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SHORT COMMUNICATION

Portal vein variations in 1000 patients: surgical and radiological importance

BINIT SUREKA, MD, MBA-HCA, YASHWANT PATIDAR, MD, KALPANA BANSAL, MD, S RAJESH, MD, PDCC, NITESH AGRAWAL, MD and ANKUR ARORA, MD, FRCR

Department of Radiology/Interventional Radiology, Institute of Liver and Biliary Sciences, Vasant Kunj, New Delhi

Address correspondence to: Dr Binit Sureka

E-mail: binit surekapi@gmail.com

Objective: The purpose of the study was to evaluate the spectrum and incidence of intrahepatic portal vein (PV) variations on triphasic abdomen multidetector CT (MDCT) and to discuss the surgical and radiological implications.

Methods: A retrospective review of 1000 triphasic MDCT abdomen scans was performed in patients sent for various liver and other abdominal pathologies between January 2014 and August 2014. A total of 967 patients ($N=967$) were included in the study. The variations in branching pattern of PV were classified according to classification used by Covey et al (Covey AM, Brody LA, Getrajdman GI, Sofocleous CT, Brown KT. Incidence, patterns, and clinical relevance of variant portal vein anatomy. *AJR Am J Roentgenol* 2004; **183**: 1055–64) and Koç et al (Koç Z, Oğuzkurt L, Uluhan S. Portal vein variations: clinical implications and frequencies in routine abdominal CT. *Diagn Interv Radiol* 2007; **13**: 75–80).

Results: Normal anatomy (Type I) was seen in 773 patients (79.94%) out of 967 patients in our study. Trifurcation (Type II) anomaly was seen in 66 (6.83%) of cases. Right posterior vein as first branch of main PV (Type III) anomaly was seen in 48 (4.96%) of cases. Type IV anomaly and Type V anomaly was seen in 26 (2.69%) and 13 (1.34%) cases, respectively. 19 cases showed other types of variations.

Conclusion: Variations in the hepatic PV branching patterns are commonly seen that are similar to variations in hepatic artery and biliary anatomy. Knowledge of these variations is extremely important for transplant surgeons and intervention radiologists.

Advances in knowledge: Awareness of the variations in PV branching patterns is essential for intervention radiologists and vascular surgeons and avoids major catastrophic events.

INTRODUCTION

The portal vein (PV) also known as “*vena portae*” is an important blood vessel that conducts blood from the gastrointestinal tract and spleen to the liver. The liver receives about 75% of its blood through the PV, with the remainder coming from the hepatic artery proper. The PV is not a true vein in the sense that it does not conduct blood directly into the heart. The PV is formed by the union of superior mesenteric and splenic vein. 6000 liver transplants are performed annually in the US¹ In the UK, there has been a steady increase in the number of patients undergoing liver transplant in last 10 years; a similar trend is being observed in China, Canada and India. Similarly, complex hepatobiliary surgical and vascular intervention procedures have increased owing to advancements in medicine and technology.

The detailed anatomical knowledge of hepatic artery, PV, hepatic veins and biliary anatomy is of clinical and radiological relevance when dealing with such complex

procedures. The purpose of this study was to identify the anatomic variations in PV anatomy.

METHODS AND MATERIALS

Patients

We retrospectively reviewed 1034 multidetector CT (MDCT) examinations performed in our institute between January 2014 and August 2014. We excluded patients with a history of major upper abdominal surgery, who had undergone previous liver resections and patients with large central tumours and other pathologies obscuring the assessment of PV variations. So finally a total of 967 ($N=967$) patients were included in the study. Our study group comprised 305 (31.5%) females and 662 male (68.45%) patients. Mean age of the patients was 47 ± 14 years (mean $\pm$ standard deviation).

CT examination protocol

Triphasic CT abdomen was performed on GE Discovery 750HD Single-source Dual Energy CT scanner (Discovery CT 750HD; GE Healthcare, Milwaukee, WI). 100 ml of

Table 1. Anatomic variations in branching pattern of portal vein used in the study

Type	Description
Type I	Classical anatomy
Type II	Trifurcation
Type III	Right posterior vein as first branch of MPV
Type IV	Segment VII branch separate branch of RPV
Type V	Segment VI branch separate branch of RPV

MPV, main portal vein; RPV, right portal vein.

non-ionic iodinated contrast material (iodine concentration, 400 mg ml^{-1}) was injected through an 18- to 20-gauge antecubital intravenous cannula at a rate of 4 ml s^{-1} . Scans were acquired in hepatic arterial, portal venous and hepatic venous phase using a Smart Prep Protocol with enhancement threshold set at 100 HU. Examination parameters were detector coverage 40 mm, 98.43 mm s^{-1} table speed, 0.6 s rotation time, pitch and speed of 0.984, 1.5 mm section thickness, 5-mm reconstruction interval, 100–120 kVp and 200–360 mA. Additional images were reconstructed with 0.625 mm reconstruction intervals for detailed interpretation.

Image interpretation

The raw imaging data obtained from MDCT were processed on a commercially available workstation for axial, coronal and axial-oblique multiplanar reformation (MPR), maximum intensity projection (MIP) and volume rendering (VR) images. The images were analysed independently by five radiologists: Radiologist 1 (SR) with 6 years, Radiologist 2 (BS) with 6.5 years, Radiologist 3 (YP) with 9 years, Radiologist 4 (AA) with 10 years

and Radiologist 5 (KB) with 11 years of experience in interpreting CT and MRI scans. We analysed the variations in branching pattern of main portal vein (MPV), right portal vein (RPV), left portal vein (LPV) and intrahepatic segmental variations if any. The difficult cases especially discrimination between PV trifurcation, right posterior portal vein (RPPV) being the first branch of the MPV and Segment VI and VII branching patterns were also studied using Myrian® XP-Liver Software Workstation 3D Surface ROI reconstruction tool (Intrasense, Paris, France). Myrian is a medical image review and aided diagnostic software used for visualization, storage, reproduction and exporting of medical images. It is used for three-dimensional imaging involving MIP and highly detailed VR and uses unique segmentation algorithms to isolate entire hepatic vascular systems, healthy parenchyma and calculate their volume with high precision. For simplification, we have classified the common PV variations into five types as classified by Covey et al (Table 1) (Figure 1).

Key definitions

Normal anatomy

The MPV divides into the RPVs and LPVs, respectively. The RPV then divides into right anterior portal vein (RAPV) and RPPV which further subdivides into superior and inferior segmental branches. The LPV trunk gives off branches to liver Segments II, III and IV.²

Main portal vein

Large vein formed by the convergence of the superior mesenteric and splenic veins which carries blood from the spleen and gastrointestinal tract to the liver's capillary beds.²

Trifurcation of main portal vein

MPV divides into three branches—RAPV, RPPV and LPV.²

Figure 1. Line diagram showing portal vein variations (Type I–Type V). LPV, left portal vein; MPV, main portal vein; RAPV, right anterior portal vein; RPPV, right posterior portal vein; RPV, right portal vein; Seg VI, Segments VI; Seg VII, Segments VII; SMV, superior mesenteric vein; SV, splenic vein.

Table 2. Hepatic portal vein variations in 967 patients

Type	Description	Number of patients (%) N = 967
MPV variations		
I	Classic branching pattern	773 (79.94)
II	Trifurcation	66 (6.83)
III	RPPV as a first branch of MPV	48 (4.96)
	Total ramification	2 (0.2)
	Absence of PV bifurcation	1 (0.1)
	Quadrifurcation	–
	Origin of the Segment IV branch from the MPV	–
	Origin of Segment VIII branch from MPV	–
RPV variations		
IV	Separate origin of the Segment VII branch from the RPV	26 (2.69)
V	Separate origin of the Segment VI branch from the RPV	13 (1.34)
	Separate origin of the Segment VI and VII branches from RPV	3 (0.31)
	Origin of the Segment VIII branch from the LPV	2 (0.2)
	Separate origin of the Segment V branch from the RPV	1 (0.1)
	RPPV trifurcation	–
	RPPV quadrifurcation	–
Segmental PV variations		
	Segment V arising from RPPV	4 (0.41)
	Accessory Segment VI branch arising from the RAPV	3 (0.31)
	Segment IV supplied by the right and left PV branches	2 (0.2)
	Segment II branch directly from MPV bifurcation	1 (0.1)
	Segment VIII supplied by the right and left PV branches	–
	Segment VIII supplied by the left PV branches	–
	Segment IV supplied by the right PV branches	–
	Segment V supplied by the right and left PV branches	–

LPV, left portal vein; MPV, main portal vein; PV, portal vein; RAPV, right anterior portal vein; RPV, right portal vein; RPPV, right posterior portal vein.

Right posterior portal vein as a first branch of main portal vein

The first branch of MPV is RPPV, which continues to the right for a short distance, and then divides into RAPV and LPV.²

Origin of right anterior portal vein from left portal vein

MPV first divides into RPPV and LPV. Then RAPV arises from LPV.²

Total ramification

All segmental portal vein branches originating from the single main portal vein with no division into right and left branches.²

Absence of portal vein bifurcation

MPV does not divide into RPV and LPV.²

RESULTS

Normal (Type I) anatomy was seen in 773 patients (79.94%) out of 967 patients in our study. Trifurcation (Type II) variation was seen in 66 (6.83%) of the cases. Right posterior vein as first branch of MPV (Type III) variation was seen in 48 (4.96%) of the cases. Type IV variation and Type V variation (Type IV—separate origin of the Segment VII branch from the RPV; Type V—separate origin of the Segment VI branch from the RPV) was seen in 26 (2.69%) and 13 (1.34%) cases, respectively.

In 19 cases (1.96%), we found other types of variations. Other variations which we encountered in our study were four cases of Segment V arising from RPPV, separate origin of Segment VI and Segment VII branch from RPV in three cases, three cases of accessory Segment VI branch arising from the RAPV, two cases of total ramification, two cases of Segment IV being supplied by

Figure 2. (a) Myrian three-dimensional image showing normal anatomy (Type I). (b) Coronal-oblique maximum intensity projection image showing corresponding Type I variation.

RPV and LPV, one case of Segment II branch directly from MPV bifurcation, two cases of Segment VIII branch arising from LPV, one case of separate origin of Segment V from RPV. Absence of PV bifurcation was seen in one case. The detailed results of our study are illustrated in (Table 2).

DISCUSSION

Normal anatomy of portal vein and embryology

Embryology

Embryologically, the PV is formed between 4th and 10th week. Initially, three paired venous systems are present: umbilical veins of chorionic origin, vitelline veins from the yolk sac and cardinal veins from the body of the embryo. Bridging anastomoses (two ventral and one dorsal to the duodenum) are present between the right and left vitelline veins. Selective involution of the vitelline veins results in the formation of PV during the second month of gestation. Normally, the stem of the PV is formed by the left vitelline vein and dorsal anastomosis; the left branch by part of left vitelline vein and cranial ventral anastomosis and the right branch of PV is formed by part of right vitelline vein. Deviation from this normal obliterative process results in variations in branching of PV.³⁻⁵

Normal anatomy

The PVs formed by the union of the superior mesenteric vein and the splenic vein just dorsal to the neck of the pancreas at about the

level of the second lumbar vertebra. The PV has a segmental intrahepatic distribution, accompanying the hepatic artery. At the hilum, main PV (MPV) divides into larger right and left PV branches (RPV and LPV). The RPV then divides into anterior (RAPV) and posterior (RPPV) truncus (Figure 2). RAPV supplies Segments V and VIII. RPPV supplies Segments VI and VII. The left PV (LPV) initially has a horizontal course to the left and then it turns medially towards the ligamentum teres giving branches to supply Segments II, III and IV and the caudate lobe. Normal portal blood flow in human beings is about $1000\text{--}1200\text{ ml min}^{-1}$. The PV contributes 40 ml min^{-1} or 72% of the total oxygen supply to the liver. Normal portal pressure is about 7 mmHg.⁶⁻⁸

Anatomic variations

Standard anatomy in branching pattern is seen in only 65% of the cases. Most common anatomic variation of MPV is trifurcation variation followed by RPPV as a first branch of MPV. Other variations described are quadrifurcation variation, the absence of PV bifurcation, total ramification etc. Other variations are listed in (Table 2). RPV variations described in the literature are separate origin of the Segment VI PV branch from the RPV, separate origin of the Segment VII PV branch from the right PV, separate origin of the Segment VI and VII PV branches from the right PV etc. (Table 2). Segmental PV variations described are Segment VIII supplied by the right

Figure 3. (a) Myrian three-dimensional image showing trifurcation variation (Type II). (b) Coronal-oblique maximum intensity projection image showing corresponding Type II variation.

Figure 4. (a) Myrian three-dimensional image showing right posterior portal vein arising from main portal vein (Type III). (b) Coronal-oblique maximum intensity projection image showing corresponding Type III variation.

and left PV branches, Segment VIII supplied by the left PV branches, Segment IV supplied by the right and left PV branches etc. (Table 2)^{7,9} (Figures 3–8).

The results of our study were similar to studies performed by Covey et al⁷ and Koç et al⁹ except for Type IV and Type V variations. Type IV anatomic variation was slightly more common in our study group. We encountered few interesting variations in our study which were not seen in study by Koç et al⁹ such as separate origin of the Segment V branch from the RPPV, Segment II branch arising directly from MPV bifurcation and Segment V branch arising from RPPV. Incidence of variations such as Segment IV supplied by the right and left PV branches was less in our study (0.2%) than in the study by Koç et al (1.6%).

Clinical and radiological significance

Portal vein embolization

Portal vein embolization (PVE) is an advanced vascular intervention technique performed before major hepatectomy to increase pre-operatively the size of the liver. Normally, hepatobiliary surgeons prefer at least 25% (in case of background healthy liver) and 40% (in diseased liver) future liver remnant (FLR) after hepatectomy. When expected FLR is low, PVE is performed in an attempt to increase FLR volume. Cross-sectional imaging for procedural planning is performed prior to PVE to document the extent of disease, FLR size and portal venous

anatomy. The procedure can be performed from an ipsilateral or a contralateral approach. Usually, an ipsilateral approach is preferred so as to safeguard the non-diseased portion of liver.

When the anatomy of PV is normal, very few technical difficulties are encountered such as hooking the right portal tree owing to severe angulation during ipsilateral approach. Complexity arises when a contralateral approach has to be used in a case of Type III variation of PV. In such cases, a reversed curved catheter may be required for the procedure. Variation in branching patterns like PV trifurcation and quadrifurcation which result in difficult and unstable catheterization carry a higher risk for migration of embolic materials and thus result in non-target embolization.^{10–12}

Liver resection

Major uncommon hepatectomy procedures like extended right hepatectomy (right trisegmentectomy) and extended left hepatectomy (left trisegmentectomy) require embolization of both right and left PV branches. Particular attention has been given prior to extended right hepatectomy (which includes Segment IV) as embolization of Segment IV branch results in better regeneration of Segments I, II and III. Such complicated procedures require detailed evaluation of PV branching pattern as to avoid reflux of the embolizing material into branches of future remnant liver tissue.

Figure 5. (a) Myrian three-dimensional image showing Segment VII branch as a first branch of right portal vein (Type IV). (b) Axial-oblique maximum intensity projection image showing corresponding Type IV variation.

Figure 6. (a) Myrian three-dimensional image showing Segment VI branch as a first branch of right portal vein (Type V). (b) Axial-oblique maximum intensity projection image showing corresponding Type V variation.

For a safe and clean hepatectomy, complete obliteration of the portal branches supplying those particular segments is required. In this context, Type III PV variation is of much clinical importance to the surgeons because if the surgeon ligates only the right anterior branch, then there is a risk of active bleeding from the posterior branch.^{10,12}

Liver transplantation

Anatomic variation in branching pattern of PV most relevant in liver transplantation surgery is Type II (trifurcation) and Type III variation. Trifurcation variant increase the complexity as intraoperative clamping becomes difficult. Type III variant has its own surgical importance in recipient as well as in donor. In recipient, two PV anastomoses have to be performed on two separate veins thus resulting in complexity of the procedure. In donor, the focus is on complete vascularization of remnant liver. If there are segmental variations, then resection of a particular lobe together with its PV branch may devascularize a particular segment (particularly Segment IV and VIII).^{13,14}

Transjugular intrahepatic portosystemic shunt

In most cases, transjugular intrahepatic portosystemic shunt (TIPS) should be created between the right hepatic vein and RPV. Key to successful TIPS creations lies on accurate knowledge

of normal and anatomic variation of PV. Puncture of extrahepatic MPV can lead to uncontrolled bleeding. Anatomic variations of significance are Type II and Type III variations. The clinical implication of some of these variants is that there is altered spatial relationship between these vessels, one main larger right trunk may not be available and thus the target may be smaller in calibre.¹⁵

Congenital extrahepatic portosystemic shunt

Congenital extrahepatic portosystemic shunt (CEPS) or Abernethy malformation is classified into two types according to the pattern of anastomoses between the PV and systemic vein: in Type 1, intrahepatic portal venous supply is absent with end-to-side anastomoses; and in Type 2, intrahepatic portal venous supply is preserved with side-to-side anastomoses. CEPSs are associated with hepatic encephalopathy, nodular liver lesions (focal nodular hyperplasia, regenerative nodular hyperplasia, hepatic adenoma) hepatopulmonary syndrome and concomitant systemic congenital anomalies.¹⁶

Association with biliary variations

Embryologically, the intrahepatic bile ducts develop from bipotent liver progenitor cells which are in contact with the mesenchyme of the PV and thus form the “ductal plates”. Thus, anatomic

Figure 7. (a) Myrian three-dimensional image showing the absence of portal vein bifurcation. (b) Coronal-oblique maximum intensity projection image showing the absence of portal vein bifurcation.

Figure 8. (a) Myrian three-dimensional image showing right anterior portal vein arising from left portal vein. (b) Coronal-oblique maximum intensity projection image showing corresponding right anterior portal vein arising from left portal vein.

variations in intrahepatic branching pattern of PV are usually associated with variant biliary anatomy since embryological development of the hepatic duct occurs later than development of the primary divisions of the PV. This association is important in liver transplantation as it may inadvertently lead to bile duct injury. Rarely, this may be associated with hepatic vein variations.

Kitami et al¹⁷ in their study have shown that classic hilar confluence pattern, where the right posterior sectoral duct connects supraportally with the right anterior sectoral duct, was less frequent in the patients with the PV variation than in the control subjects. Types of variant biliary anatomy encountered in PV variations are right posterior sectoral duct joining left hepatic duct with a supraportal course, right posterior sectoral duct joining right anterior sectoral duct with an infraportal course, trifurcation variation of biliary tree, retroportal course and left lateral segmental ducts caudal to the umbilical portion of the PV.

Segmental localization of hepatic lesions

Awareness of PV variations is important in identifying the location of liver lesions, as PVs along with hepatic veins, determine the segmental anatomy.

CONCLUSION

In conclusion, variations in PV are commonly seen in triphasic MDCT abdomen. Adequate knowledge of these variations is important for radiologists owing to projected increasing demand of liver transplantation and hepatobiliary interventions in the future. Axial-oblique images with MPR and MIP reformations are particularly important in discriminating these variations especially between PV trifurcation, RPPV being the first branch of the MPV and Segment VI and VII branching patterns. Pre-operative cross-sectional imaging workup can help identify variations in PV and also the hepatic artery and reduce procedure-related morbidity and mortality.

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