REVIEW / Cardiovascular imaging

Anatomy of liver arteries for interventional radiology

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KEYWORDS
Anatomy; Vascularisation; Liver; Angiography; Interventional radiology

Abstract The availability of intra-arterial hepatic therapies (radio and/or chemo-embolisation, intra-arterial hepatic chemotherapy) has convinced radiologists to perfect their knowledge of the anatomy of the liver arteries. These sometimes, complex procedures most often require selective arterial catheterization. Knowledge of the different arteries in the liver and the peripheral organs is therefore essential to optimize the procedure and avoid eventual complications. This paper aims to describe the anatomy of the liver arteries and the variants, applying it to angiography images, and to understand the implications of such variations in interventional radiological procedures.

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Recent progress in the endovascular treatment of liver tumours gives interventional hepatic radiology a preponderant place in the therapeutic possibilities. The administration of drugs and/or embolising agents most often requires supra-selective catheterization of the feeding arteries of the tumour in order to optimize the treatment and spare the non-tumoral liver [1].

These procedures (radio-embolisation, chemo-embolisation, intra-arterial hepatic chemotherapy) require a perfect understanding of the conventional anatomy of the arteries and its variants in order to plan and obtain the best approach possible as well as minimize the risks of intra and post-interventional complications. Therefore, embolisation of the wrong arterial branches may lead to incomplete treatment of the target lesion or the toxic exposure of the liver parenchyma or healthy organs.

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http://dx.doi.org/10.1016/j.diii.2013.12.001
This didactic article is above all intended for radiology interns who would like to perform interventional hepatic radiology. The purpose of this paper is to describe the anatomy of liver arteries and their variants, apply it to angiography images and understand the implication of such variations on the interventional radiology procedures.

Celiac artery and arterial branches to the liver

Conventional anatomy of the celiac artery

(Fig. 1) The supramesocolic arterial irrigation arises from the celiac artery, running from the anterior side of the aorta at the level of the 12th thoracic vertebra (indication for catheterization). It generally comprises three main branches: left gastric artery, coronary stomach artery, spleen artery and common hepatic artery.

Common hepatic artery

It arises from the celiac artery, runs obliquely forward and towards the right, thereby forming a concave curve from the aorta. The common hepatic artery runs to the right, along the upper border of the pancreas to the left side of the portal vein. It then splits at the omental foramen into the gastroduodenal artery and the proper hepatic artery.

Proper hepatic artery

Terminal branch of the common hepatic artery, it rises towards the liver in the hepatoduodenal ligament, running upwards and to the right, along the anterior edge of the omental foramen. The proper hepatic artery splits into a right branch and left branch of the hepatic artery. Therefore, the terms “right hepatic artery” and “left hepatic artery” are reserved for the description of the anatomic variants of the hepatic artery.

Splenic artery

The splenic artery joins the upper border of the body of the pancreas, and then runs towards the left either behind or above the pancreas to join the splenic hilum. One of its terminal branches gives rise to the left gastroepiploic artery to feed the greater curvature of stomach. The latter forms the arterial circle of the greater curvature of stomach by anastomosis with the right gastroepiploic artery arising from the gastroduodenal artery.

Left gastric artery [2]

Originating at the upper side of the celiac artery, it forms an arch until reaching the right border of the cardia. This specific anatomy requires the use of catheters (for example, Simmons, SOS catheters, etc.) whose curvature allows the catheterization. The left gastric artery then splits into two terminal branches (anterior and posterior) running towards the lesser curvature of stomach. The posterior branch anastomoses with its homologue arising from the right gastric artery to form the arterial circle of the lesser curvature of stomach. It is therefore possible to catheterize the right gastric artery via the posterior branch of the left gastric artery.

The lack of visualisation of the left gastric artery often results from an overly distal position of the catheter within the celiac artery, beyond its opening. If the injection flow rate is low during the arteriography, the contrast reflux is insufficient, not allowing for the opacification of the left gastric artery.

Anatomic variations of the celiac artery

(Fig. 2a–f) Celiac trifurcation is found in 89% of the cases in the series by Michel et al. [3]. According to this study, 15 types of variations are described. Three of them are major [4]: a hepatosplenic trunk (4.5%), a hepatomesenteric and gastroplenic trunk (2.5%), a cæliomesenteric trunk (1%).

Hepatic artery variations

Right hepatic artery

(Fig. 3) A right hepatic artery is found in 10 to 30% of the population. It originates in the superior mesenteric artery (96% of the cases), or the pancreatico-duodenal trunk (4%). It runs within the space between the pancreas and the vena cava (Fig. 4). The right hepatic artery is the first large artery to emerge from the superior mesenteric artery. When present, it almost always gives rise to the main or accessory cystic artery.

Left hepatic artery

(Fig. 5) It is found in 12 to 21% of the population. It originates in the left gastric artery and runs within the groove of Arentius. When a vascular structure is present within this groove in the CT-scan or MRI (Fig. 6), this indicates non-conventional hepatic arterial vascularisation with the presence of at least one left hepatic artery. The left hepatic artery gives rise to small branches leading to the stomach and oesophagus. In 70% of the cases, it is accompanied by another arterial variation: right hepatic artery (RHA), middle hepatic artery leading to segment IV.

Figure 1. Conventional arterial anatomy of the celiac artery: left gastric artery (LGA), splenic artery (SA), common hepatic artery (CHA), proper hepatic artery (PHA) and gastroduodenal artery (GDA).
Variations in the anatomy of the hepatic artery

The anatomy of the hepatic artery and its variants have been much described in the literature and have given rise to several different classifications. In this paper, we will use Michel’s classification [3] since it is most often used and provides the best anatomic approach. In 1955, Michel described 10 types of hepatic artery variations, from type I for the conventional anatomy and II to X for the variants (Fig. 7a–j).

The conventional anatomy (or type I) (Fig. 7a) is most common. The common hepatic artery, originating at the celiac artery followed by the proper hepatic artery, splits into the right branch and left branch of the hepatic artery. We knowingly use the terms “right branch or left branch of the hepatic artery” and not “right hepatic” artery or “left hepatic” artery. The latter terms are used to describe variants from the normal. This anatomy, defined as conventional, is found in 55 to 76% of the patients, depending on the study.

Type II according to Michel is the presence of a left hepatic artery originating from the left gastric artery feeding the left liver, and a middle hepatic artery feeding the right liver (Fig. 7b). This variant is found in 10% of the patients.

In type III, the right hepatic artery, originating in the superior mesenteric artery, feeds the right liver, and a middle hepatic artery feeds the left liver (11% of the patients) (Fig. 7c).

Type IV corresponds to the association of variants II and III, with the presence of a right hepatic artery for the right liver and a middle hepatic artery feeding the left liver (Fig. 7f).

Figure 2. Anatomic variations in the celiac artery: a: conventional anatomy of the celiac artery (89%) with common hepatic artery trifurcation (CHA), splenic artery (SA) and left gastric artery (LGA); b: hepatosplenic trunk (4.5%); c: hepato-mesenteric trunk and gastro-splenic trunk (2.5%); d: cœlio-mesenteric trunk (1%); e: hepato-spleno-mesenteric trunk (0.7%); f: hepato-mesenteric trunk (0.2%).

Figure 3. Right hepatic artery (solid arrow) originating at the superior mesenteric artery (tip of arrow).

Figure 4. Run of the right hepatic artery (tip of arrow) within the space between the pancreas and the vena cava (arterial angioscan).
Figure 5. Left hepatic artery (LHA) originating at the left gastric artery (LGA).

Figure 6. Characteristic run of the left hepatic artery (tip of arrow) within the groove of Arantius, originating from the left gastric artery (solid arrow).

Figure 7. Variations in the hepatic arterial flow, modified MICHEL classification: a: type I; b: type II; c: type III; d: type IV; e: type V; f: type VI; g: type VII; e: type VIII; i: type IX; j: type X.
liver and a left hepatic artery feeding the left liver (Fig. 7d). The celiac artery does not provide the common hepatic artery, but directly the gastroduodenal artery (rare variation, 1% of the cases).

In type V, Michel describes the presence of a left hepatic artery originating from the left gastric artery in addition to the left branch of the hepatic artery (Fig. 7e) (8% of the cases).

Type VI, associates the right hepatic artery originating from the superior mesenteric artery and the right branch of the hepatic artery (Fig. 7f) (incidence 7%).

In type VII (Fig. 7g), we find the association of variants V and VI, that is, the association of the hepatic artery proper with the right and left branch + right hepatic artery originating from the superior mesenteric artery + left hepatic artery originating from the left gastric artery.

Type VIII (Fig. 7h): the right liver is only fed by the right hepatic artery, while there is double vascularisation of the left liver via the middle hepatic artery and the left hepatic artery.

In type IX, the common hepatic artery originates from the superior mesenteric artery (1%) (Fig. 7i), and in type X it originates from the left gastric artery (0.2%) (Fig. 7j).

It should be noted that the left hepatic vein does not define a reliable separation of segments II and III. The plane separating them is complex (oblique in all planes). In practice, segment II is postero-superior and segment III antero-inferior (this is enough to recognize the sectoral branches on an arteriography). The middle hepatic vein separates the right liver from the left liver and the right hepatic vein separates the right posterior sector and anterior sector. The plane of the portal vein is used to divide the different segments into upper and lower sectors (this plane is correct for the segments of the right liver but false for segments II and III, as noted above [6].

Segment I is located in front of the vena cava. Segments II and III correspond to the left lateral sector [7].

Segment IV corresponds to the left paramedian sector, subdivided into superior IVa and inferior IVb.

Segments V and VIII correspond to the inferior and superior part of the right anterior sector, respectively.

Segment VI corresponds to the inferior part and segment VII to the superior part of the right posterior sector.

**Segmental liver vascularisation**

**Review of segmentation**

(Fig. 8) Liver segmentation corresponds to the organization of the liver in several functional units. The functional anatomy divides the liver into the right liver and the left liver by means of the portal vein.

The liver segmentation most used is that described by Couinaud [5]. He divided the liver into eight functional units. Each unit receives an artery and a portal vein (providing 30 and 70% of the blood flow, respectively), and is drained by a hepatic vein.

Hepatic segmentation is defined by the planes taken by the hepatic veins and the portal bifurcations.

The hepatic veins divide the liver into sectors, and the divisions of the portal vein divide the sectors into segments. Vertically, the sectors are separated by the plane of the hepatic veins, and horizontally by the plane passing by the portal bifurcation.

(Fig. 9) Selective arteriography of the common hepatic artery shows the proper hepatic artery (PHA) and the left branch of the hepatic artery (tips of white arrows). The characteristic appearance of the arch in arteriography should be noted (tip of red arrow) of the end of the left branch of the hepatic artery when it crosses the umbilical portion of the left portal branch.
Figure 10. Arterial branches A2 and A3 originating at the end of the left branch of the hepatic artery (arch, tip of red arrow).

Figure 11. Arterial branch A4 leading to liver segment IV, originating from the left branch of the hepatic artery (white arrows).

The hepatic artery proper, which in this case is called the segment IV artery.

Right hepatic vascularisation

Originating from the right branch of the hepatic artery, or right hepatic artery (variant of the normal, if present) (Fig. 12). This artery splits into two branches: an anterior sectoral branch running towards the top and right; and a (rather) posterior sectoral branch towards the bottom and right. Each sectoral branch (anterior and posterior) splits in two to feed a hepatic segment.

Therefore, the posterior sectoral branch gives rise to (Fig. 13): an inferior branch (A6), and a superior branch (A7) leading to hepatic segments VI and VII respectively. The path of branch A6 is inferior-lateral, to the lower part of the liver. It is usually easily recognised in arteriography since it is often the most prominent vessel and descends lowest. The path of branch A7 is parallel to the x-rays on a standard front view in an arteriography.

The anterior sectoral branch (Fig. 14) splits into an inferior branch (A5) and a superior branch (A8). Branch A5 often has the form of a group of vessels and runs towards the bottom and right. A5 is generally superior A6 in an angiography front view. Superior branch A8 gives rise to a dorsal branch running towards the diaphragm and a ventral branch.

There are several ways to recognise the anterior and posterior sectoral branches in arteriography:
- the posterior sectoral branch sometimes forms an arch by running backwards and forwards above the anterior sectoral branch (Fig. 15a);
• excluding major hepatic dysmorphism, the artery from segment VI descends lower than that from V. Therefore, by studying the branching upstream, it is possible to distinguish the anterior or posterior sectoral branches (Fig. 15b, c and d);
• the artery from segment VIII is generally in the axis of the hepatic artery proper. Therefore, during catheterisation, the microcatheter tends to spontaneously lodge itself in the right anterior sectoral branch and segment VIII. This is easy to understand since it is more difficult for the microcatheter to cross the arch of the posterior sectoral branch.

However, it is important to note that right hepatic segmental vascularisation is subject to many variations, and that in several cases, only selective catheterization and/or the use of CT reconstructions (in last generation angiography chambers) enables the formal recognition of the segmental branches.

Segment I

The vascularisation of segment I is extremely variable. It is fed by a great many small branches coming from: the right branch of the hepatic artery (35% of the cases), the left branch of the hepatic artery (12%), and by both right and left arterial branches (53% of the cases). There is no specific way to recognize the vessels from segment I. With a hyper selective injection in these vessels, it is possible to recognize a parenchymography with a “curved” edge (corresponding to the shape of segment I) during the late phase. Besides this sign, the input from new angiography chambers with 3D acquisition may be indispensable.

Non-hepatic arteries to recognise

Cystic artery [8]

(Fig. 16) The cystic artery most often originates in the right branch of the hepatic artery (72% of the cases), more rarely from the right hepatic artery (18%), or left hepatic artery (7%) both variants. The cystic artery is typically the first artery originating from the right branch of the hepatic artery. In general, it comprises two branches: a superficial peritoneal branch and a deep non-peritoneal branch. Embolisation of this artery may involve a risk of (chemical or ischaemic) cholecystitis. To avoid this type of complication, the catheter should ideally be positioned upstream from its origin. The prophylactic embolisation of the cystic artery is of no interest, except in specific cases.

Right gastric artery

(Fig. 17a and b) Yamagami [9] has shown the very great variation in the origin of the right gastric artery. It most often originates from the proper hepatic artery (51% of the cases), as well as from the left branch of the hepatic artery (23%), the common hepatic artery (9%) or the gastroduodenal artery (3%).

The right gastric artery initially runs vertically and medi- ally downwards in the direction of the pylorus and then horizontally, in the form of a curtain rod (from which origi- nate the gastric arteries of the curvature minor). It has two terminal branches at the anterior and posterior side of the lesser curvature of stomach. The posterior branch anastom- atoses with its homologue from the left gastric artery to form the arterial circle of the lesser curvature of stomach.
It sometimes presents a fairly sharp angle, rendering catheterization difficult. Several methods help overcome this difficulty: the use of angulated microcatheters, retrograde access via the left gastric artery, the coiling of the left gastric artery to artificially increase the flow and calibre of the right gastric artery, or the use of catheters with a lateral window.

**Falciform artery [10]**

The falciform artery originates at the middle hepatic artery when present, or the left branch of the hepatic artery. It runs in an oblique direction forward towards the median line, parallel to the falciform ligament. It communicates with the superior and inferior branches of the epigastric artery. The path of the falciform artery is characteristic as of its origin via the middle hepatic artery or left branch of the hepatic artery, and should not be mistaken for the cystic artery.

In case of doubt, the radiologist should obtain an angiography series with injection via the celiac artery with a right posterior oblique incidence, confirming its anterior run.

The falciform artery is erratic and is only found in 67% of the cases during a post-mortem dissection. In view of the competitive flow with the internal mammary artery or the superior epigastric artery, the falciform artery is only visible in 15% of the cases by arteriography.

It is important to recognise this artery during radioembolisation or chemo-embolisation due to the risk of cutaneous necrosis in the umbilical region. Nevertheless, prophylactic embolisation of the falciform artery is controversial.

**Intercostal arteries**

Originating in the aorta, they feed the thoracic wall, the last three branches of which may enter in the blood supply of hepatic artery tumors. Embolisation of the ‘‘healthy’’ intercostal artery is often well tolerated. However, cases of cutaneous necrosis have been described.

**Inferior phrenic artery**

(Fig. 18) Originating in the aorta or celiac artery in most cases, more rarely in the left gastric artery or right renal artery. The inferior phrenic arteries often have to be explored during intraarterial chemo-embolisation for hepatic tumours under the diaphragm, in particular in segments I, II or VII.

**Gastroduodenal artery**

Originating in the common hepatic artery, it runs between the head of the pancreas and the upper part of the duodenum. The gastroduodenal artery gives rise to: the right gastro-omental artery and the pancreatico-duodenal artery. The pancreatico-duodenal arcade (or Rio Branco’s arcade) is formed by the anastomosis of the superior pancreatico-duodenal artery originating in the gastroduodenal and inferior pancreatico-duodenal originating in the superior

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**Figure 16.** Cystic artery with its superficial branch (peritoneal, tip of white arrow) and deep (non-peritoneal, tip of black arrow).

**Figure 17.** a: arteriography of the celiac artery, with opacification of the right gastric artery (tips of white arrows) for the lesser curvature of stomach, and the gastroepiploic artery (tips of black arrows) originating from the gastroduodenal artery. Non-conventional liver vascularisation should be noted in this patient with the presence of a right hepatic artery; b: selective arteriography of the right gastric artery (tips of white arrows) originating at the proper hepatic artery. It anastomoses with the left gastric artery (tip of black arrow) to form the arterial circle of the lesser curvature of the stomach.
mesenteric. This arcade curves left, passes in front of the bile duct and then remains behind the pancreas. In case of stenosis of the celiac artery, it is useful to search for a reverse flow within the gastroduodenal artery, vascularised by the superior mesenteric artery via this Rio Branco’s arcade.

**Practical applications**

**Interventional radiology**

Intra-arterial chemotherapy catheter

The principle of hepatic intra-arterial chemotherapy (or TACE trans-arterial chemotherapy) is to deliver a toxic dose of drug, with slow and repeated perfusion cures, providing a higher local concentration of chemotherapy compared with systemic injection. The main current indication for TACE is the treatment of multiple and non-resectable hepatic metastases of colonorectal cancers.

The insertion of an intra-arterial hepatic catheter was initially a surgical technique associating cholecystectomy, ligature of the gastroduodenal artery, dissection of the common hepatic artery and insertion of the catheter in the trunk of the gastroduodenal artery with perfusion orifice at the level of the gastroduodenal/proper hepatic artery bifurcation. This technique was fairly complex and, in spite of a careful dissection and adequate positioning of the perfusion orifice, incomplete perfusion or extra-hepatic perfusion of the chemotherapy was observed in almost 45% of the procedures. This high rate is sometimes accounted for by certain inexperience of the surgeon and a lack of understanding of the anatomic variants of the hepatic arteries.

Surgical insertion was the reference method for 20 years. Now, the percutaneous insertion in interventional radiology (IR) with a 90% rate of success tends to replace it. The procedure in IR is not as complicated and only requires a simple local anaesthetic, which is faster (2–3 hours on the average) with a short period of hospitalization (24 hours).

The positioning of the perfusion orifice and the fixation of the catheter are crucial points in the success of the treatment. The procedure is subdivided into three phases: hepatic mono-pediculisation (so that the liver is vascularised by only one artery), the embolisation of the extra-hepatic arteries (right gastric, pyloric and gastroduodenal) and the implementation of the catheter in the cutaneous tissues of the groin.

Intra-arterial chemotherapy and the insertion of the intra-arterial catheter are often well tolerated by patients. However, arterial anatomic variants may complicate the procedure by resulting in incomplete perfusion of the liver parenchyma, or the perfusion of the chemotherapy in extra-hepatic territories. Most of these complications can be avoided with a perfect knowledge of the vascular anatomy of the patient in order to correctly insert the orifice of the chemotherapy catheter and embolise the extra-hepatic branches.

**Radio/chemo-embolisation of the hepatic artery**

Chemo-embolisation is based on the fact that tumoral vascularisation is above all of hepatic arterial origin, while the healthy liver is 30% vascularised by the arterial supply and 70% by portal route. Chemo-embolisation has two purposes: the delivery of a high concentration of drug in contact with the tumour cells while reducing the systemic toxicity, and provoking hypoxia of the tumour cells by obstruction of the arterial feeder.

The technical difficulties are related to the great variability in hepatic arterial vascularisation and the frequent presence of extra-hepatic tumoral arterial feeders. Hepatocellular carcinoma often has ectopic vascularisation, coming from extra-hepatic arteries [11]. Depending on the location of the tumour, it is necessary to look for these arteries in order to optimize the treatment. They are mainly [12]:

- segments I, II and VII: inferior phrenic arteries;
- segments V and VI: renal or adrenal artery;
- antero-superior portion of the liver: internal mammary artery;
- external and postero-external regions: intercostal artery;
- segments II and III: left gastric artery;
- peri-vesicular region: cystic artery.

**The liver transplant**

The liver transplant is a very effective therapeutic option, with a significant increase in the life expectancy of patients suffering from liver failure or chronic liver disease. In view of the shortage of available grafts, transplantation from a living donor has become a choice alternative. The time waiting for a graft has been considerably reduced with the increase in available grafts.

In the adult, the right liver transplant is the rule. The mapping and perfect knowledge of hepatic vascularisation is essential for the surgeon, in particular as regards the arterial supply of hepatic segment IV (surgical section plane).

As seen above, there are many variants in the arterial supply to segment IV (via the left branch of the hepatic artery, the right branch or more early via the proper hepatic artery). In the case of an exclusive supply via the right branch (about 7% of the cases), the arteries leading to segment IV cross the usual surgical section plane. A lack of understanding of this exclusive vascularisation by the surgeon exposes the donor to ischemia of hepatic segment IV.
In case of double vascularisation (right and left), the surgeon therefore sacrifices the arterial supply from the right branch during the right hepatectomy.

Conclusion

Hepatic vascularisation is complex, and anatomic variations very frequent. Nevertheless, it is essential to be able to recognize this both in convenal imaging (planning of the procedure) and on angiography for any hepatic procedure by endovascular route. This perfect understanding helps optimize the treatment and avoids the "non targeted" arteries, responsible for sometimes severe complications.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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