Portal Vein Normal Anatomy and Variants: Implication for Liver Surgery and Portal Vein Embolization

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ABSTRACT

The normal anatomy of the portal vein is defined as a division of the main portal vein into two branches—the left (supplying segments II, III, and IV) and right portal veins; the right dividing secondarily into two branches—the anterior (supplying segments V and VIII) and the posterior (supplying segments VI and VII) portal veins. Variants are frequent and account for 20 to 35% of the population. The most frequent variants are portal trifurcation with division of the main portal vein into the left, right anterior, and posterior branches, and the early origin of the right posterior branch directly from the portal vein. The presence of portal vein variants increases the risk of bile duct hilar anatomical variation. These variants must be diagnosed before complex hepatectomy, split or living donor transplantation, and before complex interventional procedures such as portal vein embolization. The purpose of this article is to review normal and variant portal venous anatomy and their implications for liver surgery and preoperative portal vein embolization.

KEYWORDS: Portal vein, hepatectomy, liver transplantation, portal vein embolization, anatomy

Intrahepatic portal vein anatomy was described many years ago on cadaveric liver dissection and with corrosion casts of explanted liver.¹ Modern imaging techniques such as multislice computed tomography (CT) or magnetic resonance imaging (MRI) now allow for three-dimensional (3D) reformation of the entire liver vascular structures, and offers an interactive platform for surgeons and interventional radiologists to decide preoperatively the best treatment options.^{2–4} Recent developments in liver surgery, with living donor transplantation⁵ or complex liver resection, and in inter-

ventional radiology with portal vein embolization (PVE) techniques^{6,7} has made mandatory the precise and reliable preoperative imaging of vascular anatomy. The purpose of this article is to review normal and variant portal venous anatomy and their implications for liver surgery and preoperative PVE.

GENERAL LIVER ANATOMY

The surgical liver anatomy is based today on the liver segmental classification established by Couinaud in

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Semin Intervent Radiol 2008;25:86–91. Copyright © 2008 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662. DOI 10.1055/s-2008-1076688. ISSN 0739-9529.

1957.¹ This classification separated the liver into eight different segments, each one having its own portal, arterial, and biliary branch and shares its hepatic vein drainage with adjacent segments. This segmental anatomy uses four planes to separate the segments: three longitudinal planes joining the inferior vena cava to respectively the right hepatic vein, the median hepatic vein, and the umbilical portion of the left portal vein. One imaginary transverse plane passing by the portal vein bifurcation is also used. This classification gave three segments to the left liver (segments II, III, and IV) fed by the left portal vein and four segments to the right liver fed by the right portal vein (segments V, VI, VII, and VIII). Segment I is located posteriorly between the portal vein and the inferior vena cava and is fed by multiple branches coming from both the left and right portal veins and does not belong either to the right or left liver.

NORMAL PORTAL ANATOMY

The normal portal vein anatomy is defined as follows. The portal trunk divides in the liver hilum into two branches: the left portal vein branch and the right portal vein branch. The right portal vein branch divides secondarily into two branches: the right anterior portal vein feeding segments V and VIII and the right posterior vein feeding segments VI and VII (type 1, Fig. 1A). Any deviation from this anatomy is considered an anatomical variant (Table 1). The normal anatomy is encountered in 65 to 80% in the studies using multidetector CT with reconstruction of the portal anatomy.^{2,4}

PORTAL VEIN VARIANTS

The most common variant is the so called “portal vein trifurcation” where the main portal vein divides into three branches: the left portal vein, the right anterior portal vein, and the right posterior portal vein (type 2, Fig. 1B). The second most common variant is a right posterior portal vein originating as the first branch of the portal vein (type 3). These two variants account for the majority of main portal vein variation. Their relative incidence varies from study to study and the reported incidence of these variants increases with the use of the most recent imaging modalities. In older reports, the incidence was ranged between 0.09 and 24%.⁸⁻¹⁰ The use of 3D reconstruction obtained from thin axial CT images seems the most efficient technique with reported incidences of 27 and 35%^{2,4,11} (Fig. 2). In the study of Atasoy and colleagues, type 3 was twice more frequent than type 2² (23.5 and 9.5%, respectively). In the study of Covey and colleagues, the reported incidence of type 2 and 3 were respectively 9 and 13%.¹¹ In another recent study including 1384

patients, trifurcation was slightly more frequent than early origin of the right posterior branch of the portal vein⁴ (11.1 and 9.7%, respectively).

Less common portal vein variations have been described but their incidence has not been found to be higher than 2%.^{2,4} The variants include quadrification in which the portal vein divides into a left portal branch and three separate right portal branches and a more complex variant is the so-called “absence of portal vein bifurcation”.⁴ In the latter case, the portal vein gives only a single right portal branch in the liver hilum, the origin of the left portal branch being absent. A large portal branch coming from segment VIII crosses segments VIII and VI and ends in the umbilical portion of the portal vein and then supplies a small segment of left portal branch that gives the segments II, III, and IV branches (Fig. 3). The last rare portal vein variation is the so called “fusion of the central plane of the liver”.¹² This variant associates the following abnormalities: (1) juxtaposition of the ligamentum teres and the gallbladder; (2) typical portal vein branching with a right posterior branch, a left posterior branch, and a main medial branch that terminates in the ligamentum teres; (3) two main hepatic veins and a hypotrophied medial hepatic vein. This variant is extremely rare and is encountered in less than 0.5% of patients.

In addition to variations of the main portal vein, there are other important variations in the anatomy of the division of right portal branches.¹³ The division of right portal branches has been assessed in the Japanese literature with the use of Takayasu classification.¹⁴ The knowledge of these variants has not been extensively disseminated because of its limited impact on most surgical and interventional procedures. However, the development of more limited anatomic resections such as those in cirrhotic patients requires precise knowledge of the anatomic situation before surgery. Recently, an extensive study focused on this point. These authors observed that the typical division of the right portal branch (i.e., two main branches)¹³ is encountered in ~70% of cases. This division gives two branches for segments V and VIII (anterior right liver) and two separate branches for segments VI and VII (posterior right liver). The most common variant (seen in 20% of cases) is the absence of definite right posterior branches but the immediate bifurcation in two branches for segments VI and VII. A further variation concerns the origin of the segment V branch originating from the right posterior portal vein or directly from the right portal vein.

Another important anatomic variation is the presence of segmental portal branches passing through the mid plane of the liver separating, theoretically, the left and the right liver. This was found in 4% of cases⁴ and this concerns only segments IV and VIII fed by branches coming from the contralateral side.

Figure 1 Three-dimensional (3D) reformation of the main types of portal vein division. (A) Anteroinferior view of 3D reformation of the portal system. The normal anatomy is defined by division of the portal trunk into a left portal vein branch (LPV), and a right portal branch (RPV) that subsequently divides in an anterior (RAPV) and a posterior (RPPV) branch. (B) Anterior view of a 3D reformation of the portal system of a patient with a trifurcation. This patient has a portal vein that divides directly in three branches the LPV, RAPV, and RPPV. (C) Anteroinferior view of a 3D reformation of a patient with a RPPV with an early origin on the portal vein (PV).

Table 1 Classification of Portal Vein Variations

Type	Definition
1	MPV divides into LPV and RPV; then RPV divides into RAPV and RPPV
2	MPV trifurcation into LPV, RAPV, RPPV
3	MPV divides into a RPPV and a common trunk, which then divides into LPV and RAPV

MPV, main portal vein; LPV, left portal vein feeding segments II, III, and IV; RPV, right portal vein feeding segments V, VI, VII, and VIII; RAPV, right anterior portal feeding segments V and VIII; RPPV, right posterior portal vein feeding segments VI and VII.

ASSOCIATION OF PORTAL VEIN VARIANTS WITH OTHER ANATOMIC VARIANTS

For a long period of time, it was postulated that there was no definite relationship between portal and biliary anatomic variation.^{1,15} More recently, the use of multidetector computed tomography cholangiography has allowed simultaneous study of portal vein and biliary anatomy. The recent study of Kitami et al³ compared 42 patients with portal anatomic variation to a control group of 153 patients without portal vein variant. These authors showed that the standard biliary configuration with a right posterior biliary duct joining the right anterior branch cranially to the right anterior portal vein branch is encountered in 74% of cases in patients without portal variant and in only 32% of cases in cases of portal vein

Figure 2 Maximal intensity projection view of the portal vein bifurcation. (A) Normal anatomy is demonstrated on this view with the division of the portal vein in right and left portal branches. (B) Portal trifurcation is shown as the portal vein divides in three branches the LPV, RAPV, and RPPV. (C) A type 3 division is shown as the RPPV originates as the first branch of the portal vein, which gives then a branch that divides after in LPV and RAPV.

variation. The conclusion of the above mentioned study was that portal vein variants are associated with a significantly higher number of biliary hilar variation.

CONSEQUENCES FOR PORTAL VEIN EMBOLIZATION

Portal vein embolization (PVE) is a technique used before major hepatectomy to increase preoperatively the size of the liver that will be left in place by the surgeon. It consists of embolizing the branches of the liver that will be ultimately resected approximately 4 weeks before surgery.^{6,7} This is used both in patients bearing liver metastases developed in an otherwise healthy liver and in patients with chronic liver disease with primary liver tumor. The procedure can be performed from a contralateral or from an ipsilateral approach¹⁶ and different embolic materials may be used. Some anatomic variations increase the complexity of the procedure from a contralateral approach such as a type 3 portal vein bifurcation. In this situation, catheterization of branches for segments V and VI may be difficult and often requires the use of a reverse curved catheter. We recommend embolizing this branch first during the procedure. Branches with difficult and unstable catheterization carry a higher risk for embolic migration mainly when n-butyl-cyanoac-

rylate is used as embolic agent. If the right posterior liver is embolized first, some embolic material may migrate into the right anterior portal vein without any consequence for the patient. The use of ethanol as an embolic material¹⁷ through an occlusion balloon is more complex in cases of portal vein trifurcation, quadrifurcation, or in type 3 portal vein division. Indeed, for right PVE, the balloon is placed into separate right portal branches (i.e., the main right portal vein does not exist when such anatomical variation is present). Consequently, it requires multiple catheterizations and injections that are difficult to achieve with the relatively large size of balloon catheter. Precise knowledge of intrahepatic segmental anatomy is of considerable importance when an atypical PVE is planned (e.g., embolization of all portal vein branches supplying all liver segments except segment VI and VII).

CONSEQUENCES FOR LIVER RESECTIONS

Portal vein variants are rarely reported on routine liver CT or MRI that are performed during a preoperative work-up. This is, however, of critical importance: to be safely performed, a hepatectomy needs complete occlusion of the portal branches that will be resected during hepatic dissection. If a portal branch remains unoccluded during

Figure 3 Absence of left portal vein. (A) On a computed tomography (CT) image passing by the liver hilum the left portal vein is not visible. (B) On a CT slice passing by segment VIII a large vein (arrows) is seen running parallel to the liver capsule and going from segment VIII to segment IV. (C) On a CT slice passing at the level of the Rex recess, the large vein coming from segment VIII enters a distal segment of the left portal vein and feeds branches of segments II, III, and IV.

parenchymal resection, the risk of bleeding is significantly increased. In this setting, type 3 portal vein bifurcation should be described before right hepatectomy. If the surgeon ligates the right anterior branch only and leaves patent a right posterior branch during resection, this may lead to active bleeding. In the same way, the liver left in place after surgery (i.e., remnant liver) needs all its portal vein feeders to regenerate after hepatectomy. Portal branch thrombosis of the remnant liver after resection has important consequences in term of portal hypertension and impairs further liver regeneration.

CONSEQUENCES OF ANATOMIC VARIATION ON LIVER TRANSPLANTATION

To perform split liver transplantation and living donor transplantation, a precise preoperative analysis of all vascular abnormalities is mandatory. Recent extensive studies have focused on this point and have demonstrated that the standard vascular anatomy is found in 35% of donors only, thus demonstrating the frequency of arterial portal and hepatic vein variant in the normal population.^{8,18} Trifurcation of the portal vein has been claimed to increase the complexity of surgical procedures, making the portal vein clamping more difficult. A type 3 portal vein variant is also more difficult for

surgery because two portal vein anastomoses have to be done on two separate veins in the recipient. Finally, the liver left in place in the donor must have all its segments perfectly vascularized and particular attention is to be paid to all portal branches. If these branches were originating from the right portal branch, the segment IV would be devascularized after right hepatic lobe harvesting.

CONCLUSION

Portal vein variants are frequent and easy to recognize with the increased quality of 3D reconstructions in CT or MRI. In case of complex surgical or interventional procedure, these variations should be described precisely in the radiological report because of their considerable impact on subsequent surgical and interventional radiology procedures.

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