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Original Article

Surgical anatomy of the vasculobiliary apparatus at the hepatic hilum as applied to liver transplantations and major liver resections

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ABSTRACT

Introduction: To evaluate the hepatic arterial, bile duct and portal venous anatomy as applicable to major liver resections.
Methods: The study was conducted on 100 formalin fixed adult cadaveric livers. The hepatic arterial, bile ductal and portal venous anatomy of the liver was dissected from their origin up to their segmental branching. Left and right hemilivers were compared with regard to the single and multiple vascular or biliary pedicles entering their respective hemilivers.
Results: The anatomy of all the three structures, ie., hepatic artery, bile duct and portal vein were conventional in 39% and variant, i.e., "triple" anomaly in 4% of liver specimens. In 57% liver specimens, the anatomy of one or two structures was variant and individual variation of hepatic artery, bile duct and portal vein anatomy was observed in 34%, 42% and 14% of livers respectively. The anatomy of hepatic artery was classified according to the Michels classification. In 9% of livers, rare variations not included in Michels classification was found. The drainage pattern of bile ducts was grouped according to Blumgart's classification. In 11% of livers, rare variations not included in Blumgart's classification were found. The branching pattern of main portal vein was classified according to the Akgul's classification. In 1% of livers, rare variations in the right portal vein were found.
Discussion: In the present study, the vasculobiliary anatomies of liver were highly complex with the existence of many anatomic variations. The increasing complexity of hepatic surgical procedures necessitates appropriate knowledge of these anatomic variations.

1. Introduction

The detailed anatomy of the liver described by Couinaud[1,2] has been the basis for major advances both in surgical techniques and in diagnostic and interventional radiology. Advances in surgical and radiologic techniques in recent years, including reduced-size liver for pediatric as well as adult transplants makes the reexamination of hepatic anatomy a current priority.[3]

The anatomic variants of bile duct (BD) and hepatic artery (HA) are more common than that of portal vein (PV). The frequencies of variant HA, BD and PV systems has been previously reported to be approximately 46%, 44% and 8% respectively.[4–8] In live donor liver transplantation (LDLT), careful manipulation of the vasculobiliary system is critical to avoid causing injury to the BD, PV and HA in the residual liver and/or the graft.[7,9]

Not all anomalies can be picked up with certainty by the modern diagnostic tools. A study reported the sensitivity of MRCP for recognizing variant BD anatomy was only 74%[10] and in another study, aberrant LHAs were not identified during pretreatment computed tomography in 31% of cases.[11] Anatomical data obtained by cadaveric studies are still considered as the gold standard to study the anatomical details because, despite all the developments, the spatial resolution of imaging tools limits visualization of small branches.[12]

The present study was thus constituted to detail the hepatic vascular and biliary anatomy as applicable to LDLT and other interventional procedures.

2. Materials and methods

The study was approved by institute's ethical committee and was performed on 100 formalin fixed adult cadaveric livers (18–80

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years of age). The vascular and biliary anatomy of the liver was dissected out under the magnascope (2.5×). The hepatic segments were derived from the classification of Couinaud.

Hepatic artery was dissected from its origin from celiac trunk (CT). Course and branching of hepatic arteries (HAs) was determined. The origin of HAs was considered standard when these originated from the common hepatic artery (CHA) or proper hepatic artery (PHA) which itself arose from the CT and was aberrant when the HAs arose from the sources other than the above mentioned. The aberrant hepatic artery was "accessory" when occurring in addition to the normal arterial supply or "replaced" representing the primary arterial supply to the liver.

Intra and extrahepatic drainage pattern of bile duct was dissected out. Normal BD anatomy was defined as drainage of right anterior (RASD) and right posterior sectoral ducts (RPSD) into the right hepatic duct (RHD) and convergence of the right and left hepatic ducts (LHD) into the common hepatic duct (CHD). The confluence patterns of the right intrahepatic BDs were classified into three patterns according to the anatomical relationship between the RPBD and the PV. The supraportal pattern was defined as an RPBD that ran dorsally and cranially to the right PV or right anterior PV and joined the distal BD at its cranial side, the infraportal pattern was defined as an RPBD that ran ventrally and caudally to the right PV or right anterior PV and joined the distal BD at its caudal side and the combined pattern in which some parts of the RPSD entered the distal BD supraportally and the remaining parts of the RPSD joined with the distal BD infraportally.

Branching and course of PV was determined. Normal PV branching was defined as bifurcation of the PV into a right and left PV and further bifurcation of RPV into right anterior (RAPV) and right posterior portal vein (RPPV).

From the view point of graft selection in adult LDLT, left and right hemilivers were compared with regard to the single and multiple HA, BD and PV stumps for each type of HA, BD and PV anatomy. Two or more vascular or biliary pedicles entering right or left hemiliver were considered variant.

3. Results

In the present study, the anatomy of all the three structures was conventional in 39% and variant, i.e., "triple" anomaly in 4% of liver specimens. In 57% liver specimens, the anatomy of one or two structures was variant and individual variation of HA, BD and PV anatomy was observed in 34%, 42% and 14% of livers respectively.

3.1. Hepatic artery

The anatomy of HA was classified according to the Michels classification (Table 1).

Table 1
Summary of patterns of origin of hepatic arteries according to Michels classification.

Type	Pattern	Present study (%)	Michels (%)
I	Normal anatomy (Fig. 1a)	66	55
	• PHA present	42	
	• Early branching of CHA (PHA absent)	24	
II	Replaced LHA from LGA (Fig. 1b)	04	10
III	Replaced RHA from SMA (Fig. 1c)	05	11
IV	Replaced LHA from LGA and Replaced RHA from SMA (Fig. 1d)	01	1
V	Accessory LHA from LGA (Fig. 2a)	11	8
VI	Accessory RHA from SMA	–	7
VII	Accessory LHA from LGA and accessory RHA from SMA	–	1
VIII	Replaced LHA from LGA and Accessory RHA from SMA or accessory LHA from LGA and replaced RHA from SMA (Fig. 2b)	03	4
IX	Replaced CHA from SMA (Fig. 2c)	01	4.5
X	Replaced CHA from LGA	–	0.5
Rare variations		09	–

3.1.1. Type I of Michels classification (66%)

This is the classic anatomical pattern described in anatomy books characterized by the normal origin of HAs.

3.1.2. Type II–X of Michels classification (25%)

Aberrant hepatic arterial anatomy was present (Table 1). All aberrant RHAs originated from the superior mesenteric artery (SMA) and displayed a retroportal course within the hepatoduodenal ligament, traversing between the main PV and inferior vena cava (IVC). All aberrant LHAs originated from the left gastric artery (LGA), coursed upward in the cranial part of lesser omentum and entered the hilar plate through fissure for ligamentum venosum. (Figs. 1 and 2)

3.1.3. Rare variations

New types not described in Michel's classifications were seen in 9% livers. These included: **a.** Absent CHA (Double hepatic artery, 2%) – CHA was absent and RHA and LHA originated independently from CT in 2% livers. In 1% of these livers, CT quadrifurcated into RHA, LHA, LGA and SA. The RHA coursed posterior to the PV and the LHA gave origin to the GDA. In another 1% livers, CT trifurcated into RHA, LHA and SA. LGA was double and both the arteries arose from LHA. The RHA gave origin to the GDA (Fig. 3a). **b.** Replaced RHA from GDA (1%) – CHA arose from CT and bifurcated into GDA and LHA. Replaced RHA (rRHA) arose from GDA and ran posterior to the PV to reach the hilum. (Fig. 3b) **c.** Accessory LHA from GDA (1%) – in addition to the normal anatomy of hepatic arteries, accessory LHA (aLHA) arose from GDA (Fig. 3c). **d.** Retroportal CHA/RHA (2%) – In 1% livers, CHA arose normally from CT, wind around the PV running from its posterior to anterior aspect. CHA bifurcated into RHA and LHA on the anterior aspect of PV. In another 1% livers, CHA originated from CT and divided into RHA and LHA near its origin from CT. RHA wind around the LHA and passed posterior to PV to reach right hemiliver. GDA and supraduodenal artery (SDA) originated from LHA (Fig. 3d). **e.** CHA forming an arterial ring (2%) – CHA after arising from CT formed an arterial polygon at the hepatic hilum in 2% livers. Branches of CHA were originating from the corners of the arterial polygon. **f.** CHA formed via union of 2 stems (1%) – CHA was formed by union of 2 stems – one branch arose from CT and another branch from SMA.

3.2. Biliary drainage of the liver

The drainage pattern of bile ducts was grouped into six types according to **Blumgart's classification** (Table 2).

Type I Conventional (58%) **-** drainage pattern of CHD was normal in 58% livers (Fig. 4a). **Type II** Triple confluence of RASD, RPSD and LHD (11%) **–** RASD draining segment 5 and 8, RPSD draining segment 6 and 7 and LHD draining left hemiliver converged into CHD in 11% livers (Fig. 4b). **Type III** Lower drainage of RPSD/RASD into CHD (8%) – RPSD draining segments 6 and 7 opened into CHD in 7% livers (Fig. 4c) and RASD draining segments 5 and 8 opened into CHD in 1% livers. **Type IV** Aberrant drainage of RPSD/RASD into LHD (11%) – RPSD draining segments 6 and 7 entered into LHD in 10% livers (Fig. 4d) and that of RASD draining segments 5 and 8 into LHD in 1% livers. **Type VI** RPSD into CD (1%) – There was an ectopic drainage of segment 6 duct (D6) into cystic duct (CD) and segment 7 duct (D7) joined the RASD to form RHD.

Fig. 1. Anterior view of the hepatic pedicle showing origin of HAs **a.** CHA is originating from CT and bifurcating into PHA and GDA. PHA is bifurcating into RHA and LHA**. b.** Replaced LHA is originating from the LGA**. c.** Replaced RHA is originating from the SMA **d.** Replaced LHA is originating from the LGA and replaced RHA from the SMA. CHA originating from CT is continuing as MHA.

3.2.1. Rare variations

New types not described in Blumgart's classification was seen in 11% livers. These included **a.** Lower drainage of RPSD into CHD and aberrant drainage of RASD into LHD (1%) (Fig. 5a) **b.** Aberrant drainage of segment 8 duct into LHD (1%) (Fig. 5b) **c.** Double RPSD (2%) – In 2% liver specimens, there was double RPSD (Fig. 5c). **d.** Double RASD (1%) – In 1% livers, there was double RASD (Fig. 5d). **e.** Lower drainage of RPSD and segment 5 duct into CHD (1%) **f.** Lower drainage of RHD into CHD (3%) **g.** Aberrant drainage of segment 7 duct into LHD (2%).

3.3. Confluence patterns of the right intrahepatic bile ducts

The confluence patterns of the right intrahepatic BDs were classified into three patterns according to the anatomical relationship between the RPBD and the PV (Table 3). **Type A** Supraportal pattern (67%) **–** RPSD joined with RASD to form the RHD (Fig. 4a), RPSD entered the confluence of RASD and LHD (Fig. 4b) and RPSD drained into LHD (Fig. 4d). **Type B** Infraportal pattern (31%) – RPSD joined with RASD to form the RHD without curving around RASD and Lower drainage of RPSD into CHD

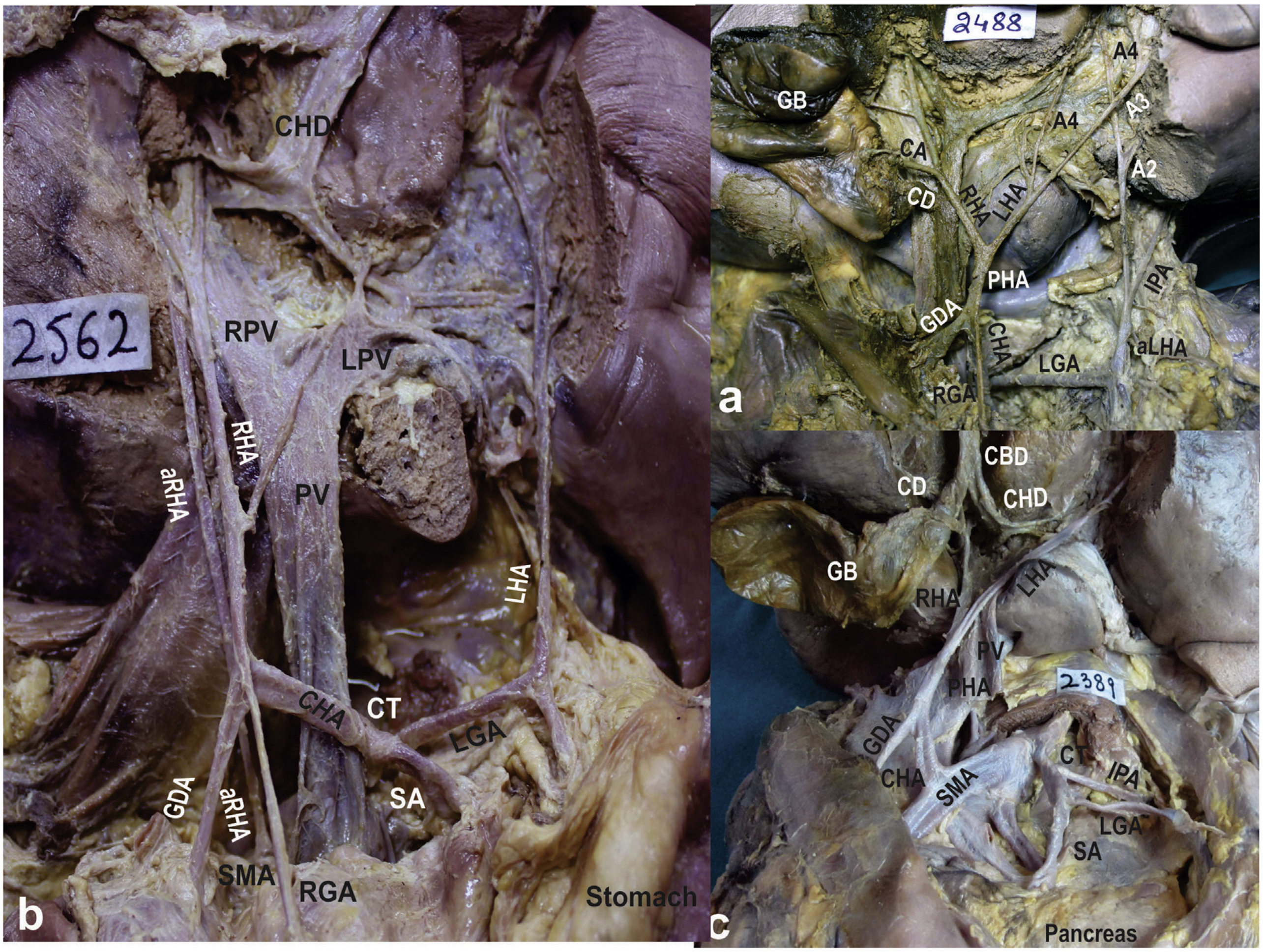

Fig. 2. Anterior view of the hepatic pedicle showing origin of HAs **a.** Accessory LHA is arising from LGA in addition to normal LHA from PHA. **b.** Replaced LHA is originating from the LGA and accessory RHA from the SMA. CHA originating from CT is continuing as RHA. **c.** Replaced CHA is originating from the SMA.

(Fig. 4c). **Type C** Combined pattern (2%) – One of the RPSD entered the distal bile duct supraportally and the other RPSD joined with the distal bile duct infraportally in cases with double RPSD.

3.4. Portal vein

Branching pattern of main portal vein (PV) were classified according to the Akgul's classification (Table 4). **Type A** Conventional/normal anatomy (86%) **-** the anatomy of PV was normal (Fig. 6a). **Type B** Trifurcation of PV into LPV, RAPV & RPPV (7%) – main PV trifurcated into RAPV, RPPV and LPV (Fig. 6b). **Type C** RPPV comes from the PV directly and LPV and RAPV are present as common trunk (2%) – RPPV branched from main PV as the first and separate branch. Main PV then continued as a common trunk for LPV and RAPV (Fig. 6c). Configuration of the gap between origin of RAPV and RPPV was used for discriminating of types B and C, if this configuration was triangular, type B was diagnosed and if rectangular, type C was diagnosed. **Type D** RPPV comes from PV directly and RAPV comes from LPV at or near the umbilical fissure (4%) – RPPV arose from main PV directly and RAPV originated from LPV near the umbilical fissure (Fig. 6d)

3.4.1. Rare variations

Linear branching of RPV **–** In 1% livers, main PV branched into RPV and LPV. The RPV instead of bifurcating into RAPV and RPPV gave off segmental branches in sequential manner. (Fig. 6e)

3.5. Comparison between right and left hemilivers

From the view point of graft selection in adult LDLT, left and right hemilivers were compared with regard to the number of HA, BD and PV stumps for each type of HA, BD and PV anatomy.

3.5.1. Hepatic artery

Among 100 livers, multiple arterial pedicles (multiple arterial stumps) entering the left and right hemilivers were encountered in 43% and 2% hemilivers respectively (43% vs 2%). Arterial pedicles entering left hemiliver were double in 38% and triple in 5% livers.

3.5.2. Bile duct

The appearance of multiple BD stumps becomes inevitable in right hemilivers with BD types II- IV, VI anatomy, i.e., triple confluence of RASD, RPSD and LHD, lower drainage of RPSD into CHD, aberrant drainage of RPSD into LHD and drainage of RPSD into CD (Table 2). Therefore, frequency of multiple stumps draining right hemiliver was 37%. No multiple BD stumps drained the left hemiliver (37% vs 0%).

3.5.3. Portal vein

Portal vein anatomy was classified into 4 types (Table 4). Single PV stump was encountered in the left hemiliver. In the right hemilivers, 13% out of 14% livers with variant PV anatomy showed multiple PV stumps with the right anterior and posterior branches

Fig. 3. Shows the livers with rare variations in the origin of HAs. Anterior view of the hepatic pedicle showing **a.** CHA is absent and CT is trifurcating into RHA, LHA and SA. LGA is double and both the arteries are arising from LHA. **b.** Replaced RHA is originating from GDA. **c.** Accessory LHA is originating from GDA. **d.** CHA is dividing into RHA and LHA near its origin from CT. RHA winds around the LHA and is passing posterior to PV to reach right hemiliver. GDA and SDA are originating from LHA.

being present adjacently or separately. The incidence of multiple PV stumps differed significantly (13% vs 0%, right vs left hemiliver).

4. Discussion

Accurate identification of HA, BD and PV anatomy in the liver is mandatory during various liver surgeries including liver transplantation, major liver resection and laparoscopic hepatobiliary surgery so as to choose the best therapeutic approach and to reduce complications.[13] Despite refinements in surgical techniques, hepatic vascular and biliary complications still account for considerable morbidity and mortality in patients with complex liver anatomy.[14]

Anatomic variants of the biliary and hepatic arterial anatomy are more frequent than the portal venous variants.[4,15–17] In the present study, variant HA, BD and PV anatomies were observed in 34%, 42% and 14% of livers respectively. The range of variant HA, BD and PV anatomy that has been reported previously is 30–46%, 22–38% and 8–18% respectively.[7,9,18] The observations of the present study are comparable with the previous published data. A little higher frequency of BD variations was observed in the present study than the previous reports.

Michels[8] in 1966 proposed an internationally recognized classification of HA variations which have served as a benchmark for further studies on HA. In the present study, the origin of HAs was aberrant in 28% of livers which is lower as compared to Michels' (45%). The prevalence of aberrant HAs has been reported previously with the range of 24–49%.[8,19–21] The results are thus in concordance with the reported data.

Clinically relevant rare variants that could not be included in Michels system have been reported in the previous literature with a range of 1–3%.[22–24] In the present study, such rare variations were

Table 2
Drainage pattern of right and left hepatic ducts into common hepatic duct according to Blumgart's classification.

Type	Pattern	Present study (%)	Blumgart's (%)
I	Conventional	58	57
II	Triple confluence of RASD, RPSD & LHD	11	12
III	Lower drainage of	8	20
	• RPSD into CHD	7	16
	• RASD into CHD	1	4
IV	Aberrant drainage of	11	6
	• RPSD into LHD	10	5
	• RASD into LHD	1	1
V	CHD is formed by union of two or more ducts from either lobe	–	3
VI	RPSD into CD	1	2
Rare variations		11	–

observed in 9% of cases. These included CHA absent (double hepatic artery, 2%), replaced RHA from GDA (1%), accessory LHA from GDA (1%), retroportal CHA/RHA (2%), CHA forming an arterial ring (2%) and CHA formed by union of 2 stems, 1 from CT and other from SMA (1%). Double hepatic artery has also been observed in few previous reports with a range of 1–5%.[25,26] Replaced RHA from GDA and accessory LHA from GDA, one of the rare type of HA variations has also been reported previously in a study[23] in 0.14% cases. Unintended embolization of the GDA in these specific anatomies may block access to the hepatic vascular territory needed for treatment. These findings emphasize the need for digestive surgeon to take care and identify arterial variations before visceral reaction.

In the present study, biliary anatomy was variant in 42% livers which is in concordance to the previous reported data (24%–57%).[6,27,28] The most common anatomic variant in the branching of the biliary tree described in the literature involve the drainage of the RPSD into the LHD (11–19%).[6,28,29] In the present study, drainage of the RPSD into the LHD (11%) and triple confluence of RASD, RPSD and LHD (11%). When performing a left hepatectomy in a living related transplant donor, it is of great importance to recognize aberrant drainage of the RPSD or RASD into the LHD, as the oversight or ligation of the stump of the RPSD/RASD will lead to biliary leakage or obstruction in the donor.[30]

Fig. 4. Shows the drainage patterns of bile ducts grouped according to Blumgart's classification. **a.** Conventional drainage pattern of CHD, i.e, RHD is forming by union of RASD and RPSD and CHD is forming by union of LHD and RHD. **b.** Triple confluence of RASD, RPSD and LHD. **c.** Lower drainage of RPSD into CHD. **d.** Aberrant drainage of RPSD into LHD.

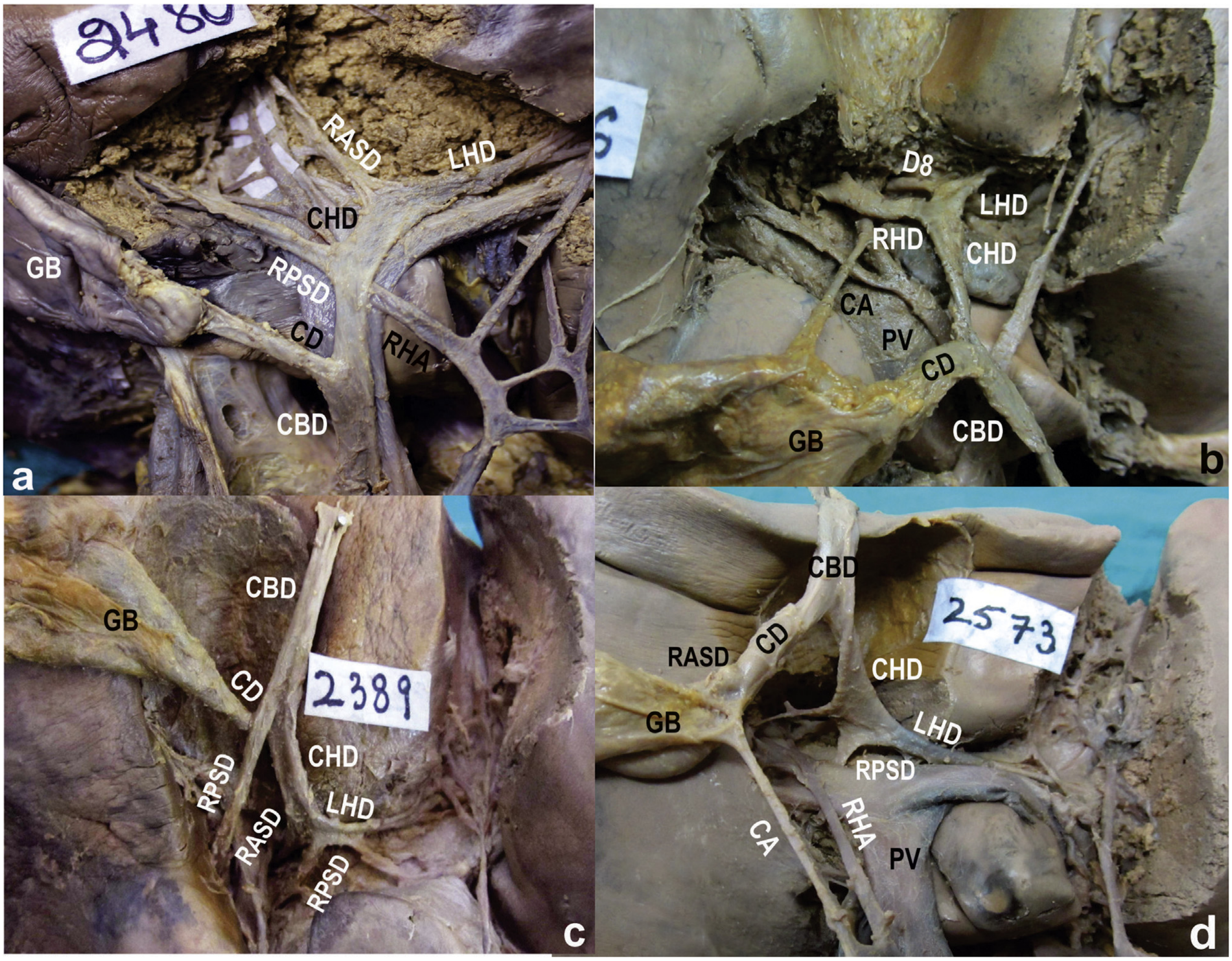

Fig. 5. Shows the rare variations in the drainage patterns of bile ducts. **a.** LHD is continuing as CHD and the RPSD is draining into CHD and RASD into LHD. **b.** There is aberrant drainage of D8 into LHD. **c.** RPSD is double. One RPSD is draining into LHD and the other into CBD. **d.** RASD is double. Additional RASD is draining into CHD.

As right liver harvesting has become increasingly common,[31,32] knowledge of the anatomic variations of the right intrahepatic BDs is very important. Confluence patterns of the right intrahepatic BDs were classified into three patterns: supraportal pattern, infraportal pattern and combined pattern. Supraportal pattern is the most common pattern seen in the previous studies (82%) and the present study (67%). Infraportal type ranges from 11.8%–18% in the previous studies. In cases of the infraportal pattern, the orifice opens caudally to the right anterior portal vein. In cases of the combined pattern, stumps are present both cranially and caudally. It is essential that both stumps must be reconstructed when they are present.[30] Biliary reconstruction of these variants is complicated and technically difficult.

The anatomy of PV is fairly constant and the normal anatomy is encountered in 70–90% of individual.[4,33–35] In the present study, PV anatomy was normal in 87% of liver specimens. The most common variant is PV trifurcation (type 2) and the second most common variant is RPPV originating as the first branch of the PV (type 3). These two variants account for the majority of main portal vein variation. In most of the previous studies, the frequency of occurrence ranges between 10–15% in case of type 2 and 0.3–9.7%

Table 3
Confluence patterns of the right intrahepatic BDs according to the anatomical relationship between the RPBD and the PV.

S. No.	Pattern	(%)
1.	Supraportal type (Normal)	67
2.	Infraportal type	31
3.	Combined type	2

Table 4
Summary of main portal vein branching patterns according to Akgul's classification.

Type	Pattern	Present study (%)	Akgul's (%)
A	Normal	86	86.2
B	Trifurcation of PV into LPV, RAPV & RPPV	7	12.3
C	RPPV comes from the PV directly & LPV & RAPV are present as common trunk	2	0.3
D	RPPV comes from PV directly & RAPV comes from LPV at or near the umbilical fissure	4	0.9
E	LPV is absent	–	–
F	RPV is absent	–	–
G	PV continues to the RPV & horizontal segment of LPV is absent. As an aberrant vessel, LPV runs transversely from RAPV at right anterior segment of liver	–	–
H	PV divides into RAPV and RPPV branches. LPV originates from RAPV	–	0.3
Rare variations		1%	

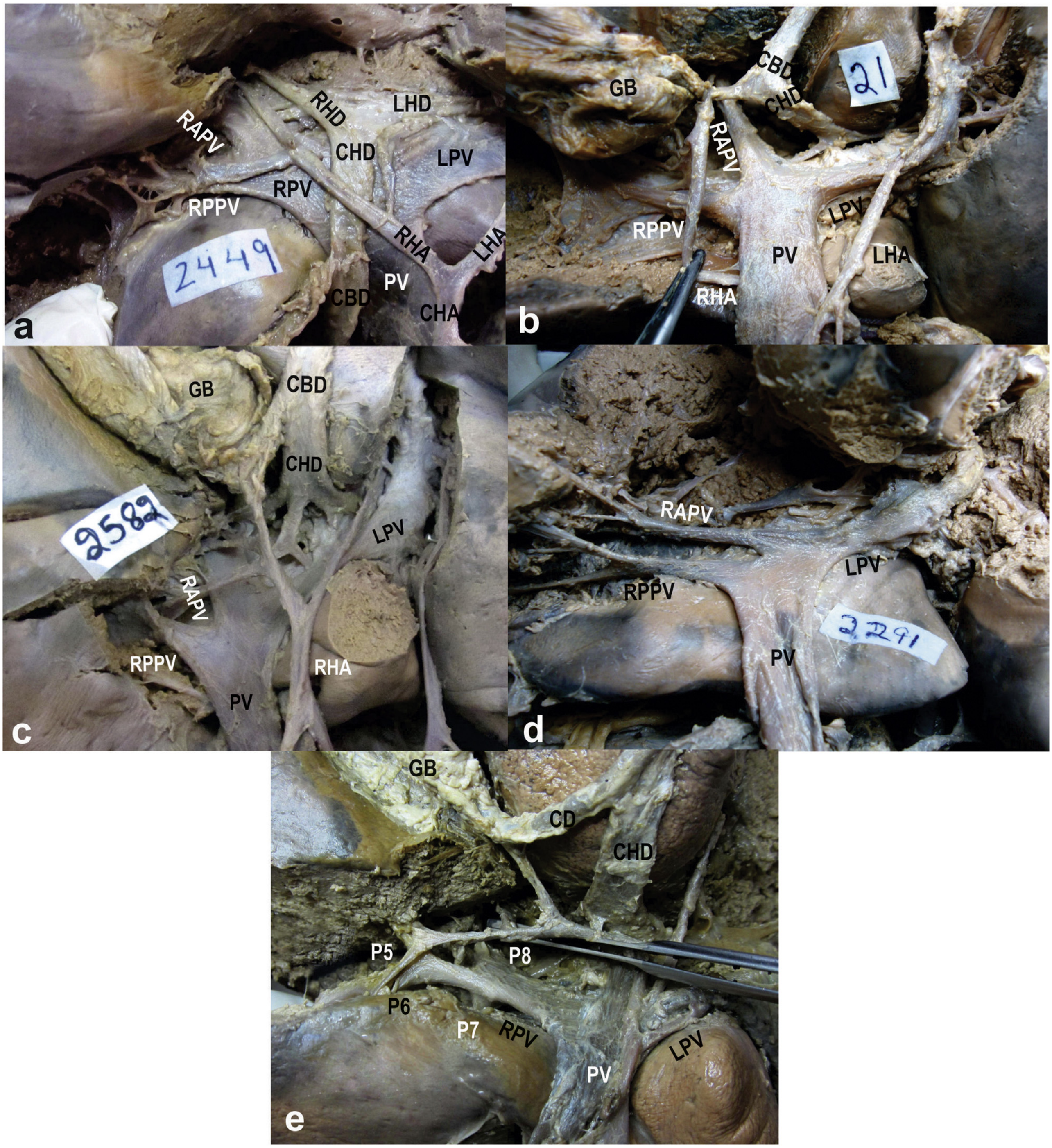

Fig. 6. Shows the main PV branching patterns according to Akgul's classification. **a.** Conventional anatomy of PV **b**. Trifurcation of PV into LPV, RAPV and RPPV. **c**. RPPV is branching from main PV as the first and separate branch. Main PV then continues as a common trunk for LPV and RAPV. **d**. RPPV is arising from main PV and RAPV from LPV. **e.** PV is branching into RPV and LPV. RPV is giving segmental branches in the sequential pattern.

in case of type 3 anatomy.[33–35] Another common variant is RAPV originating from the LPV (type 4), reported with an incidence of 0.9–4.3%. In the present study, this type was observed in 4% of livers. Recognition of type 4 PV variant during preoperative imaging evaluation must be considered as a relative contraindication of the right lobe procurement.[36] Less common PV variations have been described but their incidence has not been found to be higher than 2%.[34] In the present study, it was observed in 1% livers. Awareness of PV variations is important in identifying the location of liver lesions, as PV along with hepatic veins; determine the segmental anatomy of liver.

5. Conclusion

In conclusion, both intra and extrahepatic vasculobiliary anatomies is complex with the existence of many common and uncommon anatomic variations. The increasing complexity of hepatic surgical procedures and biliary interventions, necessitate widespread and appropriate knowledge of these anatomic variations, in order to avoid possible complications and help achieve the most effective result. Unanticipated anatomic variants may necessitate additional anastomosis, increasing graft ischemia time and risk of postoperative graft dysfunction.[37]

Conflicts of interest

None.

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