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Liver Anatomy

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Keywords

Liver; Anatomy; Surgery; Hepatic vasculature; Biliary tree

> *At present, liver resections are based upon the precise knowledge of the natural lines of division of the liver which define the anatomical surgery of the liver*.
>
> *Henri Bismuth*[1]

Although many of the advances in hepatic surgery have been linked to improvements in technology, there is no denying the impact of thorough knowledge of the internal anatomy of the liver on improved outcomes. This is largely due to the work of the French surgeon and anatomist, Claude Couinaud (1922–2008), who detailed his early work in *Le Foie: Études anatomiques et chirurgicales* (*The Liver: Anatomic and Surgical Studies*), in 1957, regarding segmental anatomy of the liver. Couinaud was able to closely examine the intrahepatic anatomy and demonstrated that hepatic functional anatomy is based on vascular and biliary relationships rather than external surface anatomy, improving the safety and feasibility of hepatic surgery today.[2]

GENERAL ANATOMY

The liver is the largest organ, accounting for approximately 2% to 3% of average body weight. The liver has 2 lobes typically described in two ways, by morphologic anatomy and by functional anatomy (as illustrated in Fig. 1).[1] Located in the right upper quadrant of the abdominal cavity beneath the right hemidiaphragm, it is protected by the rib cage and maintains its position through peritoneal reflections, referred to as ligamentous attachments (Fig. 2). Although not true ligaments, these attachments are avascular and are in continuity with the Glisson capsule or the equivalent of the visceral peritoneum of the liver.

Ligamentous Attachments

The falciform ligament is an attachment arising at or near the umbilicus and continues onto the anterior aspect of the liver in continuity with the umbilical fissure. The falciform ligament courses cranially along the anterior surface of the liver, blending into the hepatic

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peritoneal covering coursing posterosuperiorly to become the anterior portion of the left and right coronary ligaments. Of surgical importance, at the base of the falciform ligament along the liver, the hepatic veins drain into the inferior vena cava (IVC).[3] A common misconception associated with the falciform ligament is that it divides the liver into left and right lobes. Based on morphologic anatomy, this may be true; however, this does not hold true from a functional standpoint (discussed later).

Within the lower edge of the falciform ligament is the ligamentum teres (round ligament), a remnant of the obliterated umbilical vein (ductus venosus) that travels from the umbilicus into the umbilical fissure where it is in continuity with the ligamentum venosum as it joins the left branch of the portal vein. The ligamentum venosum lies within a fissure on the inferior surface of the liver between the caudate lobe posteriorly and the left lobe anteriorly, where it is also invested by the peritoneal folds of the lesser omentum (gastrohepatic ligament). During fetal life, the ductus venosus is responsible for shunting a majority of blood flow of the umbilical vein directly into the IVC, transporting oxygenated blood from the placenta to the fetus. After birth, the umbilical vein closes as the physiologic neonatal circulation begins. In the presence of portal hypertension, the umbilical vein may recanalize to allow portasystemic collateralization through the abdominal wall, known as caput medusae.

At the cranial aspect of the liver is a convex area along the diaphragmatic surface that is devoid of any ligamentous attachments or peritoneum. This bare area of the liver is attached to the diaphragm by flimsy fibroareolar tissue. The coronary ligament lies anterior and posterior to the bare area of the liver comprised of peritoneal reflections of the diaphragm. These areas converge to the left and right of the liver to form the left and right triangular ligaments, respectively. The right coronary and right triangular ligaments course posterior and caudally toward the right kidney, attaching the liver to the retroperitoneum. All attachments help fixate the liver within the right upper quadrant of the abdomen. During hepatic surgery, mobilization of the liver requires division of these avascular attachments. In upper abdominal surgery, the liver has close associations with many structures and organs.

The IVC maintains an intimate relationship to the caudate lobe and right hepatic lobe by IVC ligaments.[4] These caval ligaments are bridges of broad membranous tissue that are extensions of the Glisson capsule from the caudate and right hepatic lobe. Of surgical importance, these ligaments are not simple connective tissue but rather contain components of hepatic parenchyma, including the portal triads and hepatocytes. Hence, during liver mobilization, these ligaments must be controlled in a surgical manner to avoid unnecessary bleeding or bile leakage during hepatic surgery.

Perihepatic Organs/Anatomy

The gastrointestinal tract has several associations with the liver (illustrated in Fig. 3). The stomach is related to the left hepatic lobe by way of the gastrohepatic ligament or superior aspect of the lesser omentum, which is an attachment of connective tissue between the lesser curvature of the stomach and the left hepatic lobe at the ligamentum venosum. Important neural and vascular structures may run within the gastrohepatic ligament, including the hepatic division of the vagus nerve and, when present, an aberrant left hepatic artery as it

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courses from its left gastric artery origin. The hepatic flexure of the colon where the ascending colon transitions to the transverse colon is in close proximity or sometimes in direct contact with the right hepatic lobe. Additionally, the duodenum and portal structures are in direct association with the liver through the hepatoduodenal ligament (inferior aspect of the lesser omentum) and porta hepatis.

Anatomic understanding of the portal anatomy is essential to hepatic resection and associated vascular and biliary reconstructions. Within the porta hepatis is the common bile duct, hepatic artery, and portal vein that course in a lateral, medial, and posterior configuration, respectively. The foramen of Winslow (epiploic foramen) has important relevance to the porta hepatis and hepato-pancreatico-biliary surgery. The foramen of Winslow, originally described by the Danish anatomist Jacob Winslow in 1732, is a communication or connection between the abdominal cavity and the lesser sac. During hepatic resection, need for complete control of the hepatic vascular inflow may be accomplished by a Pringle maneuver.[5,6] This maneuver, developed by an Australian surgeon, James Hogarth Pringle, while in Glasgow, Scotland, during the management of hepatic trauma, involves occlusion of the hepatic artery and portal vein inflow through control of the porta hepatis. This may be done by placement of a large clamp on the porta hepatis or more atraumatically with the use of a tourniquet passed through the foramen of Winslow and pars flaccida (transparent portion of lesser omentum overlying caudate lobe) encircling the porta hepatis.

The gallbladder resides in the gallbladder fossa at the posterior interface of segments IV and V. It establishes continuity with the common bile duct via the cystic duct. Additionally, the cystic artery most commonly arises as a branch off the right hepatic artery. Understanding of portal vasculature and biliary anatomy is crucial given its wide anatomic variability to avoid inadvertent injury during any hepatic, pancreatic, biliary, or foregut surgery.

Additionally, the right adrenal gland lies within the retroperitoneum under the right hepatic lobe. The right adrenal vein drains directly into the IVC; hence, care should be taken during hepatic mobilization so as to avoid avulsion of the vein or inadvertent dissection into the adrenal gland as this can result in significant hemorrhage.

LYMPHATIC AND NEURAL NETWORK

The liver possesses a superficial and deep lymphatic network through which lymph produced in the liver drains.[7] The deep network is responsible for greater lymphatic drainage toward lateral phrenic nodes via the hepatic veins and toward the hilum through portal vein branches. The superficial network is located within the Glisson capsule with an anterior and posterior surface. The anterior surface primarily drains to phrenic lymph nodes via the bare area of the liver to join the mediastinal and internal mammary lymphatic networks. The posterior surface network drains to hilar lymph nodes, including the cystic duct, common bile duct, hepatic artery, and peripancreatic as well as pericardial and celiac lymph nodes. The lymphatic drainage patterns have surgical implications with regard to lymphadenectomy undertaken for cancer of the gallbladder, liver, and pancreas.

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The neural innervation and controls of liver function are complex and not well understood. However, like the remainder of the body, the liver does have parasympathetic and sympathetic neural innervation. Nerve fibers are derived from the celiac plexus, lower thoracic ganglia, right phrenic nerve, and the vagi. The vagus nerves divide into an anterior (left) and posterior (right) branch as they course from the thorax into the abdomen. The anterior vagus divides into a cephalic and a hepatic division of which the latter courses through the lesser omentum (gastrohepatic ligament) to innervate the liver and is responsible for the parasympathetic innervation. Sympathetic innervation arises predominantly from the celiac plexus as well as the thoracic splanchnic nerves.

HEPATIC VASCULATURE

The liver is a very vascular organ and at rest receives up to 25% of total cardiac output, more than any other organ. Its dual blood supply is uniquely divided between the hepatic artery, which contributes 25% to 30% of the blood supply, and the portal vein, which is responsible for the remaining 70% to 75%. The arterial and portal blood ultimately mixes within the hepatic sinusoids before draining into the systemic circulation via the hepatic venous system.[8]

Arterial Vasculature

Although the arterial vasculature of the liver is variable, the most common configurations are discussed in this article. As illustrated in Fig. 4, in the most common arterial configuration, the common hepatic artery originates from the celiac axis along with the left gastric and splenic arteries. The common hepatic artery proceeds laterally and branches into the proper hepatic artery and the gastroduodenal artery. The gastroduodenal artery proceeds caudally to supply the pylorus and proximal duodenum and has several indirect branches to the pancreas. The proper hepatic artery courses within the medial aspect of the hepatoduodenal ligament and porta hepatis toward the liver to divide into left and right hepatic arteries to feed the respective hepatic lobes. Additionally, the right gastric artery has a variable origin arising from the hepatic artery as it courses laterally. The cystic artery to the gallbladder commonly arises from the right hepatic artery. In Fig. 5, common arterial variants are illustrated. The most common variants include aberrant (replaced) hepatic arteries in which the dominant hepatic arteries do not arise from the proper hepatic artery but rather from an alternate origin. An aberrant left hepatic artery typically arises from the left gastric artery and courses through the lesser omentum to supply the left liver and is seen in approximately 15% of patients. In spite of its alternate origin, the aberrant left hepatic artery still enters the liver through the base of the umbilical fissure in a medial orientation, similar to that of a native left hepatic artery. An aberrant right hepatic artery, seen in approximately 20% of patients, most commonly arises from the superior mesenteric artery. Unlike its left hepatic artery counterpart, the aberrant right hepatic artery often courses posterolateral in the hepatoduodenal ligament to enter the right liver.

Venous Vasculature

The portal vein provides the bulk of the nutritive blood supply to the liver. As illustrated in Fig. 6, the portal vein forms from the confluence of the superior mesenteric vein and splenic

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vein behind the neck of the pancreas. Additional venous branches that drain into the portal vein include the coronary (left gastric) vein, cystic vein, and tributaries of the right gastric and pancreaticoduodenal veins. The portal vein is valveless and is a low-pressure system with pressures typically 3 to 5 mm Hg. The coronary (left gastric) vein is of particular importance clinically as it becomes a major portasystemic shunt in the face of portal hypertension and feeds the gastroesophageal variceal complex. The main portal vein courses cranially toward the liver as the most posterior structure within the hepatoduodenal ligament to divide into the left and right portal veins near the liver hilum. A small branch to the right side of the caudate is commonly encountered just before or after the main portal vein branching.

The left portal vein has two portions, an initial transverse portion and then an umbilical portion as it approaches the umbilical fissure. The left portal vein tends to have a longer extrahepatic course and commonly gives off a branch to the caudate lobe, but the caudate portal vein inflow is variable and may arise from the main or right portal vein also. The transverse portion of the left portal vein approaches the umbilical fissure and takes an abrupt turn toward it to form the umbilical portion as it enters the liver. Within the liver, the umbilical portion of the left portal vein commonly first gives off a branch to segment II before then dividing into branches to segment III and to segment IVa/IVb. The right portal vein often emerges closer to or within the hepatic parenchyma of the right liver itself. It quickly divides into anterior and posterior branches to segments V and VIII and segments VI and VII, respectively (see Fig. 1; Figs. 7 and 8).

The venous drainage of the liver is through the intrahepatic veins that ultimately coalesce into three hepatic veins that drain into the IVC superiorly. The left and middle hepatic veins may drain directly into the IVC but more commonly form a short common trunk before draining into the IVC. The right hepatic vein is typically larger, with a short extrahepatic course and drains directly into the IVC. Additional drainage occurs directly into the IVC via short retrohepatic veins and, on occasion, an inferior right accessory hepatic vein. The hepatic veins within the parenchyma are unique in that, unlike the portal venous system, they lack the fibrous, protective, encasing the Glisson capsule.[9] Ultrasonography facilitates intraoperative mapping of the internal anatomy of the liver. As seen in Fig. 9, by ultrasound, the portal venous anatomy can readily be identified by the echogenic, hyperechoic Glisson capsule surrounding the portal veins, whereas the hepatic veins lack this.

The IVC maintains an important and intimate association with the liver as it courses in a cranial-caudal direction to the right of the aorta. As the IVC travels cranially, it courses posterior to the duodenum, pancreas, porta hepatis, caudate lobe, and posterior surface of the liver as it approaches the bare area where it receives the hepatic venous outflow from the hepatic veins. Multiple small retrohepatic veins enter the IVC along its course, mostly from the right hepatic lobe. Hence, in mobilizing the liver or during major hepatic resections, it is imperative to maintain awareness of the IVC and its vascular tributaries at all times.

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BILIARY TREE

The intrahepatic biliary tree is comprised of multiple ducts that are responsible for the formation and transport of bile from the liver to the duodenum and typically follows the portal venous system. The right hepatic duct forms from an anterior sectoral duct from segments V and VIII and a posterior sectoral duct from segments VI and VII. The anterior sectoral duct courses in an anterior, vertical manner whereas the posterior duct proceeds in a lateral, horizontal manner. The right duct typically has a short extrahepatic course with some branching variability. Surgeons should be mindful of this variable anatomy when operating at the hilum of the liver. The left hepatic duct drains the left liver and has a less variable course as it parallels the left portal vein with a longer extrahepatic course. The left and right hepatic ducts join near the hilar plate to form the common hepatic duct. As the common hepatic duct courses caudally, it is joined by the cystic duct to form the common bile duct. The common bile duct proceeds within the lateral aspect of the hepatoduodenal ligament toward the head of the pancreas to drain into the duodenum through the ampulla of Vater.

Biliary drainage of the caudate lobe is variable with drainage seen through left and right hepatic ducts in approximately 70% to 80% of cases.[8] In 15%, caudate drainage is seen through the left hepatic duct alone and the remaining 5% to 10% of cases drains through the right hepatic duct system alone. Hence, as discussed previously, surgical intervention involving the caudate lobe requires attention to biliary anatomy as well as vascular anatomy.

SUMMARY

Understanding of hepatic anatomy has evolved greatly over the past 50 years. Greater knowledge of vascular anatomy along with advancement of technologies for intraoperative mapping and parenchymal transection have made liver surgery safer and more efficacious. Recognition of the presence of a dual blood supply and dependence of hepatic tumors on arterial bloody supply have made feasible various interventional techniques allowing directed chemotherapy and radioactive particles via the hepatic artery with simultaneous embolization to minimize tumoral blood supply as treatment options for various tumor types. The complexities and nuances of liver anatomy require continual respect and lifelong learning by liver surgeons.

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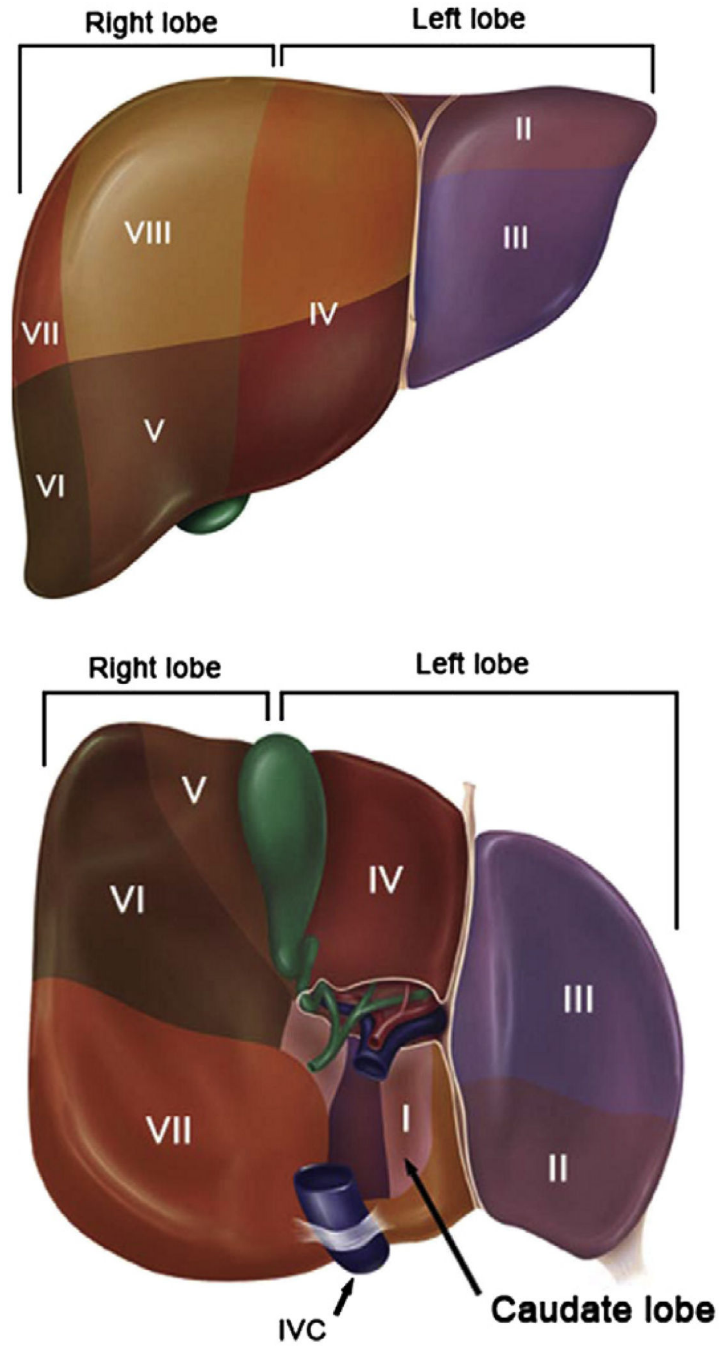

Fig. 1.

Anterior and posterior surfaces of liver illustrating functional division of the liver into left and right hepatic lobes with Couinaud's segmental classification based on functional anatomy. *From* Brunicardi FC, Andersen DK, Billiar TR, et al. Schwartz's principles of surgery. 9th edition. New York: McGraw-Hill Publishing; 2010. p. 31–3; with permission.

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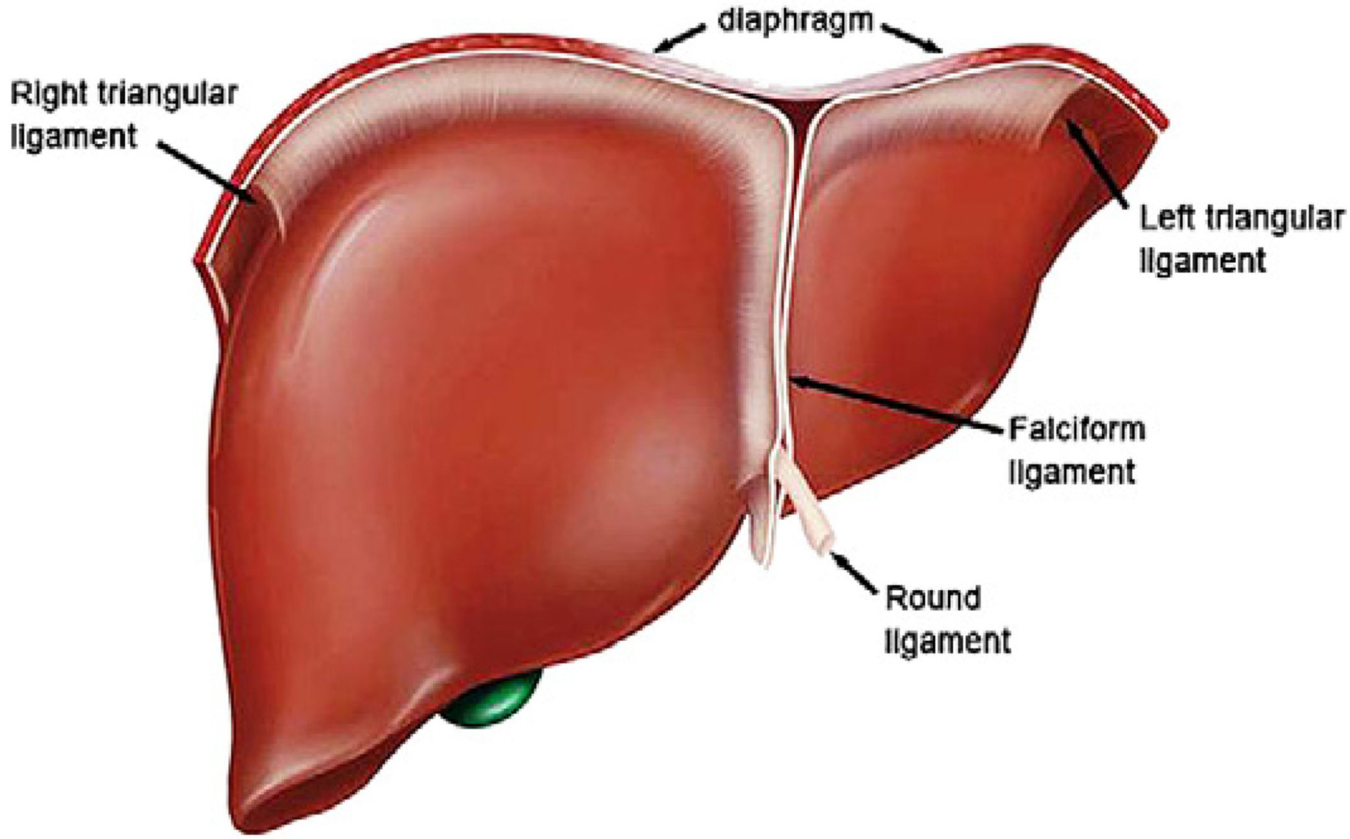

Fig. 2.

Ligamentous attachments of the liver. *From* Brunicardi FC, Andersen DK, Billiar TR, et al. Schwartz's principles of surgery. 9th edition. New York: McGraw-Hill Publishing; 2010. p. 31–2; with permission.

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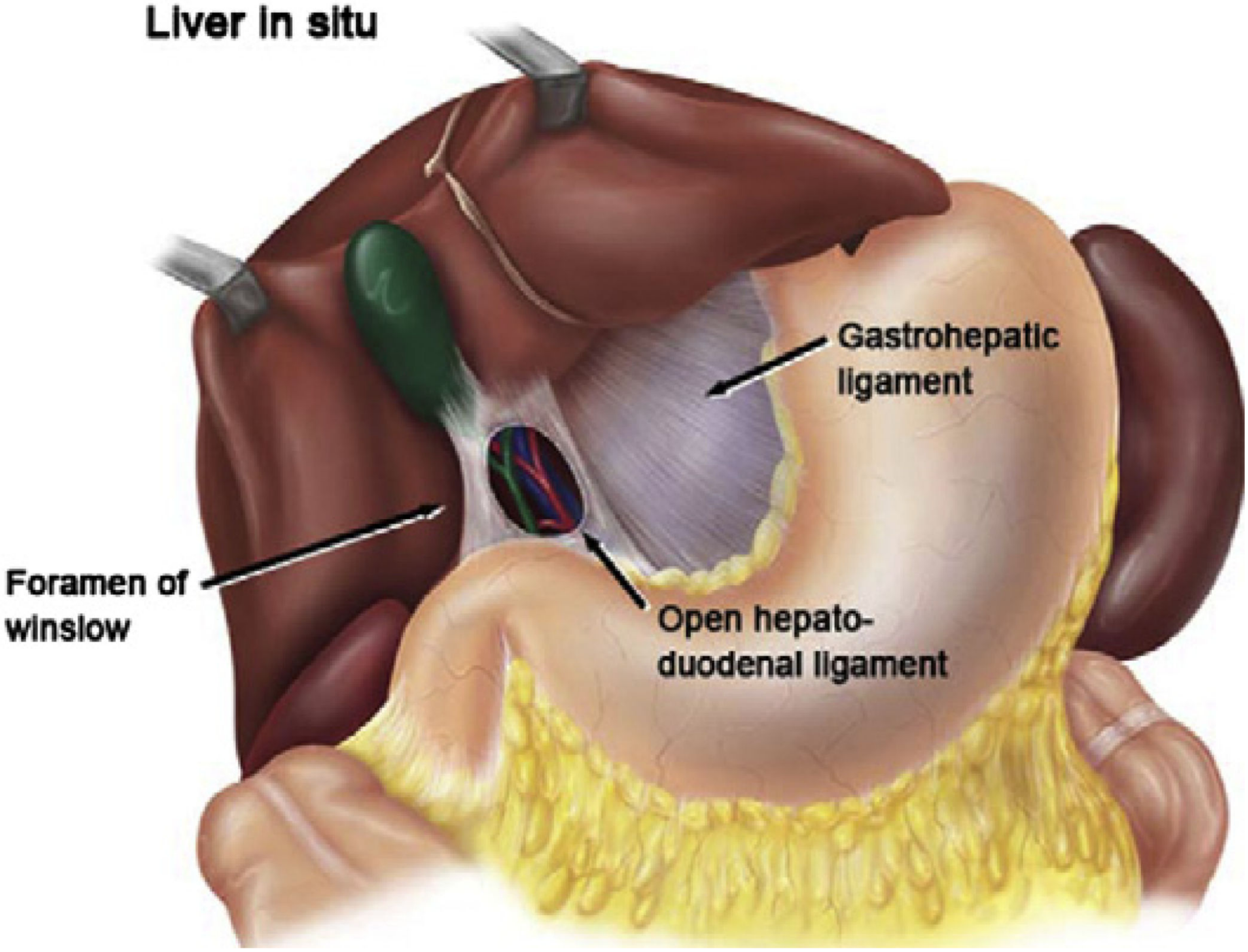

Fig. 3.

Association of stomach, porta hepatis, and hepatic flexure to the Liver. *From* Brunicardi FC, Andersen DK, Billiar TR, et al. Schwartz's principles of surgery. 9th edition. New York: McGraw-Hill Publishing; 2010. p. 31–3; with permission.

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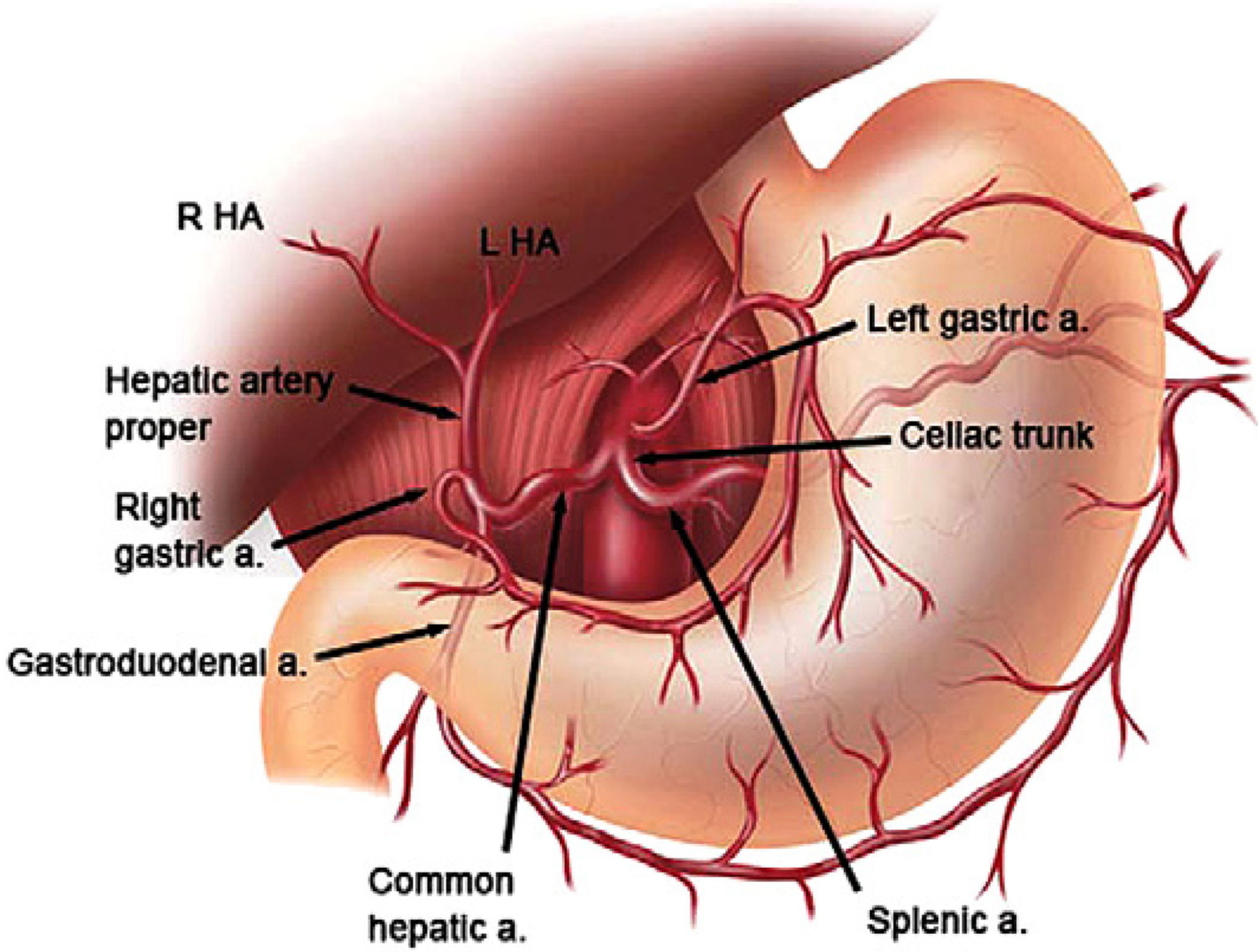

Fig. 4.

Common hepatic arterial configuration. HA, hepatic artery. *From* Brunicardi FC, Andersen DK, Billiar TR, et al. Schwartz's principles of surgery. 9th edition. New York: McGraw-Hill Publishing; 2010. p. 31–4; with permission.

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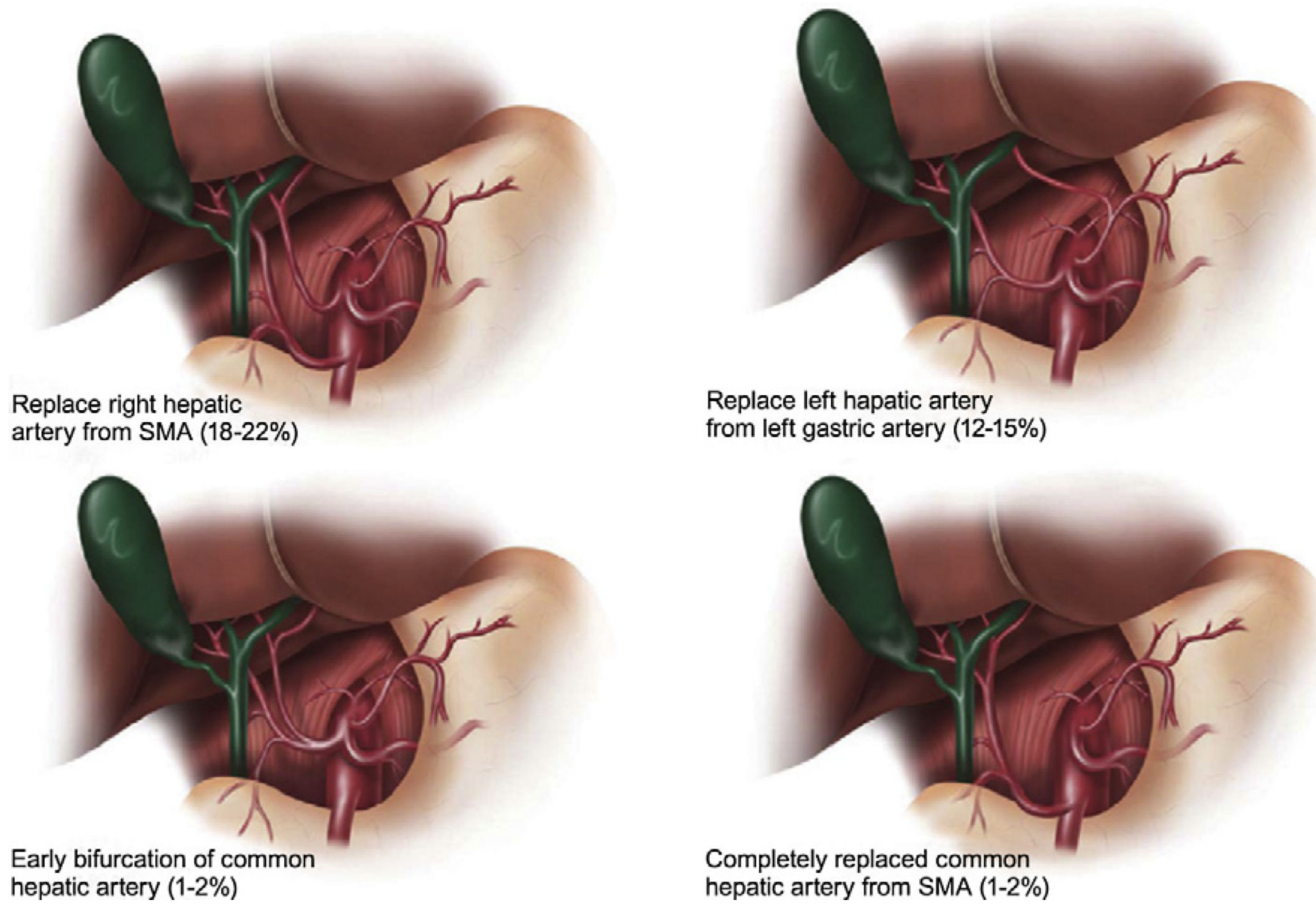

Fig. 5.

Common variations of hepatic vasculature. *From* Brunicardi FC, Andersen DK, Billiar TR, et al. Schwartz's principles of surgery. 9th edition. New York: McGraw-Hill Publishing. p. 31–4; 2010.

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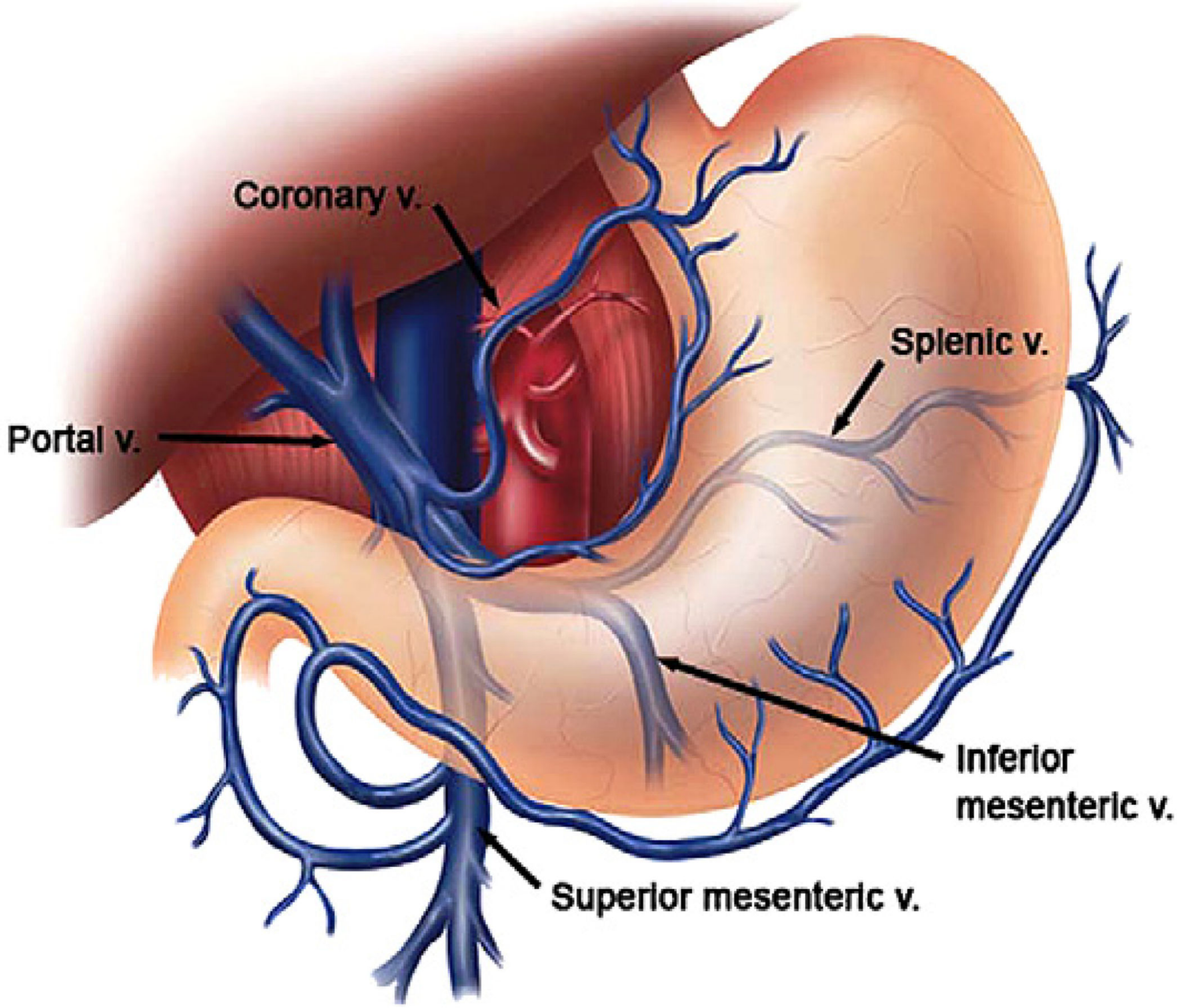

Fig. 6.
Portal vein and the hepatic venous vasculature inflow. *From* Brunicardi FC, Andersen DK, Billiar TR, et al. Schwartz's principles of surgery. 9th edition; McGraw-Hill Publishing. p. 31–5; 2010.

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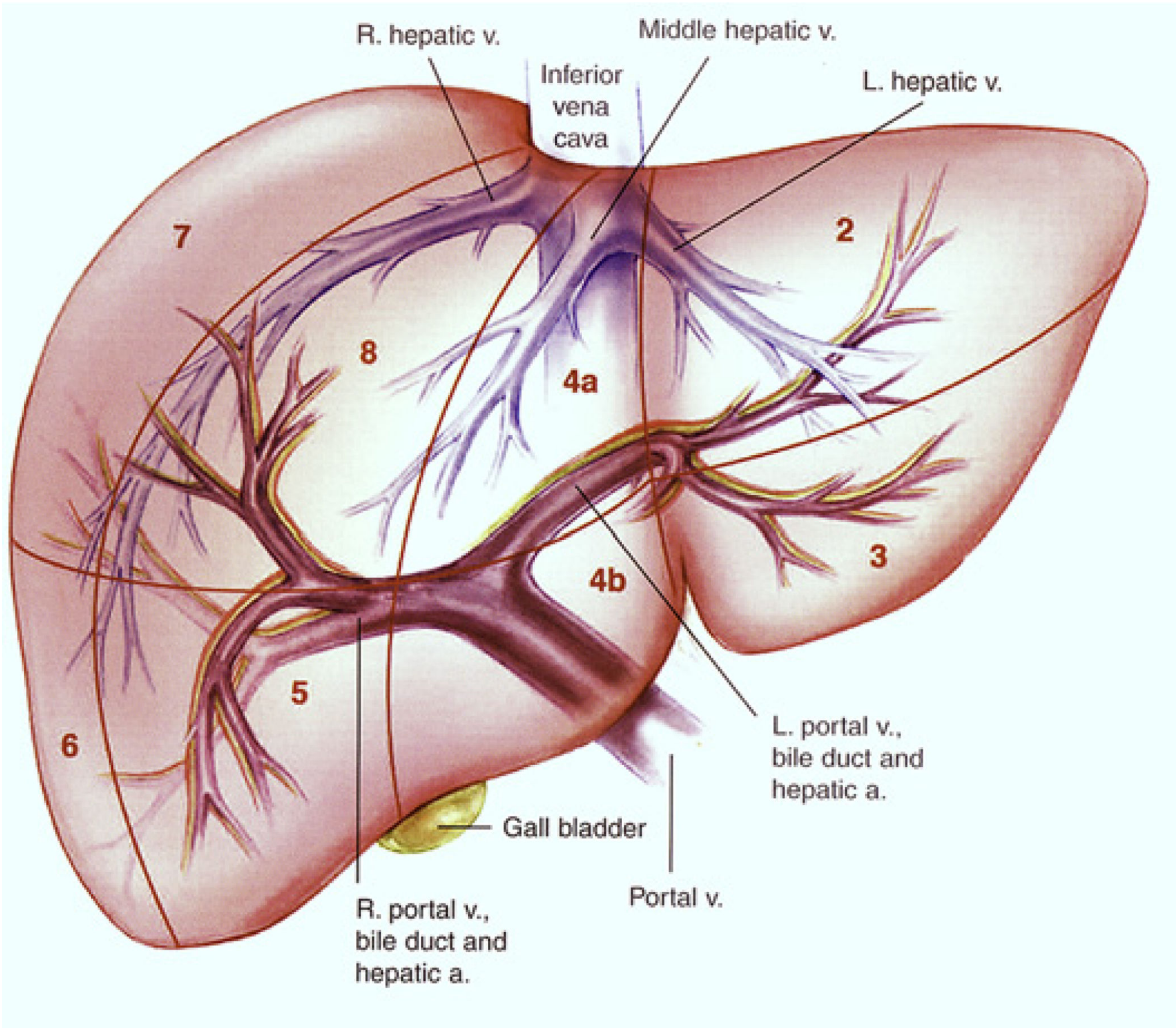

Fig. 7.

Intrahepatic vascular and biliary anatomy, anterior view. *Adapted from* Cameron JL, Sandone C. Atlas of gastrointestinal surgery, vol. 1. 2nd edition. Hamilton (ON): BC Decker; 2007. p. 121 [Fig. 1]; the People's Medical Publishing House—USA, Shelton, CT; with permission.

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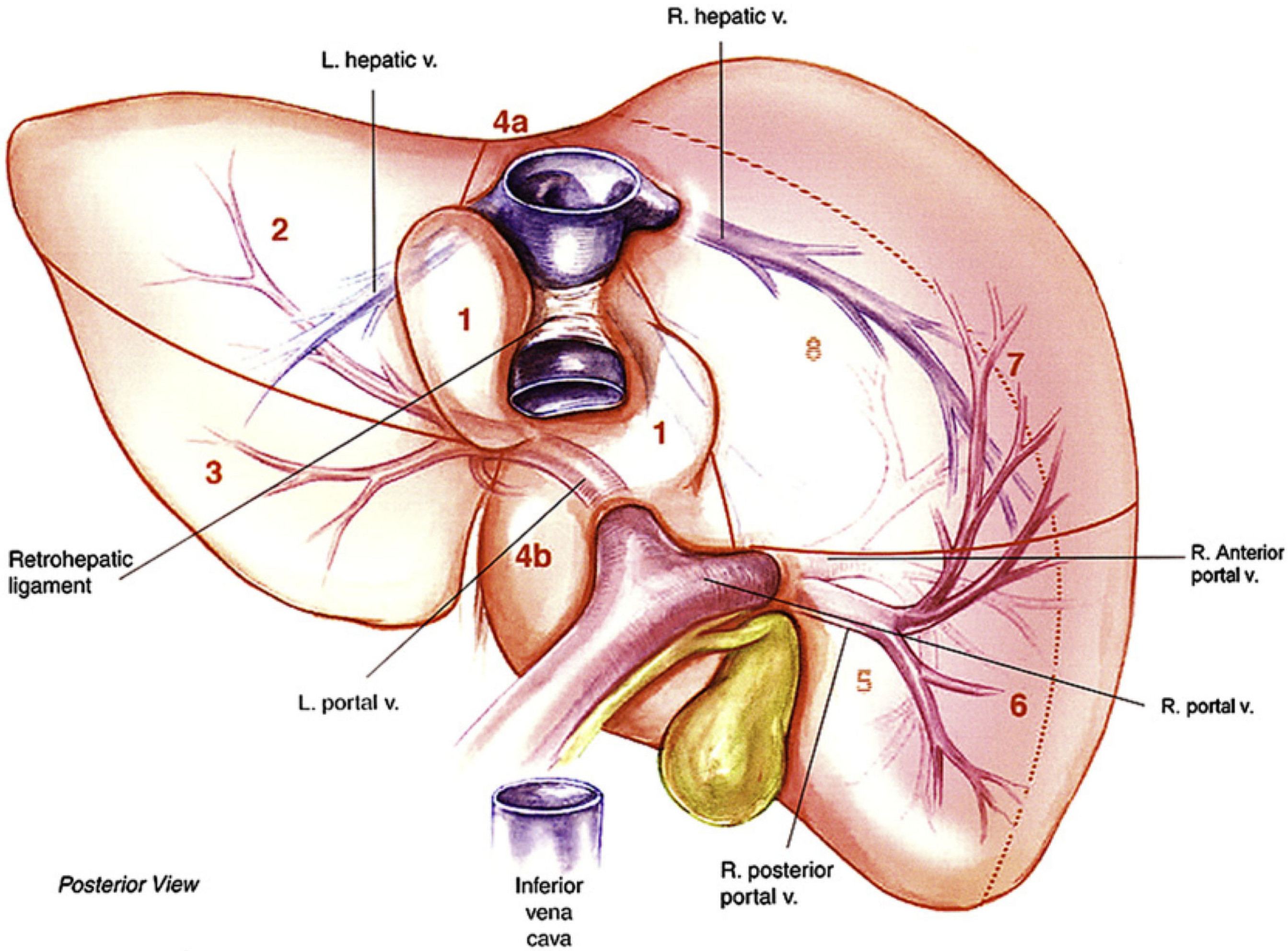

Fig. 8.

Intrahepatic vascular and biliary anatomy. posterior view. *Adapted from* Cameron JL, Sandone C. Atlas of gastrointestinal surgery, vol. 1. 2nd edition. Hamilton (ON): BC Decker; 2007. p. 124 [Fig. 2]; the People's Medical Publishing House—USA, Shelton, CT; with permission.

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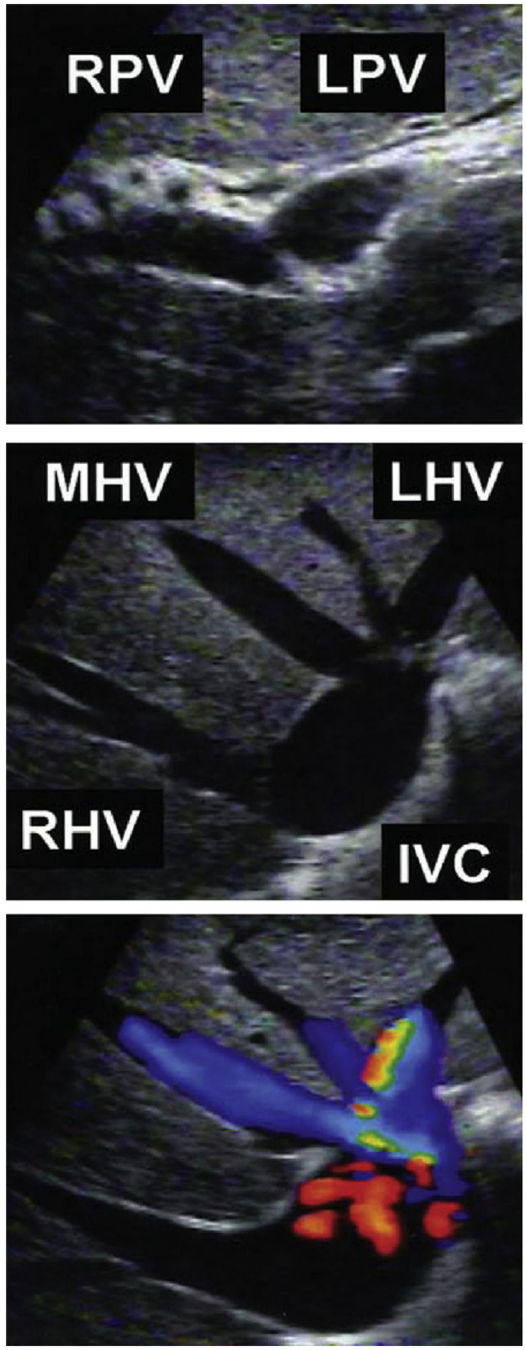

Fig. 9.

Ultrasound appearance of hepatic venous vasculature. The top panel demonstrates the left and right portal vein branches (LPV, left portal vein; RPV, right portal vein) with the hyperechoic fibrous sheath of the Glisson capsule. The middle panel demonstrates the confluence of the right, middle, and left hepatic veins (LHV, left hepatic vein; RHV, right hepatic vein; MHV; middle hepatic vein) (note accessory left hepatic vein) with the IVC. The lower panel demonstrates vascular flow within the hepatic vein confluence and IVC.

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