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ORIGINAL ARTICLE

Portal vein variations: clinical implications and frequencies in routine abdominal multidetector CT

Zafer Koç, Levent Oğuzkurt, Şerife Ulusan

PURPOSE
The aim of this study was to determine the types, prevalence rates, and clinical implications of portal vein (PV) variations using routine abdominal multidetector computed tomography (MDCT).

MATERIALS AND METHODS
The study included 1384 retrospectively evaluated patients (721 males, 663 females) that had undergone routine abdominal MDCT. Portal phase CT scans (2.5 mm collimation, table speed/rotation time, 12.5 mm/0.5 s) were acquired 60 s after contrast material injection. Two radiologists interpreted the images and reached a consensus on all findings. Types and frequencies of PV variations were noted.

RESULTS
Normal PV branching patterns were observed in 1005 (72.6%) of the patients. PV variants and anomalies were identified in 379 patients (27.4%). Normal main PV branching patterns were noted in 1087 (78.5%) of the patients. Main PV branching variations were seen in 297 (21.5%) of the patients. The most frequent types of these variations were trifurcation (n = 154, 11.1%) and right posterior PV as the first branch of the main PV (n = 134, 9.7%). Right PV variation was identified in 42 (3.9%) of the 1087 patients with type 1 anatomy. Variation of the origin of the segmental PV that traversed the interlobar boundary was identified in 55 (4%) of the 1384 patients.

CONCLUSION
The prevalence of PV variations was high in patients that underwent abdominal CT, and routine abdominal MDCT demonstrated these abnormalities very well. Clinically relevant PV variants should be reported in routine CT evaluations.

Key words: • *portal vein, variations* • *multi-detector computed tomography*

From the Department of Radiology (Z.K. ✉ *koczafer@gmail.com*), Başkent University School of Medicine, Adana, Turkey.

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Anatomic variations of the portal vein (PV) are relatively common (1, 2). Developments in complicated surgical and interventional procedures of the liver increase the significance of these variations. PV variations play a critical role in evaluations before surgical interventions, transplantation, and interventional procedures of the liver (1, 3). Lack of knowledge of these variations might prove to be dangerous during these procedures, whereas awareness of them might help in reducing complications (1, 3).

Abdominal venous anatomic variations and anomalies are commonly detected in routine examinations as a result of advances in noninvasive, cross-sectional imaging techniques. Three-dimensional (3D) imaging has been made possible with improvements in multidetector computed tomography (MDCT) systems, along with developments in computer and imaging techniques (4). 3D imaging techniques, such as maximum intensity projection (MIP), multiplanar reconstruction (MPR), and volume rendering (VR), enable detailed imaging of venous structures with MDCT (5). Routine liver MDCT examinations demonstrate PV variations simultaneously.

Studies investigating PV variations with MDCT have been previously reported (2, 3). Larger case series are needed for extended investigations, including rare variations. The aim of this study was to determine the types, prevalence rates, and clinical implications of PV variations in routine abdominal MDCT examinations among a large sample of adult patients.

Materials and methods

Patients

Images of routine abdominal MDCT examinations, performed with standard protocol, of 1396 consecutive patients (all ≥18 years old) examined between March and December 2004 were retrospectively evaluated for PV variations. A total of 12 patients with liver resection (n = 5) and extended tumor (n = 7) were excluded. As such, 1384 patients, 721 males (52%) and 663 females (48%), were included in the study. Mean age of the patients was 56 ± 15 years (mean ± SD) (range, 18–96 years).

Image reconstruction and processing

All of the CT examinations were performed with a 4-detector MDCT device (Siemens Sensation 4, Siemens, Erlangen, Germany). A mixture of 1000 ml water and 40 ml contrast material (meglumine and sodium ioxithalamate, 350 mg/ml; Telebrix-35®, Guerbet, Cedex, France) was used for bowel opacification. Portal phase images used for interpretation of abdominal venous structures were acquired 60 s after intravenous injection of 120–150 ml non-ionic contrast material (iohexol, 300 mg/ml; Omni-

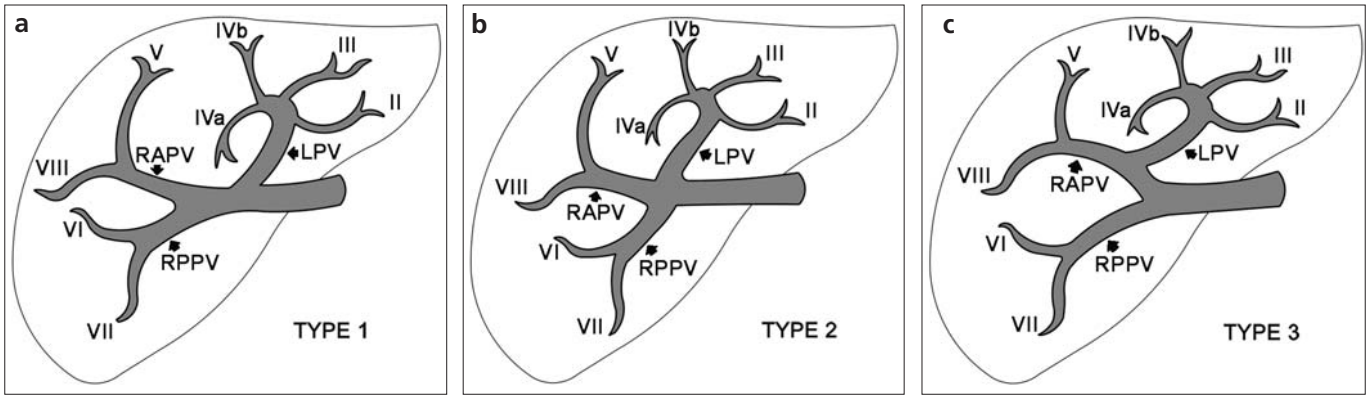

Figure 1. a–c. The most common main portal vein (PV) variants observed in this study. **(a)** Normal (classic) main PV branching pattern (type 1). **(b)** Trifurcation (type 2). **(c)** Right posterior PV as the first branch of the main PV (type 3). (LPV: left portal vein; RPV: right portal vein; RPPV: right posterior portal vein; RAPV: right anterior portal vein.)

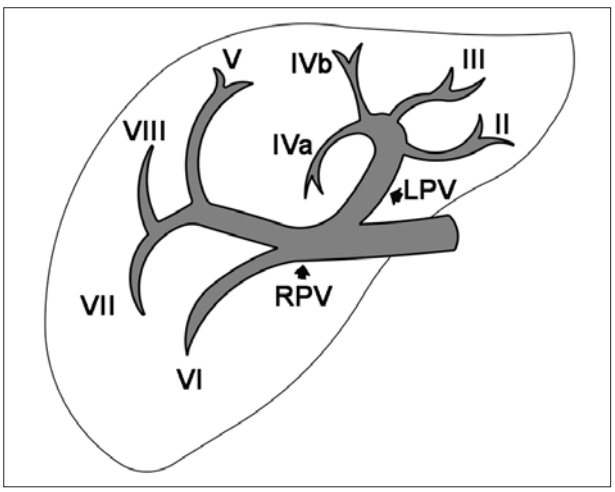

Figure 2. The segment VI branch as a separate branch of the right portal vein (PV), which was the most common right PV variant seen in this study. (LPV: left portal vein; RPV: right portal vein.)

paque, Amersham, Cork, Ireland) at a rate of 3–5 ml/min. Examination parameters were 4 × 2.5 mm collimation, 12.5 mm/s table speed, 0.5 sec rotation time, 5-mm section thickness, 5-mm reconstruction interval, and 120 kVp and 250–310 mA. Additional images were reconstructed with 1-mm reconstruction intervals for indeterminate cases.

Table 1. Main PV branching patterns

Type	Description
1	Normal (classic) branching pattern
2	Trifurcation
3	Right posterior PV as the first branch of the main PV

PV: portal vein

Interpretation of images and data collection

All CT examinations were interpreted by 2 radiology specialists experienced in abdominal imaging (Z.K. and S.U.) on a computer workstation (Volume Wizard, Siemens Medical Systems, Erlangen, Germany) with postprocessing procedures, such as MIP, MPR, and VR (3D imaging). The existence of, type, and number of PV variations were noted in all cases.

Main PV variations, right PV variations, and PV origin variations traversing the interlobar boundary were investigated as 3 separate groups. The main PV that branches into a large right PV and a smaller left PV at the level of the liver hilus in normal (classic) anatomy was classified as type 1 (Fig. 1a). The left PV lies horizontally, medial to the ligamentum teres. The main component supplies segments II and III of the liver, superior and inferior branches supply segment IV, and caudate branches supply segment I.

The right PV branches into the anterior (right APV) truncus and the posterior (right PPV) truncus. Branches of the anterior truncus supply segments V and VIII, and branches of the posterior truncus supply segments VI and VII (1, 6–9). Any configuration other than these was considered anatomic variation (Table 1). Trifurcation of the main PV into the left PV, right APV, and right PPV was considered type 2 branching pattern (Fig. 1b), while branching of the right PPV from the main PV as the first and separate branch was considered type 3 (Fig. 1c) (1, 2). Configuration of the gap between origins of the right APV and right PPV was used for discrimination of type 2 and type 3 PV (2, 10). If this configuration was triangular, type 2 was diagnosed; if rectangular, type 3 was diagnosed (2, 10).

In addition to main PV variations, right PV variations were also observed in cases with type 1 main PV anatomy. These included branching of the right APV and right PPV, and separate origin of segment VI and/or VII PV branch from the right PV (Fig. 2) (1, 2). Additionally, in all cases, origin variations of segmental PVs that cross the Cantlie line and the anatomical border of right-left lobe that is depicted by the middle hepatic vein were classified as a separate group (2,11).

Consensus was achieved with simultaneous evaluation by the 2 radiologists, or with consultation with a third radiologist in cases of conflict. Clinical data and additional CT findings were also noted in all cases.

Statistical analysis

Statistical analyses were made with the Statistical Package for Social Sciences version 12.0 for Windows (SPSS Inc, Chicago, Illinois, USA). Chi-square test was used for evaluation of the prevalences of PV variations in males and females. $P < 0.05$ was accepted as statistically significant.

Results

Normal intrahepatic PV branching patterns were identified in 1005 (72.6%) of 1384 patients. PV variations and anomalies were identified in 379 (27.4%) patients. PV variations were detected in 177 (26.7%) of the 663 female patients and 202 (28%) of the 721 male patients. A statistically significant difference was not detected between the prevalence of PV variations in male and female patients ($P = 0.582$).

A normal main PV branching pattern was identified in 1087 (78.5%) of 1384 patients (Fig 3a). Main PV branching variations were identified in 297 (21.5%) of the patients (Table 2). The most common main PV variation was trifurcation (type 2, absence of the right PV truncus), which was observed in 154 (11.1%) patients (Fig. 3b). The second most common variation was a right posterior PV branch that was the first branch of the main PV (type 3), which was noted in 134 (9.7%) patients (Fig. 3c). A few unusual variations were also seen: quadrification was detected in 3 (0.2%) patients (Fig. 4a); a single PV (absence of PV bifurcation) was detected in 2 patients (Fig. 4b); total ramification of the PV branches coursing similarly to the umbilical vein was detected in one patient; origin of the segment VIII branch from the main PV was detected in one patient (Fig. 4c).

Right PV variations were identified in 42 (3.9%) of 1087 patients with type 1 anatomy (Table 3). The most common right PV variation was separate origin of the segment VI PV branch from the right PV (Fig. 5a). Proximal origin of the segment VII PV branch was detected in 2 patients. Right PV trifurcation (Fig. 5b) was seen in 3 cases. One case demonstrated the type 3 main PV variant simultaneously with branching of the segment VI PV from the right APV (Fig. 5c). Origin variation of the segmental PV traversing the interlobar boundary was identified in 55 (4%) of 1384 patients (Table 4). The most com-

Table 2. Main PV variations detected in 1384 patients

Type	Description	Number of patients	%
1	Normal (classic) branching pattern	1087	78.5
	Variations		
2	Trifurcation	154	11.1
3	Right posterior PV as the first branch of the main PV	134	9.7
	Quadrification	3	0.2
	Absence of PV bifurcation	2	0.1
	Collective branching intrahepatic PV (total ramification)	1	0.1
	Origin of the segment IV PV branch from the main PV	1	0.1
	Origin of segment VIII PV branch from main PV	1	0.1
	Congenital portocaval shunt	1	0.1
	Total	297	21.5

PV: portal vein

Table 3. Right PV variations in 1087 patients with type 1 main PV anatomy

Type	Number of patients	%
Normal (classic) branching pattern	1045	96.1
Variations		
Separate origin of the segment VI PV branch from the right PV	26	2.4
Separate origin of the segment VII PV branch from the right PV	7	0.6
Separate origin of the segment VI and VII PV branches from the right PV	2	0.1
Origin of the segment VII PV branch from the left PV	1	0.1
Right posterior PV trifurcation	5	0.5
Right posterior PV quadrification	1	0.1
Total	42	3.9

PV: portal vein

Table 4. Segmental PV variations traversing the interlobar boundary in 1384 patients

Description	Number of patients	%
Segment VIII supplied by the right and left PV branches	18	1.3
Segment VIII supplied by the left PV branches	11	0.8
Segment IV supplied by the right and left PV branches	22	1.6
Segment IV supplied by the right PV branches	2	0.1
Segment V supplied by the right and left PV branches	2	0.1
Total	55	4

PV: portal vein

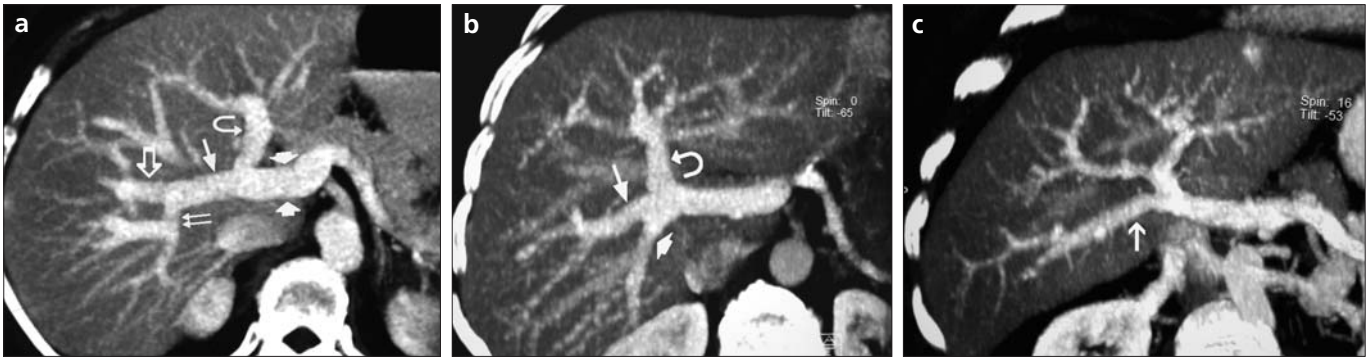

Figure 3. a–c. Portal vein (PV) variations: **(a)** In the normal PV branching pattern (type 1) demonstrated on an axial maximum intensity projection (MIP) CT image, the main PV *(large solid arrows)* branches into the right PV *(arrow)* and left PV *(curved arrow)*; the right PV branches into the anterior *(open arrow)* and posterior *(double arrow)* branches. **(b)** In the trifurcation (type 2) variation demonstrated on an axial MIP CT image, the right anterior PV *(arrow)* and posterior PV branch *(large solid arrow)* originate with the left PV *(curved arrow)* at the same level. **(c)** Right posterior PV *(arrow)* as the first branch of the main PV (type 3) is demonstrated on a coronal oblique (MIP) CT image.

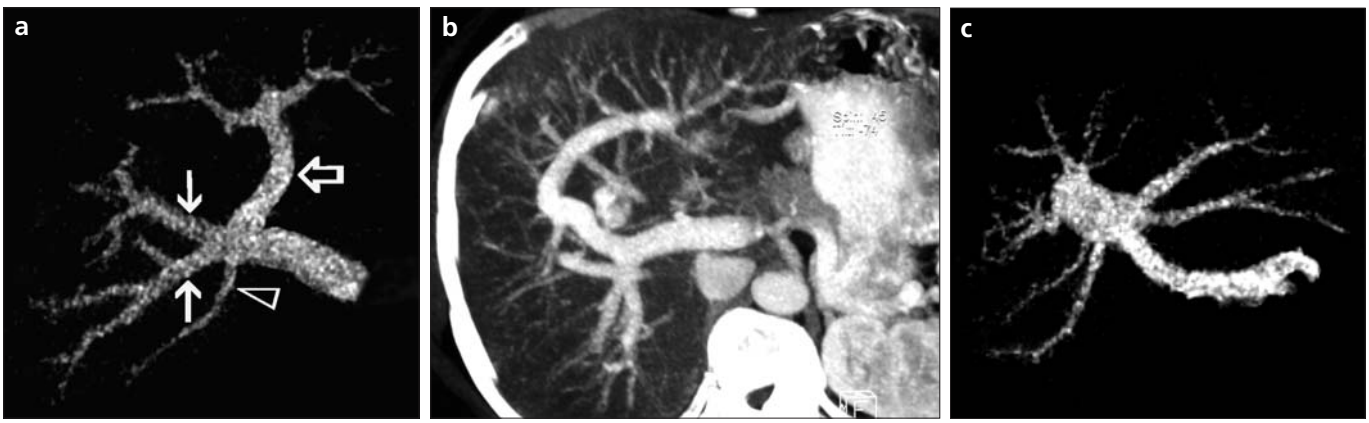

Figure 4. a–c. Rare portal vein (PV) variations. **(a)** PV quadrification demonstrated on an anteroinferior volume rendered CT image appears with the origination of segment VI PV branch *(arrowhead)*, the other 2 branches of the right lobe *(arrows)*, and the left PV *(open arrow)* at the same level. **(b)** Absence of the PV bifurcation variant, characterized by a single PV producing only segmental branches, is demonstrated on an axial oblique maximum intensity projection (MIP) CT image. **(c)** In the collective branching of the PV (total ramification variant) ending similar to the umbilical vein demonstrated in an inferior volume rendered CT image, all segmental PV branches originating from the slightly wider end of the single PV looks like the umbilical vein.

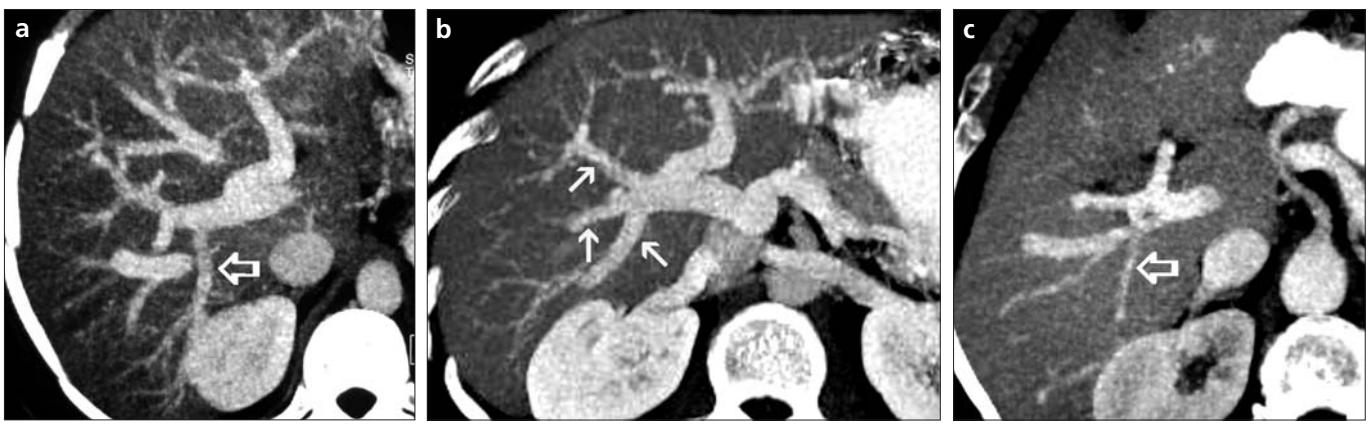

Figure 5. a–c. Right portal vein (PV) variations. **(a)** Separate origin of the segment VI PV branch from the right posterior PV *(open arrow)* is demonstrated on an axial maximum intensity projection (MIP) CT image. **(b)** Right PV trifurcation *(arrows)* is demonstrated on an axial oblique MIP CT image. **(c)** The type 3 main PV variant along with the segment VI PV branch originating from the right anterior PV *(open arrow)* is seen on an axial oblique MIP CT image.

mon form of this variation was supplement of segment IV with right and left PV branches, which was observed in 22 (1.6%) patients.

Discussion

This study showed that the prevalence of PV variations was as high as 27.4%. The rate of main PV branching variation was 21.5%, right PV variation was 3.9%, and segmental PV origin traversing the interlobar boundary was 4% in our study. PV variations might

be demonstrated well with routine abdominal MDCT examinations. The most common main PV variations were trifurcation (11.1%) and the right posterior PV branch being the first branch of the main PV (9.7%). Interpretation and determination of the prevalence of rare PV variations were possible as a result of a large study sample. A statistically significant difference in the prevalences of PV variations was not detected between male and female patients ($P = 0.582$).

Most abdominal venous variations are asymptomatic, but awareness of the existence of these variations decreases the complication rates in surgical procedures (1, 3, 12). Knowledge of PV variation types enables the recognition of these variations in routine liver imaging. Clinically significant PV variations should be noted in routine CT reports.

Modern, noninvasive imaging methods make it possible to correctly determine vascular anatomic variations (5, 12). Digital image processing and 3D imaging methods were used for PV interpretation of all cases in this study. This feature is referred to as real-time rendering (5). This technology makes interpretation of a wide range of PV variations, along with rare ones, possible. Definitive determination of PV variation types might not be possible based on the interpretation of axial CT images alone (5). We think axial-oblique and coronal-oblique thin-slice MPR and MIP images, and VR images were the best for interpretation of PV variations in our series. This plays a particularly important role in discrimination between the variations of PV trifurcation and the right posterior PV branch being the first branch of the main PV (Fig. 3b, c). Source images with thinner collimation and reconstruction intervals than those used for routine VR examinations, as well as oral contrast material, might create a limitation for VR images.

Embryologically, the PV is formed during the second month of gestation by selective involution of vitelline veins, which have multiple bridging anastomoses, anterior and posterior of the duodenum. Alterations in the pattern of these anastomoses result in PV variations (1). Main PV branching variations are generally categorized into 3 major types (Table 1) (1, 2, 12). The main PV normal branching pattern is denoted as type 1. Anterior and posterior branches of the right PV and left PV originate at the same level in trifurcation (type 2). The first branch of the main PV is the right PPV in cases with type 3 PV variation (1, 2). Left PV origin of the right APV branch, or the right PPV branch being the first branch of the main PV (type 3) did not require different surgical approaches; therefore both were considered type 3 variations in our study (1).

The prevalence of PV variation in our study (27.6%) was similar to another study performed with MDCT (3). Although the prevalence of PV variation and the type 3 variant (9.7%) was smaller in our series compared with a recent study performed with CT-arterial portography in 200 donor candidates (1) and an MDCT study (2), the prevalence of the type 2 PV variant was higher (11.1%) in our series. The fact that the prevalence of main PV variation was smaller in our study than in 2 previous studies (1, 2) might have been due to the difference in examination techniques. Recognition of the main PV type 2 variant is preoperatively important in right liver lobe donor candidates because preoperative or intraoperative lack of awareness could result in injury. Discrimination of type 2 and type 3 PV variants is also important because type 3 complicates surgical procedures in transplant donor candidates (2). Discrimination of type 2 and type 3 might be difficult in patients with a short right APV-left PV truncus, and 3D imaging is useful in this condition. Other variations important for donor candidates are rare variants, such as main PV quadrification, origin of the segment V and/or VIII PV branch from the left PV, origin of the segment IV branch from the right PV, and a single PV (absence of PV bifurcation) (9, 13, 14). The rate of these variations important in donor candidates was detected to be 22.5% and the combined rate of the most common variations (types 2 and 3) was 20.8% in our study. In a study of right liver lobe donor candidates (13), the prevalence of variation that might affect transplant surgery was 12%, whereas in another study of donor candidates (14) this prevalence was 9%. The combined prevalence of type 2 and type 3 variations were 9% and 10%, respectively, in these studies (13, 14). These results are significantly different than ours and might be due to differences in examination techniques and study populations. A few rare and dramatic PV variations, such as accessory PV, quadrification, congenital absence of PV, single PV (absence of PV bifurcation), and total ramification of the PV ending similar to the umbilical vein, have been reported (1, 8, 9, 15, 16). Three branches of the right and left PV originate at the same level in quadrification (Fig. 4a). A single PV is present in the collective branching intrahepatic PV variant (Fig. 4c), and all segmental PV branches originate from the slightly wider ending of a single PV resembling umbilical vein (9). A single PV enters the right liver and travels into the left, providing only segmental branches along its course in the absence of PV bifurcation (Fig. 4b), and this kind of variation is extremely rare (8, 9). Some of these rare variations were detected in our study, and included quadrification (n = 3), absence of PV bifurcation (n = 2), origin of the segment IV branch from the main PV (n = 1), origin of the segment VIII branch from the main PV (n = 1), and collective branching of the PV ending similar to the umbilical vein (total ramification) (n = 1). PV agenesis, accessory PV, or preduodenal PV was not detected in any of our cases. 3D imaging is generally quite useful in the detection and detailed interpretation of these rare variations, according to our experience.

Right PV variations are important in right lobe posterior segment resection or transplantation and detailed interpretation can be useful, as the clinical importance is different (2). The relatively low prevalence rate of right PV variations in our study, compared to another study performed with MDCT (2), emphasizes the importance of smaller collimation and reconstruction intervals in the interpretation of small PV branches. The most common right PV variant detected in our series was separate origin of the segment VI PV branch from the right PV. Proximal origin of the segment VII PV branch was observed in 2 patients, but this variation was not investigated systematically in our study.

As the variation of the origin of the segmental PV traversing the interlobar boundary crosses the hepatectomy plane, it becomes particularly important when it is a dominant supplier of a segment in transplant patients and/

or donor candidates (11). Segmental PV branches traversing the interlobular boundary were noted in 4% of patients in our study (Table 4). Despite this, the dominant supplier of segment VIII was the left PV branch in 0.8% of our sample, and the dominant supplier of segment IV was the right PV branch in 0.1%.

Awareness of PV variations is important in identifying the location of liver lesions, as PVs, along with hepatic veins, determine the segmental anatomy (1). Awareness of PV variations is important in the selection of donors for living adult right liver lobe transplantation, but occasionally results in exclusion of the donor candidate (12). Preoperative detection of the type 2 variant (trifurcation) is important because it has been previously reported that right liver lobe resection or transplant donor surgery might be dangerous when it is present (15, 17–19). It has also been reported that biliary variants, which are important in these types of surgery, accompany PV variations as well (20). Type 3 main PV and right PV variants play a critical role in selecting a safe hepatectomy plane in living donor adult liver transplantation (2, 3, 12, 16). Awareness of PV variations also plays an important role in percutaneous interventional procedures, like transhepatic PV embolization and transhepatic intraparenchymal portosystemic shunt placement (1, 17).

In conclusion, PV variants are commonly observed in routine CT examinations, and MDCT can demonstrate these variants in detail. Awareness of PV variations is critically significant in surgical resection and transplant patients, especially during pretreatment planning, in order to reduce the incidence of complications. Recognition of PV variation types enables detection of these variants with routine liver imaging. Clinically relevant PV variants should be reported in routine CT evaluations.

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