Anatomy of the Hepatic Hilum

1

W.Y. Lau, S.H.Y. Lau, and E.C.H. Lai

1.1 Introduction

A thorough knowledge of anatomy around the hepatic hilus is essential to carry out surgery on hilar cholangiocarcinoma.

The term "hepatic" means "of the liver". It originates from the Greek word "hepar", the liver. The term "hilum" means "a slit-like opening through which ducts, blood vessels lymphatics or nerves enter or leave an organ or a gland". Thus, the term "hepatic hilum" refers to the anatomical region where bile ducts, hepatic arterial branches, portal vein branches, lymphatics and nerves enter or leave the liver. The anatomy around this region is complicated, and is confounded by common occurrence of anomalies of bile ducts and blood vessels.

1.2 Surgical Anatomy of the Hepatic Hilum

A key point in the thorough understanding of the surgical anatomy of the liver and its biliary and vascular supply is to realize that there is a prevailing pattern of anatomy. The prevailing pattern is the most common anatomical pattern, and it may be present almost always or in less than 50 % of patients. Variations from the prevailing pattern in the portal triad (bile duct, hepatic arterial branches and portal vein branches) may affect all its components. Furthermore, variation in one component is independent of variations in either or the other two [1].

Anomalies are variations from the prevailing pattern, and may be common or rare. They may be anomalies of position, number, or size of structures. Aberrancy refers to abnormal position of a structure. An accessory structure is one that is in addition to the "normal" structure in the prevailing pattern and whose function can be deleted without loss of overall function of the organ. The term replaced is used synonymously with aberrant when referring to aberrant arteries in the liver [2].

In this chapter, we shall use the Brisbane 2000 Terminology of Liver Anatomy and Resection as recommended by the International HepatoPancreatoBiliary Association [3].

1.2.1 Prevailing Patterns of the Biliary System (Fig. 1.1)

As the hepatic hilum is the region where structures of the intrahepatic portal triad join the extrahepatic portal triad, a brief overview of the whole biliary system is necessary, especially on the surgical anatomy, for treatment of hilar cholangiocarcinoma.

1.2.1.1 Intrahepatic Biliary Tract

Bile canaliculi are formed by parts of the membrane of adjacent liver parenchymal cells, and they are isolated from the perisinusoidal space by junctions. Bile flows from the canaliculi through ductules (canals of Hering) into the subsegmental and segmental bile ducts which are surrounded by the Glissonian sheath.

1.2.1.2 The Right Hepatic Duct

The right hepatic duct is formed by the union of the anterior and the posterior sectoral branches with each of these two sectoral branches further bifurcating into the superior and inferior segmental branches. Thus, the right anterior sectoral

W.Y. Lau, MD (CUHK), DSc (CUHK), FRCS, FACS, FRACS (Hon) (✉)
Faculty of Medicine, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong
e-mail: josephlau@cuhk.edu.hk

S.H.Y. Lau, MBChB (CUHK), MRCS (Ed)
Department of Surgery, Queen Elizabeth Hospital, Kowloon, Hong Kong

E.C.H. Lai, MBChB (CUHK), MRCS (Ed), FRACS, FCSHK, FHKAM (Surgery)
Department of Surgery, Pamela Youde Nethersole Eastern Hospital, Chai Wan, Hong Kong

Department of Surgery, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong

W.Y. Lau (ed.), *Hilar Cholangiocarcinoma*,
DOI 10.1007/978-94-007-6473-6_1, © Springer Science+Business Media Dordrecht and People's Medical Publishing House 2013

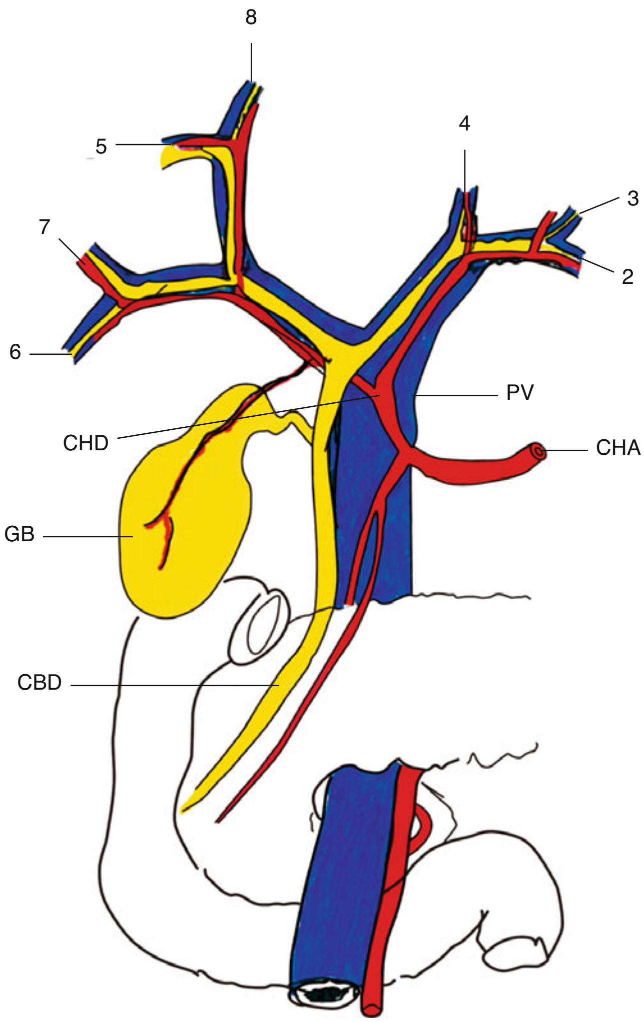


Fig. 1.1 *PV* portal vein, *CHA* common hepatic artery, *CHD* common hepatic duct, *CBD* common bile duct, *GB* gall bladder, *2, 3, 4, 5, 6, 7, 8*, portal triad to segments 2, 3, 4, 5, 6, 7, 8 respectively

branch drains liver segments 8 (right anterior superior segment) and 5 (right anterior inferior segment), while the right posterior sectoral branch drains liver segments 7 (right posterior superior segment) and 6 (right posterior inferior segment). The right hepatic duct, having an average length of 0.9 cm, is formed intrahepatically [4], but it runs a short extrahepatic course to join the left hepatic duct at the bile duct confluence which is totally extrahepatic.

In the prevailing pattern, the right posterior sectoral duct joins the right anterior sectoral duct to form the right hepatic duct, which joins the left hepatic duct to form the confluence of the bile ducts. Instead of the anterior and the posterior sectoral ducts joining together in a Y pattern, the posterior sectoral duct runs superiorly, dorsally, and then inferiorly (Hjortsjo Crook) around the right branch of the portal vein to make a "north-turn" (Fig. 1.2).

Because of this prevailing pattern of the north-turning bile duct branch of the Hjortsjo Crook, resection of the right anterior sector of the liver (segments 5 and 8) can damage the right posterior sectoral duct if the resection is done too close to the bifurcation of the right portal vein into the anterior and posterior sectoral branches. The correct procedure is to stay away from the bifurcation of the right portal vein (Fig. 1.3).

1.2.1.3 The Left Hepatic Duct

The biliary branches of the left medial sectional bile duct (draining liver segment 4) and the left lateral sectional bile duct (draining liver segments 2 and 3) converge to form the left hepatic duct. The medial and the left sectional bile ducts unite at the umbilical fissure (or the left hepatic fissure) in 50 % of cases, to the right in 42 % or to the left in 8 %, according to the study by Healey and Schroy [5]. The left hepatic duct has an average length of 1.7 cm. Again it is formed intrahepatically but it runs extrahepatically to join the right hepatic duct at the bile duct confluence [4]. As the left hepatic duct is longer than the right hepatic duct, palliative bypass is technically easier to the left than the right hepatic duct.

1.2.1.4 Bile Ducts Draining the Caudate Lobe

The caudate lobe can be divided into three parts, each receiving its own vasculo-biliary pedicle: (1) Spiegelian lobe is located to the left of the ligamentum venosum. The prevailing pattern of the vasculo-biliary supply to the Spigelian lobe is by one or two caudate portal triad(s) which originates from the left hepatic pedicle of the portal triad. (2) The paracaval portion lies in front of the retrohepatic portion just to the right of the Spigelian lobe and it is closely attached to the right and middle hepatic veins. It is usually supplied by one or two caudate portal triads which originate from the right posterior sectional pedicle. (3) The caudate process is a small projection between the inferior vena cava and the adjacent portal vein anteriorly. It lies just to the right of the paracaval portion and its vasculo-biliary triad originates from the right hepatic pedicle or from the bifurcation of the main portal triad [6]. As the bile ducts to the caudate lobe arise very near to the confluence of the hepatic ducts, hilar cholangiocarcinoma involves the caudate lobe early. Curative resection of hilar cholangiocarcinoma should be combined with caudate lobectomy.

1.2.1.5 Confluence of Right and Left Hepatic Ducts

The right and left hepatic ducts emerge from the liver and unite at the right margin of the porta hepatis to form the common hepatic duct in a T-shaped manner. The confluence of the right and left hepatic ducts occurs anterior to the portal venous bifurcation and it overlies the origin of the right portal vein. The right hepatic artery usually runs posterior to the common hepatic duct, i.e. posterior and inferior to the confluence of the right and left hepatic ducts. The extrahepatic segment of the right duct is short, but the left duct has a

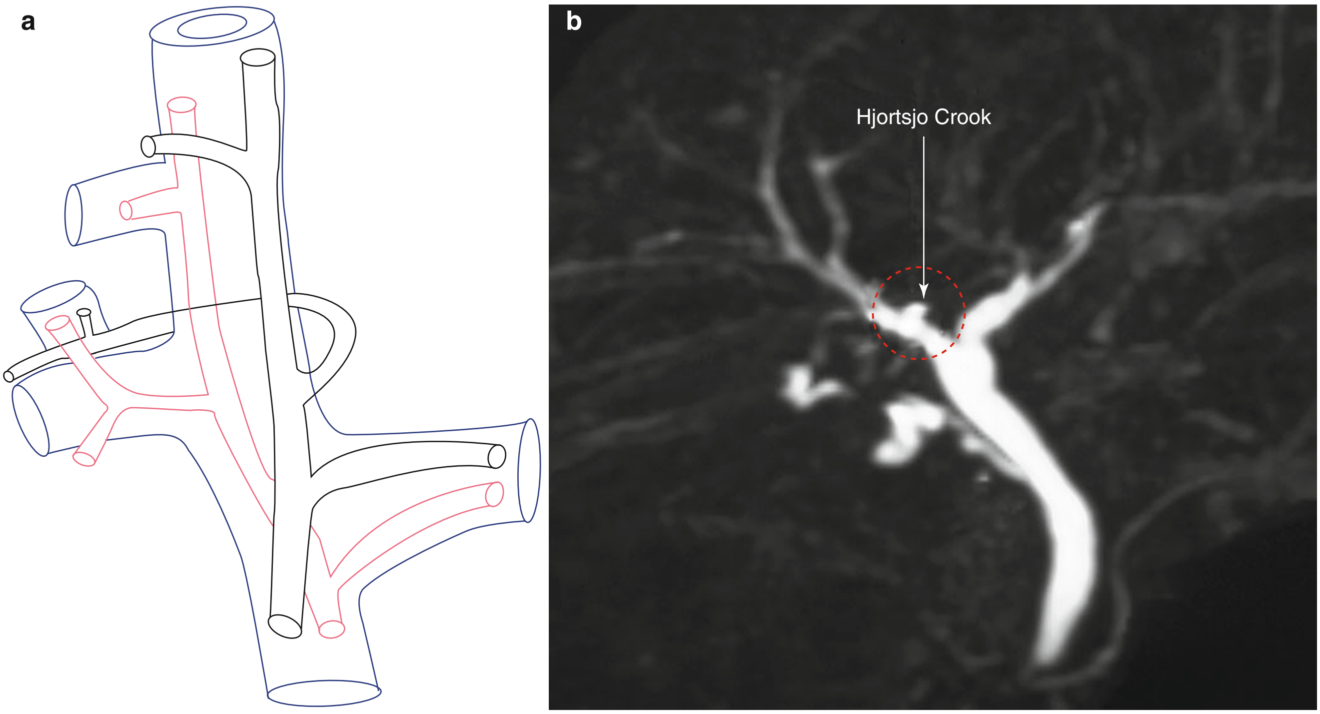


Fig. 1.2 (**a**) Hjortsjo Crook; (**b**) magnetic resonance cholangiopancreatogram showing the Hjortsjo Crook

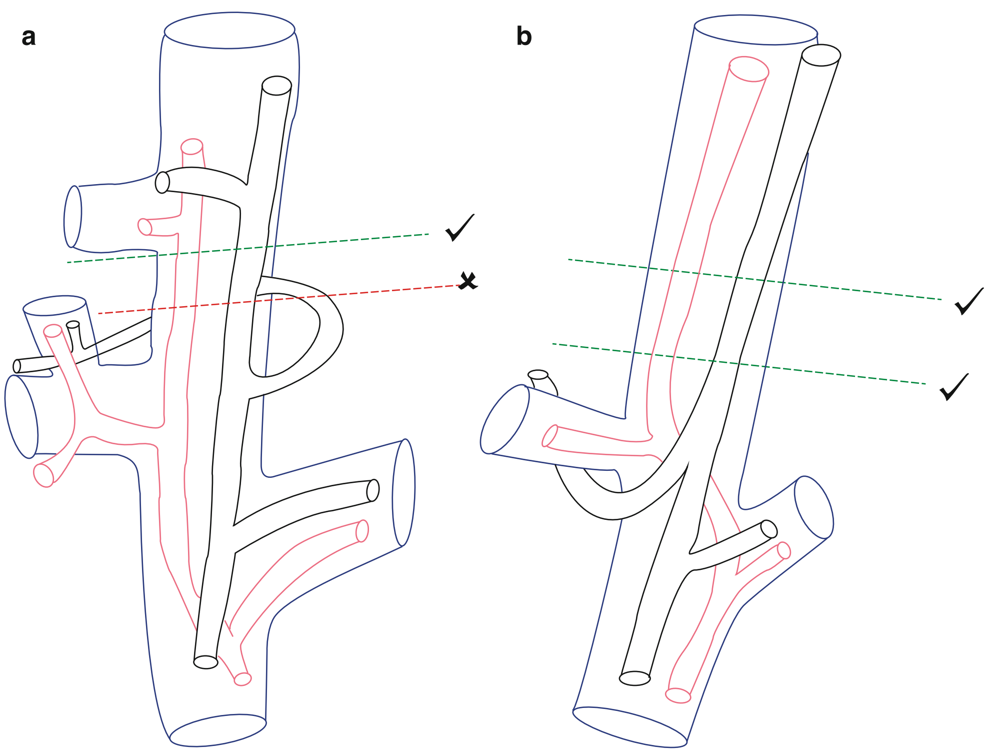


Fig. 1.3 Hjortsjo Crook and its clinical significance. (**a**) The north-turning right posterior sectoral bile duct (majority of people). (**b**) The south-turning right posterior sectoral bile duct (minority of people)

much longer extrahepatic course. The biliary confluence is separated from the posterior aspect of the quadrate lobe of the liver (i.e. segment 4b) by the hilar plate, which is the fusion of connective tissues enclosing the biliary and vascular elements with Glisson's sheath. Because of the absence of any vascular interposition, it is possible to open the connective tissue constituting the hilar plate at the inferior border of the quadrate lobe (segment 4b), and by elevating it to display the biliary convergence and left hepatic duct [7]. This surgical procedure is called lowering of the hepatic hilar plate.

1.2.1.6 Other Components of the Extrahepatic Biliary System

The common hepatic duct is about 4 cm long with a diameter of 4 mm. It lies in the free edge of the lesser omentum in front of the right edge of the main portal vein and with the hepatic artery on its left. The cystic duct usually joins the common hepatic duct on the right, about 1 cm above the first part of the duodenum to form the common bile duct. The common bile duct is about 8 cm long and 8 mm in diameter. It can be divided into the supradudodenal portion which lies in the free edge of the lesser omentum, the retroduodenal portion which runs behind the first part of the duodenum, the paraduodenal portion which runs in the groove between the back of the head of the pancreas and the second part of the duodenum, and the intraduodenal portion which runs obliquely through the wall of the duodenum. The common bile duct joins the pancreatic duct at an angle of about 60° at the ampula of Vater which opens into the posteromedial wall of the second part of the duodenum at the major papilla.

The gallbladder is a reservoir for bile and it is located on the undersurface of the right liver within the gallbladder fossa. It is separated from the liver parenchyma by the cystic plate, which is composed of connective tissue closely applied to the Glisson's capsule and is continuous with the hilar plate.

1.2.2 Anomalies of the Biliary System

It is not the intention of the authors to discuss on all the possible anomalies of the biliary system. Our intention is to discuss on anomalies which are relevant to surgery on hilar cholangiocarcinoma only. As anomalies of the confluence of the right and left hepatic ducts are closely related to either anomalies of the right hepatic duct or the left hepatic duct, these anomalies will be discussed together.

1.2.2.1 Bile Ducts Draining the Right Hemiliver

"South-Turning" Hjortsjo Crook

Instead of making a north-turn as described previously, the right posterior sectoral bile duct courses ventrally and inferiorly around the right branch of the portal vein (the south-turning bile duct branch). This anomaly makes resection of the right anterior sector of the liver (segments 5 and 8) safer than the prevailing pattern, and it is of little clinical significance to recognize.

Absence of Right Hepatic Duct

Absence of the right hepatic duct is an anatomical variation that results during development.

There are three anatomical variations in which the right anterior and posterior sectoral ducts do not come together to form the right hepatic duct, thus resulting in absence of the right hepatic duct (Fig. 1.4) [5, 8–10].

The anomalies which can result in absence of the right hepatic ducts are:

Shifting of the Entry of the Right Bile Duct Inferiorly

This set of anomalies involves the insertion of the right bile duct, or one of its branches, inferiorly into the biliary tree at a lower point than the prevailing site of the biliary confluence (Fig. 1.5).

Low union may affect the main right bile duct, a right sectoral duct (usually the anterior one and this anomaly results in absence of right hepatic duct), a segmental duct, or a subsegmental duct. The duct unites with the common hepatic duct below the prevailing site of the biliary confluence, or in about 2 % of patients, unites first with the cystic duct, and then the common hepatic duct. These anomalies place a greater risk of ductal injury during laparoscopic cholecystectomy.

Trifurcation of Bile Duct

When performing a right hemihepatectomy, a left hemihepatectomy, an anterior right sectionectomy, a right posterior sectionectomy, a right trisectionectomy or a left trisectionectomy, a stricture is likely to develop at the biliary trifurcation site if no normal biliary safety margin is left at the site of the transection. It is always safer to divide the biliary tree with a safety margin of at least 1 cm from the site of the biliary confluence (Fig. 1.6).

Anterior or Posterior Sectoral Branch Joining the Left Hepatic Duct

The right posterior sectoral duct inserts with the left hepatic duct in 20 % of patients and the right anterior sectoral bile duct does so in 6 %. In both cases, there is no right hepatic duct as both join the left hepatic duct, one to the left of the midline and the other in the midplane. A right sectoral bile duct inserting into the left hepatic duct to the left of the midplane is in danger of injury during left hepatectomy, therefore, in left hepatectomy, the left bile duct should be divided close to the umbilical fissure so as to avoid injury to a possible right sectoral duct. If the left duct is divided at the normal site of confluence of the right and left hepatic duct, the right sectoral duct can be injured (Fig. 1.7). It is good practice to obtain an intraoperative cholangiogram through the cystic duct when performing left hepatectomy to detect this anomaly. Please take note that even with these anomalies, a right hepatectomy is safe.

1.2.2.2 Anomalies of Bile Ducts Draining the Left Hemiliver

The prevailing pattern of bile duct draining from the left liver is shown in Fig. 1.8a, and this is present only in 30 % of individuals. Thus, variations are present in the majority of individuals.

The segmental ducts from segments 2 and 3 (B2 and B3 respectively) unite to form the left lateral sectional duct. This

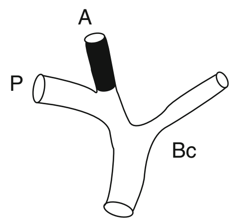
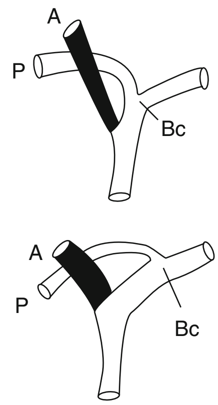
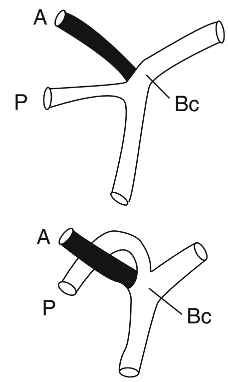
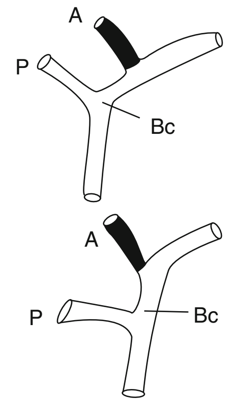
	Presence of a right hepatic duct	Absence of a right hepatic duct		
	Prevailing pattern	Posterior sectoral duct joining to the left hepatic duct	3-branch type	Anterior sectoral duct joining to the left hepatic duct
Variations in the anatomy of the anterior sectoral bile duct				
Healey (1953) (n = 96)	72.0 %	22.0 %	—	6.0 %
Couinaud (1981) (n = 102)	53.5 %	24.3 %	14.0 %	8.4 %
Kida (1987) (n = 104)	71.2 %	8.7 %	11.5 %	8.6 %
Ishiyama (1999) (n = 41)	58.4 %	26.9 %	7.3 %	7.3 %

Fig. 1.4 Variations in the anatomy of the right hepatic duct and their incidences, based on analysis of liver casts. *A* anterior sectoral branch, *P* posterior sectoral branch, *Bc* bile duct confluence

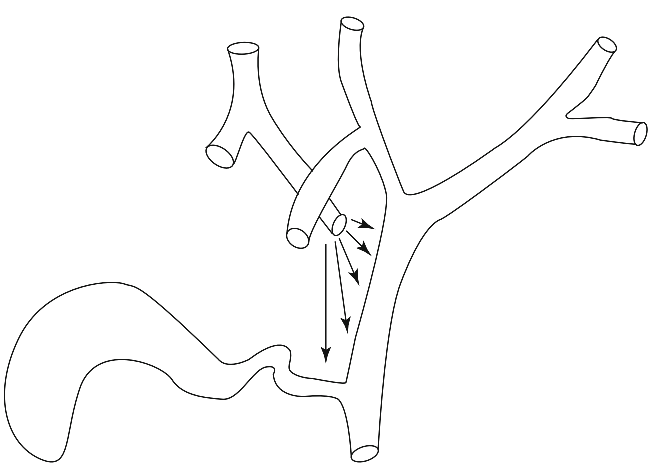


Fig. 1.5 Shifting of entry of right bile duct (or one of its branches) inferiorly

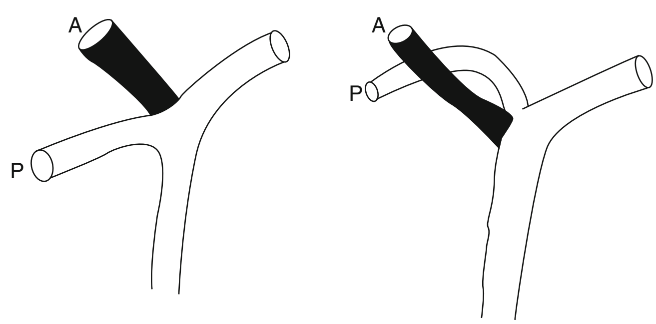


Fig. 1.6 Trifurcation of bile duct. *A* right anterior sectoral branch, *P* right posterior sectoral branch

duct passes behind the umbilical portion of the portal vein and unites with the duct(s) from segment 4 (B4), also called the left medial sectional duct. The union of these ducts to form the left hepatic duct occurs about one third of the

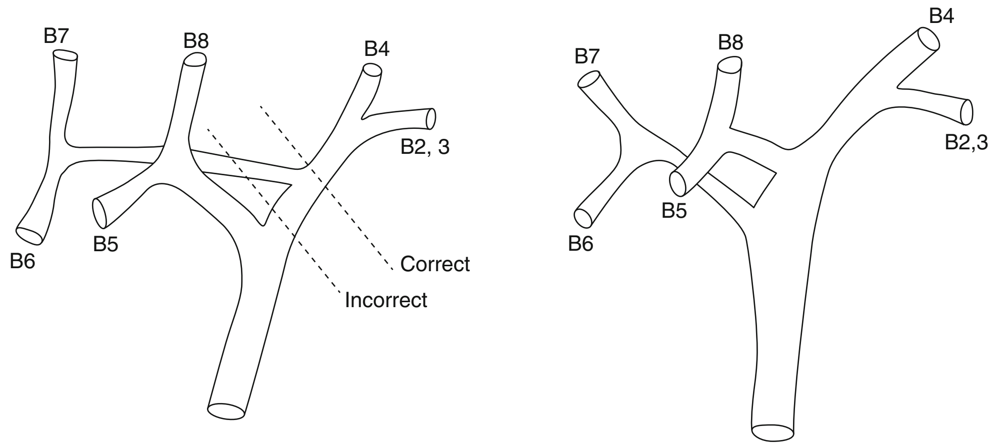


Fig. 1.7 Separate entry of right anterior and right posterior sectoral ducts (no right hepatic duct)

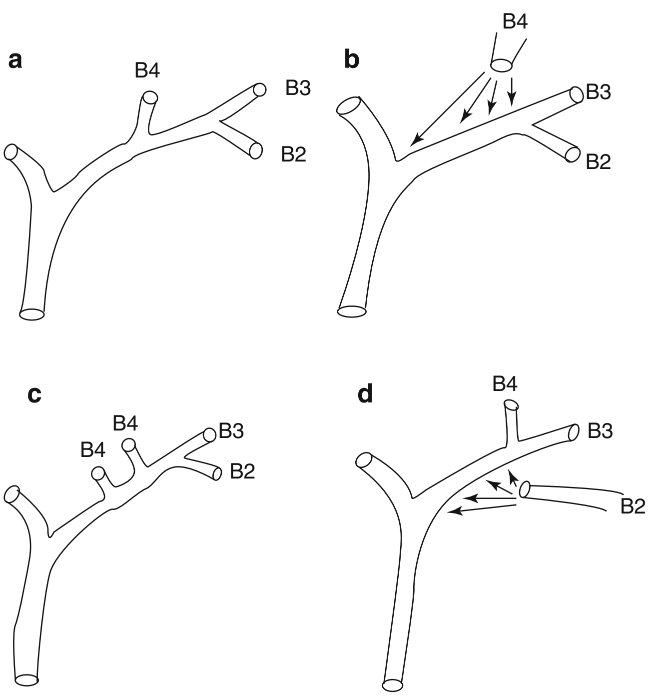


Fig. 1.8 Variations in formation of left hepatic ducts. (**a**) Prevailing pattern of left bile duct; (**b**) insertion of B4 shifted to right or left; (**c**) multiple ducts draining B4; (**d**) B3, B4 form common channel before insertion of B2

distance between the umbilical fissure and the confluence of the left and right ducts.

The surgically important anomalies of the left ductal system involve variations in site of insertion of B4 (Fig. 1.8b), multiple ducts coming from B4 (Fig. 1.8c) and primary union of B3 and B4 with subsequent union of B2 (Fig. 1.8d). B4 may join the left lateral sectional duct to the left or right of its point of union in the prevailing pattern (Fig. 1.8b). In the former case, the insertion may occur at any place to the right of the prevailing location up to the point where the left lateral sectional duct unites with the right bile duct. In the latter instance, which according to Couinaud, is present in 8 % of individuals, there is no left hepatic duct, instead the common hepatic duct is formed by the confluence of three ducts—the right hepatic duct and two left hepatic ducts (B4 and the left lateral sectional duct of B3 and B2).

The commonest variations in the left bile duct are: Type 1 common joining of B2 with B3, B4 then joins near to the left hepatic duct; Type 2 common joining of B4, B3 and B2 near to the same point; Type 3 common joining of B4 with B3 before B2 joins in (Fig. 1.9).

The left hepatic duct runs at a variable angle. In some individuals, it is almost horizontal, but in others it runs sharply upwards. It is much easier to expose a long length of the left hepatic duct in the former type.

1.2.3 Prevailing Pattern of the Portal Venous System

Few variations are found in the major portal vein branches because the portal vein develops during the very earliest part of the gestational period.

The prevailing pattern of the portal vein and its intrahepatic branches are shown in Fig. 1.10.

The main portal vein divides into the right and the left portal vein. The right portal vein subdivides into the right anterior sectoral portal vein which further branches into the segment 8 (superior) and segment 5 (inferior) branches supplying the corresponding liver segments. The posterior sectoral portal vein branches into the segment 7 (superior) and segment 6 (inferior) branches, supplying the corresponding liver segments. The transverse portion of the left portal vein only sends out a few small branches to segment 4 and one or two small branches to segment 1. All large branches from the portal vein to the left liver arise exclusively beyond the attachment of the ligamentum venosum, i.e. from the umbilical portion of the

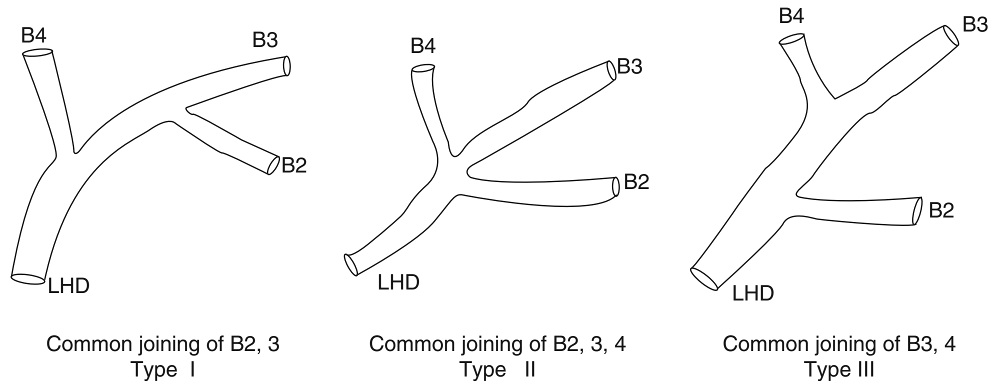


Fig. 1.9 Common variations in the anatomy of the left bile duct

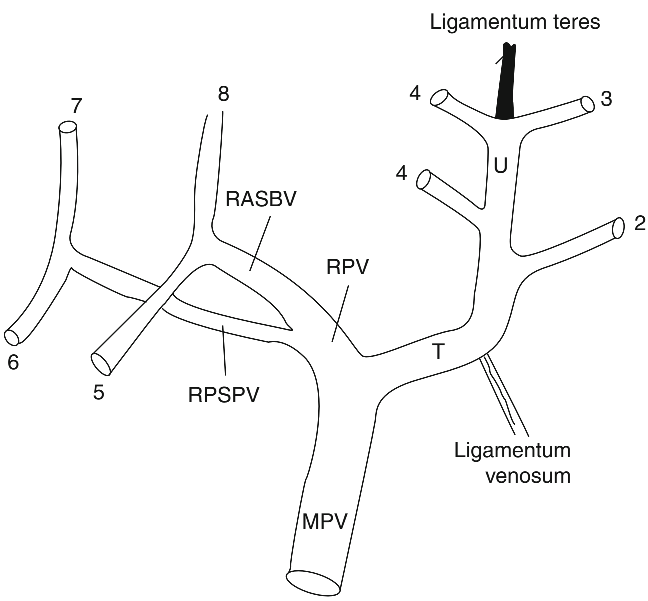


Fig. 1.10 The portal vein and its intrahepatic branches. *MPV* main portal vein, *RPV* right portal vein, *RASPV* right anterior sectoral portal vein, *RPSPV* right posterior sectoral portal vein *U* umbilical portal of left portal vein *T* transverse portion of left portal vein

vein. There are usually more than one branch which supplies segment 4 of the liver coming out from the right side of the umbilical portion of the vein. On the left side, there is usually one branch which goes to segment 2, but one or more branches which go to segment 3. The left portal vein terminates where it joins the ligamentum teres at the free edge of the liver.

1.2.4 Anomalies of the Portal Venous System

Reports by three investigators revealed three principal anomalies of the portal vein in the hilar region (Fig. 1.11) [8, 9, 11].

Kida et al. reported that variations in the anatomy of biliary tract are mostly (81 %), but not invariably, associated with variations in the anatomy of the portal vein.

In operations on patients with trifurcation of the right anterior sectoral vein, right posterior sectoral vein and the left portal vein, it is important to leave a safety margin of at least 1 cm on the portal vein stump to avoid subsequent stricture formation in the portal vein left after liver resection.

In the anomaly where the anterior sectoral vein joins the left portal vein, an unsuspecting surgeon who carries out a right hemihepatectomy may divide the posterior sectoral vein thinking that it is the right portal vein, and will consequently be confused when the anterior sector vein is come upon during hepatic transection. In left hemihepatectomy, the anterior sectoral portal vein is inadvertently damaged, resulting in subsequent ischemia to liver segments 5 and 8.

A very rare but potentially devastating anomaly is the absent extrahepatic left portal vein (Fig. 1.12). In this case, the apparent right portal vein is actually the main portal vein, a structure which enters the liver, gives off the right portal vein, and then loops back within the liver substance to supply the left liver. The vein looks like a right portal vein in position, although it is larger. Transection of this vein results in total portal vein disconnection from the liver. This anomaly should always be searched for in computer tomography, as right hepatectomy is not possible when it is present. Identification of the umbilical portion of the left portal vein in the umbilical fissure on computed tomography can preclude the presence of this problem. A left hepatectomy is possible with this anomaly.

1.2.5 Prevailing Pattern of the Arterial Blood Supply

This occurs in approximately two-third of individuals [1]. The common hepatic artery arises from the coeliac trunk which divides into the common hepatic artery, the left gastric artery and splenic artery. The common hepatic artery divides into the gastroduodenal and the proper hepatic artery (this is referred to in many anatomical textbooks as the common hepatic artery). The proper hepatic artery usually lies lateral and slightly posterior to the common bile duct in the portal pedicle and divides into its terminal branches, usually to the left and below the confluence of the right and left hepatic ducts. The course of the terminal branches is highly variable, they may

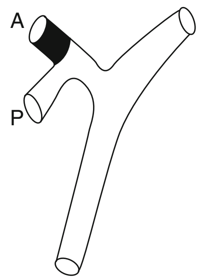
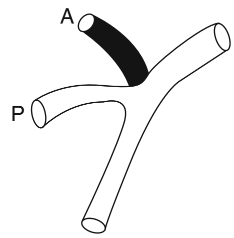
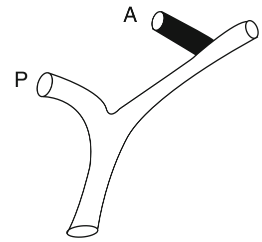
	Presence of a right portal vein	Absence of a right portal vein	
	Prevailing pattern	3-branch type	Anterior sectoral vein joining to the left portal vein type
Variations in the anatomy of the anterior sectoral portal vein			
Couinaud (1981) (n = 111)	83.5 %	7.7 %	8.8 %
Kumon (1985) (n = 23)	73.9 %	8.7 %	17.4 %
Kida (1987) (n = 104)	79.8 %	11.5 %	8.7 %

Fig. 1.11 Variations in the anatomy of the right portal vein and their incidences (analysis of liver cyst). *A* anterior sectoral branch, *P* posterior sectoral branch

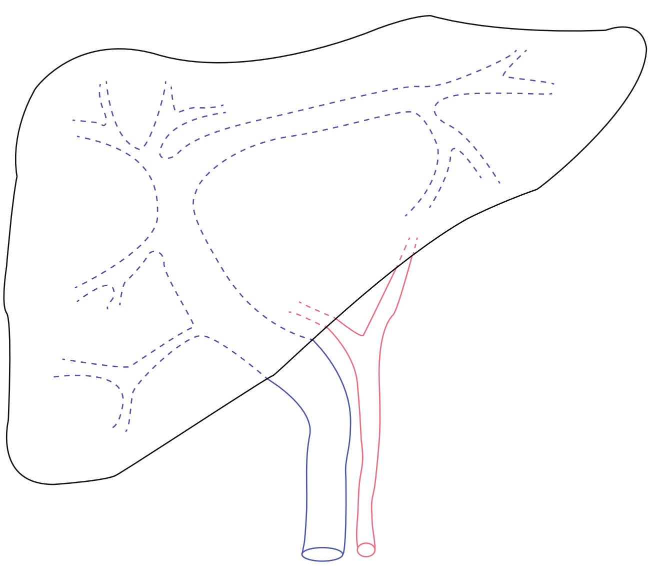


Fig. 1.12 Absent exhraheptic left portal vein

pass posterior (more commonly) or anterior to the bile ducts. The right hepatic artery may lie anterior and to the right of the main bile duct, thereby coming in close contact with the gallbladder where it can be damaged during cholecystectomy. The right hepatic artery generally supplies the right liver and the left hepatic artery the left liver. In 92 % of cases, segment 4 of the liver is supplied by a branch of either the right or the left hepatic artery. This is called the middle hepatic artery by some authors. The arterial blood supply to the caudate lobe is usually from both the right and left hepatic arteries.

1.2.5.1 Variations in Hepatic Arterial Blood Supply

Embryologically, the hepatic artery develops late in the gestational period, and thus variations are common (33–45 %). More than ten variations in the anatomy of the hepatic artery, including an accessory or replaced artery, have been identified [12]. Fortunately some of these variations are rare. Figure 1.13 shows the important variations [13, 14].

Analysis of the anatomy showed the hepatic artery courses dorsal to the hepatic duct in 76 % of the population, and ventrally to it in 24 % of the population. In 9 % of the population, the right hepatic artery runs dorsal to the portal vein, making it necessary to pay special attention to the anatomy of the vessels and ducts of the hilar area during surgical dissection of this area.

1.2.5.2 Blood Supply of the Gallbladder

In 85 % of the population, the cystic artery arises from the right hepatic artery. It divides into an anterior and a posterior branch close to the wall of the gallbladder. The posterior branch of the cystic artery may be anastomosed to the

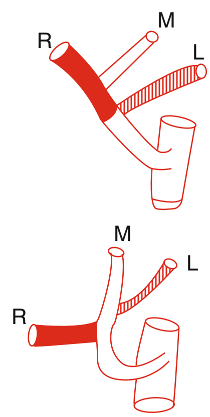
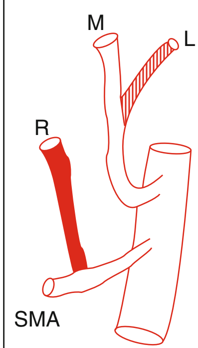
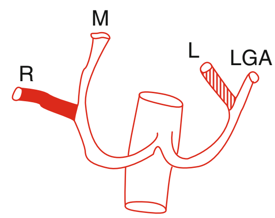
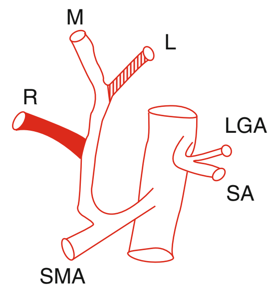
	Prevailing pattern	Right hepatic a. from the SMA	Left hepatic a. from the LGA	Common hepatic a. from the SMA
				
Michels (1966) (n = 200)	71.0 %	13.0 %	11.0 %	5.0 %
Suzuki (1982) (n = 100)	72.0 %	14.0 %	12.0 %	2.0 %

Fig. 1.13 Variations in the anatomy of the main hepatic arteries exclusive of accessory hepatic arterials. *R* right hepatic artery, *M* middle hepatic artery, *L* left hepatic artery, *SMA* superior mesenteric artery, *LGA* left gastric artery, *SA* splenic artery

arterial branches supplying the hepatic parenchyma around the gallbladder fossa.

The origins of the cystic artery may be highly variable, arising from any part of the hepatic artery, coeliac axis, the superior mesenteric artery or any of its branches. If the cystic artery has a low origin, it may participate extensively in the vascularization of the main bile duct [1].

1.2.5.3 Arterial Blood Supply to the Supraduodenal and Retroduodenal Portions of the Extrahepatic Bile Ducts

The arterial blood supply to the supraduodenal and retroduodenal portions of the extrahepatic bile ducts originates from the coeliac and the superior mesenteric arterial branches (Fig. 1.14).

According to the study by Chen et al. [15], the right and left hepatic ducts, the common hepatic duct, and the supraduodenal and retroduodenal portions of the common bile duct are supplied by at least seven arteries which supply different amounts of blood to the different portions of this extrahepatic ductal system. These arterial branches can be divided into the upper and the lower groups according to their distributions as related to the ducts. The upper group includes the cystic artery, right hepatic artery, and left hepatic artery which are located in the region near to the common hepatic duct (Fig. 1.15). The lower group consists of the posterior superior pancreaticoduodenal artery, the gastroduodenal artery, the anterior superior pancreaticoduodenal artery and the retroportal artery, all of which are located near the retroduodenal portion of the bile duct (Table 1.1) (Fig. 1.16).

1.2.5.4 Arterial Blood Supply to the Paraduodenal and Intraduodenal Portions of the Extrahepatic Bile Ducts

The paraduodenal (or pancreatic) and intraduodenal portions of the common bile duct is supplied by arterial branches coming from the posterior superior pancreaticoduodenal artery (coming from the coeliac artery) and the posterior inferior pancreaticoduodenal artery (coming from the superior mesenteric artery) (Fig. 1.16).

There has been some confusion of nomenclature. The term posterior superior pancreaticoduodenal artery whose description by Shapiro [16] in 1948, was the most exact, but it is called the retroduodenal artery in some publications, or less frequently, the right superior pancreaticoduodenal artery. The term posterior superior pancreaticoduodenal artery should be used, whereas the term retroduodenal artery indicates another and quite different artery in some anatomic textbooks [17].

The retroportal artery (R) is worth a more detailed discussion (Fig. 1.15). It was first described by Northover and Terblanche [18] in 1978 and is present in more than 90 % of individuals [15, 18]. It arises from the mesenteric artery in

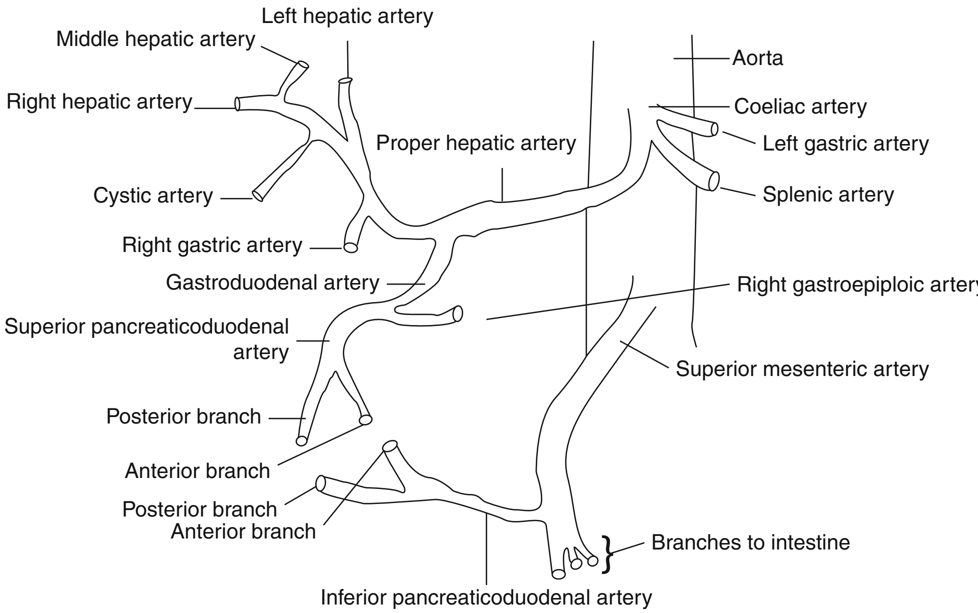


Fig. 1.14 Arterial blood supply to the extrahepatic bile ducts

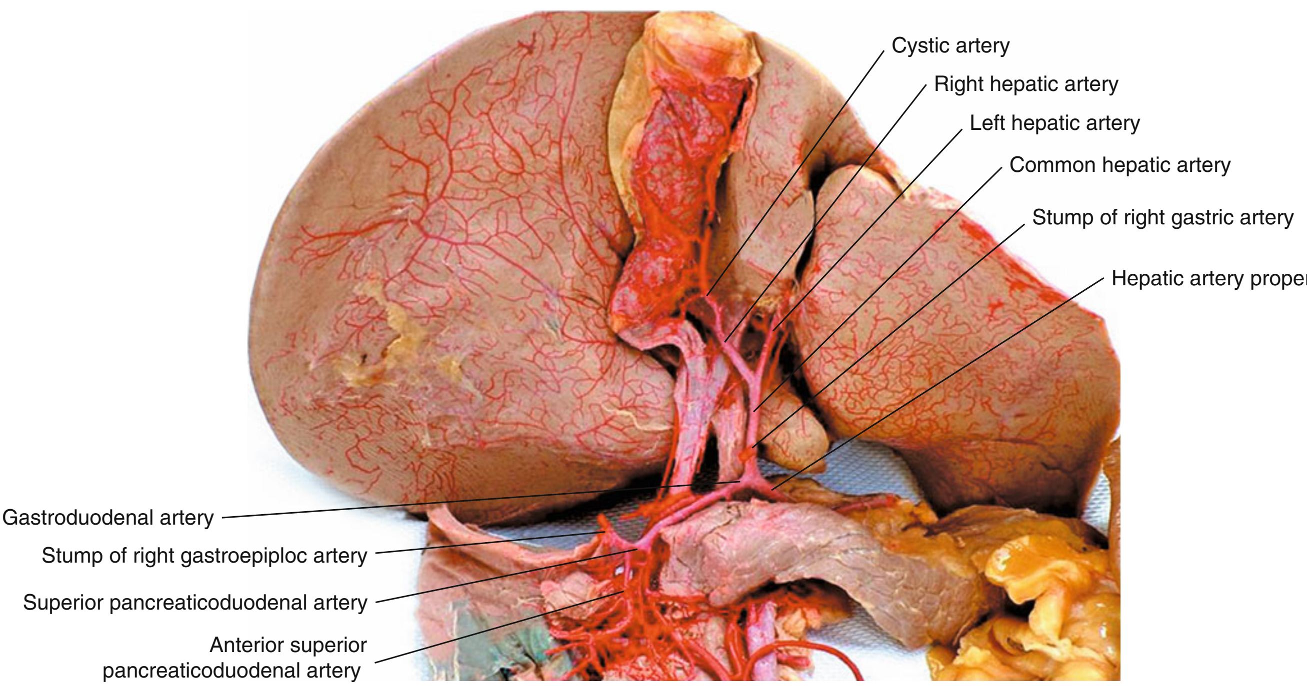


Fig. 1.15 Arterial blood supply to the supraduodenal and retroduodenal portions of the extrahepatic bile duct (anterior view) (Photograph provided by Academician Zhong Shizhen whose injection cast carried out 20 years ago clearly shows the arterial blood supply that we now understand)

58.3 % of individuals, and from the coeliac trunk in 41.7 % according to the study by Chen et al. [15]. After arising from close to the origins of one of these major arteries from the aorta, it passes to the right, posterior to the portal vein and the posterosuperior margin of the pancreatic head to reach the posterior part of the retroduodenal portion of the common bile duct. It then terminates either by joining the posterior superior pancreaticoduodenal artery to form an arterial circle (Type I by Chen et al. [15]), or passing upward along the posterior surface of the supraduodenal part of the bile duct to anastomose with the descending branches of the cystic and the right hepatic artery via two pathways: either joining the right hepatic artery after passing up the posterior surface of the bile duct, or joining the branches of the posterior superior pancreaticoduodenal artery close to the lower end of the common bile duct, from where branches travel superiorly to join the descending branches [1] (Type II by Chen et al. [15]) These two components, anterior as described by Parke et al. [19] in 1963 and posterior as described by Northover and Terblanche [18] in 1978 are freely anastomosed to each other [1]. In about a quarter of patients, the retroportal artery runs inferior to the pancreas [15].

1.2.5.5 Arterial Network of the Extrahepatic Biliary System

Previous investigations on the arterial blood supply to the extrahepatic biliary system are scarce, and most were confined to the common bile duct and/or hepatic ducts [15]. The results were conflicting, and in some cases contradictory [17]. These differences are partly due to the different techniques employed and partly due to the different ages of the subjects studied (adult or fetus). Shapiro and Robillard [16] and Pforriager [20] reported that the bile duct were supplied by end arteries, while studies by Douglas and Cutter [21], Northover and Terblanche [18, 22], Rath et al. [17] and Chen et al. [15] proposed the presence of a rich arterial network around the duct. It is now accepted that arterial anastomoses are found on the surfaces of the extrahepatic biliary system [17]. To understand the arterial blood supply better, it is necessary to divide the extrahepatic biliary system into four portions as each portion has its own special characteristics [15].

First Portion: Cystic Duct and Gallbladder

The cystic artery has two branches, an anterior and a posterior branch which pass closely along the right and left margins respectively (superificial and deep surfaces) of the gallbladder. Arterial branches arborize and anastomose with each other to form a rich arterial network on the wall of the gallbladder (Fig. 1.15). As mentioned previously, the posterior branch of the cystic artery may be anastomosed to the arterial branches supplying the hepatic parenchyma around the gallbladder fossa.

Second Portion: Right and Left Hepatic Ducts

These ducts have a comparatively sparse arterial network. The arteries here run closely along each duct. According to Chen et al. [15], one branch travels on the lateral side of the left hepatic duct. The right hepatic artery and its branches travel on the latero-inferior side of the right hepatic duct (Fig. 1.17).

Third Portion: Common Hepatic duct, and Supra- and Retro-duodenal Portions of the bile duct (Fig. 1.17)

In this portion, a special and sparse longitudinal arterial anastomotic chain is found. This chain passes close to the lateral sides of the duct, where it is named the right or left marginal arteries, respectively (or the 9 O'clock or 3 O'clock marginal arteries, respectively). According to Chen et al. [15], the left margin artery is present in 95 % of individuals, and it arises from the posterior superior pancreaticoduodenal artery in 86 %, or gastroduodenal artery in 13.2 %. It runs distally to join the right hepatic artery (63.2 %) or the cystic artery (26.3 %) or others (5.3 %). The right margin artery is present in 82.5 % of individuals. It arises from the posterior superior pancrea-

Table 1.1 Arterial blood supply to the supraduodenal and retroduodenal portions of the extrahepatic bile ducts

Artery	Percent of contribution of blood flow (%)
Superior group	
Cystic	56.4
Right hepatic	11.9
Left hepatic	0.8
Inferior group	
Posterior superior pancreaticoduodenal	22.8
Retroportal	3.4
Gastroduodenal	1.5
Anterior superior pancreaticoduodenal	1.4
Others	1.8
	100.0

According to Chen et al. [15]

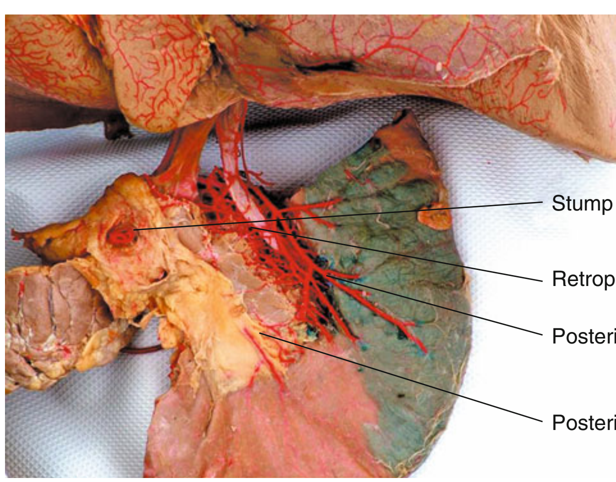


Fig. 1.16 Arterial blood supply to the paraduodenal and intraduodenal portions of the extrahepatic bile ducts (posterior view) (Photograph provided by Academician Zhong Shizhen whose injection cast carried out 20 years ago clearly shows the arterial blood supply that we now understand)

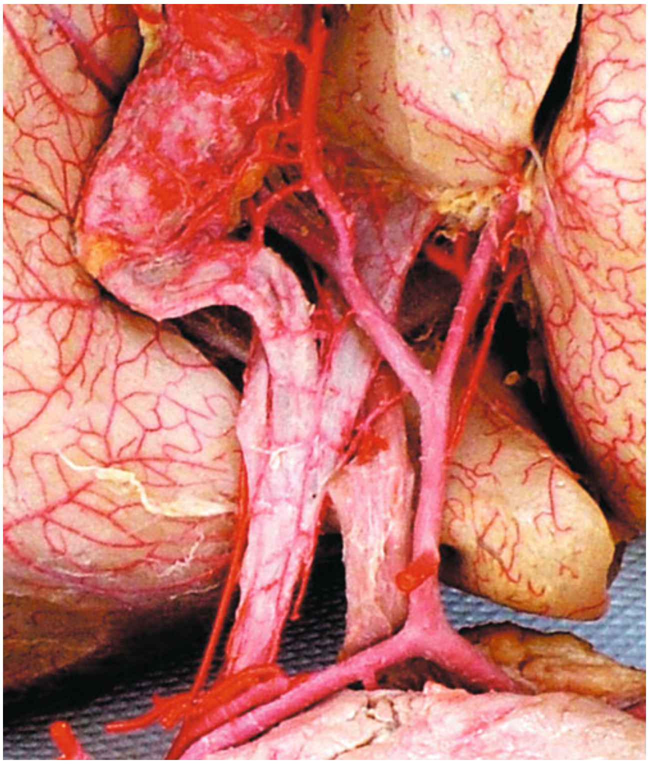


Fig. 1.17 Anterior network on extrahepatic biliary system. Please note the right and left marginal arteries on the right and left borders of the common hepatic and common bile ducts. This specimen represents an axial distribution with two arches in the classification by Rath et al. [17] (Photograph provided by Academician Zhong Shizhen whose injection cast carried out 20 years ago clearly shows the arterial blood supply that we now understand)

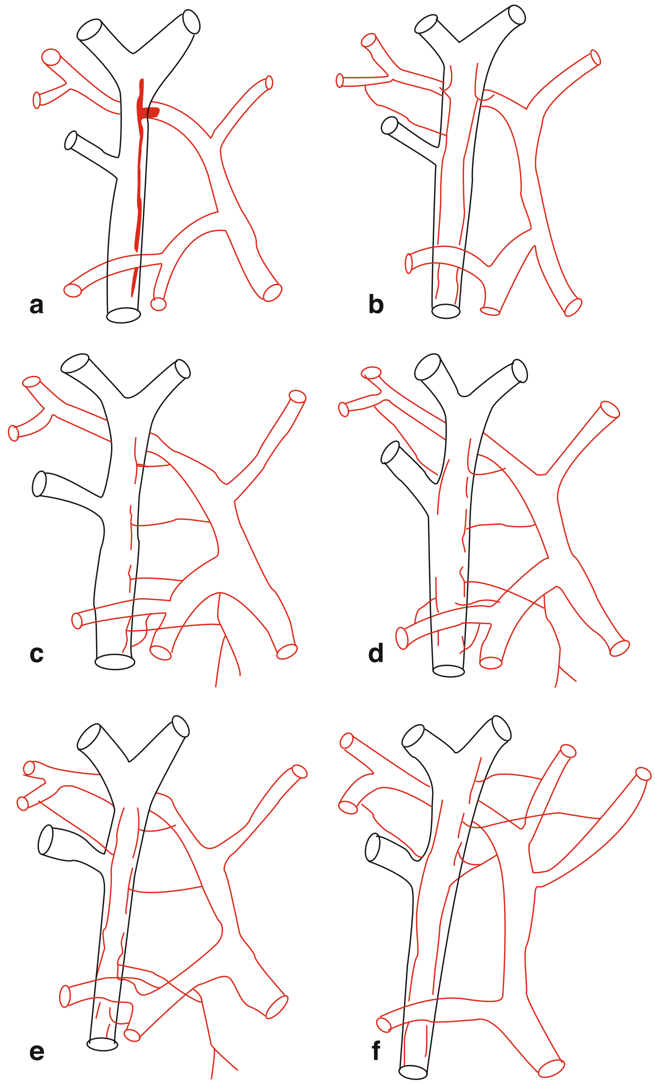


Fig. 1.18 The different types of vascularity of the common hepatic and common bile ducts according to Rath et al. [17] (**a**) axial type with left arch; (**b**) axial type with right and left arches; (**c**) single ladder at left border; (**d**) double ladder, right and up; (**e**) mixed left: left ladder and right arch; (**f**) mixed type, left ladder, left arch and right arch

ticoduodenal artery (87.9 %), or gastroduodenal artery (12.1 %) and runs upward to join the cystic artery (66.7 %) or the right hepatic artery (33.3 %).

Rath et al. [17] identified three types of vascular distribution to this portion of the extrahepatic biliary system (Fig. 1.18):

1. An axial distribution (76.7 %)
   This is represented by a single vascular arch in 18.3 % of individuals in the study by Rath et al. [17], and by two (right and left) arches in 58.3 % of individuals. When only one arch is present, it usually skirts the anterior left aspect of the bile duct. Only very occasionally is an arch formed by a right marginal artery. When two arches are present, they more or less follow the right and left borders of the biliary tract, corresponding to the arterials at 3 and 9 O'clock described by Northover and Terblanche [18]. Anastomosis between the two arches are observed on the arterial aspects of the common bile duct and common hepatic duct. Occasionally there are one or more posterior anastomotic arches in the posterior aspects of these ducts.

The study by Northover and Terblanche [18] also showed that the axial distribution is the most common.

2. Ladder distribution
   This was found to be present in 8.3 % of individuals in the study by Rath et al. [17]. In the majority of patients with a ladder distribution of arterial blood supply to the common ducts, the blood supply comes from both the right and the left sides. The arterial branches divide at the right and the left borders of the biliary tract into ascending and descending branches which anastomose among themselves. In the minority of individuals, the arteries arise exclusively from the left side of the bile ducts, dividing into the ascending and descending branches at the left border of the biliary tree, and anastomosing among themselves.
3. Mixed type
   This type of arterial supply was present in 15 % of individuals in the study by Rath et al. [17]. It can be a combination

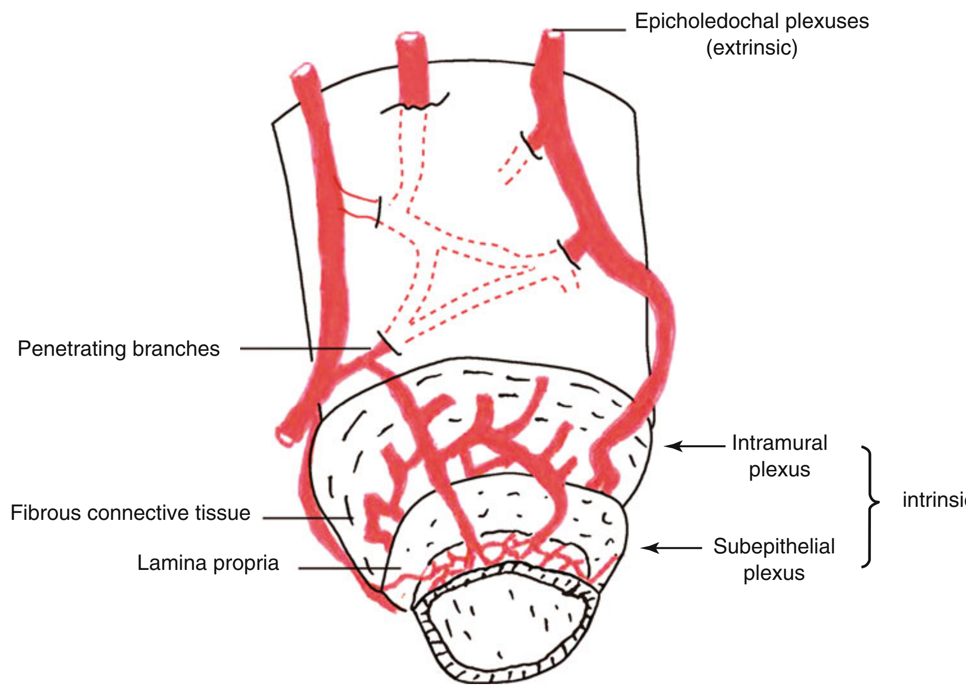


Fig. 1.19 The Anastomosing arterial plexuses of the main bile duct (According to Parkes et al. [19])

of a right marginal arch with a left ladder arrangement, or a right marginal arch with a left ladder arrangement for the common hepatic duct and a left arch for the common bile duct (Fig. 1.18a–f). Other mixed types are possible but are uncommon.

Fourth Portion: Pancreatic and Intraduodenal

The arterial network to this portion of the extrahepatic biliary system is comparatively abundant. It originates mainly from an arterial circle formed by the anastomoses of the retroportal artery, the posterior superior pancreaticoduodenal artery, and the posterior inferior pancreticoduodenal artery located on the posterior surface of the pancreatic portion of the bile duct and the head of the pancreas in the retroportal type I as described by Chen et al. [15] (Fig. 1.16), or from the branches of these arteries in the retroportal type II by Chen et al. [15].

1.2.5.6 Arterial Plexuses of the Main Bile Duct Wall

Parkes et al. [19] in 1963 showed that in addition to the epicholedochal plexus, collateral arterial circulation of the duct is enhanced by two intramural plexuses: an intramural plexus between the connective tissue sheath and the mucosa, and a subepithelial plexuse. The intramural, epicholedochal and subepithelial plexuses anastomose through penetrating branches (Fig. 1.19), thus adding to the anastomotic pathways in the event of compromise to the epicholedochal plexus.

1.2.5.7 Surgical Significance of Arrangement of Arterial Supply to the Major Bile Ducts

The arrangement of the arterial blood supply to the extrahepatic biliary system, especially to the common hepatic and common bile ducts, has considerable surgical significance.

Appleby [23] in 1959 made the following importance recommendations with respect to exposure of the main bile duct and choledochotomy:

1. For exposure of the main bile duct it should never be stripped;
2. It should be opened longitudinally through an area devoid of visible vessels, with its fascial envelop left intact;
3. When resutured, all vessels should be avoided; and
4. Ligate the cystic artery close to the gallbladder.

One point which is still unsettled is that of the advisable level for transection section of the main bile duct with a view to perform bilio-alimentary anastomosis after a Whipple's procedure or a liver transplantation. Both Northover and Terblanche [18] and Parke et al. [19] have recommended transecting the main bile duct closer to the hilum than the duodenum, because the predominant source of blood supply to the main duct is from below (mainly from the gastroduodenal or posterior superior pancreaticoduodenal arteries), while the vessels from above (mainly from the cystic artery and right heptic artery) are more delicate and smaller in diameter and are thus less likely to be able to sustain a long length of the remnant bile duct. This view now seems to be adopted by most hepatobiliary surgeons. However Rath et al. [17] basing on their study on the vascularization of the extraheptic bile duct recommended transection of the main bile duct around the junction of the inferior border of the cystic duct with the common duct in liver transplantation for both donor and recipient. They argued that this would allow simple resection of the two ends should the blood-supply prove unsatisfactory. In this way, end-to-end bilio-biliary anastomosis could be made without tension.

1.2.5.8 Venous Drainage of the Extrahaptic Biliary System: The Parabiliary Venous System

Couinaud [24] in 1989 extensively studied the network of small veins which surrounds the main bile duct and hepatic artery in the portal pedicle and he described it as the parabiliary venous system.

The plexus originates from the veins draining the gastric pylorus, duodenum and pancreas, ascends in the portal pedicle and drains into the segmental portal veins at the hilum of the liver (mainly those supplying liver segments 1, 4 and 5). This plexus is, therefore, a venous anastomosis between the right and the left hemilivers.

The veins draining the gallbladder vary considerably. Those from its upper surface lie in the areolar tissue between the gallbladder and liver and usually run directly into the liver through the gallbladder fossa and the cystic plate to join the hepatic veins. Those from other parts of the gallbladder join to form one or two cystic veins on the neck of the gallbladder, and these commonly enter the liver, either directly or after joining with the parabiliary venous system draining the hepatic ducts and the upper part of the bile duct. Only rarely does a single or double cystic vein drain directly into the right branch of the portal vein.

In patients with portal hypertension, the veins in the parabiliary system may become particularly large, giving rise to troublesome bleeding when the portal pedicle is being dissected. In the event of portal vein thrombosis, the large collaterals venous channel in the portal pedicle are hypertrophied veins of the parabiliary venous system.

1.2.5.9 Lymphatic Drainage of the Extrahepatic Biliary System

The lymphatic drainage of the extrahepatic biliary system was extensively studied and reported by Caplan [25] in 1982 (Fig. 1.20).

1.2.5.10 Lymphatic Drainage of the Supraduodenal and Retroduodenal Portions of the Extrahepatic Bile Ducts

The lymphatic drainage follows two pathways both of which ultimately drain into the thoracic duct:

1. Superior Pathway (or the left pathway by Nimura)

   A superior pathway follows the lymphatics and lymph nodes along the cystic duct (inconstant), the hepatic artery, the anterior and medial aspects of the portal vein and the coeliac axis.

   Using the lymph node station numbers used by the Japanese Gastric Cancer Association [26] published in 1998, the pathway of spread along the nodes is #12a → 8 → 9 → 16.

   The pathway is a more important pathway of spread of malignancy from the extrahepatic bile ducts than the inferior pathway.

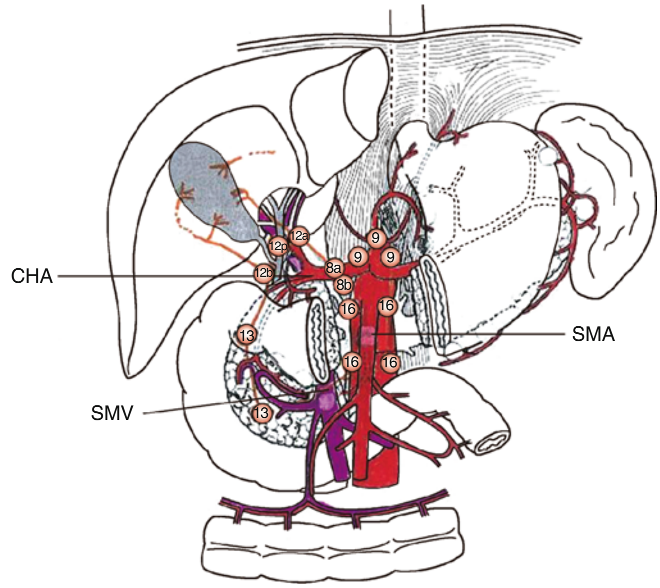


Fig. 1.20 Lymphatic drainage of the extrahepatic biliary system. *SMA* Superior mesenteric artery, *SMV* Superior mesenteric vein, *CHA* Common hepatic artery. *Numbers*: lymph node station numbers used by the Japanese Gastric Cancer Association [26]

2. An inferior pathway (or the right pathway by Nimura)

   The pathway of spread of lymphatics is from the lymph nodes along the cystic duct, the anterior and lateral aspects of the portal vein, the posterior aspect of the pancreas, between the aorta and the inferior vena cava, and the left aspect of the aorta under the left renal vein.

   In the Japanese system, the spread is #12b → 13a → 16.

1.2.5.11 Lymphatic Drainage from the Paraduodenal and Intraduodenal Portions of the Extrahepatic Bile Ducts

The lymphatic drainage from this portion of the bile duct is to the adjacent lymph nodes in the portal pedicle, and then via either the superior (left) or the inferior (right) pathway.

1.2.5.12 Lymphatic Drainage from the Gallbaldder

According to the study by Caplan [25], the lymphatic drainage is more complicated and there are four possible routes of lymphatic drainage from the gallbladder to reach the two pathways as described above:

1. Superior and external pedicle

   Present in 6 % of individuals, draining the fundus of the gallbladder through the hepatic parenchyma of liver segment 5, to join the inferior (or right pathway).
2. Superior and medial pedicle

   Present in 10 % of individuals. Draining the medial aspect of the gallbladder to the hilum after transversing the hepatic parenchyma of liver segment 4 to join the left pathway.

3. Inferior and external pedicle
   Present in 82 % of individuals. Draining the body of the gallbladder to the portal pedicle, finally joining the right pathway.
4. Inferior and medial aspect of pedicle
   This is constant. Drainage from the body of the gallbladder to the lymphatics along the anterior and medial aspects of the portal vein and the left pathway (Fig. 1.20).

1.2.5.13 Clinical Significance of Pattern of Lymphatic Drainage of the Extraheptic Biliary System

The significance is:

1. Lymphatic spread of tumours of the gallbladder and bile duct can be extensive, and it follows two main pathways, thereby making cure by radical surgery even with lymphatic clearance difficult;
2. Carcinoma of gallbladder can spread to the parenchyma of the liver by lymphatic spread making concomitant liver resection necessary for radical surgery.

1.2.5.14 Innervation of the Biliary Tract

A detailed discussion of the innervation of the biliary tract is beyond the scope of this chapter. Only a brief summary of the extrinsic innervation is presented.

The extrinsic nerve supply to the biliary tract is both autonomic (parasympathetic and sympathetic) and sensory. The anterior and posterior vagus nerves carry both parasympathetic motor fibres and sensory fibres. The sympathetic nerve supply is from both the coeliac ganglion and the superior mesenteric ganglion. The pain fibres to the target tissues are post-ganglionic fibres, explaining why sympathetectomy may be effective in the relief of pain.

The intrinsic nerve supply consists of ganglionatic plexuses within the wall of the gallbladder, bile ducts and sphincter of Oddi. Nerve fibres from the ganglia innervate the mucosa, blood vessels and muscle of the biliary tract. The nerve fibres from the extrinsic sources may innervate the target tissues directly, or they may provide neural inputs to the intrinsic ganglia. The arrangement is very complex and this complex neural supply is important in controlling motility of the gallbladder and sphincter of Oddi, blood flow either to the whole biliary tract or to any part thereof, or may even facilitate changes in mucosal transport of water and electrolyte (e.g., in the gallbladder) [1].

1.2.5.15 Hepatic Hilar Plate System

The fusion of Glisson's capsule with the connective tissue sheaths surrounding the biliary and vascular elements at the inferior aspect of the liver constitute to the hepatic hilar plate system. This plate system contains a larger number of lymphatics, nerves and a small vascular network. Although most workers consider the portal triad to be within the plate system, Couinaud states that the bile duct and hepatic artery are located within the plate system, but the portal vein is covered with a separate sheath of loose connective tissues. This is the reason why the plate containing the extrahepatic bile duct and hepatic artery can be separated easily from the portal vein [8, 24].

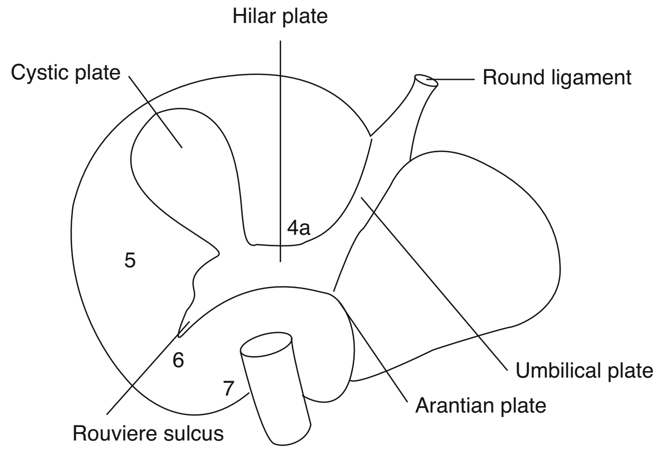


Fig. 1.21 Visceral surface of liver showing the hepatic hilar plate system. Please note that Rouviere sulcus separates the right anterior section (segments 5, 8) and posterior section (segments 6, 7)

The hepatic hilar plate system includes the hilar plate above the biliary confluence, the cystic plate at the gallbladder fossa, the umbilical plate situated above the umbilical portion of the left portal vein, and the Arantian plate covering the ligamentum venosum [27] (Fig. 1.21).

1.2.5.16 Clinical Significance of the Hepatic Hilar Plate System

The clinical significance is:

1. Hepp and Couinaud in 1956 described a technique where, by lifting the liver segment 4 upwards and incising the Glisson's capsule at its base, good exposure of the hepatic hilar structures can be obtained [28]. This technique is now referred to as lowering of the hilar plate. It can be carried out with safety since there is only exceptionally (in 1 % of cases) any vascular interposition between the hilar plate and the inferior aspect of the liver. The manoeuvre is of particular value in exposing the extrahepatic segment of the left hepatic duct since it has a long courses beneath segment 4. This technique is important for the identification of the left hepatic duct during bile duct repair following injury, or for a palliative side-to-side left duct to jejunum bypass in patients with unresectable hilar or right ductal carcinoma.
2. In treatment of hilar cholangiocarcinoma, it is important to resect the hilar duct confluence en bloc with the hilar plate (and in most cases, combined with liver resection including segment 1 of the liver) because tumour cells can easily invade into the adjacent plate tissues (and along the bile duct branches into segment 1 of the liver).

References

1. Padbury P, Azoulay D. Anatomy. Chapter 1. In: Toouli J, editor. Surgery of the biliary tract. New York: Churchill Livingstone; 1993. p. 3–19.
2. Strasberg SM. Liver terminology and anatomy. Chapter 2. In: Lau WY, editor. Hepatocellular carcinoma. New Jersey: World Scientific; 2008. p. 25–50.
3. Terminology Committee of the IHPBA. The Brisbane 2000 terminology of liver anatomy and resection. HPB. 2000;2:333–9.
4. Skandalakis JE, Shandalakis LE, Shandalakis PW, et al. Hepatic surgical anatomy. Surg Clin North Am. 2004;84:413–35.
5. Healey Jr JE, Schroy IC. Anatomy of the biliary ducts within the human liver: analysis of the prevailing pattern of branchings and the major variations of the biliary ducts. Arch Surg. 1953;66: 599–616.
6. Lau WY. Caudate lobe. Chapter 3. In: Lau WY, editor. Applied anatomy in liver resection and liver transplantation. Beijing: People's Medical Publishing House; 2010. p. 22–30.
7. Blumgart LH, Hann LE. Surgical and radiologic anatomy of the liver, biliary tract and pancreas. Chapter 1. In: Blumgart LH, editor. Surgery of the liver, biliary tract, and pancreas. Philadelphia: Saunders Elsevier; 2007. p. 3–29.
8. Couinaud C. Controlled hepatectomies and exposure of the intrahepatic bile ducts. Anatomical and technical study. Paris: C. Couinaud; 1981.
9. Kida H, Uchimura M, Okamoto K. Intrahepatic architecture of bile and portal vein (in Japanese). Tan To Sui (J Biliary Tract and Pancreas). 1987;8:1–7.
10. Ischiyama S, Yamada Y, Narishima Y, et al. Surgical anatomy of the hilar bile duct carcinoma (in Japanese). Tan To Sui (J Biliary Tract and Pancreas). 1999;20:811–29.
11. Kumon M. Portal vein and bile duct branches of the caudate lobe: analysis of liver casts and clinical cases (in Japanese). Kanzou (Acta Hepatol Jpn). 1985;55:1193–9.
12. Lau WY. Intrahepatic Glissonian triad. Chapter 6. In: Lau WY, editor. Applied anatomy in liver resection and liver transplantation. Beijing: People's Medical Publishing House; 2010. p. 45–59.
13. Michels NA. Newer anatomy of the liver and its variation in blood supply and collateral circulation. Am J Surg. 1966;112:337–46.
14. Syzuki H. Correlation and anomalies of the vascular structure in Glisson's area around the hepatic hilum, from the standpoint of hepatobilairy surgery (in Japanese). Nihon Geka Hokan. 1982;51:713–31.
15. Chen WJ, Ying DJ, Liu ZJ, et al. Analysis of the arterial supply of the extrahepatic bile ducts and its clinical significance. Clin Anat. 1999;12:245–9.
16. Shapiro AL, Robillard GL. The arterial blood supply of the common and hepatic bile ducts with reference to the problems of common duct injury and repair. Surgery. 1948;23:1–11.
17. Rath AM, Zhang J, Bourdelat D, et al. Arterial vascularization of the extrahepatic tract. Surg Radiol Anat. 1993;15:105–11.
18. Northover JM, Terblanche J. Bile duct blood supply. Its importance in human liver transplantation. Transplantation. 1978;26:67–9.
19. Parke WW, Michels NA, Ghosh GM. Blood supply of the common bile duct. Surg Gynecol Obstet. 1963;117:47–55.
20. Pforringer L. Die gerfarbe des ducts choledochus. Acta Anat. 1971;79:389–408.
21. Douglass TC, Cutter WW. Arterial blood supply of the common bile duct. Arch Surg. 1948;57:599–612.
22. Northover JMA, Terblanche J. A new look at the arterial supply of the bile duct in man and its surgical implications. Br J Surg. 1979;66:379–84.
23. Appleby CH. Indwelling common duct tubes. J Int Coll Surg. 1959; 31:631–43.
24. Couinaud C. Surgical anatomy of the liver revisited. Paris: C. Couinaud; 1989.
25. Caplan I. Drainage lymphatique intra at extra-hepatique de la vesicule biliarie. Bulletin Mein. Acad Med Belg. 1982;137:324–34.
26. Japanese Gastric Cancer Association. Japanese classification of gastric cancer—2nd English edition. Gastric Cancer. 1998;1: 10–24.
27. Lau WY. Hepatic Hilar plate system. Chapter 4. In: Lau WY, editor. Applied anatomy in liver resection and liver transplantation. Beijing: People's Medical Publishing House; 2010. p. 31–40.
28. Hepp J, Couinaud C. Approach to and use of the left hepatic duct in reparation of the common bile duct. Presse Med. 1959;64:947–8.