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Intra hepatic portal vein variations in western region of India; surgical and radiological importance in living-donor liver transplantation: Our center experience

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Abstract
Background: The portal vein variations are usually asymptomatic and mostly identified incidentally during surgeries and diagnostic angiographies. They are easy to recognize with 3D reconstruction of Computed Tomography. It has significant impact on living-donor liver transplantation.
Aim: To determine the spectrum and incidence of the anatomic variations in Intra Hepatic Main and Right Portal vein anatomy detected on Multi-detector CT Hepatic angiography of living liver donor of western Indian population and to discuss its surgical and radiological implications.
Material and Method: A retrospective review of multi-detector CT hepatic angiography was performed in patients sent for liver donor evaluation in our radiology department. Over a 6 year period, 132 donors were eligible for CT Hepatic angiography for possible living-donor liver transplantation (LDLT). The variations in branching pattern of main portal vein and segmental variation of right portal vein were classified according to Nakumura classification and classification proposed by Couinaud respectively.
Results: Normal (Type A) anatomy was seen in 108 donors. (81.8%). Trifurcation (Type B) variation was seen in 14 cases (10.6%). Right posterior vein as first branch of MPV (Type C) variation was seen in 10 cases (7.57%). Type D variation and Type E variation were not seen our study. Eighty three (76.85%) of 108 donors with conventional MPV branching (type A) also had conventional RPV branching whereas 25 (23.1%) of these donors had variant RPV branching.
Conclusion: Variant portal vein anatomy is commoner than previously reported. Although anomalous anatomy is not always a contradiction for liver donation, its knowledge is critical in ensuring the safety of the donors and aids in selection of suitable candidates.

Keywords: CT scan, portal vein variation, living-donor liver transplantation

Introduction

The portal vein (PV) variations are usually asymptomatic and mostly identified incidentally during surgeries and diagnostic angiographies. They are easy to recognize with 3D reconstruction of Computed Tomography (CT) and Magnetic resonance (MR) imaging. Liver transplantation is the choice for the treatment of many liver disease like chronic liver failure, acute liver failure, primary hepatic malignancy and inborn errors of metabolism [1]. Due to shortage of deceased donor organs and ability of liver to regenerate gained worldwide acceptance of living-donor liver transplantation (LDLT). Because of technical advances achieved in recent years, post-transplant results also steadily improved.

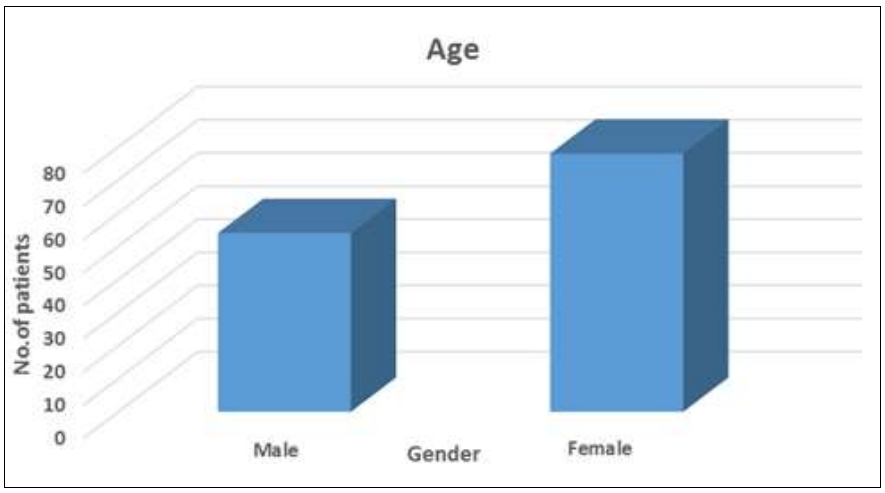
The portal vein (PV) is an important blood vessel that conducts blood from the gastrointestinal tract and spleen to the liver. The reported incidence of varied PV in LDLT ranges from 0.09% to as high as 24% [2]. Selection and evaluation of donors have become highly specialized, because donor safety is crucial and cannot be compromised at any cost, nevertheless the result for the recipient, even death: there can be no exception to that rule [2]. Multidetector Computed tomography (CT) now allow for three dimensional (3D) reformation and volume rendering (VR) of liver vasculature and has been reliably used to map portal veins in donors. According to our knowledge ours is the only and first study which involves western region of Indian population.

Aim

To determine the spectrum and incidence of the anatomic variations in Intra Hepatic Main and Right Portal vein anatomy detected on Multi-detector CT Hepatic angiography of living liver donor in western region of India and to discuss its surgical and radiological implications.

Methods and Materials

Patients A Retrospective review of multi- detector CT hepatic angiography was performed in donors sent for living liver donor evaluation in our radiology department between September 2013 and November 2019. Over a 6 year period, total of 191 donors underwent for Plain CT scan for evaluation of liver attenuation index and out of them: 132 donors were eligible for CT Hepatic angiography for possible living-donor liver transplantation. Fifty four (40.9%) of the donors were male and seventy eight (59.1%) were female [Graph1]. The age range was 19 to 65 years. The study was approved by ethical committee of our institute.



Graph 1: shows prevalence of portal vein variations according to gender

CT examination protocol

CT Hepatic angiography was performed on 64 slice Somatom sensation CT scan by Siemens. 120ml to 140 ml of non-ionic iodinated contrast material (iodine concentration, 350 mg I/ml contrast medium (iohexol, contrapaque 350) was injected through an 18 gauge antecubital intravenous cannula at a rate of 4.5ml/sec. Scans were acquired in five phases in all donors; early arterial phase at 15 seconds), late arterial phase (at 22-25 seconds), portal venous phase(at 40 seconds), venous phase (at 80 seconds) and delayed hepatic venous(at 100 seconds) using a Smart Prep protocol with enhancement threshold set at 100HU in descending thoracic aorta. Examination parameters were detector coverage 40mm, collimation 0.6x64mm, table speed 38.4mm/rotation, rotation time 0.33s, section thickness 1.5mm, 5-mm reconstruction interval, 120kVp and variable mA exposure using the automated exposure control method to reduce patient radiation dose. Additional images were reconstructed with 0.75mm to 1 mm reconstruction intervals for detailed interpretation.

Image interpretation

Portal venous phase was considered for interpretation. The raw imaging data obtained from CT were processed on a Syngo workstation for axial, coronal and axial oblique multiplanar reformation (MPR), maximum intensity projection (MIP) and volume rendering (VR) images. The images were analyzed by radiologists: We analyzed the variations in branching pattern of main portal vein (MPV), right portal vein (RPV) and its intrahepatic segmental variations in case of type A anatomy if any. The difficult cases were also studied using Myrian® XP-Liver Software Workstation 3D Surface region of interest (ROI) reconstruction tool (Intrasense, Paris, France). It is used for Three-dimensional imaging involving MIP and highly detailed VR and uses unique segmentation algorithms to isolate entire hepatic vascular systems.

Key definitions

Normal anatomy (Type A): The Main portal vein (MPV) divides into the right portal vein (RPV) and left portal vein (LPV) respectively. The right portal vein then gives rise to anterior and posterior sectorial branches that supply couinaud liver segments V and VIII and segments VI and VII, respectively branches. The LPV trunk gives off branches to couinaud liver segments II, III and IV.

Trifurcation of main portal vein (Type B): MPV divides into three branches—RAPV, RPPV and LPV Extra parenchymal branching of the anterior branch of RPV from the LPV (Right posterior portal vein as a first branch of main portal vein) (Type C): The first branch of MPV is RPPV, which continues to the right for a short distance, and then divides into RAPV and LPV. Intra parenchymal branching of the anterior branch from the LPV (origin of right anterior portal vein from left portal vein) (Type D): MPV first divides into RPPV and LPV. Then RAPV arises from LPV Undivided main portal trunk (Total ramification(Type E): All segmental portal vein branches originating from the single main portal vein with no division into right and left branches. There are various classification available for main portal vein variation; Nakamura's and Cheng/Covey classification are popular [3, 4, 5]. For simplification, we have classified the common PV variations into five types as classified by Nakamura's *et al*. The ramification patterns of right portal vein were evaluated from the first order branches of main portal vein and right portal vein (right anterior trunk and right posterior trunk) to segmental branches of right portal vein. Segmental anatomy of right lobe of liver was adhered to the classification proposed by

Couinaud [6]. We did not investigate the segmental anatomy of the left lobe of liver because the left lobe rarely contains anatomic variations, and anatomic resections usually are performed along the well-defined plane of the umbilical fissure.

Results

Normal (Type A) anatomy was seen in 108 patients (81.8%) out of 132 donors in our study [Figure 1]. Trifurcation (Type B) variation was seen in 14 (10.6%) of the cases [Figure 2]. Right posterior vein as first branch of MPV (Type C) variation was seen in 10 (7.57%) of the cases [Figure 3]. Type D variation and Type E variation were not seen in our study. [Table 1 and Graph 2]

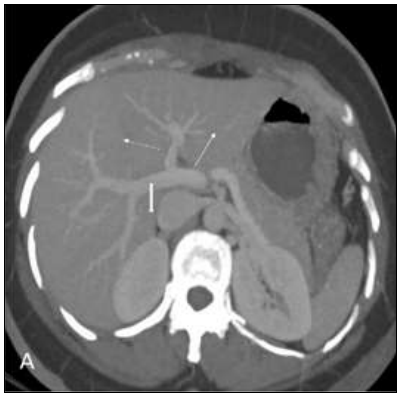


Fig 1 A: Type A anatomy. Maximum intensity projection image of CT scan, axial view, shows MPV(white thin arrow) bifurcation in left portal vein(LPV)(dotted thin white arrow) and right portal vein(RPV) (thick white arrow), which later divides in to right anterior portal vein(RAPV) and right posterior portal vein(RPPV).

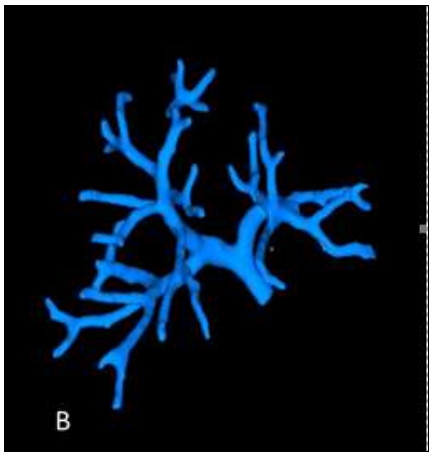


Fig 1 B: Volume rendered image, shows MPV bifurcation in left portal vein (LPV) and right portal vein (RPV), which later divides in to right anterior portal vein (RAPV) and right posterior portal vein (RPPV).

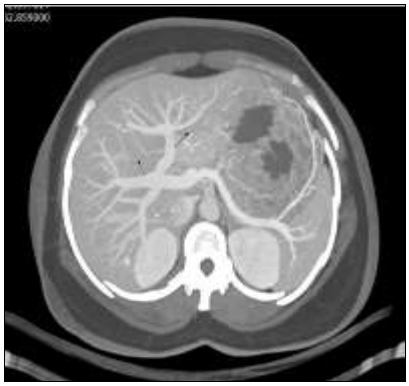


Fig 2: Type B anatomy. Maximum intensity projection image of CT scan, axial image shows MPV trifurcation in to RAPV (black dotted arrow), RPPV (white arrow) and LPV (black arrow).

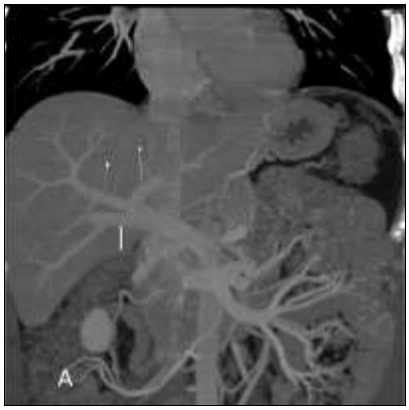
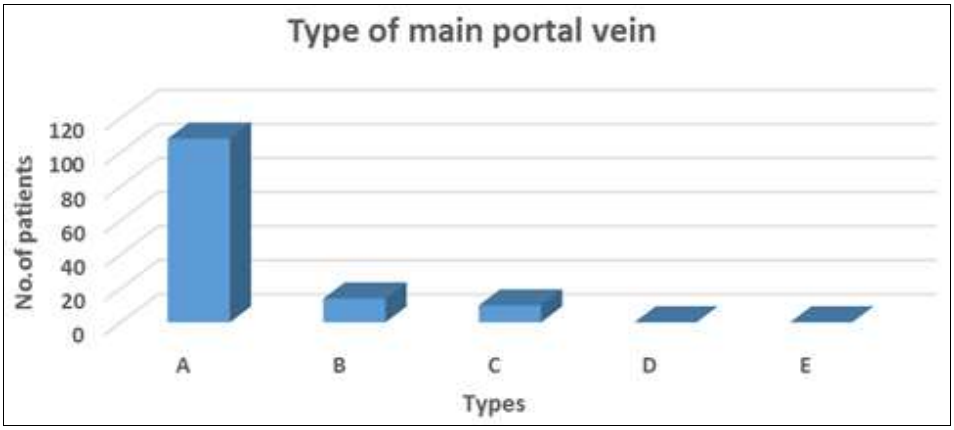


Fig 3 A: Type C anatomy. Maximum intensity projection image of CT scan, coronal view, shows RPPV as first branch of MPV (thick white arrow), then common trunk divides in to RAPV (dotted white arrow) and LPV (white arrow).

Fig 3 B: Type C anatomy. Volume rendered image, shows RPPV as first branch of MPV, Common trunk divides in to RAPV and LPV.

Table 1: Study result of branching pattern of main portal vein

Type	Type of main portal vein	Patients-132	
		N	%
A	Normal anatomy	108	81.8%
B	Early bifurcation or trifurcation	14	10.6%
C	Extra-parenchymal branching of the anterior branch from the LPV	10	7.57%
D	Intra-parenchymal branching of the anterior branch from the LPV	0	-
E	Undivided main portal trunk	0	-

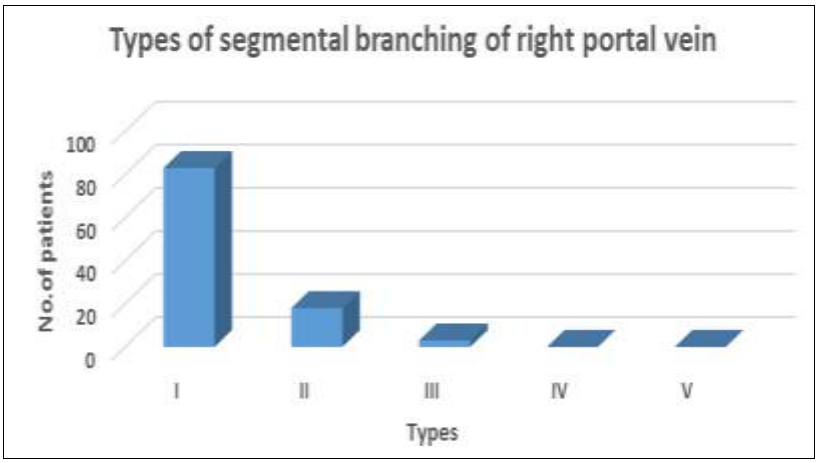


Graph 2: shows prevalence of branching pattern of Main portal vein (according to Nakamura's classification) among the study subjects

Eighty three (76.85%) of 108 patients with conventional MPV branching (type A) also had conventional RPV branching (division in to RAPV and RPPV branches) whereas 25 (23.1%) of these patients had variant RPV branching. [Table 2 and Graph 3]. Out of 83 donors with RPV bifurcates, three had bifurcation of RPV in to RAPV (which gave segment V, segment VI and segment VIII veins) and in to Segment VII vein. Twenty two (20.3%) of the donors had RPV trifurcation. In 18 of these donors: the RPV trifurcated into the RAPV (gave segment V and segment VIII veins), segment VI and segment VII veins [Figure 4]; in two donor RPV trifurcated into the RAPV(gave segment V and segment VIII) and RPPV (gave segment VI vein and segment VII vein)and a separate segment V vein [Figure 5]; in one donor RPV trifurcates into the RAPV(gave segment V and segment VIII) and RPPV (gave segment VI vein and segment VII vein) and a separate segment VI vein; in one donor RPV trifurcates in to RPPV(gave segment VI vein and segment VII vein), segment V vein and segment VIII vein [Figure 6]. We found three cases of quadrification of RPV[Figure7]; two out of them showed segment VII, segment VIII, segment V and segment VI separate braches of RPV; one out of them showed RAPV(gave segment V and segment VIII vein), segment VII, segment VII and accessory segment VIII vein.

Table 2: Study result of branching pattern of right portal vein

Types of Segmental branching of right portal vein in case of Type A anatomy	Patients- 108	
	N	%
I: Classic ramification pattern with right anterior portal vein (RAPV) and RPPV giving off the superior and inferior segmental branches to VIII/V and VII/VI respectively.	83	76.8%
II: Separate segmental branches to VII and VI without a definite main stem of RPPV	18	16.6%
III: Whisk-like ramification pattern of RPV without definite main stem of RAPV and RPPV	3	2.7%
IV: RAPV gave off a branch to VIII alone and RPPV gave off branches to V, VI, and VII consecutively.	0	-
V: RPV as a main trunk which was ramifying into segmental branches	0	-



Graph 3: Shows prevalence of segmental branching of right portal vein among Type a anatomy study subjects

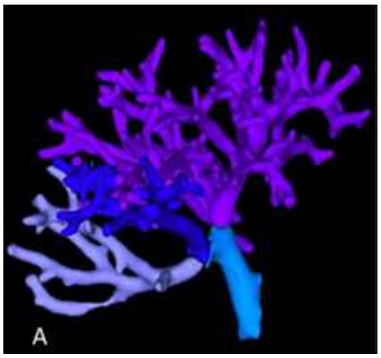


Fig 4 A: Volume rendered image show trifurcation of Right Portal vein in to RAPV (dark purple colour), Segment 6 (dark blue colour) and Segment 7 vein (light purple colour)

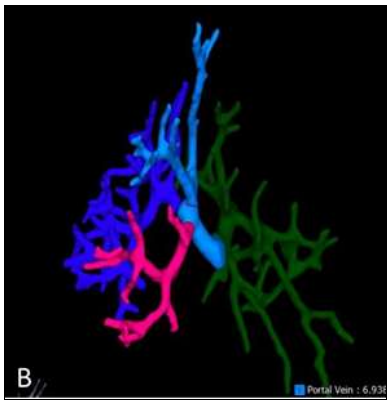


Fig 4 B: Volume rendered image show trifurcation of Right Portal vein in to RAPV (light blue colour), Segment 6(dark blue colour) and Segment 7 vein (pink colour) & Left portal vein (green colour)

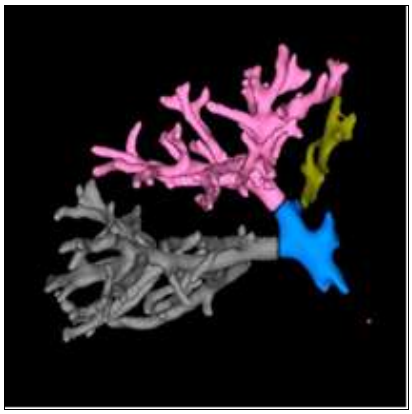


Fig 5: Volume rendered image show Right portal vein trifurcation in to RAPV (light pink colour), RPPV (grey colour) and segment V vein (green colour)

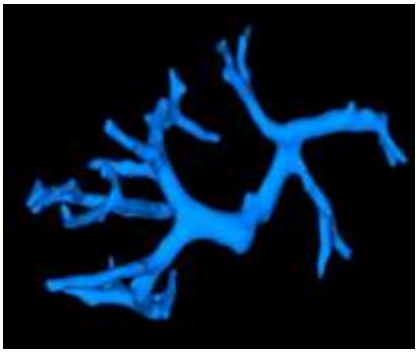


Fig 6: Volume rendered image show RPV trifurcation in to RPPV, Segment V and segment VIII vein

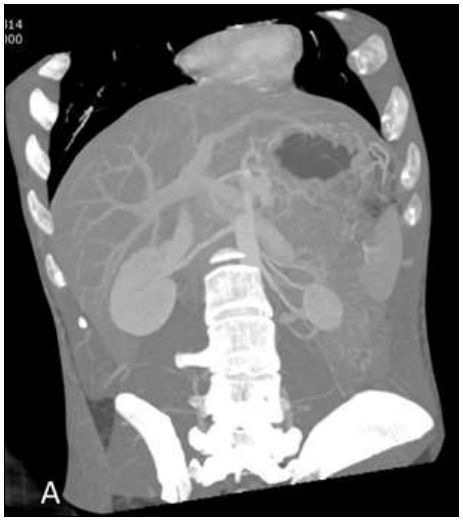


Fig 7 A: Maximum intensity projection image of CT scan, oblique coronal view shows Quadrification of right portal vein

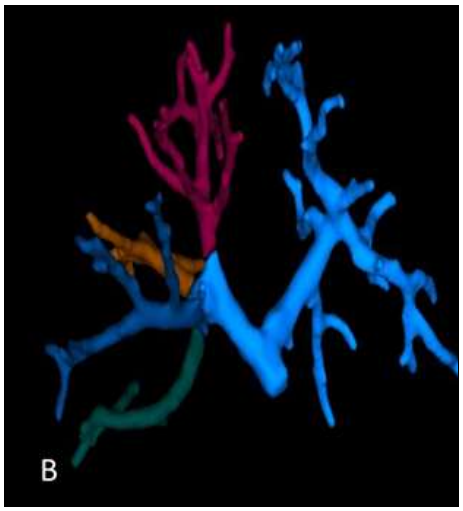


Fig 7 B: Volume rendered image shows Quadrification of right portal vein in to segment V vein (pink colour), segment VIII vein (yellow colour), segment VI vein (dark blue colour) and segment VII vein (green colour)

In 10 cases (7.57%) out of 132 donors, we found other types of variations; three cases of accessory segment V arising from RAPV; two cases of accessory segment VII arising from main RPV; one case of accessory segment VIII vein from RAPV; accessory segment VI vein from RAPV; accessory segment V vein from RPPV; accessory segment V vein from Segment VI vein; accessory segment VIII vein from main RPV each. In donors with type C anatomy, the length of the common RAPV–LPV trunk ranged from 2.1 to 6.3 mm. We did not see dominant venous supply of the left lobe arising from the right lobe veins or vice versa. There were, however, tiny portal branches traversing the border between the right and left lobes in 41 (31.0%) of the patients. The diameter of these veins ranged from 0.5 to 2.0 mm. 25 out of 41 donors showed right lobe veins traversing border and entering in to left lobe. 16 out of 41 donors showed left lobe veins traversing border and entering in to right lobe of liver. In four case we found that crossing of tiny portal branches from both sides we found caudate lobe vein originating from LPV in 108(81.81%) cases, originating from RPV in 9(6.81%) cases and directly from MPV in 11(8.3%) cases. In one case caudate lobe vein

originated from common trunk of RAPV-LPV in type C variation [Figure 8]. In three cases we found two caudate lobe veins; one originated from LPV and other from RPV.

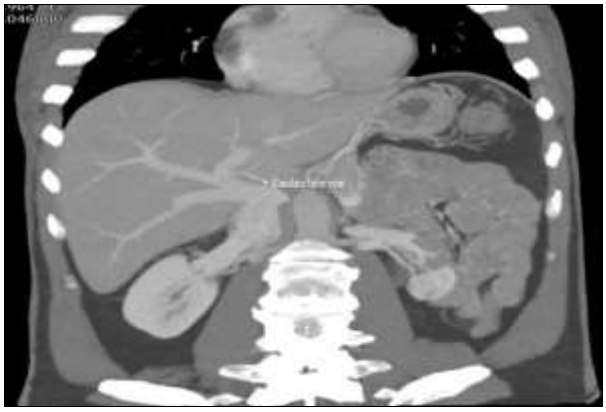


Fig 8: Maximum intensity projection image of CT scan, coronal view shows Type C anatomy with origin of caudate lobe vein from common trunk of RAPV and LPV.

Discussion

As liver interventions by both surgeons and radiologists is expanding, increasing awareness of standard and variant anatomy is necessary. Awareness regarding segmental anatomy is important before harvesting organ in liver transplantation, resection of liver mass, during the procedure of transjugular intrahepatic portosystemic shunts placement and for exact tumor localization before any surgical procedure. Living donor liver transplantation has more advantages; direct availability of organ, less chance of morbidity & mortality and better quality of graft over deceased donor organ. In most of the cases, pre surgical cross-sectional imaging; shows variants of portal vein on the images, but they are not routinely reported. Embryologically, the portal vein is developed during the second month of gestation. It is formed due to selective involution of the vitelline veins. Vitelline veins have multiple bridging anastomoses anterior and posterior to the duodenum. Any alterations pattern of obliteration in these anastomoses can lead to anatomical variants [7].

About 1000-1200ml/min blood flow noted in portal vein. Normal portal vein pressure is about 7mmHg. About 80% blood supply of liver is supplied by main portal vein. Generally main portal vein is formed just behind the neck of pancreas after joining of splenic and superior mesenteric vein approximately at level of L2 vertebrae. Main PV (MPV) divides into right and left PV branches (RPV and LPV) at level of liver hilum. Initially left portal vein courses horizontally towards left side, then turns medially gives branches to segment II, III, IV and caudate lobe. RPV divides in to right anterior portal vein trunk (RAPV) supplies segment V and VIII and right posterior portal vein trunk (RPPV) supplies segment VI and VII respectively.

Anatomic variations

Standard anatomy of portal vein and its branching pattern is seen in only 65% of the cases. Most common anatomic variation of MPV is trifurcation followed by RPPV as a first branch of MPV. Other variations described are quadrification of portal vein, absent PV bifurcation, total ramification etc. 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 RPV, separate origin of the segment VI and VII PV branches from the RPV etc. Segmental PV variations described are segment VIII supplied by the right and left PV branches, segment VIII supplied by the left PV branches, segment IV supplied by the right and left PV branches etc. [5, 8].

Association with biliary variations

Embryologically, the intrahepatic bile ducts i.e. ductal plates, originated from bipotent liver progenitor cells which are in contact with the mesenchymal tissue of the PV. Hence embryological development of the hepatic duct occurs later than development of the primary divisions of the PV, anatomic variation of portal vein is associated with variation in biliary anatomy. It has importance in living-donor liver transplantation because during surgery it may lead to accidental biliary injury. Kitami *et al.* [9] found that classic hilar confluence pattern, where the right posterior sectoral duct connects supraportally with the right anterior sectoral duct, was unusual in the PV variation patients than in the control subjects.

Surgical and radiological significance in living-donor liver transplantation

In liver transplantation surgery; Type B and Type C variation of main portal vein branching pattern is generally found. Right lobe (RL) is generally preferred because large size availability in adult LDLT. Higher incidence of vascular and biliary variations are found in right lobe grafts as compare to left lobe grafts.

Differentiation between type B and type C variation is important during surgery. Hwang *et al.* [10] studied and made differentiation based on shape of gap between RAPV and RPPV origin. Type B has triangular shape of gap while in type C it has rectangular shape of gap. Due to close relation of RAPV and RRPV in type B anatomy; still single portal lumen can be procured. Two transections of RAPV and RRPV are needed in case of type C anatomy, resulting in two anastomosis of portal lumens and thus making surgery more difficult. If we fail to observe this type of C variation then accidental devascularization of segment V and VIII of right lobe of liver has occurred during left trisegmentectomy or left lobe of live is taken for transplantation [11, 12]. The length of common RAPV–LPV trunk has also surgical significance and it is measured from its origin to its bifurcation. If the common RAPV-LPV trunk has short length, two donor portal braches (RRPV and RAPV trunks) can be anastomosed to the recipient's portal bifurcation; donor RPPV is anastomosed with recipient's RPV and donor RAPV is anastomosed with recipient's LPV. This Y-graft anastomosis permits reperfusion of liver at the same time. If RAPV-LPV trunk has long length means donor veins are widely spaced then extension type graft is needed for reconstruction of donor RAPV. Reconstruction of RAPV may take time and result in delayed reperfusion of anterior segments of right lobe of liver [13]. The length of the RAPV–LPV trunk in our study ranged from 2.1mm to 6.3mm. As far as we know, no cutoff value has been reported for length of the RAPV–LPV trunk above which surgeons have to use an extension graft. In case of right posterior segmental procurement type C anatomy has more advantageous as compare to whole right lobe graft acquirement. Origin of dominant segment IV portal vein from RPV rejects the right lobectomy. This rare situation was found in 2% of the

population. Origin of dominant segmental right portal veins branches from the LPV is also relative contraindication to right lobe harvesting [14]. Nonstandard miscellaneous variations beyond the described Types A to E variants were seen in 8% of cases. Table 3 shows review and comparison of previous studies and present study in terms of anatomical variations of portal vein. As per our knowledge, this is the first study involving West Indian population. Previous studies have shown the prevalence of variant portal venous anatomy ranging from 0.09% to 24% [2, 11]. The prevalence in our series (18.2%) was quite similar to previously reported.

Table 3: shows review and comparison of previous studies and present study in terms of anatomical variations of portal vein.

Authors	Study of region	Imaging modality	No. of patients	Types of variations in%				
				Type A	Type B	Type C	Type D	Miscellaneous
Cheng *et al.*	Taiwan	AP	688	70.9	15.0	7.0	6.4	0.8
Fraser-hill *et al.*	Canada	USG	18550	99.91	0.01	0.01	0.01	0.06
Akgul *et al.*	Turkey	CT scan	585	86.2	12.3	0.3	0.9	0.05
Atri *et al.*	Canada	USG	507	79.9	10.9	4.7	4.7	0.2
Soyer *et al.*	Baltimore, USA	CTAP	69	94.2	4.3			1.5
Nakamura's *et al.*	Japan	CT & Doppler	120	92.5	2.5	2.5		
KOC Z *et al.*	Turkey	MDCT	1384	78.5	11.1	9.7		
Atasoy *et al.*	Turkey	MDCT	200	65.5	9.5	23.5		1.5
Sureka B *et al.*	North Indian	MDCT	967	79.94	6.83	4.96		
Covey *et al.*	New York, USA	MDCT	200	65	9	13		
Vijay kumar *et al.*	South Indian	MDCT	100	68	11	18		3
Carr JC *et al.*	Chicago, USA	MRI	25	76	16	8		
Hwang *et al.*	Seoul, Korea	MDCT	197	79.7	7.6	12.7		
Present study	Western Indian	MDCT	132	81.8	10.6	7.57		

CTPA: Computed tomography during arterial portography AP- Arterio-portography
Type I: classical, Type II-(trifurcation of MPV, Type III-RRPV from MPV &RAPV from LPV
Type IV: RRPV from MPV & RAPV from LPV

RPV branching pattern variation are also common. Segmental resection of right lobe of liver is not easy and is challenging as compare to left lobe because in right hemi liver there is no any consistent landmark, it has deep anatomical position and has major drainage veins in transection plane. There are several types of variations of RPV branching are there but the most common is trifurcation, which most frequently involved separate origins of segment VI and VII veins from the RPV. Before the resection of segment vascular control of supplying vessels is necessary. It reduces the chances of intraoperative bleeding during resection of parenchyma. Control of vascular supply also helpful in demarcation of resection line based on color change of surface of liver due to ischemia of tissue. Isolated sub segmentectomy of segment VI and segment VII from hilar approach with a better bleeding control may be alternative to wedge resection and posterior segmentectomy in case of type II variation. Posterior segmentectomy of right liver from hilar approach is difficult due to late branching of right posterior portal vein or extended portal territory to segment V in case of type IV and type V variations. If this two type of variations identified before the operation, lengthening of operation time and any uneventful procedure can be avoided after doing some technical modification in term of clamping of RPPV with direct parenchyma dissection toward hepatic hilum [23].

Review literature

Hwang *et al.* [10] reported that almost no candidate with type A and only 3.6% of those with type B anatomy were suitable for right posterior graft procurement, whereas 35.2% of patients with type C portal veins were more favorable for this procedure. In Cheng *et al.* [4] study, 7% of patients were determined to be unsuitable candidates or to potentially require a more technically challenging surgery such as a venous graft because of variant portal vein anatomy. Again, only conventional arterioportography was used, so they may have missed some uncommon but relevant anomalies. In our study no patient was rejected for donation in case of portal vein variation.

Carr JC *et al.* study [22] did not recognize cases of right portal vein variation in term of a single segment of right portal vein as a first branch (segment VI or VII). According to Leeuwen *et al.* study [24], he found different ramification pattern of right portal vein in to 27% cases while it was 23% in our study group. A cadaveric study by Hata *et al* [25]. found 33.5% of cases of RPV variation while in our study it was also 23.1%. Types D & E represent absolute contraindications for right lobe donation. We did not found dominant portal venous supply crossing the interlobar boundary, although surgically insignificant small veins that originated from the RPV and supplied segment IV were present 18.9% and veins originated from LPV and supplied segment V/VIII in to 12% of the our study group. Interlobar crossing from right lobe to left lobe and from left lobe to right lobe is seen in 3% cases of our study. Wide range of prevalence may be due to the use of different sample sizes and variations in the techniques used to outline the portal anatomy in various study. Many portal vein variations may be missed on thick axial scans. In those cases 3D reformatted images are decisive for accurate imaging.

Limitation of the study is that it involved only a specific group of the subjects: involving only liver donors and smaller sample size. Lack of surgical correlation due to less number of donors undergoing hepatectomy due to varied reason. However not a single donor was rejected due to portal vein anatomy variation at our institute.

Conclusion

Variant portal vein anatomy is commoner than previously reported and is increasingly relevant to the practice of safe and efficacious surgical and percutaneous hepatobiliary intervention. Although anomalous anatomy is not always a

contradiction for liver donation, knowledge of it is critical in ensuring the safety of the donors and aids in selection of suitable candidates. In this group of patients, the portal vein is almost always depicted on preoperative MDCT and critical attention to portal vein anatomy may prevent significant complications.

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Abbreviations

PV- Portal vein
MPV – Main portal vein
RPV- Right portal vein
LPV- Let portal vein
RAPV- Right anterior portal vein
RPPV- Right posterior portal vein
LDLT- Living- donor liver transplantation
3D reformation - Three dimensional reformation
VR- Volume rendering
MPR- Multiplanar reformation
MIP- Maximum intensity projection
ROI- Region of interest
CT- Computed Tomography
MRI- Magnetic Resonance Imaging

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