CHAPTER 1

The cross-sectional anatomy of the liver and normal variations

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Knowledge of cross-sectional anatomy of the liver is essential for the determination of localization of disease processes and for their management. To have a good knowledge and sense of the cross-sectional anatomy of the liver on computerized tomography (CT) and magnetic resonance imaging (MRI) studies, the segmental anatomy of the hepatic parenchyma and the anatomy of hepatic fissures, hepatic vessels, and bile ducts should be understood.

Liver anatomy can be described using two different approaches, including morphological anatomy and functional anatomy (1).

Morphological anatomy of the liver describes the liver anatomy depending on external appearance of the liver (1). Four lobes of the liver including the right, left, caudate and quadrate can be identified on the basis of the fissures of the liver surface (1). Morphological anatomy is not sufficient for the needs of modern radiology, hepatology, and hepatobiliary surgery.

Functional anatomy of the liver describes the functional segments of the liver on the basis of the anatomy of hepatic vessels and bile ducts (1). Functional anatomy is necessary to meet the needs of modern radiology, hepatology, and hepatobiliary surgery. Functional anatomy of the liver has been described by a number of different nomenclature systems for the determination of anatomic segments of the liver. A single, universally accepted classification system for the functional segmental anatomy of the liver does not exist. The Goldsmith and Woodburne system (1957), the Couinaud system (1957) and the Bismuth system (1982) are the most commonly used nomenclaturel systems (1).

Functional anatomy

The segments of the liver

The Bismuth system, which is a modified version of the Couinaud system, is the most commonly used anatomic nomenclature system, particularly in the United States. This hepatic segmental nomenclature system meets the needs of modern surgical techniques (Table 1.1) (1 – 5) and allows hepatobiliary surgeons, hepatologists, and radiologists to use a common nomenclature that meets their needs and enables them to understand each other.

The three vertical planes (scissurae) hosting the hepatic veins, and a transverse plane passing through the right and left portal vein branches are used to describe the segments of the liver (1,5).

The three vertical scissurae hosting the hepatic veins divide the liver into four sectors and a transverse plane passing through the right and left portal vein branches divides these sectors into the eight segments, which are numbered clockwise on the frontal view. These segments can be described in a straightforward approach by combining the definitions of two systems including the Bismuth, and Goldsmith and Woodburne systems (Table 1.1). These liver segments, including the caudate lobe, can be described on the basis of this approach as follows: caudate lobe (I), left lateral superior (II), left lateral inferior (III), left medial superior (IVa), left medial inferior (IVb), right anterior inferior (V), right posterior inferior (VI), right posterior superior (VII), and right anterior superior (VIII) (Figures 1.1 and 1.2).

In the Bismuth system, each segment has an independent vascular supply, including arterial, portal, and venous supplies, as well as independent lymphatic and biliary drainage (1 – 5).

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Table 1.1 Description of the liver segments according to the three most commonly used nomenclature systems.

Part	Nomenclature system					
	N. Goldsmith and R. Woodburne (1957)		C. Couinaud (1957)		H. Bismuth (1982)	
	Segment	**Subsegment**	**Sector**	**Segment**	**Sector**	**Segment**
Dorsal	Caudate L.		Caudate L.	I	Caudate L.	I
Left	Lateral	Superior	Lateral	II	Posterior	II
		Inferior	Paramedian	III	Anterior	III
Left	Medial	Superior		IV		IVa
		Inferior				IVb
Right	Anterior	Inferior	Paramedian	V	Anteromedial	V
		Superior		VIII		VIII
Right	Posterior	Inferior	Lateral	VI	Posterolateral	VI
		Superior		VII		VII

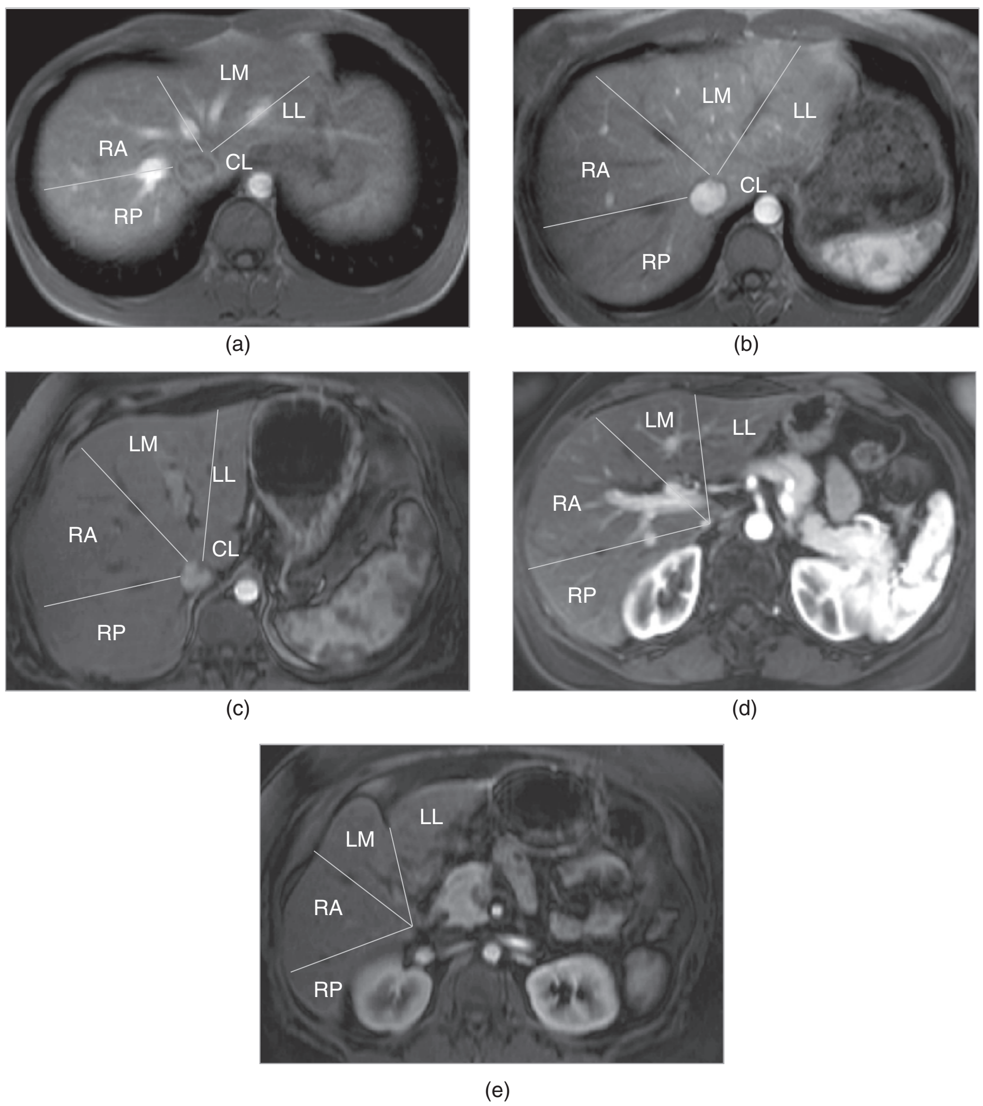

Figure 1.1 *Segments of the Liver*. T1-weighted axial hepatic venous (a) and hepatic arterial dominant (b–e) phase 3D-GE images acquired at different levels demonstrate the segments of liver, which are determined based on the distribution of diagonal planes (lines) hosting hepatic veins according to Goldsmith and Woodburne classification. RP, Right lobe posterior segment; RA, Right lobe anterior segment; LM, Left lobe medial segment; LL, Left lobe lateral segment; CL, Caudate lobe.

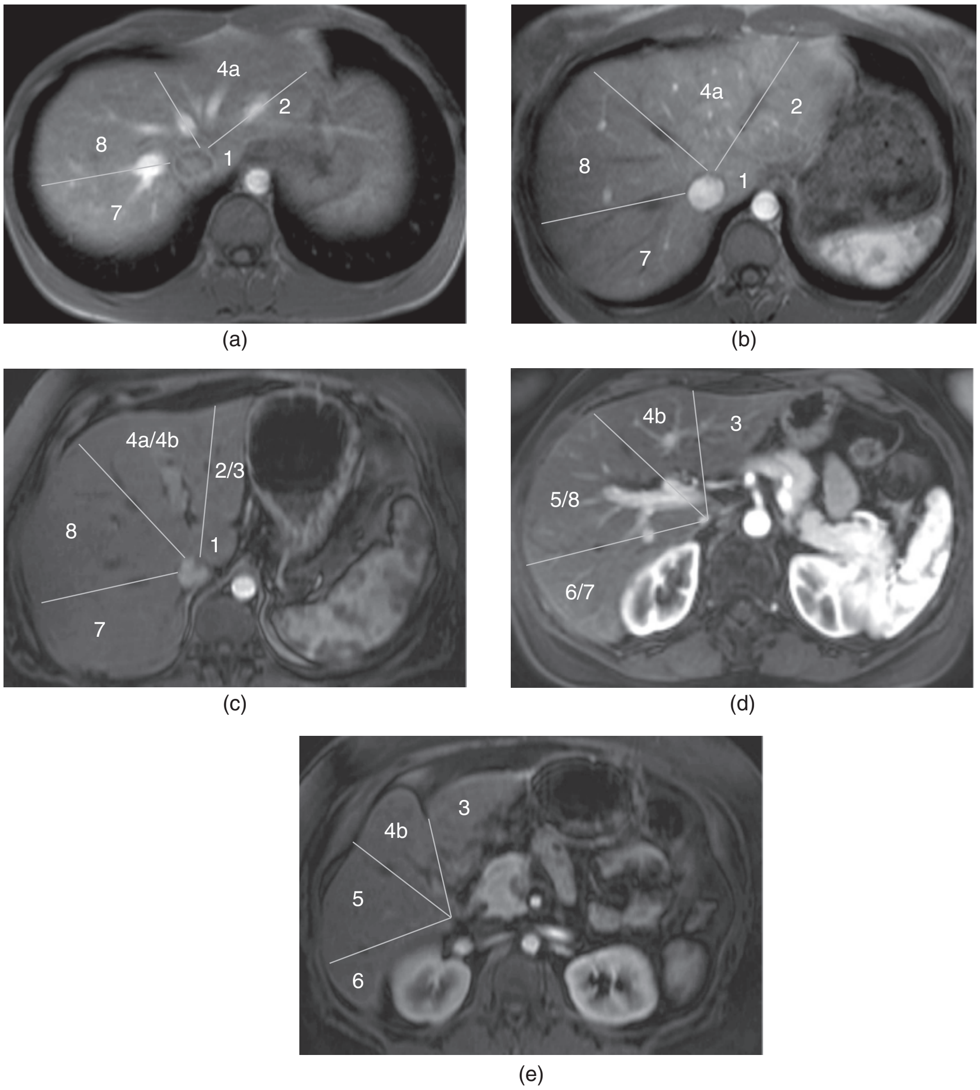

Figure 1.2 *Segments of the Liver*. T1-weighted axial hepatic venous (a) and hepatic arterial dominant (b–e) phase 3D-GE images acquired at different levels demonstrate the segments of liver, which are determined based on the distribution of diagonal planes hosting hepatic veins (lines) and transverse planes hosting portal veins according to Bismuth classification. 1: Caudate lobe. 2: Left Lateral inferior segment. 3: Left lateral superior segment. 4a: Left medial superior segment. 4b: Left medial inferior segment. 5: Right anterior inferior segment. 6: Right posterior inferior segment. 7: Right posterior superior segment. 8: Right anterior superior segment.

The caudate lobe has been described as a separate sector in the Bismuth system (1,5). The caudate lob or segment I is located posteriorly, and positioned between the fissure for ligamentum venosum, the inferior vena cava (IVC), and porta hepatis (Figure 1.2) (1,5). It is anatomically different from other segments as it may often have direct connections to the IVC through hepatic veins, which are different from the main hepatic veins (1,5). The caudate lobe may also be supplied by both branches of the right and left hepatic arteries, and both branches of right and left portal veins (1,5). Because of its different blood supply, the caudate lobe may be spared and/or may be hypertrophied to compensate for the loss of normal liver parenchyma in some liver disorders such as the Budd–Chiari syndrome or cirrhosis.

The corresponding branches of the hepatic arteries, portal veins, and tributaries of the bile ducts are intra-segmental and serve the corresponding segments of the liver by traveling together, while the hepatic veins run independently and are located inter-segmental (1,5). The hepatic arteries, hepatic veins, portal veins, and bile ducts demonstrate frequent variations which may affect surgical procedures in liver transplantations and liver resections.

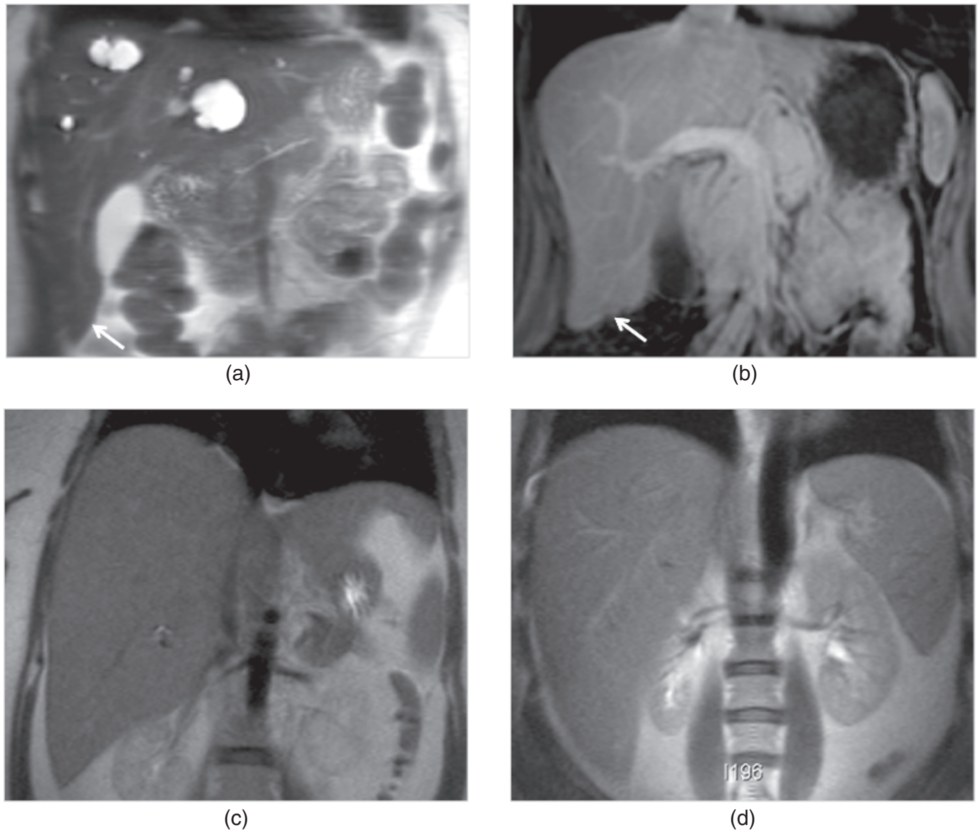

Figure 1.3 *Riedel Lobe*. Coronal T2-weighted single shot echo train spin echo (a) and T1-weighted post-gadolinium fat-suppressed hepatic venous phase (b) images acquired at 3.0 T demonstrate the Riedel lobe as a downward tongue-like vertical elongation of the right lobe with tapered inferior margin with narrow angles (arrows; a, b) in two different patients. Note the cysts in the liver in the first patient (a). Coronal T2-weighted single shot echo train spin echo images acquired at 1.5 T (c, d) demonstrate enlarged liver, with blunt and obtuse angles except the inferior tip of the right lobe, in two different patients with acute hepatitis (c) and fatty liver (d).

Normal variations of the liver segments

One of the most common normal variations of the segments of the liver is Riedel's lobe, which is characterized by the vertical elongation of the right lobe and it appears as a downward tongue-like projection of segment V and VI (Figure 1.3). It is more frequent in women. The Riedel's lobe has frequently a tapered inferior margin with narrow angles on all imaging planes, best appreciated on the coronal plane; however, hepatomegaly often results in a rounded inferior contour with blunt and obtuse angles (Figure 1.3).

Another common normal variation of the liver is the horizontal elongation of the lateral segment of the liver which wraps around the anterior aspect of the upper abdomen and extends laterally to the spleen (Figure 1.4). Focal lesions located in the horizontally elongated left lateral segment, particularly when they are exophytic, may be overlooked or misinterpreted as lesions arising from the adjacent organs such as the stomach or spleen.

Another common variation is the hypoplasia or aplasia of segments of the liver (Figure 1.5). It is more common in the segments VII – VIII – IV. When these segments are hypoplastic, the colonic segments are frequently inter-posed between the normal segments of the liver.

Another common variation is the interposition of the colon between the morphologically normal liver and the chest wall. Rarely, the colon, particularly hepatic flexura, may be interposed between the liver and right hemidiaphragm. The interposition of the colon between the hypoplastic / aplastic liver segments, between the chest wall and the normal liver or between the diaphragm and the liver may require critical technical modifications for the performance of the interventional procedures such as percutaneous biopsies, percutaneous biliary drainage, or transjugular intrahepatic portosystemic shunt creation.

Another variation of the liver segments is the presence of contour undulation resulting from the diaphragmatic insertions along the lateral aspect of the liver. These contour undulations tend to be multiple and closely related to overlying ribs and usually appear as wedge shaped capsular margins (Figure 1.6). They may occasionally appear as longitudinal striations of decreased signal due to the presence of diaphragmatic muscular tissue on T1- and T2-weighted sequences. They may also occasionally appear as rounded pseudolesions along the

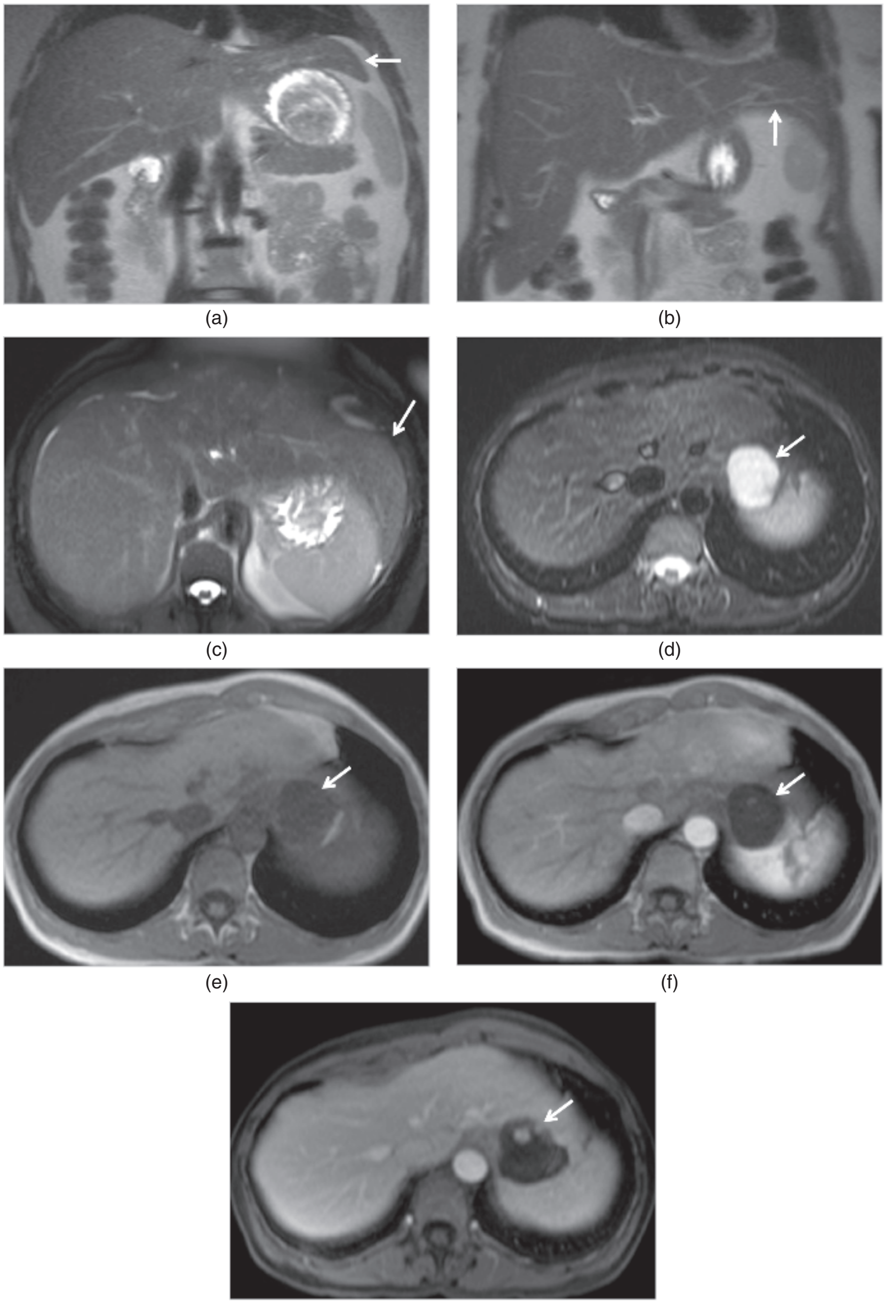

Figure 1.4 *Horizontal Elongation of the Lateral Segment of the Liver*. Coronal (a, b) and transverse fat-suppressed (c) T2-weighted single shot echo train spin echo images show elongated left lateral segment of the liver (arrows, a – c) which wraps around the anterior aspect of the upper abdomen and spleen in three different patients. Transverse T2-weighted fat-suppressed echo train spin echo (d), T1-weighted in-phase SGE (e), T1-weighted postgadolinium hepatic arterial dominant phase SGE (f) and hepatic venous phase fat-suppressed 3D-GE (g) images acquired at 1.5 T show an exophytic hemangioma (arrows, d – g) taking origin from the elongated left lateral segment. The hemangioma, which is adjacent to the spleen, demonstrates markedly high signal on T2-weighted image (d) and peripheral nodular enhancement on post-gadolinium images (f, g). Coronal T2-weighted single shot echo train spin echo (h), transverse T1-weighted pre-contrast SGE (i), T1-weighted post-gadolinium fatsuppressed hepatic arterial dominant phase (j) and hepatic venous phase (k) 3D-GE images acquired at 1.5 T show an exophytic focal nodular hyperplasia (FNH) (arrows, j, k) located in the left lateral segment adjacent to the spleen. The FNH is isointense to the liver on precontrast images (h, i), and demonstrates higher enhancement on the hepatic arterial dominant phase (j) and becomes isointense on the hepatic venous phase (k); compared to the liver parencyhma. Transverse T2-weighted fat-suppressed single shot echo train spin echo (l), T1-weighted pre-contrast SGE (m), post-gadolinium fat-suppressed hepatic arterial dominant phase (n) and hepatic venous phase (o) 3D-GE images demonstrate an exophytic hepatocellular carcinoma (HCC) (arrows, l, m) located in the left lateral segment of the liver. Heterogenous signal consistent with hemorrhage is detected within the tumor on pre-contrast images (l, m). The tumor showed heterogeneous enhancement on the hepatic arterial dominant phase (n) and washout with capsular enhancement on the hepatic venous phase (o).

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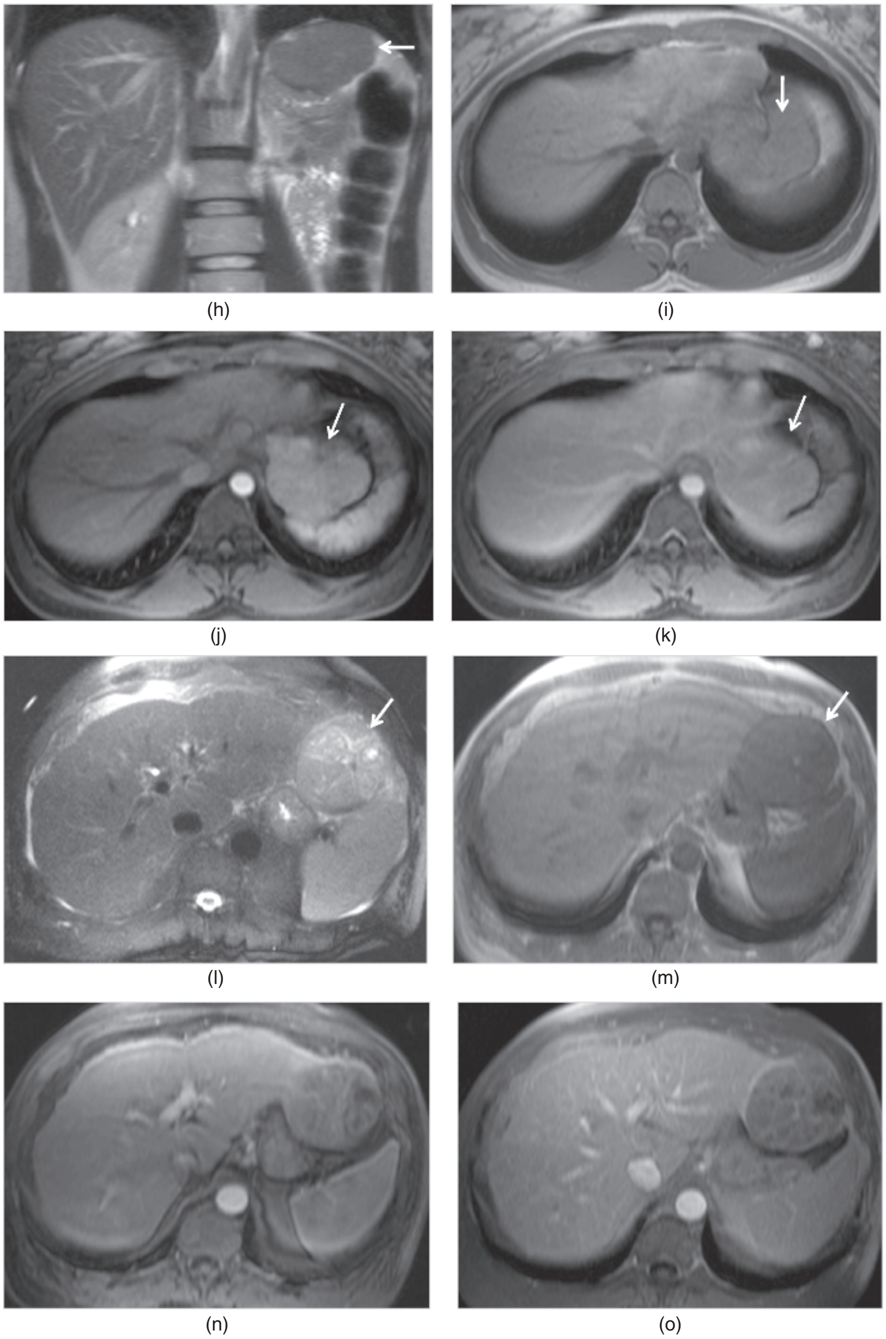


Figure 1.4 (*Continued*)

liver edge (Figure 1.6). These pseudolesions form due to the prominent diaphragmatic insertions and contain perihepatic fat tissue, which shows high signal on both T1- and T2-weighted sequences.

The hepatic vessels and bile ducts

The hepatic arteries

The celiac axis has three branches typically, including the common hepatic artery, splenic artery, and left gastric artery (3,6). The common hepatic artery has three branches typically, including the proper hepatic artery, right gastric artery, and gastroduodenal artery (Figure 1.7) (3,6). The proper hepatic artery is the artery feeding the liver. This classical hepatic arterial anatomy is seen in 60% of the population and the proper hepatic artery classically divides into right and left hepatic arteries feeding the right and left lobes of the liver, respectively (Figure 1.7) (3,6). However, the right and left hepatic arteries demonstrate significant amount of variations (3,6).

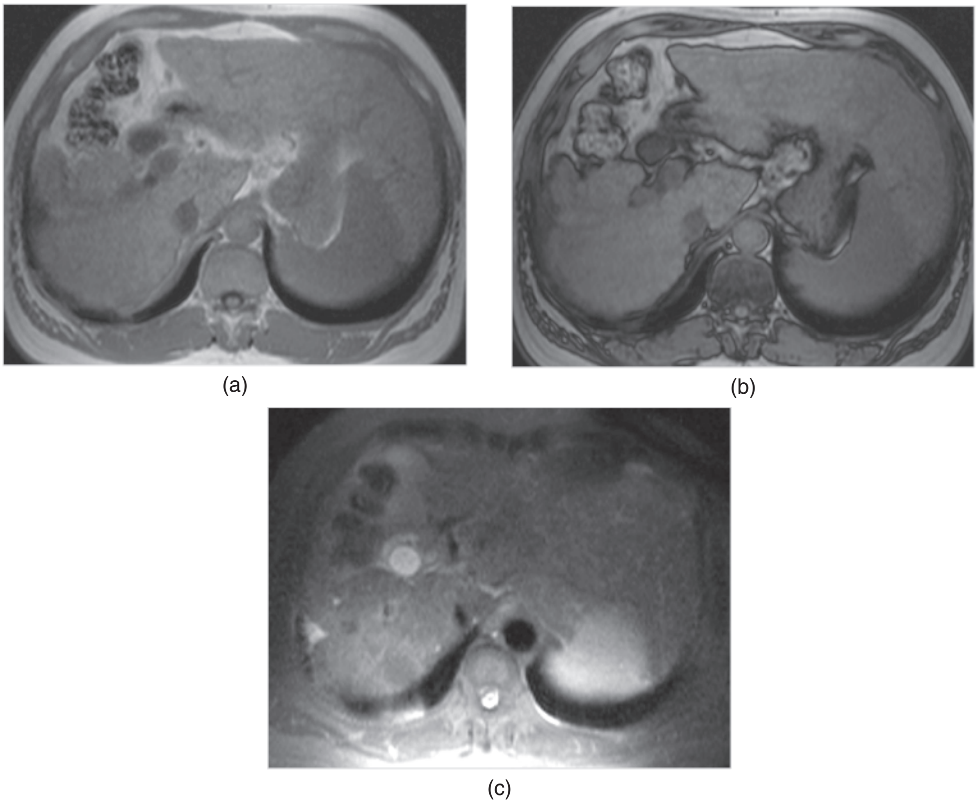


Figure 1.5 *Hypoplasia or Aplasia of the Segments of the Liver*. Segments 8 and 4 are hypoplastic, and the hepatic flexura is interposed between the liver segments. Note that the liver is cirrhotic, and the left lateral segment of the liver is elongated and enlarged.

The right hepatic artery arises from the proper hepatic artery in 55–60% of the population. The right hepatic artery may arise from the common hepatic artery, superior mesenteric artery, celiac artery, gastroduodenal artery, or right gastric artery in 9–11%. The left hepatic artery arises from the proper hepatic artery in 55–60% of the population, but may arise from the common hepatic artery, left gastric artery, the celiac artery, or splenic artery in 4–10% of the population. Both right and left hepatic arteries may arise from the arteries other than the proper hepatic artery in 0.5–1%. The entire hepatic artery proper arises from the superior mesenteric artery in 2–4.5% of the population and from the left gastric artery in 0.5%. The accessory left or right hepatic arteries or both may also be present in 13–16% of the population. The accessory left or right hepatic arteries may arise from the common hepatic artery, left or right hepatic arteries, gastroduodenal artery, superior mesenteric artery, splenic artery, celiac artery, or left or right gastric artery. The hepatic arteries may arise from the arteries other than the proper hepatic artery in the presence of additional accessory hepatic arteries in 2–3% of the population. The middle hepatic artery which is an extrahepatic branch of the proper hepatic artery may also exist in 40% of the population (Figure 1.7). The cystic artery arises from the right hepatic artery in 75% of the population, from the middle hepatic artery in 13%, from the gastroduodenal artery in 7%, and from the left hepatic artery in 4.5% (3,6).

The portal veins

The main portal vein is classically formed by the confluence of the superior mesenteric vein and splenic vein behind the neck of the pancreas (Figure 1.8) (2,5). It drains the blood from the gastrointestinal tract and spleen (2). It also receives blood from the inferior mesenteric, gastric, and cystic veins. The main portal vein and the right and left portal veins are in the hilar fissure (Figure 1.8). The portal bifurcation may be extrahepatic (48% of cases), intrahepatic (26%), or located at the entrance of the liver (26%) (2). The right portal vein has two sectoral portal branches including the anterior and posterior branches which supply segments V, VIII and VI, and VII, respectively (Figure 1.8) (2). The left portal vein consists of two parts, including the horizontal (extrahepatic) and vertical (intrahepatic) parts (Figure 1.8) (2). The vertical part supplies segments IV, III, and II (2). One segmental branch usually supplies segments II, VI, and VII and more rarely segment III (2). Segments IV, V, and VIII are generally supplied by more than one segmental branch (2).

Anatomic variants of the portal vein are uncommon and seen in only 10–20% of the population (2,3). Normal classic branching pattern, which is characterized by the bifurcation

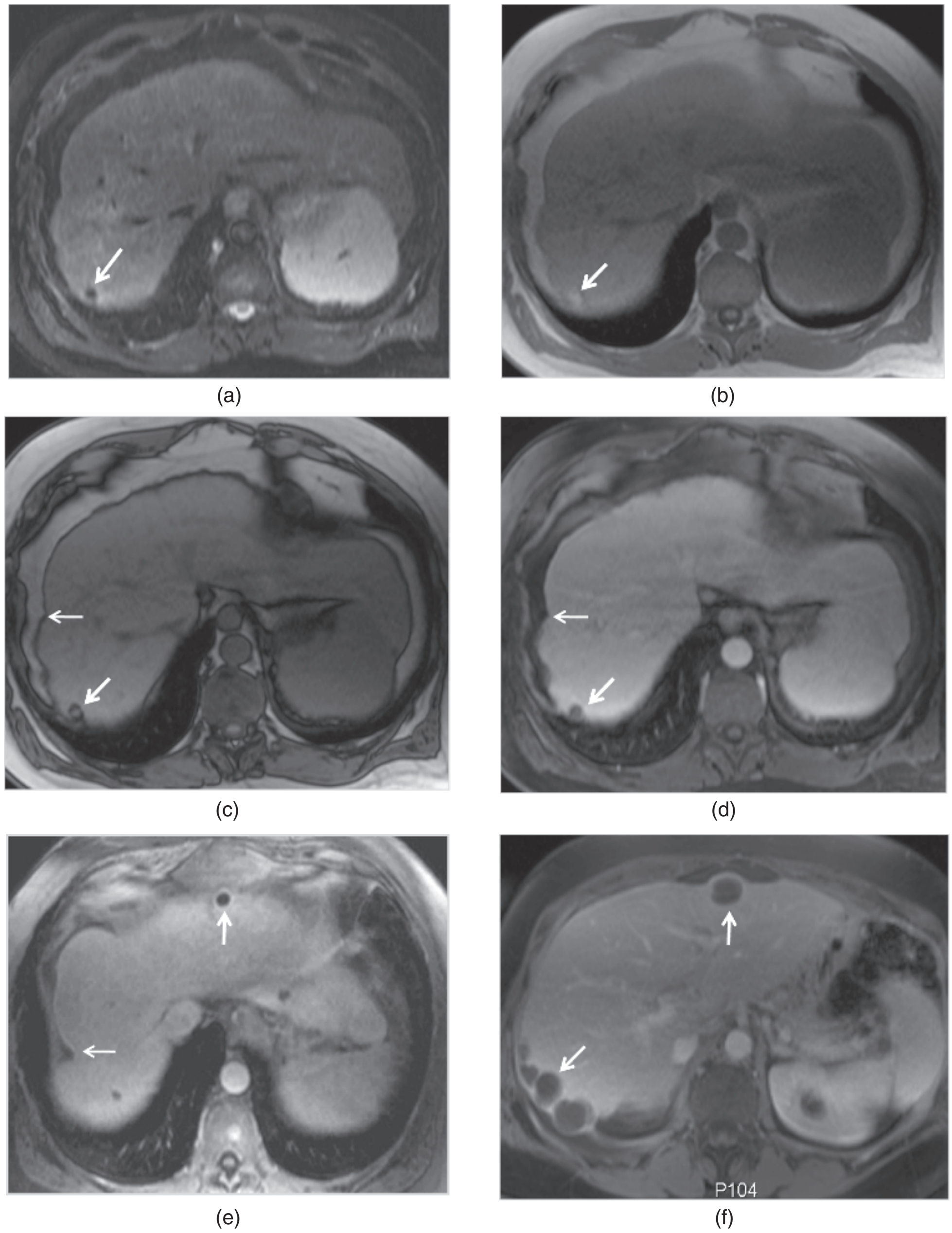


Figure 1.6 *Diaphragmatic Insertions on the Liver Surface*. The liver surface shows contour undulations (thin arrows, c – e) due to diaphragmatic insertions. Note that a round pseudolesion (thick arrows, a – d), which forms due to a prominent diaphragmatic insertion, shows fat signal and no enhancement. These pseudolesions should not be confused with capsular and subcapsular lesions such as metastases. Cystic metastases (thick arrows, e, f) in another patient show peripheral wall enhancement in addition to their contour bulging and high fluid content (not shown).

of the main portal vein into right and left portal veins, is seen in 78.5% (2,3,5). Trifurcation of the main portal vein into right anterior portal vein, right posterior portal vein and left portal vein is seen in 11% of the population (Figure 1.8) (2,3,5). The right anterior segment branch may arise from the left portal vein in 4% of the population (2,3,5). The left portal vein may arise from the right anterior segment branch. The right posterior branch may arise from the main portal vein as the first and separate branch, while the right anterior branch forms a bifurcation with the left portal vein in 5 – 10% of the population (2,3,5). Quadrification of the portal vein consisting of the branches for segment VII and VI, the right anterior sector branch, and the left portal vein may also be present in a few (2,3,5). Branches for subsegments or segments may directly arise from the portal bifurcation very rarely (2). Another very rare variation is the absence of portal vein bifurcation, and in this case, the solitary portal vein passes through the entire liver (2).

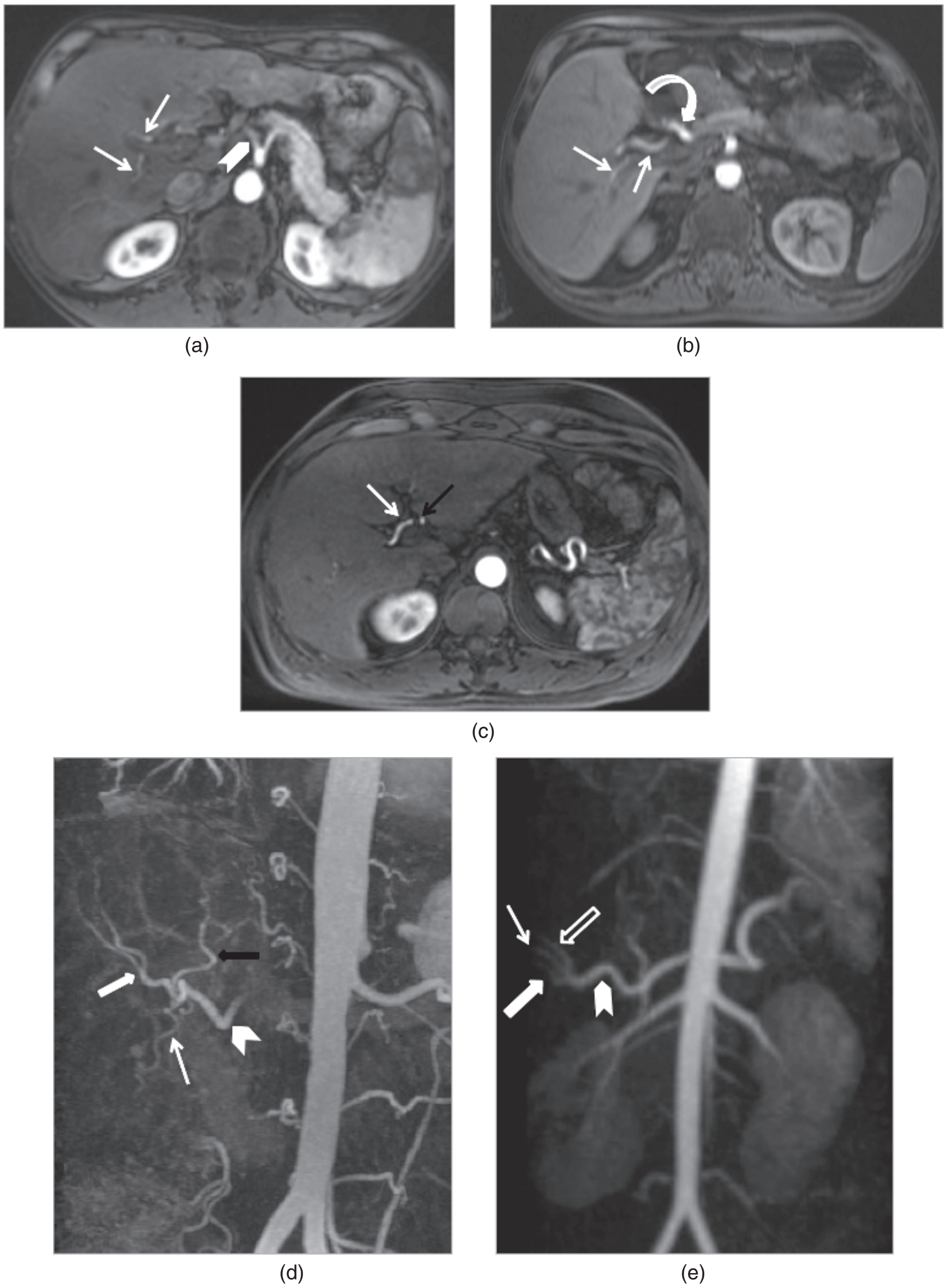


Figure 1.7 *Hepatic Arteries*. T1-weighted axial hepatic arterial phase 3D-GE images demonstrate the common hepatic artery (arrowhead, a), proper hepatic artery (curved arrow, b), right hepatic artery and its branches (white arrows, a – c) and left hepatic artery (black arrow, c) at different levels. Maximum intensity projection images reconstructed from 3D-GE MR angiography coronal source images can also demonstrate the common hepatic artery (arrowhead, d), proper hepatic artery (arrowhead, e), right hepatic artery (white thick arrow, d; white thick arrow, e), left hepatic artery (black arrow, d; white hollow arrow, e), middle hepatic artery (white thin arrow, e), and gastroduodenal artery (white thin arrow, d).

The hepatic veins

The hepatic veins drain into the IVC at the dome of the liver (Figure 1.9) (1). The right hepatic vein drains the segments V – VII and part of VIII (1). The middle hepatic vein drains the segments IV, V, and VIII, although it mainly drains segment IV (1). The left hepatic vein drains the segments II – III and part of IV (1). Variations of the hepatic veins are common. The middle and left hepatic veins form a single trunk before draining into the IVC in 60% of the population (3). Right inferior accessory hepatic veins draining the segment V – VII

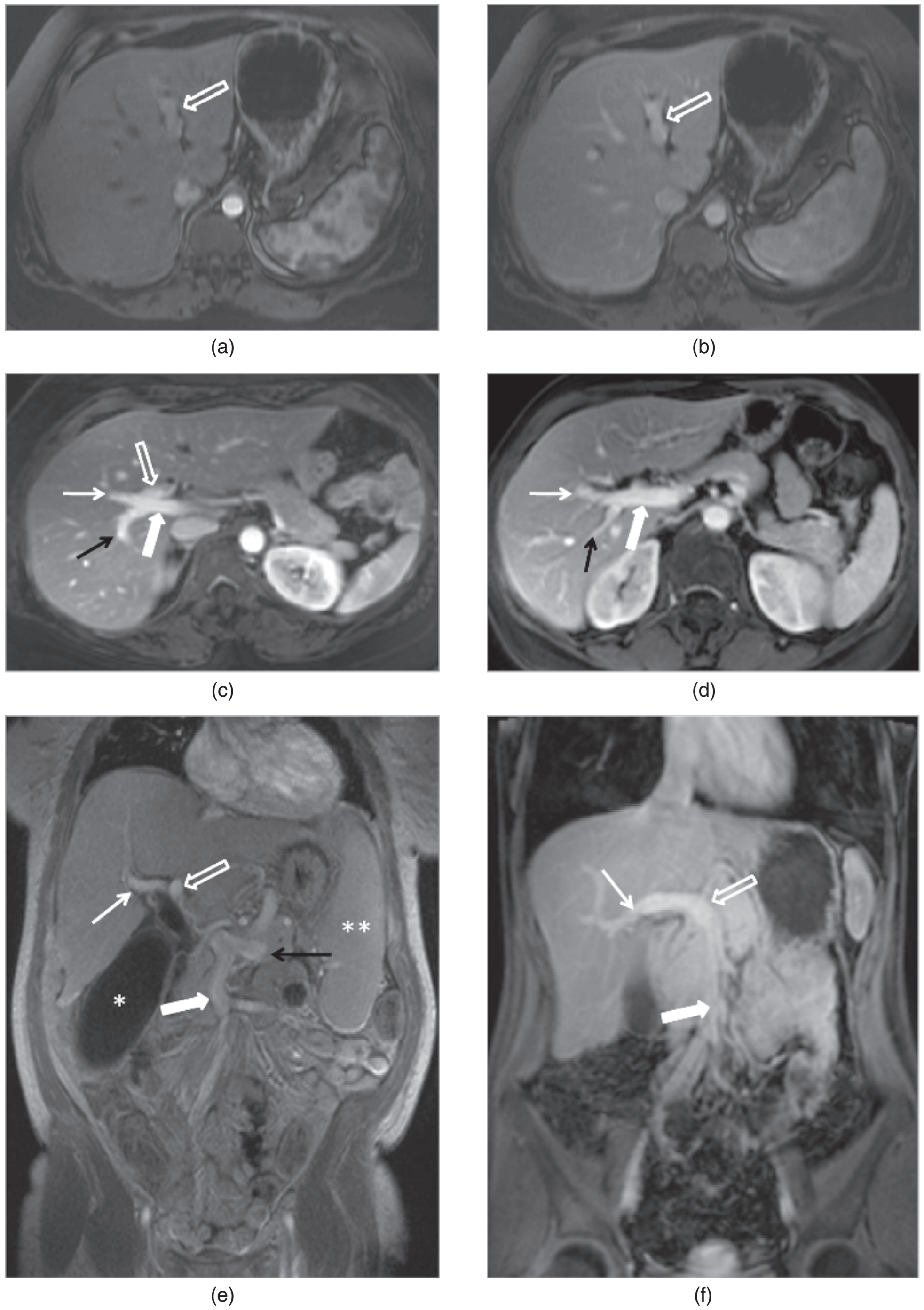
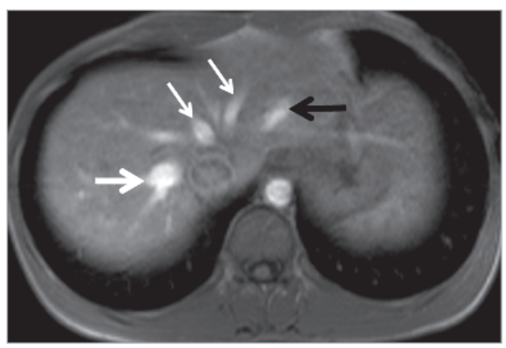


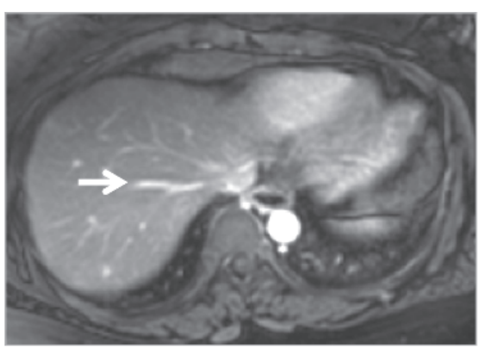
Figure 1.8 *Portal Vein*. T1-weighted axial hepatic arterial dominant (a), hepatic venous (b – d) 3D-GE images demonstrate horizontal part of left portal vein (white hollow arrows, a – c), right portal vein (white thick arrows, c – d), anterior (white thin arrows, c – d), and posterior (black arrows, c, d) branches of right portal vein. Note the trifurcation of the main portal vein (white thick arrow, c) into the right anterior (white thin arrow, c), right posterior (black arrow, c) and left portal vein (white hollow arrow, c) which is the most frequent variation of the main portal vein and its branches. T1- weighted coronal hepatic venous phase magnetization prepared rapid gradient echo (e) and 3D-GE (f) images demonstrate the main portal vein (hollow arrow, e, f), right portal vein (thin arrow, e, f), superior mesenteric vein (thick arrow, e, f) and splenic vein (black arrow, e). Note that the gall bladder (single asteriks, e) is hydropic and the spleen (double asteriks, e) is enlarged. Maximum intensity projection images reconstructed from 3D-GE MR angiography coronal source images can also demonstrate the portal vein (arrow, g) and its branches on the venous phase.

(g)

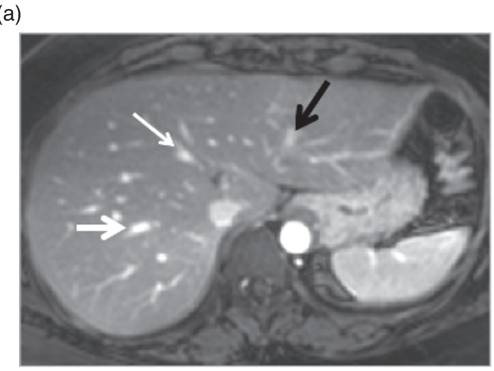
Figure 1.8 (*Continued*)



(a)

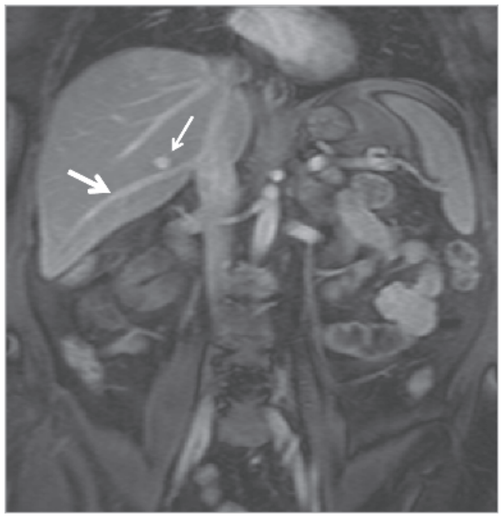


(b)



(c)

Figure 1.9 *Hepatic Veins*. T1-weighted axial hepatic venous phase 2D-GE (a) and 3DGE (b, c) images demonstrate right hepatic vein (white thick arrow, a – c), middle hepatic vein and its tributaries (white thin arrows, a – c) and left hepatic vein (black arrow, a – c) at different levels. T1-weighted coronal hepatic venous phase 3D-GE image demonstrates the accessory right hepatic vein (thick arrow, d) draining the segment 6. Note the small hemangioma (thin arrow, d) which shows prominent and continuous enhancement on the hepatic venous phase.



(d)

Figure 1.9 (*Continued*)

(a) (b) (c) (d)

Figure 1.10 *Bile Ducts*. Maximum intensity projection images (a–b) reconstructed from coronal thin section source images demonstrate normal (a) and mildly dilated biliary ducts (b) in two different patients. In a patient with normal biliary system (a); intrahepatic bile ducts, right (white thick dashed arrow, a) and left (white thick arrow, a) hepatic ducts, common hepatic duct (white hollow arrow, a), cystic duct (white thin short arrow, a), gall bladder (asteriks, a), common bile duct (white filled arrow, a), and pancreatic duct (white thin long arrow, a). Note that ampulla of Vater (arrowhead, a) which is located at the second portion of the duodenum is visualized well. In another patient with mildly dilated biliary system (b); right (dashed arrow, b) and left (arrow, b) hepatic ducts demonstrate low insertion to the common hepatic duct. Note that fourth order branches of intrahepatic bile ducts can be visualized if they are dilated. Maximum intensity projection images (c, d) reconstructed from coronal thin section source images demonstrate mildly dilated (c) and normal biliary ducts (d) in two different patients. In another patient with mildly dilated biliary system, the right posterior duct directly drains into the left hepatic duct (arrow, c), which is the most common variation of the biliary system. In another patient with normal biliary system, the right posterior duct (arrow, d) drains directly into the common hepatic duct, which is not an uncommon variation. Source: Semelka 2010. Reproduced with permission of Wiley.

may also be commonly seen (Figure 1.9) (3). Right inferior accessory hepatic veins and the drainage of segment V and VIII veins into the middle hepatic vein affect surgical procedures (3).

The bile ducts

Peripheral bile ducts drain into the right and left hepatic ducts, which unite to form the common hepatic duct (Figure 1.10) (3,5). The cystic duct drains into the common hepatic duct, and they together form the common bile duct (Figure 1.10). The common bile duct and main pancreatic duct (duct of Wirsung) unite and form the ampulla of Vater which opens into the second portion of the duodenum at the major papilla (Figure 1.10). The right hepatic duct drains the segments of the right liver lobe [V–VIII] and has two major branches: the right posterior duct draining the posterior segments [VI, VII], and the right anterior duct draining the anterior segments [V, VIII]. The right posterior duct usually runs posterior to the right anterior duct and fuses it from a medial approach to form the right hepatic duct (1). The left hepatic duct is formed by segmental branches draining the segments of the left liver lobe [II–IV] (1). The bile duct draining the caudate lobe usually joins the right and left hepatic ducts at their bifurcation. This normal biliary anatomy is seen in approximately 58% of the population (Figure 1.10) (3).

The most frequent anatomic variation is the drainage of the right posterior hepatic duct into the left hepatic duct in 13–19% of the population (Figure 1.10) (3,5). Simultaneous drainage of the right anterior hepatic duct, right posterior hepatic duct, and left hepatic duct into the common hepatic duct is seen in 11% of the population (3,5). The drainage of the right posterior hepatic duct into the common hepatic duct is seen in 5% of the population (Figure 1.10), and the drainage of the left hepatic duct into the right hepatic anterior duct in 4% of the population (3,5). Accessory hepatic ducts are seen in 2% of the population (3).

The cystic duct also demonstrates three common types of variations as follows: (i) cystic duct's insertion from a lower level, (ii) medial cystic duct insertion and (iii) parallel extension of the cystic duct and common hepatic duct.

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