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REVIEW

The hepatic capsular arteries: imaging features and clinical significance

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Abstract

Background Although the anatomical features of the hepatic capsular arteries have been previously reported, the radiological and clinical importance of these arteries has not been well documented.

Imaging findings We injected barium sulfate into the intra- and extra-hepatic arteries in cadavers to investigate the hepatic capsular arteries. The web-like hepatic capsular arteries derived from the capsular branch of the peripheral hepatic arteries are called isolated arteries. There were anastomoses between the intra- and extra-hepatic arteries (inferior phrenic artery, superior falciform ligament artery, and cystic artery) through the hepatic capsular arteries.

Clinical significance We reviewed the radiology database and assessed clinical cases. When the hepatic artery is occluded, the collateral vessels, such as the inferior phrenic artery and the superior falciform ligament artery, develop via the hepatic capsular arteries at the right triangular ligament and falciform ligament, respectively. Bleeding from capsular arteries causes extensions of the subcapsular hematoma.

Conclusion The hepatic capsular arteries spread along the hepatic surface and constitute the vascular network throughout the liver. These arteries play an important role in collateral circulation in various clinical situations, as well as subcapsular hematoma.

Keywords Hepatic capsular artery · Isolated artery · Superior falciform ligament artery · Inferior phrenic artery

Introduction

The hepatic capsular arteries were described as a beautiful plexus covering the surfaces of the liver by Kiernan in 1833 [1]. Segall subsequently performed a barium injection study in 1923 and showed an intricate network of anastomoses that are present over the entire surface of the liver [2]. Although when injected with barium sulfate, the capsular arteries are easy to recognize at dissection and the intra-hepatic structure of the arteries is well visualized on a radiograph, the radiological features of the capsular arteries have not been well documented [3]. In a recent study, the terminal branch of the hepatic artery that penetrates the liver parenchyma and connects to the capsular arteries is called the isolated artery [4]. Subcapsular hematoma dissects the capsule from the hepatic parenchyma, rupturing the capsular arteries [5]. However, there are a few reports with respect to the clinical significance of the capsular arteries. We performed cadaveric studies for anatomical and radiological descriptions and showed clinical cases for clinical implications.

This pictorial review describes (1) the anatomical and radiological features of the hepatic capsular arteries and the isolated arteries using a barium injection study and (2) the clinical significance of the hepatic capsular arteries as various forms of collateral circulation, as well as subcapsular hematoma.

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Materials and methods

Cadaveric studies

The surface of the liver is covered with a fibrous capsule. The capsule was manually detached from the liver parenchyma and observed macro- and microscopically. We exposed the right or left hepatic arteries at the hepatic hilum, punctured these arteries, inserted 4–5 Fr catheters, and injected barium sulfate suspension (79% w/v) into the hepatic arteries in four cadavers. The surface of the liver was then thoroughly and carefully examined to observe the vessels. We also injected barium sulfate directly into the cystic arteries in two cadavers, the right inferior phrenic arteries in three cadavers, and the superior falciform ligament arteries in two cadavers to observe the capsular arteries derived from those vessels. The 2.7 Fr microcatheters were used for the cystic and the inferior phrenic arteries. The 30G-butterfly needle and 34-G micropipette were utilized for the superior falciform ligament artery. The specimen was examined radiologically using a digital mammography system to identify the communication between the hepatic capsular arteries and isolated arteries.

Clinical applications

We reviewed the radiology database for the cases of the abdominal angiography and the abdominal CT scans in

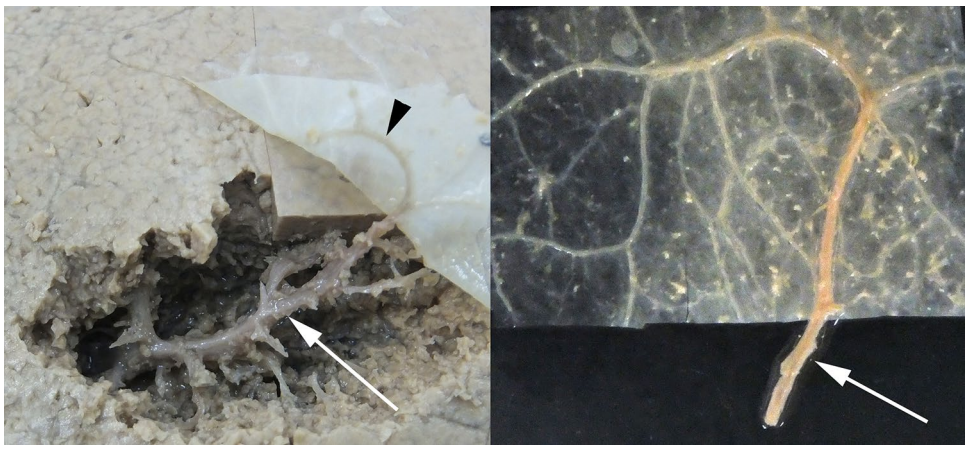

Fig. 1 Macroanatomical features of the hepatic capsular arteries. **a** When the hepatic capsule was detached, the intrahepatic vessel called the isolated artery (arrow) connected with the capsular artery (arrowhead) attached to the capsule was revealed. **b** Detached hepatic capsule. The web-like arterial network, capsular arteries, was attached to the thin hepatic capsule. The stalk (arrow) corresponded to the isolated artery

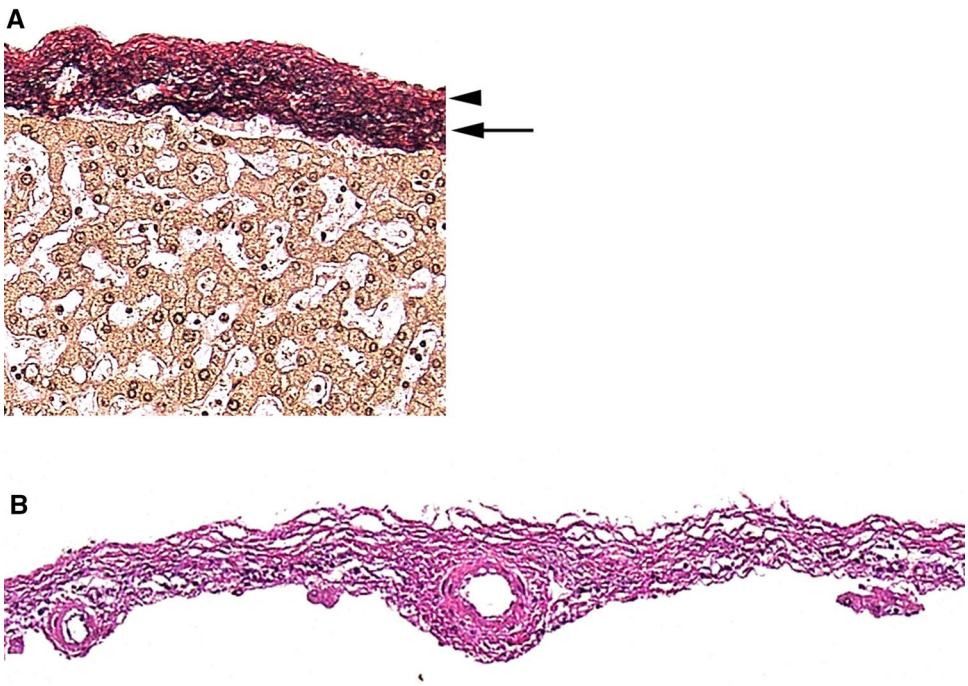

Fig. 2 Microanatomical features of the hepatic capsular arteries. **a** Liver surface (Elastica van Gieson stain). The hepatic capsule consisted of the thin superficial and thick deep layers, which were composed of collagenous (arrowhead) and elastic fibers (arrow), respectively. **b** Hepatic capsule (Hematoxylin–Eosin stain). The detached hepatic capsule with capsular arteries. The capsular arteries were located at the inner aspect of the deep layer and were surrounded by elastic fibers

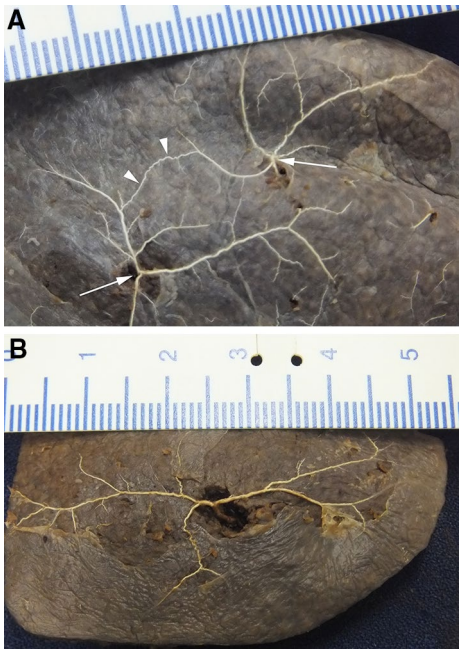

Fig. 3 Hepatic capsular arteries at the surface of the liver. Barium sulfate was injected into the hepatic arteries through the indwelling catheter at the hepatic hilum and the surface of the liver was observed. **a** Common type. The distance between the origin (arrows) of the hepatic capsular arteries (the terminal of the isolated arteries) varies individually but is usually 2–3 cm. The anastomosis between each capsular artery network can be recognized (arrowheads). **b** Long type. Some of the capsular arteries were longer than usual; however, their caliber was the same as that of the common type

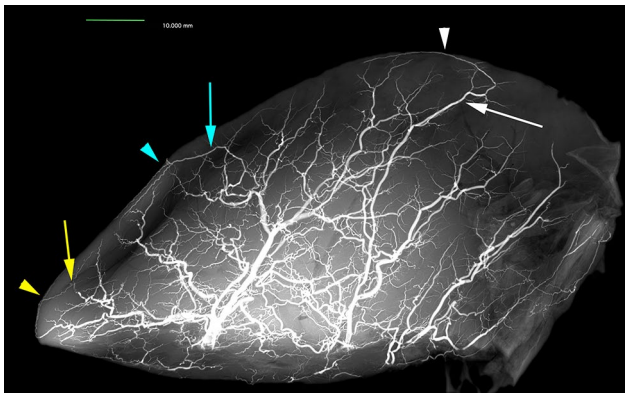

Fig. 4 Specimen radiograph of the capsular arteries. We injected barium sulfate into the hepatic artery through a catheter and observed the hepatic capsular arteries. Subsequently, the specimen obtained using a mammographic system was used for the radiograph. Each capsular artery (arrowheads) is derived from the isolated artery (arrows), which is the capsular branch of the peripheral intra-hepatic artery. The diameter of the capsular artery is approximately 100 µm. Furthermore, note that there are different sizes of the capsular branches: small (yellow), middle (blue), and large (white)

our hospital and identified clinical cases to reveal the relationship between the hepatic capsular arteries and the extra-hepatic arteries such as the inferior phrenic artery, superior falciform ligament artery, and the cystic artery.

Results

Cadaver studies

General anatomy of the liver surface

Macroscopic anatomy When the hepatic capsule was detached from the surface of the liver, multiple vessels were removed from the hepatic surface. The detached hepatic capsule contains the web-like capsular arteries, radiating from the point where the capsular branch of the hepatic artery, the isolated artery, reaches the surface of the liver (Fig. 1).

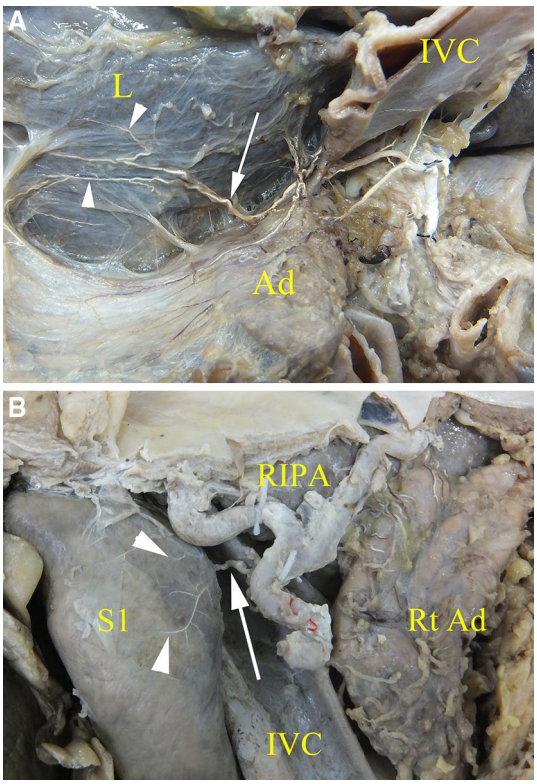

Fig. 5 Hepatic capsular arteries from the right inferior phrenic artery. The right inferior phrenic artery was identified first around the celiac artery in the cadaver. We cut its origin and inserted a microcatheter into the lumen. Then barium sulfate was injected into the hepatic arteries through this catheter. **a** A branch (arrow) of the right inferior phrenic artery reached the posterior aspect of the liver (L) and communicated with the hepatic capsular arteries (arrowheads). The branches to the inferior vena cava (IVC) and the right adrenal gland (Ad) are also shown. **b** The hepatic capsular arteries of the caudate lobe. The small branch (arrow) of the right inferior phrenic artery reached the posterior aspect of the caudate lobe (S1) and anastomosed with the hepatic capsular arteries (arrowheads). *RIPA* right inferior phrenic artery, *IVC* inferior vena cava, *Rt Ad* right adrenal gland

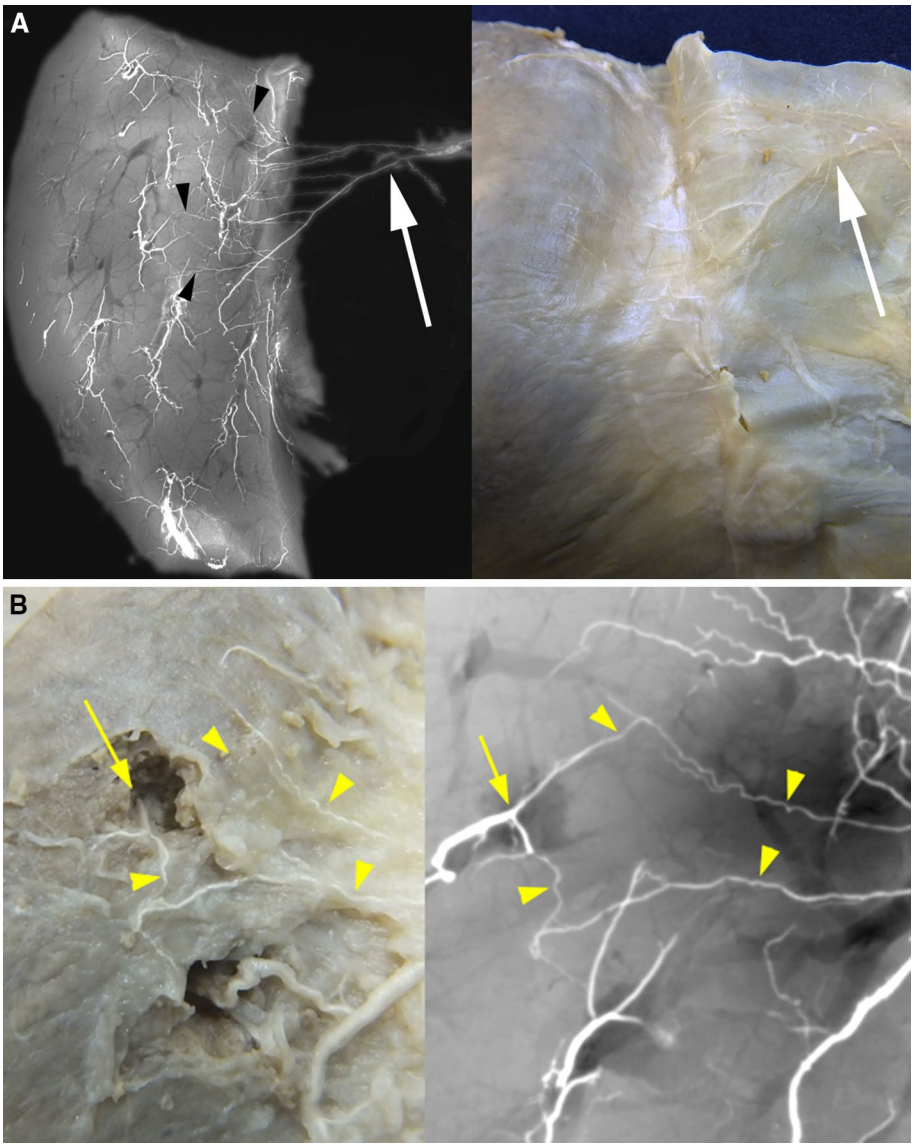

Fig. 6 The hepatic capsular arteries and the superior falciform ligament arteries. **a** Left: Specimen radiograph. Right: Specimen. The superior falciform ligament artery was cannulated by a 30G needle, and barium sulfate was injected. Barium sulfate was also injected into the hepatic artery. The anastomosis between the intrahepatic artery and the superior falciform ligament artery (arrow) via the capsular arteries (arrowheads) are shown. **b** Left: Specimen. Right: Specimen radiograph. Enlarged view of the anastomosis between the superior falciform ligament artery and the isolated artery. The parenchyma around the transition indicates the isolated arteries to the capsular arteries were excavated, so the anastomosis between the superior falciform ligament arteries and the isolated arteries (arrows) can be seen via the capsular arteries (arrowheads)

Microscopic anatomy The hepatic capsule consists of two layers: a thin superficial layer and thick deep layers. These layers are composed of collagenous and elastic fibers, respectively. The web-like capsular arteries are located at the inner aspect of the deep layer and are surrounded by elastic fibers (Fig. 2).

Barium injection study

The hepatic capsular arteries from the isolated arteries

The whitish vessels radiating at the liver surface are the capsular arteries and the distance between each isolated artery depends on the individuals (Fig. 3a). The diameter of the capsular artery is approximately 100 μm. Some capsular arteries are longer, and distribution of these arteries is wider (Fig. 3b). The liver tissue, including the capsular arteries, was removed with 5 or 6 cm thickness. Then, the radiographs of the front and the perpendicular view of the extracted liver tissue were taken to investigate the relationship between the capsular arteries and the isolated arteries (Fig. 4). The larger the distribution of the capsular artery was, the prominent the isolated artery was.

The capsular arteries and the extra-hepatic artery *Right inferior phrenic artery* There are several hepatic branches of the right inferior phrenic artery, as well as the adrenal and phrenic branches. These hepatic branches anastomo-

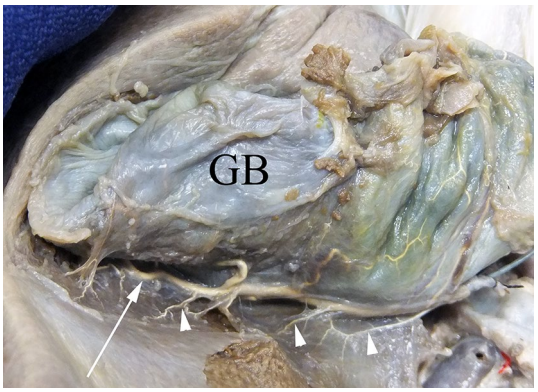

Fig. 7 Hepatic branches of the cystic artery. The cystic artery was identified at the Calot triangle. We cut the origin of the cystic artery, place a microcatheter into it, and injected barium sulfate into the cystic artery. There are two types of hepatic arteries derived from the deep branches. One is an artery with a large caliber (arrow) directly supplying the hepatic parenchyma, and the other is the arteries with small caliber (arrowheads) that correspond to the hepatic capsular arteries

sed the hepatic capsular arteries (Fig. 5a) at the posterior aspect of the right and the caudate lobe of the liver (Fig. 5b). As the capsular arteries are derived from the hepatic artery, the right inferior phrenic artery communicates with the hepatic artery via the hepatic capsular arteries. The branches to the surface of the inferior vena cava from the right inferior phrenic artery are also shown. The area where the right inferior phrenic artery communicates with the capsular arteries is the lower portion of the right triangular ligament.

Superior falciform ligament artery The superior falciform ligament arteries arising from the internal thoracic artery are distributed in the falciform ligament [6, 7], also known as Sappey's superior arteries (although Sappey only defined the veins in the falciform ligament) [8]. The superior falciform ligament arteries are not the same as the "hepatic falciform ligament artery" derived from the left hepatic artery [9]. When the barium sulfate was directly injected through this group of arteries, it spread along the falciform ligament towards the liver surface, confirming the communication between the superior falciform ligament arteries and the hepatic capsular arteries (Fig. 6). Conversely, barium sulfate injected into the hepatic artery also appeared in the superior falciform ligament arteries through the hepatic capsular arteries.

Cystic artery It is well known that there are two branches of the cystic artery, the superficial and deep branches.

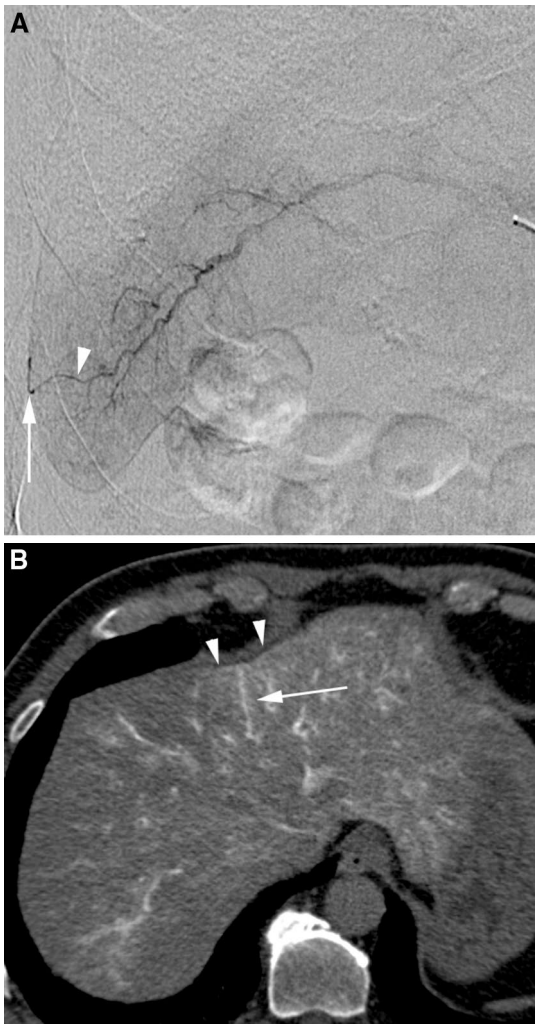

Fig. 8 The isolated arteries demonstrated on angiography and CT during hepatic angiography. **a** Angiography. The selective angiography of the posterior inferior branch of the right hepatic artery shows the isolated artery (arrowhead), capsular branch of the intra-hepatic artery, and capsular artery (arrow) on the surface of the liver. **b** CT during hepatic angiography. The proper hepatic artery was selectively cannulated using a microcatheter during angiographic study. Iodine contrast (150 mgI/mL) was injected through this catheter at a rate of 1.5 mL/s for a total of 35 mL. The CT scan was started 20 s after the contrast material injection was initiated. The isolated artery (arrow) was identified in the left lobe of the liver and the enhancement of the hepatic surface (arrowheads) owing to the capsular arteries was also observed. Note that (**a**) and (**b**) are different cases

According to Michels' [10] and Hollinshead's [11] descriptions, the deep cystic branch gives off liver "twigs" to the medial sides of the gallbladder that correspond to the hepatic capsular arteries (Fig. 7). The other hepatic artery of the deep branch directly supplies the hepatic parenchyma next to the gallbladder fossa.

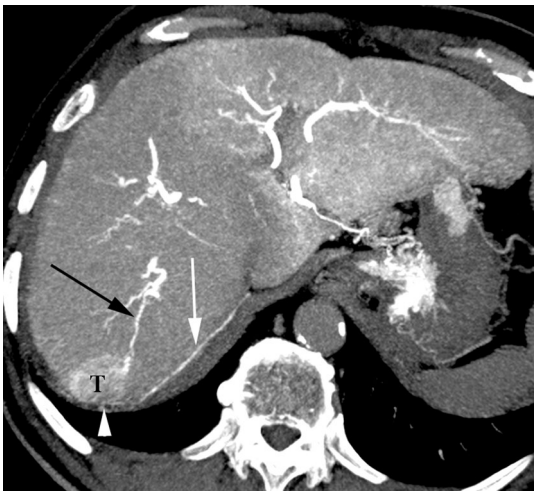

Fig. 9 Communication between the right inferior phrenic artery and the hepatic artery through the tumor and capsular arteries demonstrated on the CT during hepatic angiography. The right posterior hepatic artery (black arrow) supplied the tumor (T), which abutted the posterior aspect of the liver. The contrast media filled in the tumor exuded into the capsular arteries (arrowhead) and then regurgitated into the right inferior phrenic artery (white arrow)

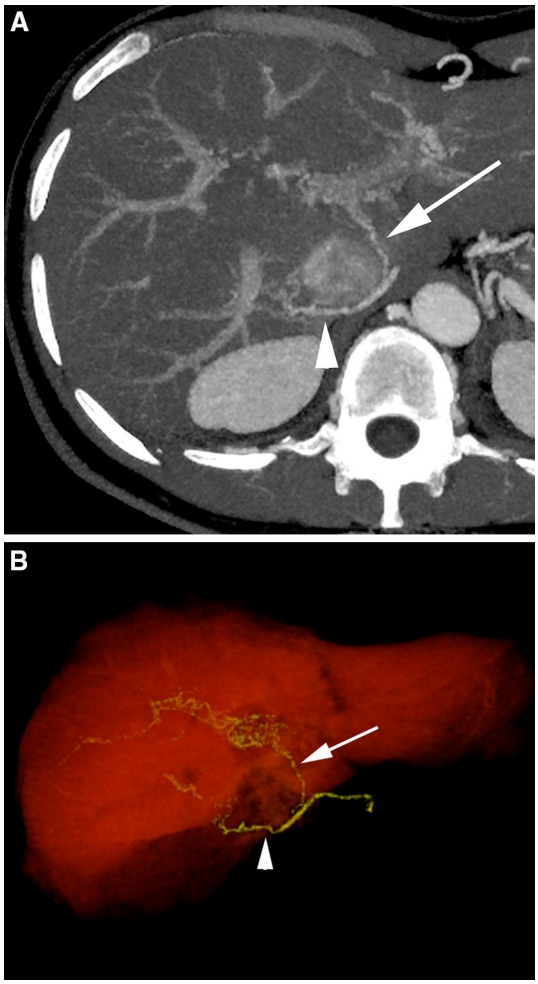

Fig. 10 Collateral circulation via the capsular arteries at the posterior aspect of the liver demonstrated on CT scan in a patient with proper hepatic artery occlusion. **a** MIP image and **b** 3D image of the dynamic CT scan, early phase. The right inferior phrenic artery (RIPA) was dilated and scattered around the posterior aspect of the right lobe of the liver (arrowhead). In addition, the anastomosis between the right inferior phrenic artery and the caudate branch (arrow) of the hepatic artery was also demonstrated

Clinical applications

Radiological features of the isolated arteries and capsular arteries

The radiological features of the capsular arteries have not been well recognized except for the cadaver study [3, 4]. When the peripheral branches of the hepatic artery in the right lateral edge on angiography were evaluated in detail, some short branches perpendicular to the liver surface (Fig. 8) were occasionally noted. These arteries represent the isolated arteries, the capsular branches of the hepatic artery.

The CT scan obtained after a transarterial chemoembolization (TACE) using iodized oil also demonstrated linear high density at the liver surface representing the retained iodized oil on the surface of the liver [4].

Inferior phrenic artery and capsular arteries

When a hepatic tumor is protruding and infiltrating the diaphragm, the tumor is often supplied by the right inferior phrenic artery. The right inferior phrenic artery also supplies the intra-hepatic tumor via the capsular arteries without invasion of the diaphragm (Fig. 9). In addition, the right inferior phrenic artery can supply the liver parenchyma through the capsular arteries, especially in patients with proper hepatic artery obstruction (Fig. 10).

Conversely, when the proximal portion of the right inferior phrenic artery is severely stenotic or occluded, the selective hepatic artery angiography can demonstrate the right inferior phrenic artery through the capsular arteries. Radiograph after TACE using iodized oil via the posterior branch of the right hepatic artery demonstrated retention of the iodized oil in the peripheral branches of the right inferior phrenic artery (Fig. 11) in such cases.

Superior falciform ligament artery

The superior falciform ligament arteries have been considered clinically insignificant; however, Hur et al. recently reported that superior falciform ligament arteries could be demonstrated on the C-arm hepatic arteriography [12]. The collateral arteries originating from the superior falciform

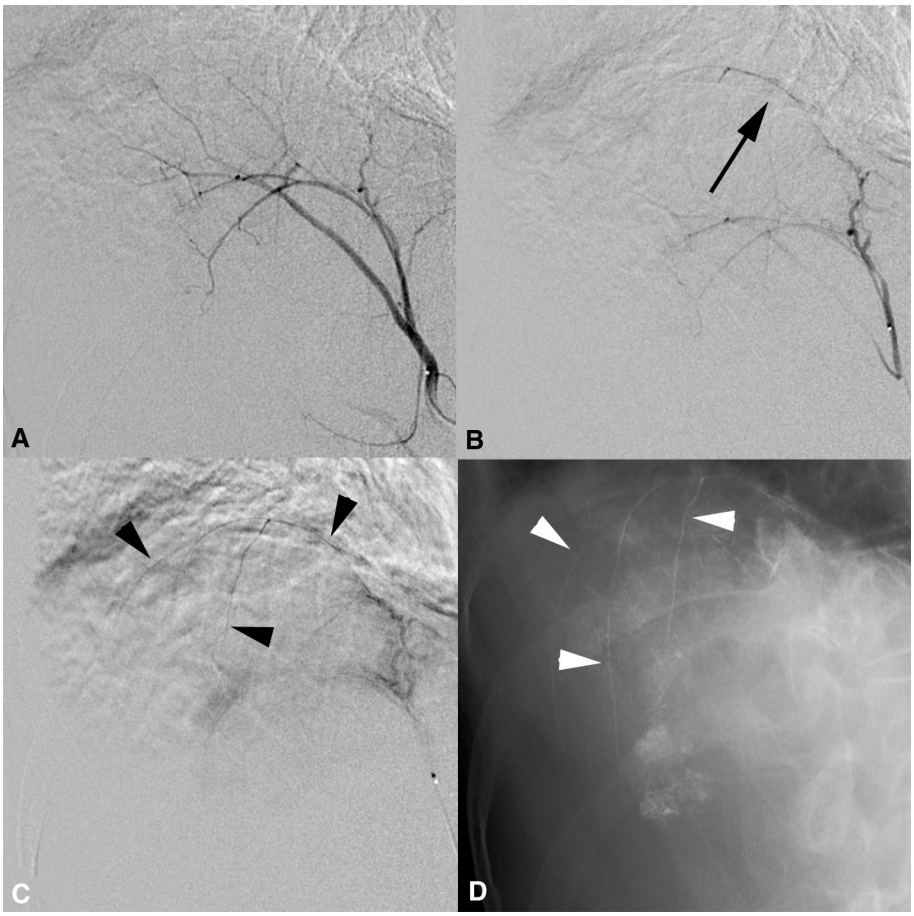

Fig. 11 Communication between the right inferior phrenic artery and the hepatic artery demonstrated on angiography in a patient with hepatocellular carcinoma. **a** The right hepatic artery angiography was performed to localize the tumor. **b** and **c** The mid portion (arrow) and the distal portion (arrowheads) of the right inferior phrenic artery were gradually filled with contrast medium in the late phase. **d** Post embolization radiograph. The accumulation of iodized oil was noted in the distal portion (arrowheads) of the right inferior phrenic artery after the chemoembolization of the right hepatic artery using iodized oil and gelatin sponge

ligament arteries were demonstrated at the anterior and superior aspect of the liver on the arterial phase of the dynamic CT scan in patients with occluded proper hepatic artery (Fig. 12). As we demonstrated in the cadaver study, the contrast media injected from the hepatic artery was regurgitated into the superior falciform ligament artery on the CT during hepatic angiography (Fig. 13).

When a hepatic tumor is located at the superior aspect of the liver, the tumor is sometimes fed by the peripheral branches of the internal thoracic artery, which are often reported as the phrenic branches of the internal thoracic artery [13]. However, according to the anatomical point of view described above, the superior falciform ligament arteries originating from the internal thoracic artery must also feed the tumor.

Cystic and capsular arteries on angiography

The deep branch of the cystic artery gives off hepatic branches to the medial sides of the gallbladder in two ways, directly or indirectly through the capsular arteries (Fig. 14). Therefore, a hepatic tumor next to the gallbladder fossa is sometimes supplied by the cystic artery [14]. Conversely, even if iodized oil was injected only into the hepatic artery, the cystic artery was filled with iodized oil (Fig. 15), as the surplus iodized oil over the vascular volume of the tumor and hepatic parenchyma regurgitated into the cystic artery via the hepatic capsular arteries.

Subcapsular hematoma

Subcapsular hematoma is caused by various diseases, such as rupture of a liver tumor abutting the liver surface [5], post-endoscopic retrograde cholangiopancreatography complication [15], and "hemolysis, elevated liver enzymes, and a low platelet count" (HELLP) syndrome [16]. Terayama [5] suggested that once a subcapsular hematoma occurs, it dissects the capsule from the hepatic parenchyma, causing interruption of numerous terminals of the isolated arteries (Fig. 16).

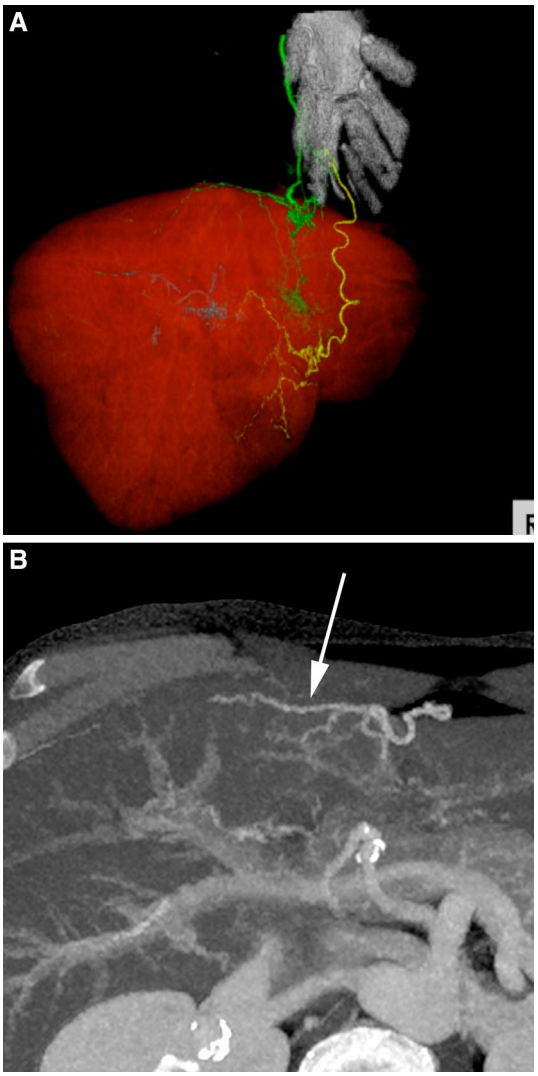

Fig. 12 Collateral pathway via the falciform ligament in a patient with proper hepatic artery occlusion. **a** 3D angiography. There were two peripheral branches of the internal thoracic artery towards the liver, the upper (green) and the middle (yellow) branches of the superior falciform ligament arteries that were located in the falciform ligament. The upper branch spreads along the superior aspect of the left lobe, and the middle branch spreads along the anterior aspect of the medial segment of the left lobe. **b** MIP image (axial plane). It is well demonstrated that the middle branches (arrowhead) spread along the anterior surface of the medial segment of the left lobe of the liver

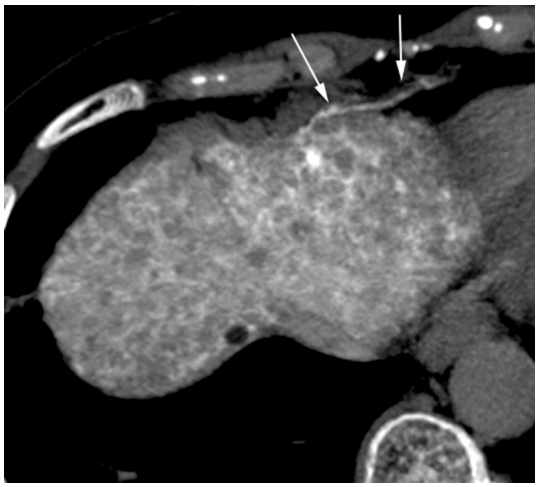

Fig. 13 Communication between the superior falciform ligament artery and the hepatic artery demonstrated on the CT during hepatic angiography. Although the apparent long isolated artery was not recognized, the contrast media filled in the liver exuded into the superior falciform ligament artery (arrows) through the capsular arteries

Conclusion

The hepatic capsular arteries spread along the hepatic surface and constitute a vascular network throughout the liver. The hepatic capsular arteries arising from the isolated arteries communicate with various extra-hepatic arteries surrounding the liver, such as the inferior phrenic artery at the posterior aspect of the liver (the right triangular ligament), the superior falciform ligament artery at the anterior and superior aspect of the liver (the falciform ligament), and the cystic artery at the gallbladder fossa (Fig. 17). The hepatic capsular arteries play an important role in the collateral circulation in various clinical situations.

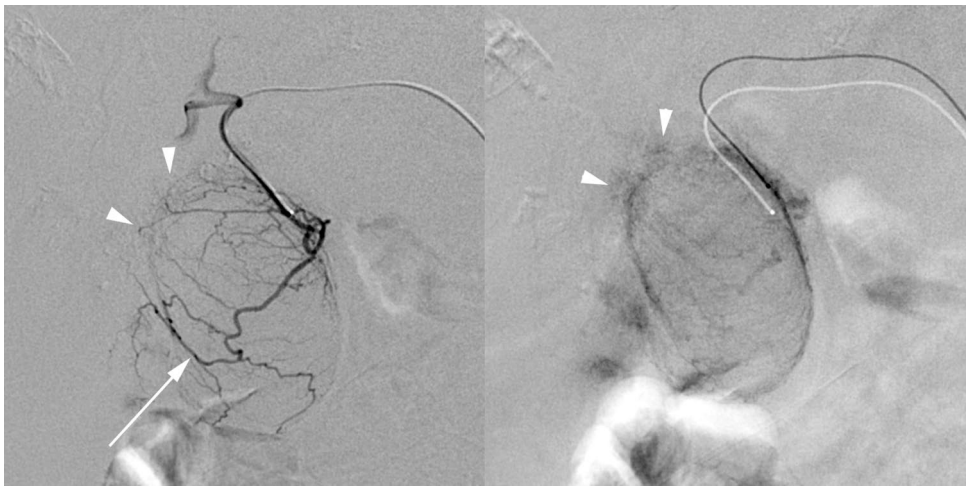

Fig. 14 Two types of hepatic branches of the cystic artery. **a** Early phase**, b** Late phase of the selective cystic artery angiography. The cystic artery supplies not only the gallbladder but also the hepatic parenchyma next to the gallbladder fossa. There are two kinds of branches supplying hepatic parenchyma, the hepatic parenchymal branch and the hepatic capsular branches. The former branch (arrow) apparently supplies the liver parenchyma beyond the cystic wall. The latter branch also supplies the surface of the liver, but the stain is faint (arrowheads) compared to the former

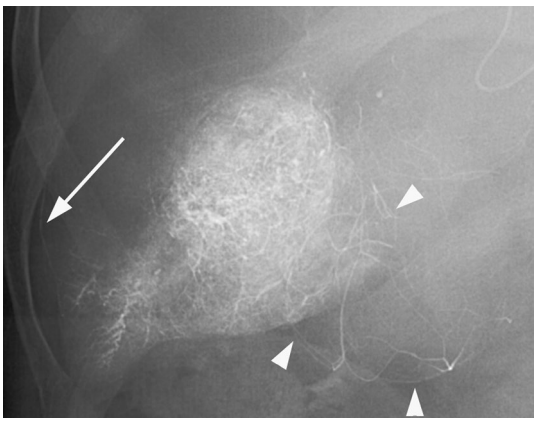

Fig. 15 Anastomosis between the hepatic arteries and cystic arteries via the capsular arteries in a patient with hepatocellular carcinoma. The anterior inferior branch of the right hepatic artery was selectively embolized using iodized oil and gelatinous particles. Iodized oil accumulated in the capsular artery (arrow) as well as the liver parenchyma and the tumor were seen in this post embolization radiograph. In addition, the cystic arteries was also observed (arrowheads) due to the regurgitation of iodized oil in the liver parenchyma via the capsular arteries

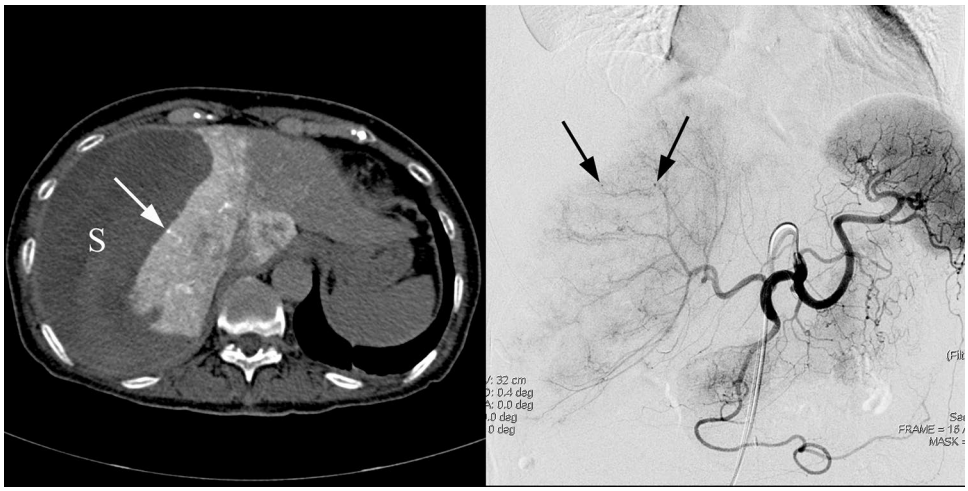

Fig. 16 Spontaneous subcapsular hematoma of the liver. **a** CT during hepatic angiography. Subcapsular hematoma (S) and extravasation (arrow) of the contrast media are demonstrated at the right lateral aspect of the liver. **b** Angiography. Celiac angiography shows several petechiae (arrows) in the liver, which correspond to extravasation of the contrast media demonstrated on CT scan. We assume that the subcapsular hematomas were caused by the cutting of the hepatic capsular arteries from the isolated arteries

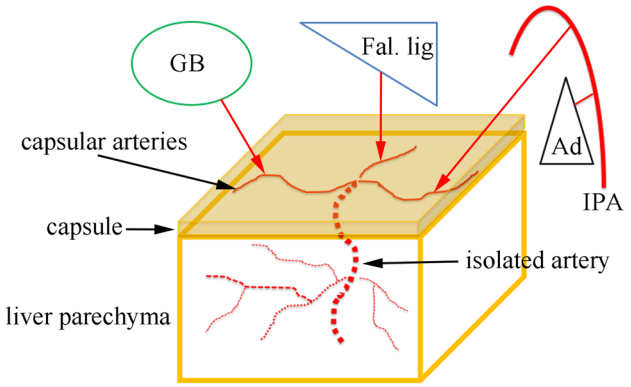

Fig. 17 Schema of the hepatic capsular arteries, isolated arteries, and extra-hepatic arteries. The hepatic capsular arteries arising from the isolated artery spread along the hepatic surface constitute the arterial network and communicate with the extra-hepatic arteries surrounding the liver, such as the inferior phrenic artery, superior falciform ligament artery, and cystic artery. Therefore, the hepatic capsular arteries will play an important role in collateral circulation, when the hepatic artery is occluded. GB: gallbladder, Fal. lig: falciform ligament, Ad: adrenal gland, IPA: inferior phrenic artery

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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