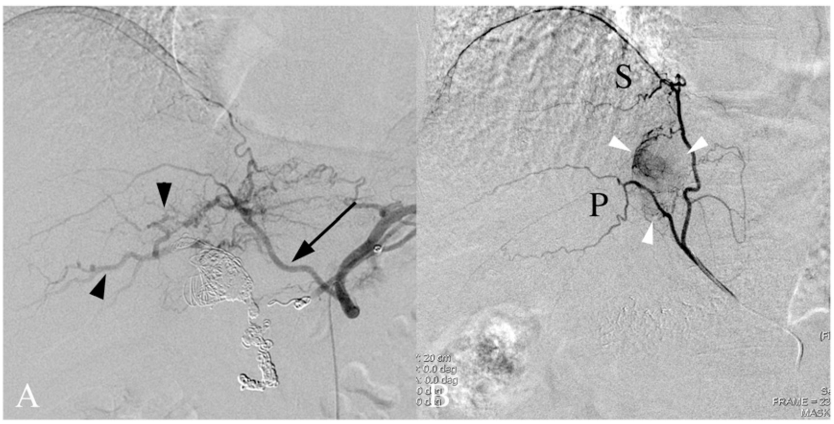
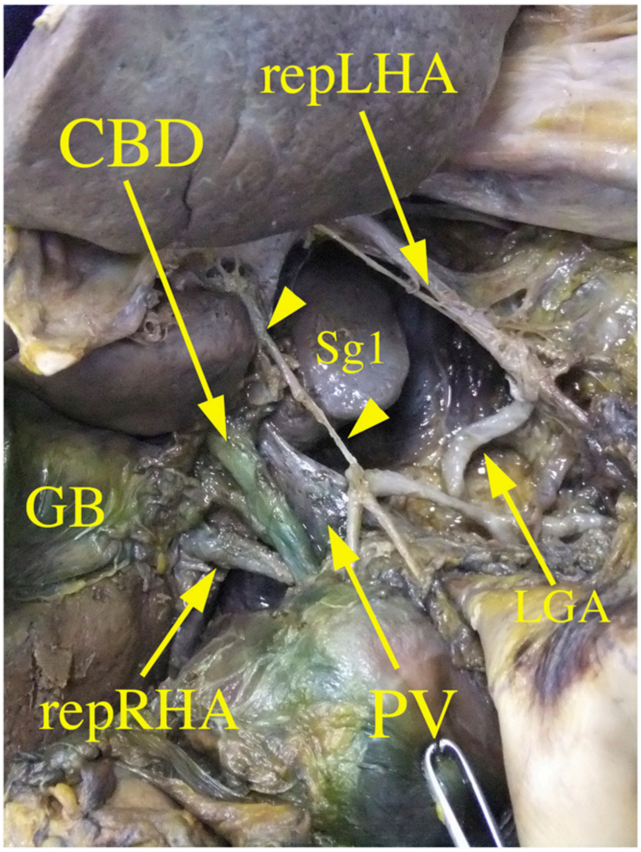


Figure 14. The replaced right and left hepatic arteries in the lesser omentum in a cadaver. The membranous portion of the lesser omentum was removed. The replaced left hepatic artery (repLHA) that arises from the left gastric artery (LGA) at the upper portion of the lesser omentum (hepatogastric ligament) was demonstrated. It can be noted that the caudate lobe (Sg 1) was identified behind the replaced LHA. The middle hepatic artery (arrowheads), the portal vein (PV), the replaced right hepatic artery (repRHA) and the common bile duct (CBD) were located at the right margin of the lesser omentum (hepatoduodenal ligament). GB: gallbladder.



identified in 14.2% of hepatic angiographies (Figure 16a). The gastric wall stain in the capillary phase of angiography may mimic a hepatic tumour. The ac-LGA is continuous with the LHA and appears tapered or tortuous near the cardia of the stomach.

Aberrant left hepatic artery that derives from the left gastric artery This type of hepatic artery anatomy was called as Michel's type II anatomy (Figure 16b).[38] Misrecognition of the aberrant left hepatic artery may cause bleeding when the lesser omentum is excised *via* laparoscopic gastrectomy. Furthermore, the division of the LGA at the proximal site to the replaced LHA may cause ischaemic liver damage.[40]

Aberrant left inferior phrenic artery that derives from the ab-LHA or accessory left gastric artery The LIPA typically arises from the celiac artery or the abdominal aorta (Figure 16c). Tanaka et al[41] reported that the LIPA rarely arises from the LHA, ab-LHA or ac-LGA. The proximal portion of the ac-LIPA is located in the hepatogastric ligament and the distal portion runs in front of the oesophageal hiatus and distributes into the left hemidiaphragm.

Hepatoduodenal ligament

The CBD typically lies at the right border of the hepatoduodenal ligament; the hepatic artery lies to the left of the CBD, and the portal vein is behind the CBD and the hepatic artery.[26] In addition to these vessels, there are various small vessels in this ligament as subsequently described.

Vein

Vascular anatomy The right gastric vein (sometimes referred to as the pyloric vein) is small and is identified in approximately 80%; it terminates in the anterior aspect of the portal vein in 75% of the cadavers.[42] Petren[43] indicated that the aberrant right gastric vein (also referred to as the suprapyloric vein) directly drained into the inferior aspect of the left lobe of the liver.

Vellar[44] described that the venous plexus on the surface of the supraduodenal common hepatic duct and CBD drained laterally into 3 o'clock (right) and 9 o'clock (left) marginal veins. Inferiorly, the venous plexus communicated with the posterior–superior pancreaticoduodenal vein. Superiorly, the venous plexus communicated with the portal vein branches.

Clinical imaging and application

Pseudolesion caused by the aberrant right gastric vein Takayasu et al[45] reported the communication between the RGV and the left portal vein *via* right gastric artery (RGA) angiography. Matsui et al[46] reported that the aberrant right gastric vein (Figure 17a) is the main cause of the pseudolesions in the posterior edge of medial segment of the left lobe (Sg 4) *via* CTAP.

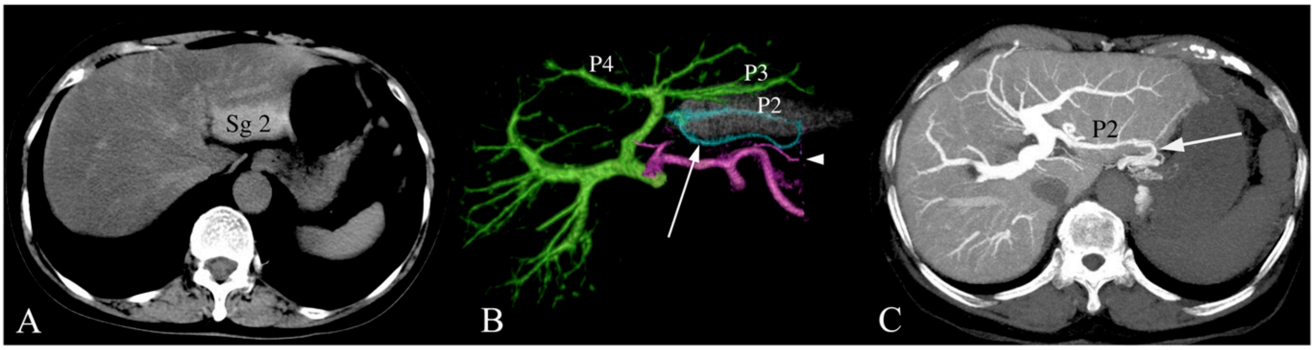
Cavernous transformation of the portal vein in patients with portal vein obstruction Ohnishi et al[47] reported that the multiple irregular winding veins in the porta hepatis that flow into the liver *via* portography in patients with portal vein occlusion and the cavernous transformation of the portal vein appear to be a compensatory phenomenon that counteracts for the loss of portal blood flow (Figure 17b).

Artery

Vascular anatomy The RGA is derived from the LHA (40.5%), the common hepatic artery (40%) and the gastroduodenal artery (GDA) (8%).[38]

Stapleton et al[48] reported that the bile ducts are surrounded by a vascular plexus supplied from the right hepatic artery and LHA, segmental arteries, GDA and accessory hepatic arteries, and the plexus is closely associated with the arteries that supply the caudate lobe (Sg 1).

Figure 15. Hepatopetal and hepatofugal portal venous flow in the aberrant left gastric vein. (a) The axial image of pre-contrast-enhanced CT in a patient with focal density abnormality in the liver: the fatty change of the liver, with the exception of the lateral superior segment (Sg 2) of the left lobe of the liver, was noted. (b) The volume-rendered image of contrast-enhanced CT: the vessel (arrow) that arises from the lesser curvature of the stomach drained into Sg 2 and anastomosed with the intrahepatic portal vein (P2), which was the aberrant left gastric vein (ab-LGV). As the fat is not metabolized in the stomach, the fat content of the blood in the ab-LGV is less than that of the blood in the superior mesenteric vein (SMV). The Sg 2 is especially supplied by the ab-LGV and the other segments are supplied by the SMV in this particular case. Therefore, the difference between the Sg 2 and the others in terms of the density on CT scan is demonstrated. The accompanying artery, the left gastric artery (arrowhead) was also noted. (c) Axial image of CTAP (maximum intensity projection) in a patient with portal hypertension: the aberrant left gastric vein (arrow) that arises from P2 drained into the stomach (hepatofugal portal flow) in a patient with portal hypertension. Note that the direction of the blood flow of ab-LGV in this patient was hepatofugal, which was opposite compared with that of the flow (hepatopetal portal flow) in the patient of (a).



Clinical imaging and application

Collateral pathways through the hepatoduodenal ligament in patients with arterial obstruction When the PHA was occluded, multiple collaterals in the periportal route developed from the GDA and pancreaticoduodenal arcades.[1] Thus, it was very difficult to embolize the hepatic artery for HCC in this specific situation. However, when the RGA was patent and branched off from the LHA, the catheter could be negotiated through the pathway between the LGA and RGA (Figure 18a).

Arterial complications from hepatic artery chemoinfusion catheters Fluid collections or soft-tissue densities along the hepatic artery (Figure 18b) seen on the CT scan should be recognized as possible complications, such as extravasation of the chemotherapeutic agent, periarterial oedema and arteritis in

Figure 16. CT appearance of the arteries that run through the hepatogastric ligament. (a) The accessory left gastric artery (ac-LGA) on the axial image of CT hepatic arteriography (CTHA): the enhancement of the stomach (*) was demonstrated by the accessory left gastric artery (arrow) derived from the left hepatic artery (LHA). As the ac-LGA derives from the proximal portion of the left haptic artery, the catheter should be advanced enough to avoid the ischaemic gastric complication owing to migration of the embolic materials to the ac-LGA, during hepatic artery embolization. (b) The aberrant left hepatic artery on the axial image (maximum intensity projection) of contrast-enhanced CT: the aberrant (replaced) left hepatic artery (arrow) that arises from the left gastric artery (arrowhead) was identified in front of the caudate lobe (*). The catheter should be advanced beyond the gastric branches, when the LHA embolization is attempted. (c) The accessory left inferior phrenic artery (LIPA) on the axial image of CTHA: the distribution of the artery (arrowheads) that arises from the LHA is not the stomach but the left hemidiaphragm; thus, this artery is defined as the accessory LIPA. The embolization of the LHA with this artery may cause the ischaemic change of the left diaphragm or left shoulder pain. It can be noted that the shape of the LIPA is similar to the corresponding veins demonstrated in Figure 10.

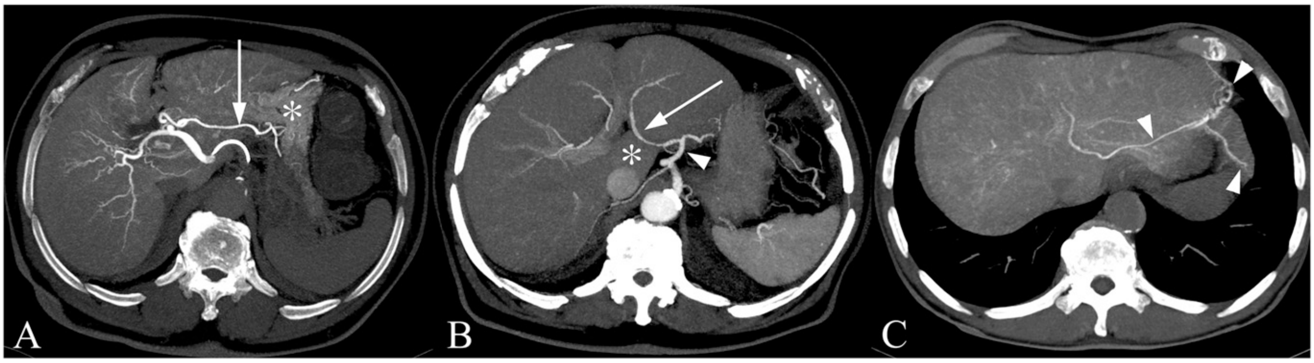
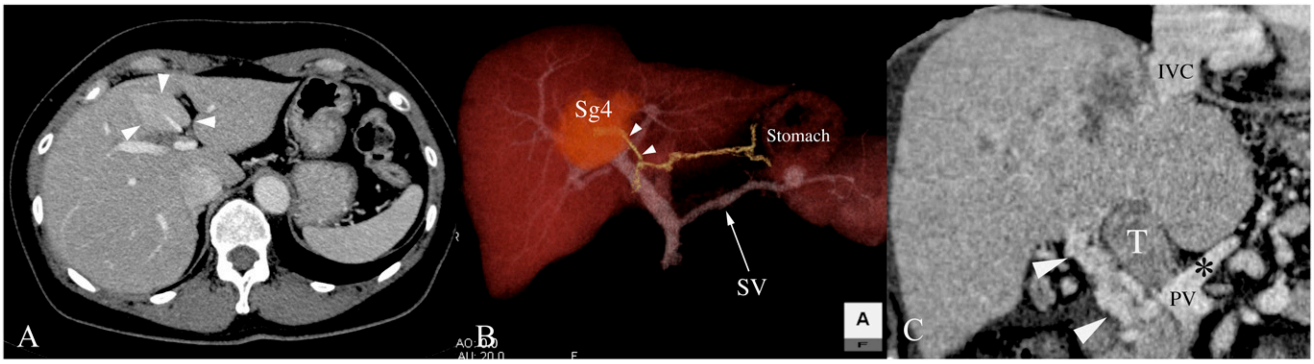


Figure 17. Veins that run through the hepatoduodenal ligament. (a) The axial image of contrast-enhanced CT (CECT) in a patient with focal abnormal density of the liver: the inferior and posterior aspects (arrowheads) of the medial segment of the left lobe were more enhanced than other segments, and the dilated vein that drained into this area can also be noted. (b) The volume-rendered image of CECT: the right gastric vein (RGV) usually drained into the portal vein; however, this RGV (arrowheads) drained into the inferior aspect of the medial segment (Sg 4) of the left lobe. Therefore, this vein was called as the aberrant RGV. (c) The coronal image of CECT in a patient with tumour thrombus in the main portal vein. As the tumour thrombus in the intrahepatic portal vein extended into the main portal vein (T), the cavernous transformation (arrowheads) as the hepatopetal collateral portal flow developed around the common bile duct located at the right aspect of the portal vein. It can be noted that the confluence between the left gastric vein (*) and the portal vein (PV) was patent. IVC, inferior vena cava; SV: splenic vein.

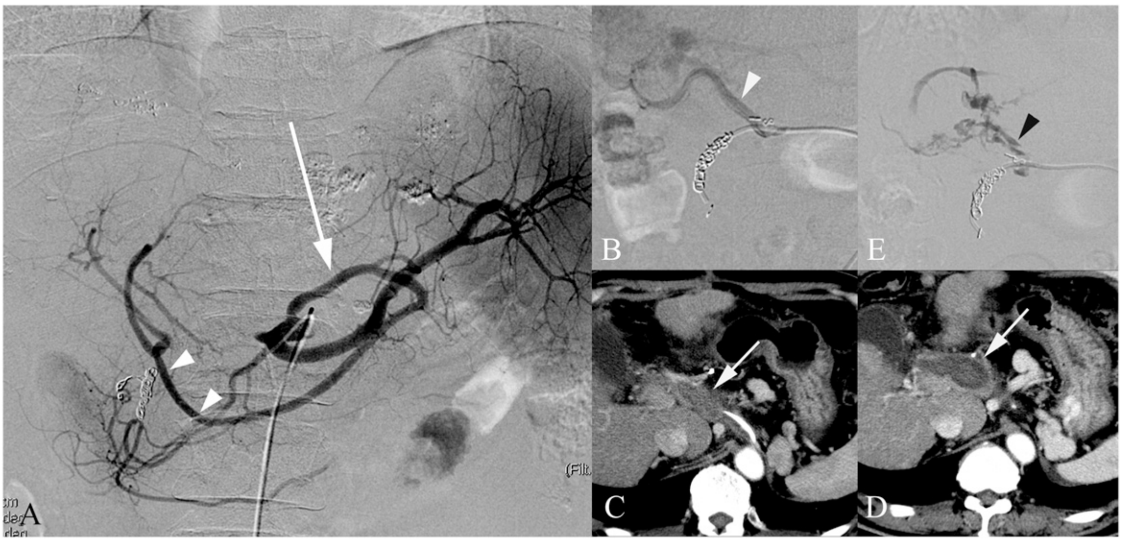


patients with a catheter placed into the hepatic artery for infusion chemotherapy.[49]

CONCLUSION

The knowledge of the vascular anatomy of the various hepatic ligaments helps to understand the mechanism of the development of the portosystemic shunt, pseudolesion and collateral vascularization to the liver or hepatic tumour. The multiplanar reformation and volume-rendering images obtained by multidetector CT provide precise anatomical information; therefore, these images are crucial to the strategy of further treatment, especially for patients with hepatic tumours.

Figure 18. Arteries that run through the hepatoduodenal ligament: (a) celiac artery angiography in a patient whose common hepatic artery was occluded by iatrogenic dissection. The right and left hepatic arteries were reconstituted by the right gastric artery (arrowheads) through the left gastric artery (arrow). Thus, we could perform hepatic artery chemoembolization through the gastric arteries. (b) Catheter complication in a patient with hepatic artery infusion catheter: the proper hepatic artery (white arrowhead) was demonstrated by angiography of the infusion catheter at the time of placement. (c, d) The CT scan revealed soft-tissue density (arrow) along the hepatoduodenal ligament at 2 months after the placement of infusion catheter and 2 months later, it gradually increased in size. (e) Angiography *via* the infusion catheter at 4 months after the placement demonstrated the extravasation (arrowhead) of the contrast material in the hepatoduodenal ligament, most likely due to the obstruction of the proper hepatic artery.



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