REVIEW / *Gastrointestinal imaging*

Liver segmentation: Practical tips

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Abstract   The liver segmentation system, described by Couinaud, is based on the identification of the three hepatic veins and the plane passing by the portal vein bifurcation. Nowadays, Couinaud's description is the most widely used classification since it is better suited for surgery and more accurate for the localisation and monitoring of intra-parenchymal lesions. Knowledge of the anatomy of the portal and venous system is therefore essential, as is knowledge of the variants resulting from changes occurring during the embryological development of the vitelline and umbilical veins. In this paper, the authors propose a straightforward systematisation of the liver in six steps using several additional anatomical points of reference. These points of reference are simple and quickly identifiable in any radiological examination with section imaging, in order to avoid any mistakes in daily practice. In fact, accurate description impacts on many diagnostic and therapeutic applications in interventional radiology and surgery. This description will allow better preparation for biopsy, portal vein embolisation, transjugular intrahepatic portosystemic shunt, tumour resection or partial hepatectomy for transplantation. Such advance planning will reduce intra- and postoperative difficulties and complications.

For a long time, the liver was described only by using a ''morphological'' anatomy referring to its outer appearance, as seen by laparotomy, for example. Since the beginning of the 20th century, a new approach based on a vascular division of the liver has been developed by several authors. Couinaud then formalised it in 1957 [1]. This so-called ''functional'' anatomy is currently most employed since it is best adapted for surgery and has become essential in monitoring intra-parenchymal lesions. Nevertheless,

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a study carried out at the Dijon University Hospital over a year on 138 CT-scan and MRI, examined for a second opinion for liver nodules, reveals the absence of liver segment indication in 27% of the cases. This study also revealed the existence of 39% topographic errors when the segment is indicated and notes the complete lack of information about the hepatic vascular anatomy in 100% of the cases. In fact, the segmentation and location of liver lesions is most often determined by using the modal anatomy of the vascular pedicles, without taking into account any anatomic variations leading to the errors [2]. In view of these results and the potential practical implications in interventional radiology or surgery, knowledge of portal and venous anatomy as well as the principle variants is essential in the proper systematisation of the liver, allowing for the exact detection of a lesion or the preparation of an intervention. Therefore, this review aims at explaining how to use simple anatomic references to quickly segment the liver during a routine examination and avoid mistakes.

After a brief review of embryology, we will return to the anatomy of the hepatic veins and portal system by noting their most common variants. Simple references will be provided to avoid mistakes in liver segmentation. We will then discuss the main practical, diagnostic and therapeutic applications.

Embryology review

The portal venous system forms during the second and third months of gestation from two vitelline (or omphalomesenteric) veins providing the drainage of blood from the yolk sac to the heart [3]. These two veins form a plexus around the duodenum by three anastomoses, then cross the septum transversum (future diaphragm). The proliferation of liver buds here breaks up this network and creates a vascular labyrinth, giving rise to the liver sinusoids. Above the liver, the vitelline veins become the right and left hepatic-cardiac canals and run into the sinus venosus. The subsequent disappearance of the left horn of the sinus venosus and the homolateral hepatic-cardiac channel redistributes the liver circulation towards the right hepatic-cardiac channel, giving rise to the suprahepatic segment of the inferior vena cava. The selective regression of paraduodenal anastomoses by hemodynamic laws favouring the shortest paths after the rotation of the duodenum [4], forms a single vessel: the portal trunk. Several portal variants result from a modification in the involution of these anastomoses [5]. The right sub-hepatic portion of the vitelline vein becomes the superior mesenteric vein; the left portion disappears after the degeneration of the yolk sac [6]. The umbilical (or umbilical-allantoid) veins, that transport oxygenated blood from the placenta, merge with the sinusoids during the development of the liver. Afterwards, the right umbilical vein and the hepatic portion of the left umbilical vein disappear, while an ''extra-hepatic shunt'' called Arantius' duct appears between the left umbilical vein and the inferior vena cava along with an increase in embryo circulation. This communication disappears at birth and the left umbilical vein gives rise to the round ligament and Arantius' duct gives rise to the venous ligament [7].

The morphology of the hepatic veins and the portal system, as well as the run of their branches, results from these successive stages in the development of the embryo. Any modification inducing anatomic variations may have diagnostic or therapeutic implications.

Radiological anatomy of the liver

Anatomy of the hepatic veins and variants

Most often, there are three hepatic veins (right, middle and left) that run into the inferior vena cava (Fig. 1). The left hepatic vein runs in the left portal scissura. It is formed by the union of drainage veins of segments II and III [8], giving rise to a short and posterior venous trunk. It adheres to Arantius' venous ligament to the rear, and forms a common trunk with the middle hepatic vein (Fig. 2) in 60% to 95% of all cases, according to the authors [9—11], before draining in the inferior vena cava. The middle hepatic vein is located in the middle or main portal scissura, separating the left liver from the right liver. It drains segment IV, and sometimes receives branches from segments V or VIII [8]. The right hepatic vein is the largest. It runs in the right portal scissura, and drains the veins of segments V, VI, VII and VIII [8]. It connects with the right border of the inferior vena cava, laterally and below the middle hepatic vein. Accessory hepatic veins (one to four) independently drain segment I in the retro-hepatic vena cava.

The hepatic venous variants, clearly seen in routine abdominal CT-scans, are more common in women than in men [12]. The main variant is the presence of an accessory right inferior hepatic vein in 52.5% of the cases [9], directly draining the right posterior-inferior segment in the middle part of the retro-hepatic inferior vena cava, or even two accessory veins (12%) (Fig. 3), or an accessory vein draining the caudal lobe (12%). Next come the absence of common trunk of the middle and left hepatic veins (Fig. 4), the absence of right hepatic vein and the splitting of the left or middle hepatic veins. In 9% of the population, a venous branch from segment VIII drains in the middle hepatic vein and may result in venous congestion, necrosis and atrophy of the segment if damaged during surgery [13,14].
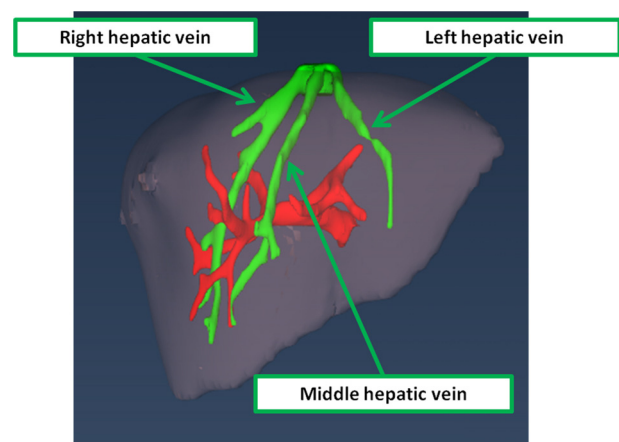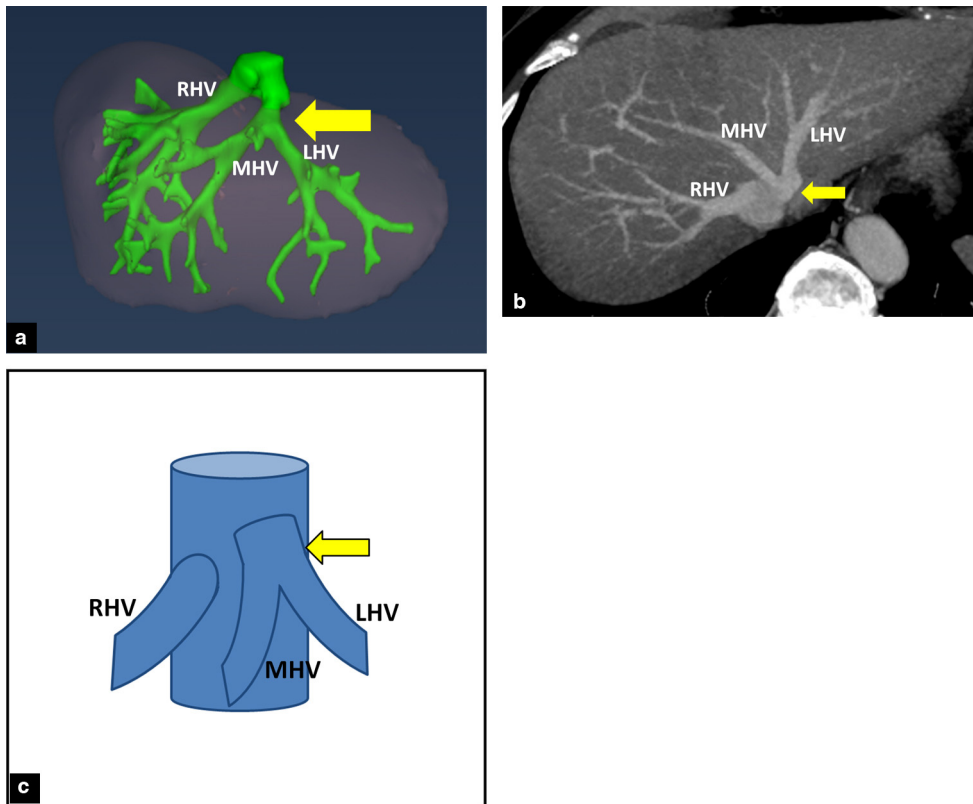

Figure 1. The hepatic veins (3D image).

Figure 2.   Common trunk of the left and middle hepatic veins (yellow arrow) (RHV = right hepatic vein, MHV = middle hepatic vein, LHV = left hepatic vein): a: anterior view (3D image); b: axial CT section MIP image; c: diagram.
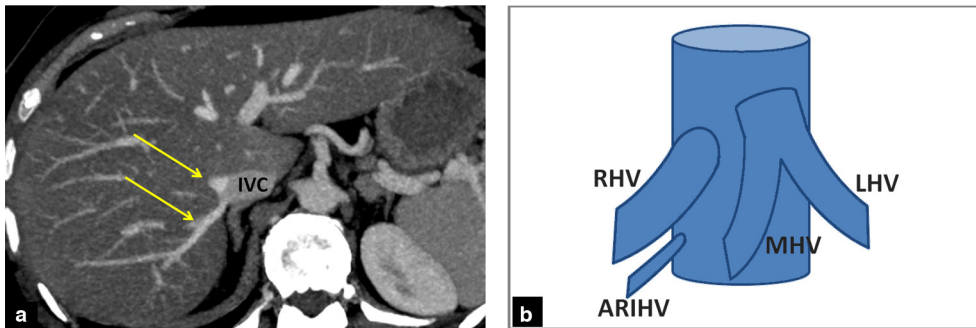

Figure 3.   Presence of one or two accessory right inferior hepatic veins (ARIHV and yellow arrows) (RHV = right hepatic vein, MHV = middle hepatic vein, LHV = left hepatic vein): a: axial CT section MIP image (IVC = inferior vena cava); b: diagram.

Anatomy of the portal system and variants

The portal vein is formed by the union of the superior mesenteric vein and the spleno-mesenteric trunk, itself formed by the splenic vein and the inferior mesenteric vein. Certain variants exist, such as a union of these three veins, or two mesenteric veins joined by the splenic vein. The resulting portal trunk enters the hepatic pedicle, obliquely at the top, to the right and slightly forward. Horizontalisation of the portal vein is the most common variant [15]. In the hepatic hilum, conventional portal bifurcation, found in 70 to 80% of the cases [16] presents (Fig. 5 and Fig. 6):
- a right branch 1 to 3 cm long then splitting into two anterior and posterior sectoral branches;

- a left branch, with a portion horizontal at first and then a concave umbilical portion in front in the direction of the round ligament to end by the Rex recessus [17].

Intra-hepatic portal variations are visible in about 20% of the population [18—21]. The classification most often used to describe them is that proposed by Cheng [22] (Fig. 7):
- type 1: modal anatomy with bifurcation in right portal branch and left portal branch (70.9—86.2%);
- type 2: trifurcation with a right posterior sectoral vein, a right anterior sectoral vein and a left portal branch arising from the same place (10.9—15.0%) (Fig. 8);
- type 3 or type Z: the right posterior sectoral vein comes directly from the portal vein and arises first at the lower part of the hepatic hilum (0.3—7.0%) (Fig. 9);
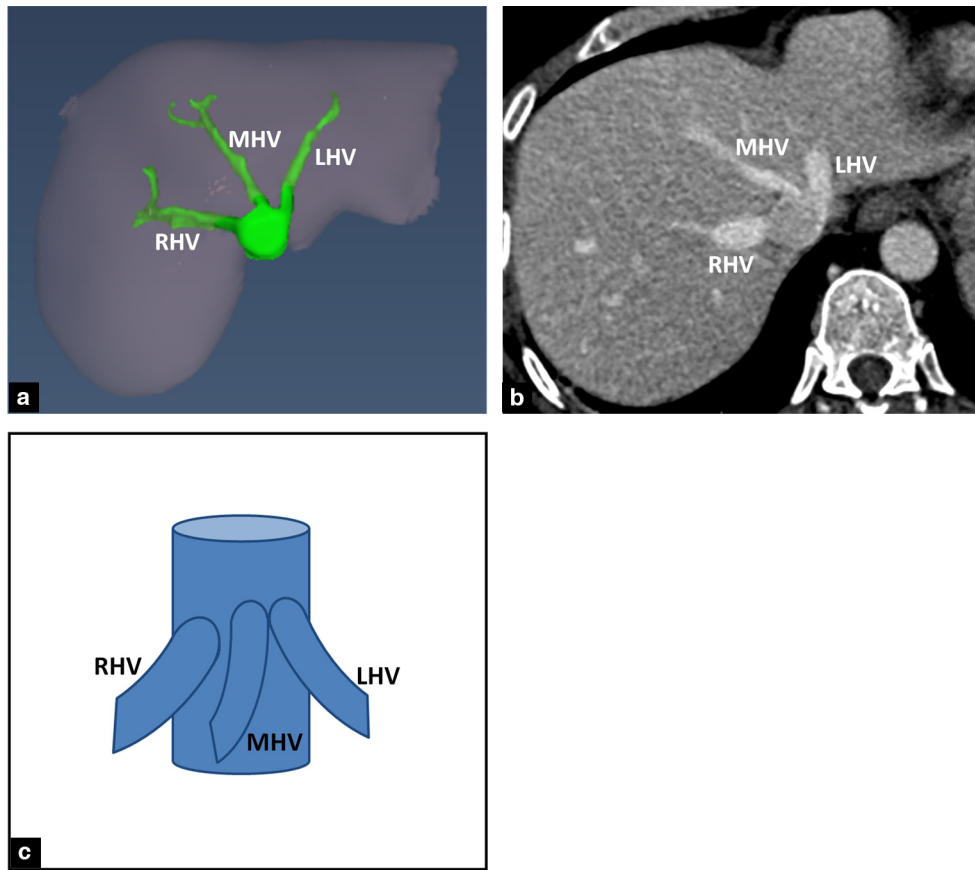
Figure 4. Absence of common trunk of the middle and left hepatic (RHV = right hepatic vein, MHV = middle hepatic vein, LHV = left hepatic vein): a: upper view (3D image); b: axial CT section; c: diagram.
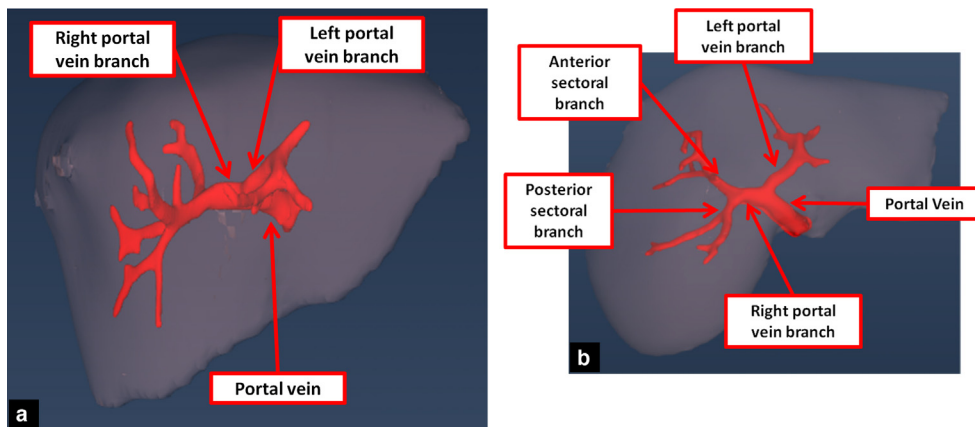

Figure 5. The portal system (3D image): a: anterior view; b: upper view.

- type 4: the right anterior sectoral vein comes from the left portal branch (0.9—6.4%) (Fig. 10).

The most common anatomic variations may simply be due to the slipping of the right anterior sectoral branch towards the left, passing from the modal anatomy (type 1) to trifuration by a slight slipping or to type 4 by more considerable slipping. Others are more rare, such as:
- the left portal branch is absent, resulting in the absence of the left lobe (0.3%);

- the right portal branch is absent, resulting in the absence of the left lobe (0.2—0.3%);
- the left portal branch comes from the right anterior sectoral vein without horizontal segment (0.2—0.4%);

One or both segmental branches of the right posterior sector arise directly from the portal vein, called quadrifurcation (0.3%) [20] (Fig. 11).

In less than 1% of the cases, a portal branch may vascularise a contralateral segment, the right network-feeding segment IV or the left network segment VIII. However,
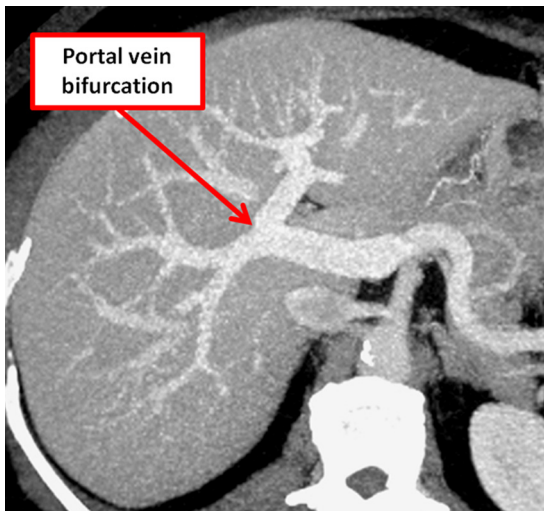
Figure 6. Conventional portal bifurcation (axial CT section MIP image).

there is no anastomosis between these portal networks, as opposed to the arterial network.

The occurrence of these variants varies from one study to the next and increases with the most recent means of imaging [23]. For example, 35% anatomic portal variants, detected by CT-scan, were described in the study by Covey in 2004 [24]. In fact, the CT-scan, MRI or MRA are very reliable, non-invasive techniques, with the same precision in vascular

mapping [25,26]. Variations in the left branch are more rare, mainly involving the number of segmental pedicles more or less near each other. Besides anatomic variants, congenital malformations exist that may be pathological, such as agensis of the portal branches [27] or the portal vein itself, a preduodenal portal vein, duplication of the portal vein, the portal vein communicating with the vena cava or aneurysm of the portal vein [28,29].

Systematic approach to segmentation

We use the terms ''liver'', ''lobe'', ''sector'' and ''segment'' in accordance with Couinaud's classification [30] (Table 1).

Step 1

Couinaud described the system of segmentation most currently used. It is based on the identification of three hepatic veins and the plane passing by the portal vein bifurcation [1]. The first step consists of finding the vascular structures (Fig. 12). Three axial sections are used in the imaging, above, in the plane and below the portal vein bifurcation.

Step 2

The second step consists of determining the plane of separation between the right and left livers. It should not be confused with the right and left hepatic lobes
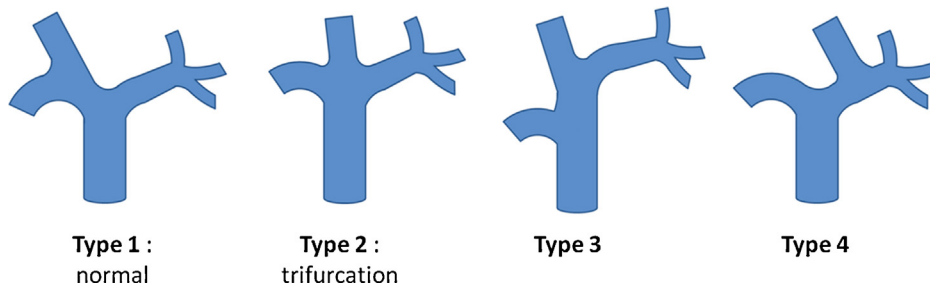

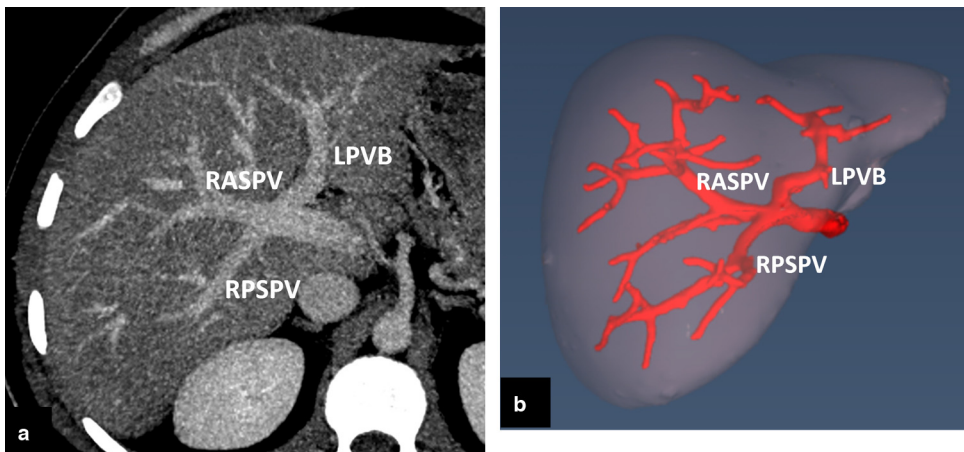Figure 7. Diagrams of the most common portal variations (according to Cheng).

Figure 8. Examples of portal trifurcation (RPSPV = right posterior sectoral portal vein, RASPV = right anterior sectoral portal vein, LPVB = left portal vein branch): a: axial CT section MIP image; b: upper view (3D image).
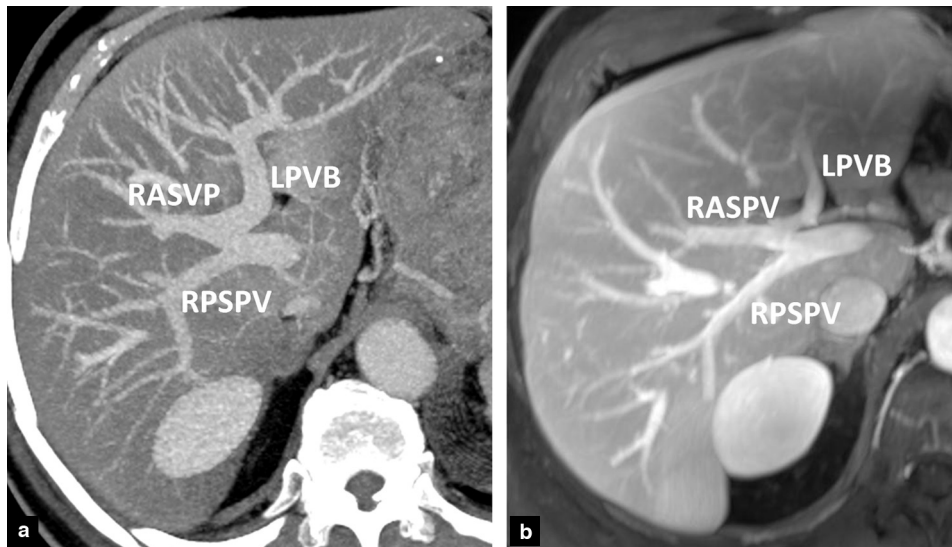
Figure 9. Examples of the right posterior vein arriving directly from the portal vein (type 3) (RPSPV = right posterior sectoral portal vein, RASPV= right anterior sectoral portal vein, LPVB = left portal vein branch): a: axial CT section MIP image; b: axial MRI section MIP image.

Table 1 Definitions of the terms of liver segmentation according to Couinaud's classification.

Term	Definition
Lobes	The right and left lobes are separated by the umbilical scissura
Livers	The right and left livers are separated by the plane of the middle hepatic vein or the plane of the gallbladder
Sectors	Parts of a hemi-liver vertically separated by the plane of the right, middle and left hepatic veins
Segments	Independent functional units receiving an artery, a portal vein, and drained by a hepatic vein, horizontally separated by the plane passing by the portal vein bifurcation

separated by the falciform ligament (or umbilical scissura) and based on an anatomic surface description. Above the plane passing by the portal vein bifurcation, it corresponds to the plane passing by the **middle hepatic vein**. Below, it is determined by ''Cantlie's line'' going from the middle of the gallbladder to the left border of the inferior vena cava (Fig. 13). A trap is the fusion of the central plane, where the gallbladder is deviated towards the left by the left portal branch, thereby aligning with the umbilical scissura. In this case, Cantlie's line no longer represents the limit between the left and right livers [31].

Step 3

The third step is to locate segment I which is very variable and is also called Spigel's lobe. It is defined by the portal bifurcation and the fissure of the ligamentum venosum in front and inside, by Cantlie's line outside and by the
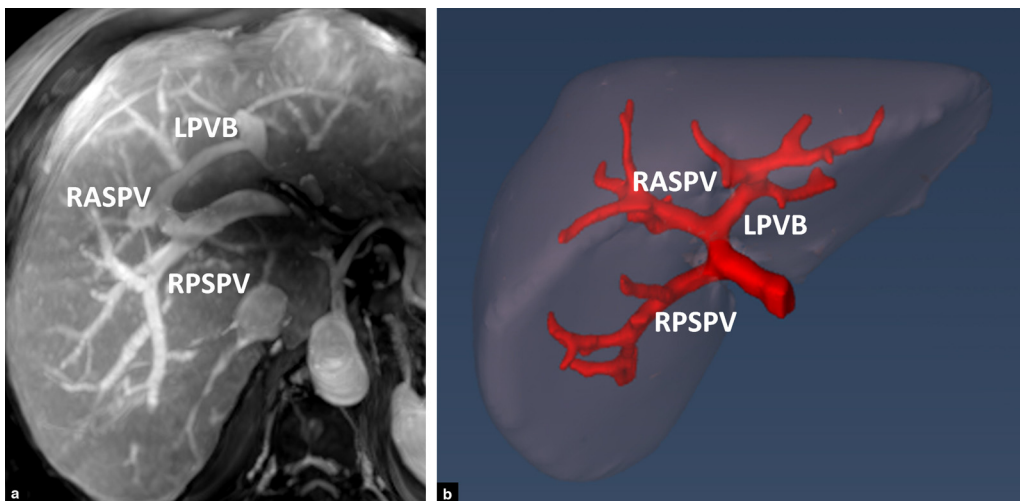

Figure 10. Examples or right anterior vein arriving from the left portal branch (type 4) (RPSPV = right posterior sectoral portal vein, RASPV = right anterior sectoral portal vein, LPVB = left portal vein branch): a: axial MRI section MIP image; b: upper view (3D image).
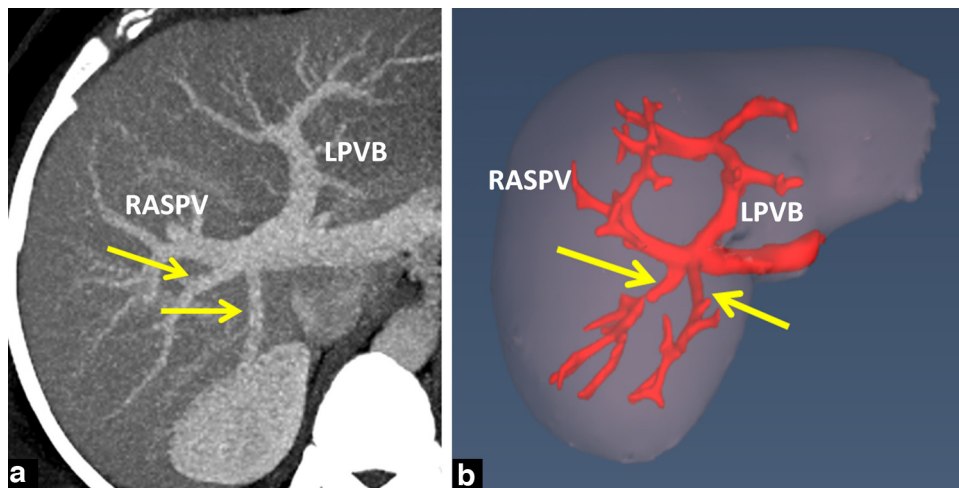
Figure 11. Quadrifurcation: the segmental branches of the right posterior sector (yellow arrows) arrive directly from the portal vein (RASPV = right anterior sectoral portal vein, LPVB = left portal vein branch); a: axial CT section MIP image; b: upper view (3D image).
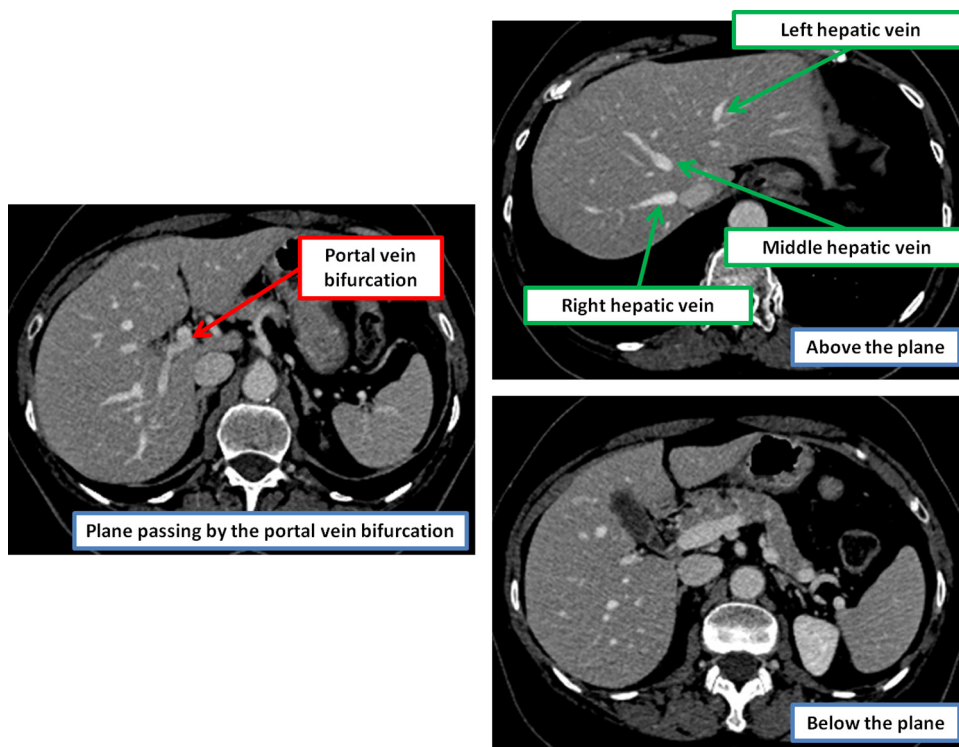

Figure 12. Step 1: locate the hepatic veins and the plane passing by the portal vein bifurcation (axial CT-sections above, in the plane and below the portal bifurcation).

posterior hepatic capsule and inferior vena cava behind [32] (Fig. 14).

Step 4

The fourth step consists of the identification of the plane passing by the right hepatic vein. This vein is visible in almost all sections of the liver. Outside of this line, we define the anterior (or paramedian) sector, and outside the posterior (or posterior-lateral) sector. With respect to the plane passing by the portal vein bifurcation, segment VIII is

the upper portion and segment V the lower portion of the right anterior sector. Segment VII is the upper portion and segment VI the lower portion of the right posterior sector (Fig. 15). Certain authors refer to the transverse scissura to separate the upper segments from the lower segments [33,34] (Fig. 16).

Step 5

The fifth step involves the delimitation of segment IV, located between the plane passing by the middle hepatic
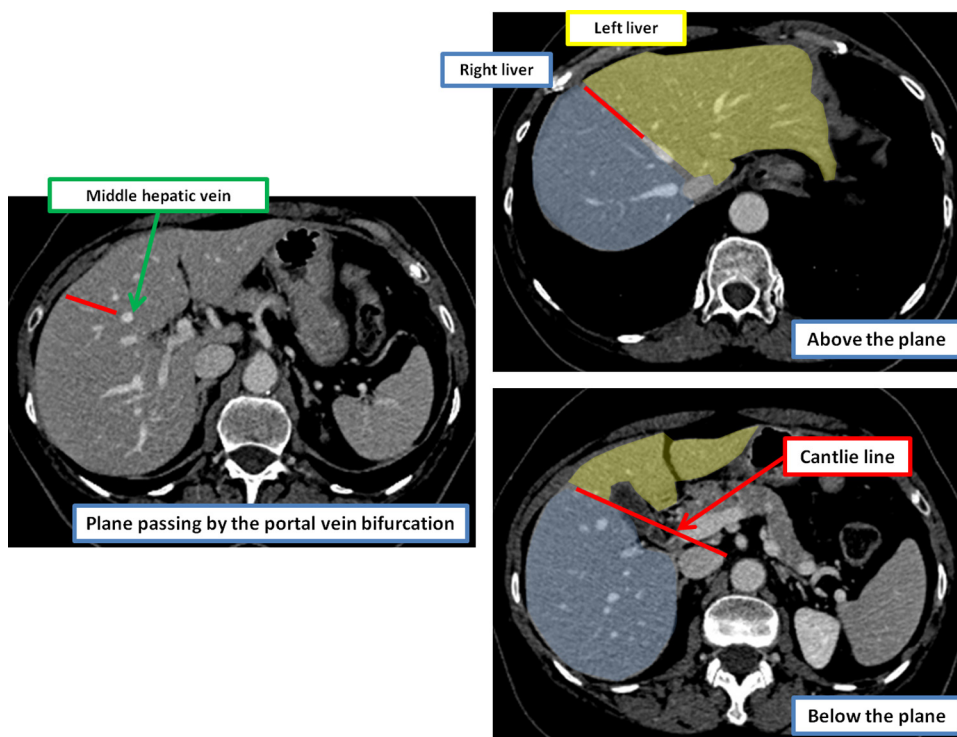
Figure 13. Step 2: distinguish the right liver from the left liver.
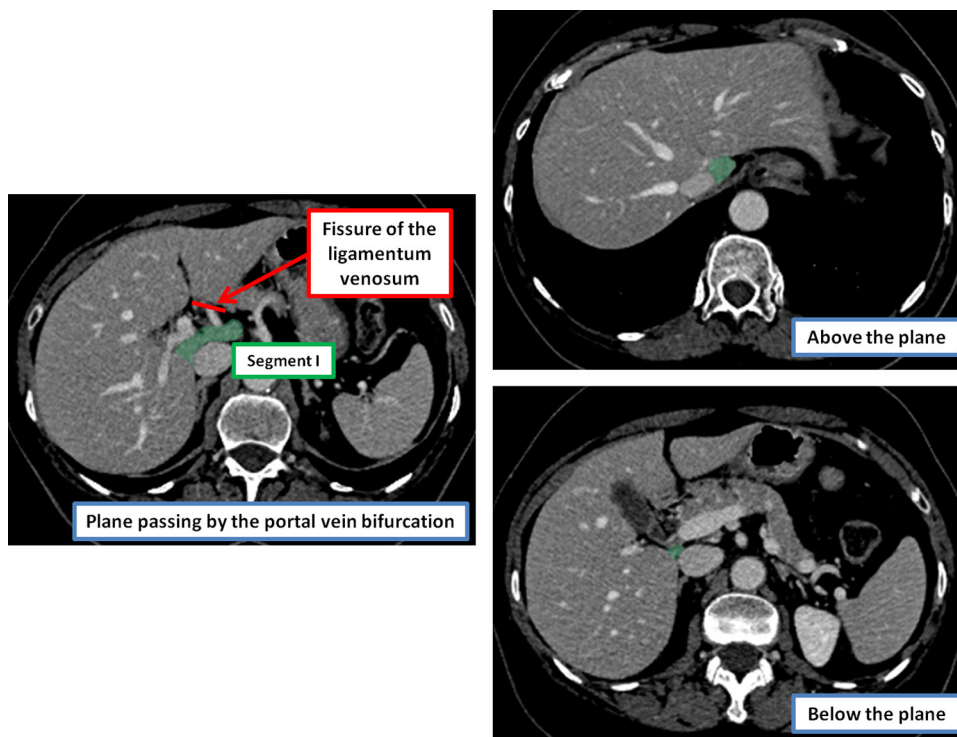
Figure 14. Step 3: delimit segment I.

vein on the right and the axis of the umbilical scissura on the left. This segment can be divided into two subsegments, upper IV A and lower IV B, separated by a line passing through the umbilical portion of the left portal vein [35] (Fig. 17).

Step 6

The sixth and final step involves the division of the left hepatic lobe into segments II and III. The plane of separation is complex, oblique in all planes with segment III

Figure 15.   Step 4: divide the right liver into anterior and posterior sectors, then into segments V, VI, VII and VIII.
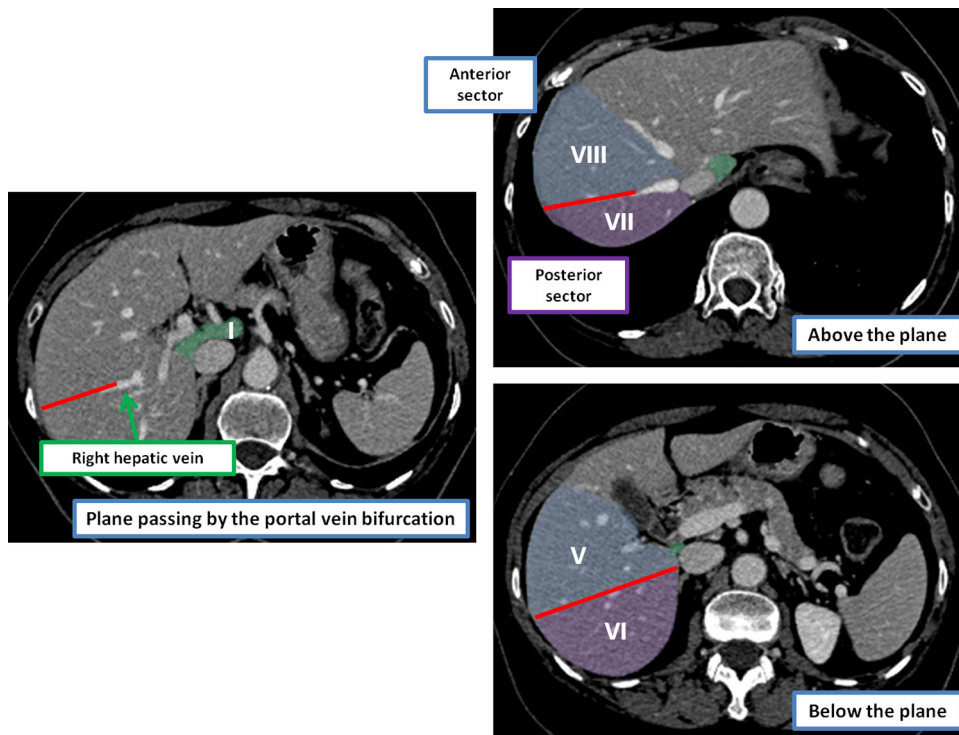
anterior-inferior and segment II posterior-superior. Therefore, to make things easier, certain authors consider that the left lobe is divided into segment II above the plane passing by the portal vein bifurcation, and into segment III below [36], since their exact distinction does not have any practical incidences in surgery (Fig. 18).

Nomenclature

In short, segments II, III and IV form the left liver, and segments V, VI, VII and VIII the right liver. Segment I is a little different because it is part of the right and left livers due to its multiple vascular pedicles, its venous anastomoses and
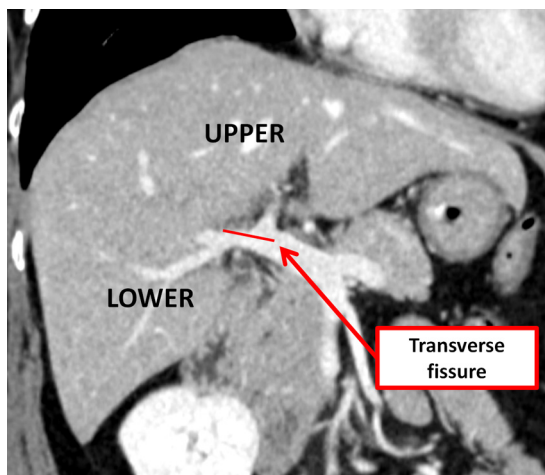

Figure 16.   Oblique coronal CT section showing the transverse scissura allowing for separation of the upper segments (UPPER) from the lower segments (LOWER).

its direct drainage into the inferior vena cava, accounting for its hypertrophy in Budd-Chiari syndrome [37]. The right lobe contains segments IV, V, VI, VII and VIII, and the left lobe segments II and III. In practice, the terms ''quadrate lobe'' and ''caudate lobe'' are often used, although often incorrectly. The lower and anterior part of segment IV, or more globally segment IV B, is the quadrate lobe. Couinaud described a dorsal hepatic sector in 1998 [38], extending forward and on the sides of the retro-hepatic portion of the inferior vena cava, and consisting of two segments: the right segment or segment IX behind the right branch of the portal vein, and the left segment corresponding to segment I. The caudate lobe is the left lateral portion of segment I. It is important to distinguish ''liver'', ''lobe'', ''sector'' and ''segment'' in order to facilitate communication. Confusion in the nomenclature is sometimes found due to the scientific literature published in English where the liver is divided into two ''lobes'' and not ''livers'' by the middle scissura, into four ''segments'' equivalent to ''sectors'' and into eight ''portions'' replacing the ''segments'' [39].

Practical applications

Localisation of lesions

The localisation of lesions should be exact, using Couinaud's system of classification, in order to facilitate their identification, whether for a follow-up, a biopsy, an interventional procedure or surgical removal. The problem arises when the lesion is at the edge of different segments, in particular in the hepatic dome, where the precision is poor. In fact, lesions located above and slightly to the rear of the right hepatic vein may belong to segment VIII and not segment VII
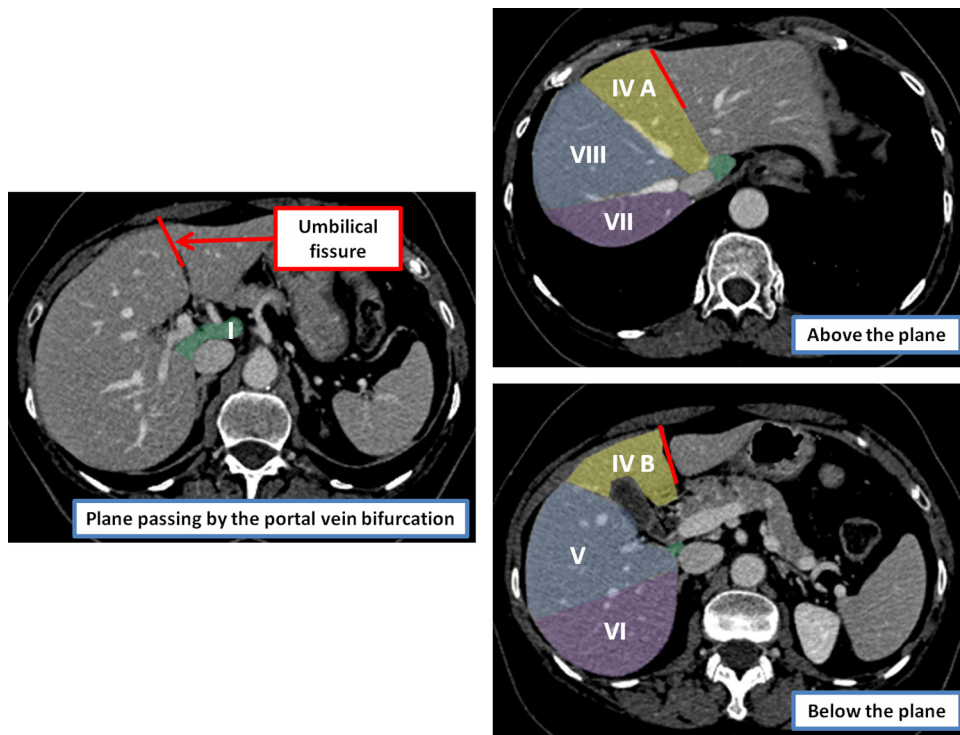
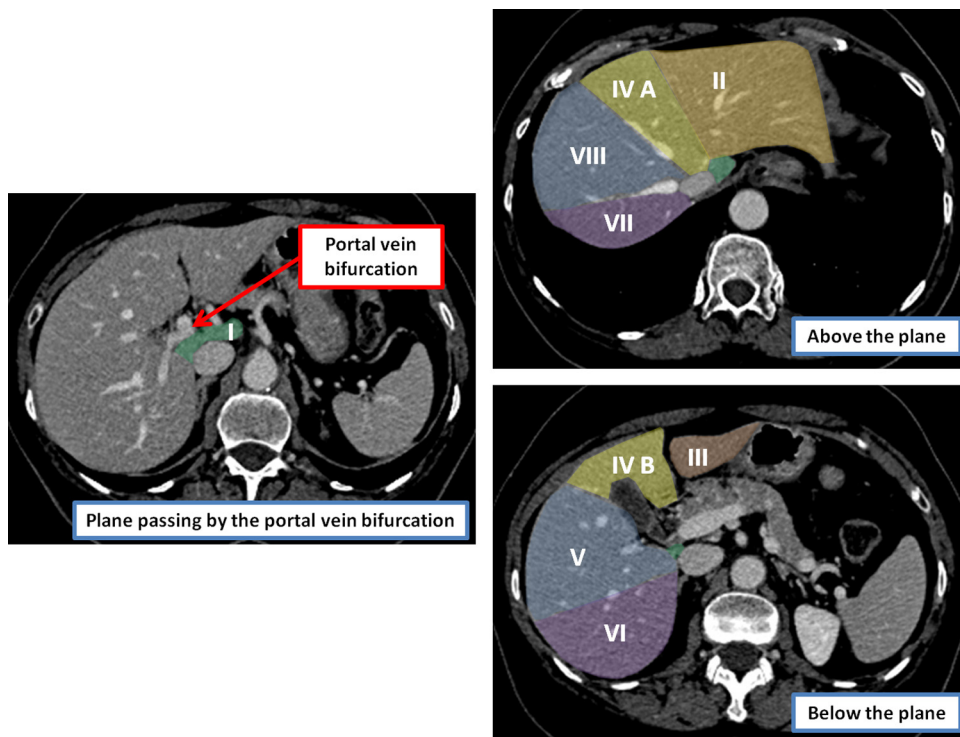**Figure 17.**   Step 5: delimit segment IV.

Figure 18.   Step 6: divide the left lobe into segments II and III with the plane passing by the portal vein bifurcation (easier than the real separation plane, but in practice not having any incidence in surgery).

in 16% of the cases [40]. In addition, segment IV may extend into segment VIII above and to the rear. In case of doubt in the CT imaging, the use of thick MIP slices, 3D reconstructions (Fig. 19) or MR imaging are of great help. In fact, MPR and 3D reconstructions of vessels may provide a better segment localisation of focal hepatic lesions than simple axial images, thereby helping better predict the type of resection required during pre-surgery [41,42].

Liver volumetry

The volume is obtained by adding all of the liver surfaces in the different sections. A data processing programme of measurements may calculate this from several surfaces determined manually. The measurements are very reliable, with good intra and inter-observer reproducibility, provided that the same anatomic references are used [43]. The volumetries are important in planning hepatectomies, in particular major ones [44]. In fact, it is necessary to leave a sufficient volume of liver to ensure the post-surgical hepatic function, before regeneration. For example, at least 25% of the functional liver has to be left in case of the absence of liver disease, while at least 40% is necessary in case of cirrhosis [45]. The pre-surgical volumetry is used to decide on the type of surgery, the value of pre-surgical portal embolisation [45] or even differ the intervention when the volume of liver is too small, including after portal embolisation. Following the same principle, in the case of assessments in living donor liver transplantation (or LDLT), the volume of the remaining liver should exceed 30—35% of the total volume of the liver [46], in order to avoid a small-for-size syndrome, the source of infectious complications and an increase in mortality. An insufficient volume was the reason for the exclusion of 57.4% of the potential donors in the study by Tsang [47]. By way of example, a right hepatectomy, comprising segments V to VIII, removes about 65% of the total volume of the liver [48].

Interventional procedures

The radiologist is essential in the identification of vascular variants. The interventional radiologist or surgeon should have good knowledge of it before the intervention, whether simple or complex, in order to decide on the most appropriate technique, anticipate any additional stages and also reduce the risk of intra or post-intervention complications.

As mentioned above, portal embolisation consists of embolising the portal branches of the liver that will be removed about 4 weeks before the surgery, in order to increase the volume of the liver left in place, by redistribution of the portal blood flow [45,49,50]. Portal anatomic variations increase the complexity of this procedure. For example, in the present of portal trifurcation, the two right branches should be obstructed separately after portal catheterisation. If the left portal branch arises from the anterior sectoral vein, a great deal of care is required during the portal embolisation so as to avoid embolising the left liver. Therefore, recognition of these variations is essential [51,52]. In the same way, the insertion of a transjugular intrahepatic portosystemic shunt (TIPS) consists of conducting a blind catheterization of the portal vein from a hepatic vein, using certain empirical references. A venous or portal variant may make this procedure very complex. Certain authors recommend looking for any possible variations by imaging in sections before carrying it out [53,54].

Liver surgery

Before resection of a tumour or a partial hepatectomy in view of adult living donor transplantation, the detection of anatomic variants reduces the risk of intra and post-surgical complications. Teamwork between the radiologist and surgeon is absolutely necessary during the non-invasive pre-surgical evaluation of a patient with CT or MR imaging [55,56]. For example, during a right hepatectomy, the surgeon has to make sure that there isn't a type 3 portal variant before sectioning the right portal branch in the hilum of the liver [57], or a type 4 variation before sectioning the liver according to the theoretical right hepatectomy plane (Fig. 20) which would provoke a ligature or a section of the left portal branch. These two cases would be catastrophic in post-surgery due to the disappearance of portal vascularisation in the residual left liver. During transplantation, trifurcation would require a double anastomosis for the two branches of the right liver or the formation of a common trunk to perform an anastomosis with the portal vein of the receiver [58]. As regards the venous variants, the presence of a right inferior accessory vein of segment VI, found in about half of all cases, enables the resection of segments VII and VIII while leaving in place segments V and VI for which it provides the drainage [59]. In case of transplantation, it
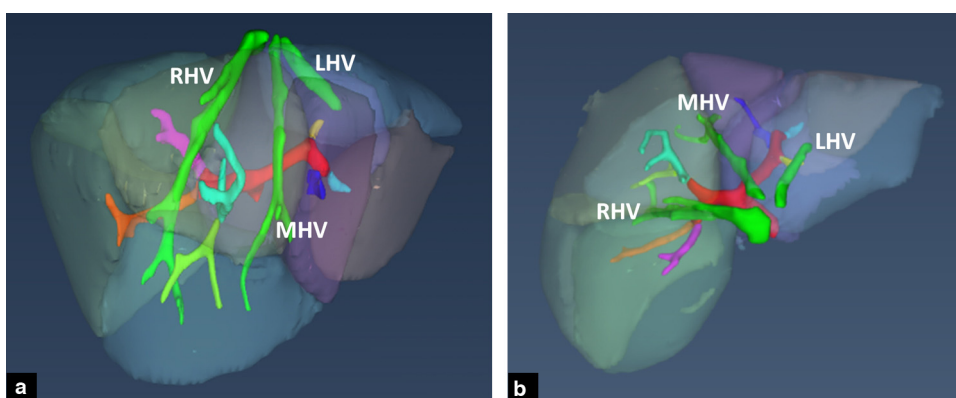

Figure 19. Liver segmentation in 3D (RHV = right hepatic vein, MHV = middle hepatic vein, LHV = left hepatic vein): a: anterior-lateral view; b: upper view.

should be recognised before the intervention in order to perform a venoplasty or a separate anastomosis of the inferior vena cava and thereby avoid haemorrhagic complications [56]. In addition, during the assessment of potential living donors for a liver transplantation, it is necessary to detect the hemi hepatectomy plane (Fig. 21). This plane separates the right liver from the left liver, passing by a line located 1 cm to the right of the middle hepatic vein then Cantlie's line under the portal bifurcation, a little vascularised zone [55]. In most donors, the angioscan, faster and cheaper than MRA, detects a wide range of vascular anatomic variations crossing the hemi hepatectomy plane [60], requiring a mod-
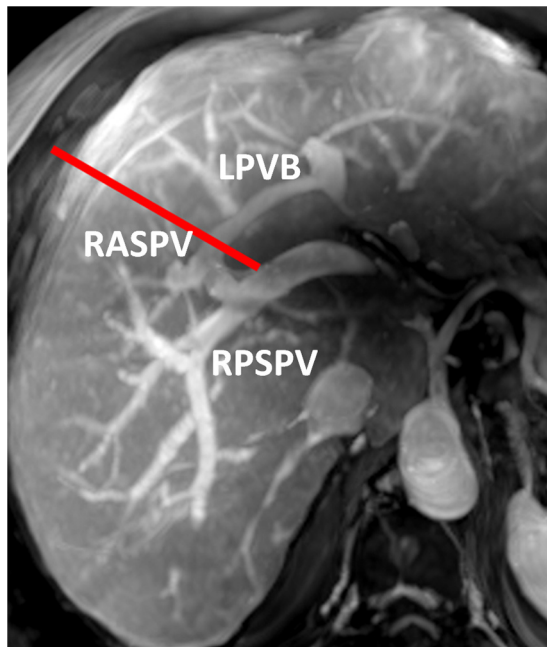
ification in the surgical technique, or even the exclusion of potential donors in certain cases (10% in the study by Tsang in 2008 [47]).

Conclusion

Using several simple anatomic references, it's easy to segment the liver with certainty on imaging in sections, CT-scan or MRI. Exact information is required both in the location of the lesions and in the estimate of the hepatic volumes, in order to determine the best therapeutic, radiological or surgical care. Any venous or portal vascular anatomic variant should be exactly described, so as to let the interventional radiologist or surgeon plan their procedure in advance and, if necessary, modify their technique, thereby greatly reducing the inter and post-surgical difficulties and complications.

Disclosure of interest

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

Figure 20. Axial MRI section showing the theoretical plane of right hepatectomy, cutting off the portal flow from the left liver in the presence of a type 4 portal variant (RPSPV = right posterior sectoral portal vein, RASPV = right anterior sectoral portal vein, LPVB = left portal vein branch).
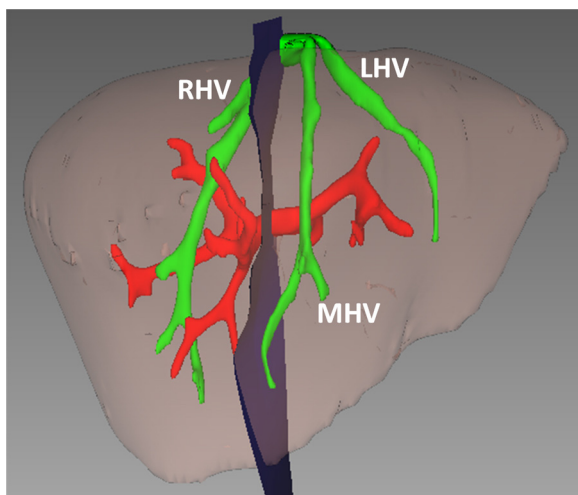
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Figure 21. Example of a hemi hepatectomy plane (anterior view, 3D image) (RHV = right hepatic vein, MHV = middle hepatic vein, LHV = left hepatic vein).

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