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NARRATIVE REVIEW

Celiac trunk arterial variations and their clinical implications: Role of imaging

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Abstract

The awareness of anatomical variations of hepatic arteries and celiac trunk is very important in interventional radiology, liver transplant and intra-abdominal oncologic surgeries. Radiology plays an important role in the identification of these variants non-invasively. Digital subtraction angiography was the gold standard for their identification. Computed tomography (CT) angiography non-invasively provides detailed knowledge of various anatomical vascular variations. This pictorial review highlights the role of multidetector computed tomography (MDCT) in the identification of celiac trunk–hepatic arterial system variations and clinical consequences.

Keywords Digital subtraction angiography · Hepatic arterial variations · Multidetector computed tomography

Introduction

Anatomical variations of hepatic arteries and celiac trunk are seen in about 50% of the world population [1]. Pre-procedural awareness of these anatomical variations is very important in interventional radiology, liver transplant and intra-abdominal oncologic surgeries [2, 3]. Unawareness of anatomical variations in those patients can result in inadvertent hepatic vascular injury. Hence, it is important to know and study hepatic arterial anatomical variations before hepatic interventional procedures and liver surgeries [4]. Computed tomography (CT) angiography of the abdominal aorta provides detailed knowledge of various anatomical variations. However, digital subtraction angiography (DSA) is regarded as the gold standard for the evaluation of vascular structures [4, 5]. Due to the invasive nature of DSA, it is less commonly used compared to CT angiography. CT angiography is usually performed by injection of non-ionic contrast and the arterial phase of the scan is utilized for the evaluation of arterial variations. Thin and thick slab maximum intensity projection (MIP) images in axial and coronal sections best demonstrate the arterial anatomy. Three-dimensional volume-rendered (VR) post-processed images will be complimentary to interpret the arterial variations. Multidetector computed tomography (MDCT) allows rapid acquisition of high-resolution images, can determine the extent of tumor spread and vascular involvement and helps in tumor resectability [6–8]. This pictorial review aims to highlight the anatomical variations that occur in the celiac trunk–hepatic arterial system on MDCT and their consequences in various clinical scenarios.

Embryologic basis

The first trimester is the period for the development of the celiac trunk (hepatic-mesenteric arterial system). Paired dorsal aorta are formed during the third week of embryonic development. Paired ventral branches arise from paired dorsal aorta to supply primitive gut and its derivative. During the fourth to fifth week of development, paired dorsal aorta fuse to form future abdominal aorta. With the formation of the abdominal aorta, these ventral branches fuse and form several unpaired segmental vessels. Subsequently, ventral splanchnic branches regress and only three vessels persist as the celiac trunk, superior mesenteric artery (SMA) and inferior mesenteric artery (IMA). Hence, any error in the

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fusion or in the pairing process leads to these arterial variants [1, 9].

Classification of hepatic arterial variations

According to Michel's classification, the following 10 types of hepatic arterial variation patterns can be encountered [10] (Table 1).

Type I—This is the most common and classic anatomical pattern, in which celiac trunk gives rise to the common hepatic artery (CHA), left gastric artery (LGA) and splenic artery. Common hepatic artery divides into the gastroduodenal and proper hepatic arteries; the latter divides distally into right hepatic artery (RHA) and left hepatic artery (LHA) (Fig. 1).

Type II—In this pattern, replaced LHA originates from the LGA and courses through the fissure for ligamentum venosum and umbilical fissure to supply the segments of the left hepatic lobe (Fig. 2a).

Type III—In this pattern, replaced RHA originates from the SMA. The normal RHA usually courses anterior to the right portal vein; however, the replaced RHA originates from the SMA and courses posterior to the main portal vein in the portocaval space and ascends postero-lateral to the common bile duct (CBD) (Fig. 2b).

Type IV—In this pattern, replaced LHA originates from the LGA and a replaced RHA originates from the SMA.

Type V—In this pattern, accessory LHA originates from the LGA and it follows the same course through fissure for ligamentum venosum and umbilical fissure as does the replaced LHA. This accessory artery provides an additional source of arterial blood to the segments of the left hepatic lobe and may be ligated without compromising the arterial supply to the left hepatic lobe (Fig. 2c).

Type VI—In this pattern, accessory RHA arises from the SMA and it follows the same course similar to that of a replaced RHA. This accessory artery provides an additional source of arterial blood to the segments of the right hepatic lobe and may be ligated without compromising the arterial supply to the right hepatic lobe (Fig. 2d).

Type VII—In this pattern, an accessory LHA originates from the LGA and an accessory RHA from the SMA.

Type VIII—In this pattern, a replaced LHA originates from the LGA and an accessory RHA from the SMA or vice versa (Fig. 2e).

Type IX—In this pattern, SMA gives rise to the common hepatic artery (CHA) (Fig. 2f).

Type X—In this pattern, common hepatic artery (CHA) arises from LGA.

Table 1 Ten types of hepatic arterial variation patterns

Anatomical variation of hepatic artery	Michel classification
Normal anatomy	Type I
LHA branch LGA	Type II
RHA branch SMA	Type III
Type I and II association	Type IV
LHA accessory LGA	Type V
RHA accessory SMA	Type VI
LHA accessory LGA + RHA accessory SMA	Type VII
LHA accessory LGA + RHA branch SMA	Type VIII
CHA branch SMA	Type IX
RHA and LHA branch LGA	Type X

LHA left hepatic artery, *LGA* left gastric artery, *RHA* right hepatic artery, *SMA* superior mesenteric artery, *CHA* common hepatic artery

Beside the above described arterial variants, other variations can also be encountered, for example, CHA arising from the aorta (Fig. 3).

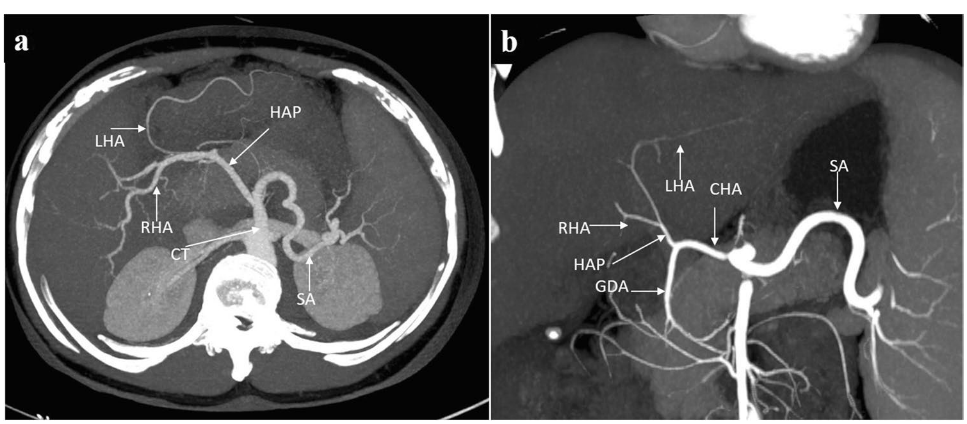

Fig. 1 **a**, **b** Michel's type-I (classic) arterial anatomy in a 48-year-old living donor for liver transplantation. Axial (**a**) and coronal (**b**) MIP images showing the normal anatomy of the hepatic artery. *CT* celiac trunk, *CHA* common hepatic artery, *HAP* hepatic artery proper, *LHA* left hepatic artery, *RHA* right hepatic artery, *GDA* gastroduodenal artery, *SA* splenic artery, *MIP* maximum intensity projection

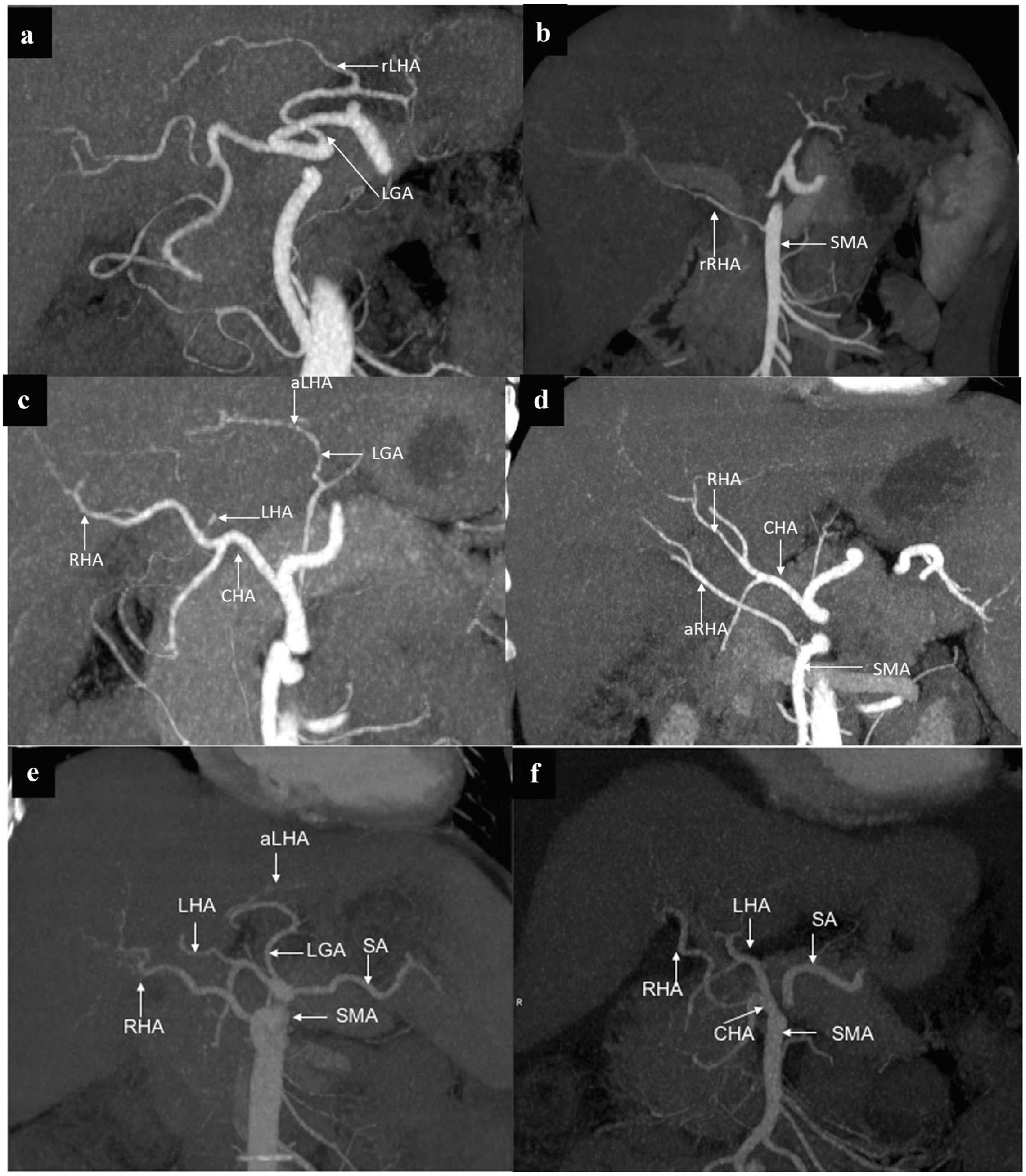

Fig. 2 **a**–**f**, **a** Michel's type-II anatomy. Replaced left hepatic artery from the left gastric artery. **b** Michel's type-III anatomy. Replaced right hepatic artery from the superior mesenteric artery. **c** Michel's type-V anatomy. Accessory left hepatic artery from the left gastric artery. **d** Michel's type-VI anatomy. Accessory right hepatic artery from the superior mesenteric artery. **e** Michel's type-VIII anatomy. Accessory LHA form the left gastric artery and replaced right hepatic artery from the superior mesenteric artery. **f** Michel's type-IX anatomy. Common hepatic artery arising from the superior mesenteric artery. *CHA* common hepatic artery, *LHA* left hepatic artery, *RHA* right hepatic artery, *rLHA* replaced left hepatic artery, *rRHA* replaced right hepatic artery, *aLHA* accessory left hepatic artery, *aRHA* accessory right hepatic artery, *SMA* superior mesenteric artery

Clinical implications

Trans-arterial chemoembolization (TACE)

Trans-arterial chemoembolization (TACE) is an interventional procedure in which chemotherapeutic drug along with lipiodol is selectively delivered to a malignant lesion by catheterizing the selective artery supplying the tumor. Less of the drug will escape to the systemic circulation and thereby producing less number of side effects [11]. Intermediate stage (Barcelona Clinic Liver Cancer-B [BCLC-B]) hepatocellular carcinoma (HCC) and non-resectable hepatic metastases

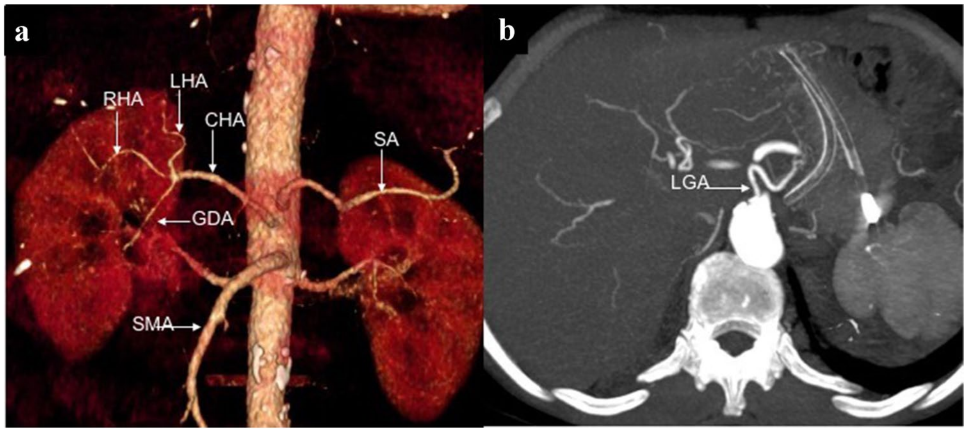

Fig. 3 **a**, **b** Unclassified arterial variants. **a** Common hepatic artery from the abdominal aorta. **b** Left gastric artery from the abdominal aorta. *LGA* left gastric artery, *CHA* common hepatic artery, *LHA* left hepatic artery, *RHA* right hepatic artery, *GDA* gastrodudenal artery, *SMA* superior mesenteric artery, *SA* splenic artery

from colorectal cancer and neuroendocrine tumors are the current indications for TACE [12–15]. Through the transaretrial route, the catheter is inserted and selective hepatic arterial catheterization is done and then the drug is injected [16]. Previously, the catheter was placed surgically in the hepatic artery intra-operatively, which was more invasive and associated with increased morbidity and mortality [17]. Inadvertent selection of different arteries can lead to failure of the procedure or spillage of the drug into the systemic circulation leading to various complications [18]. To prevent such complications, diagnostic and interventional radiologists should be familiar with cross-sectional and volume-rendering technique (VRT) images. Check angiogram should always be performed before attempting any hepatic angiography procedure to prevent complications associated with arterial anatomical variations [19] (Figs. 4 and 5).

Hepatic trauma

In the last two decades, management of hepatic trauma has greatly changed. Treatment of hepatic trauma has moved from extensive hepatic resection earlier to more widespread use of conservative management with the use of hepatic angioembolization in selected sub-group of patients [20, 21]. Patient with hepatic arterial bleeding requires angioembolization in two scenarios. First when the patient is hemodynamically stable and imaging shows hepatic vascular injury like pseudo aneurysm or active extravasation and when

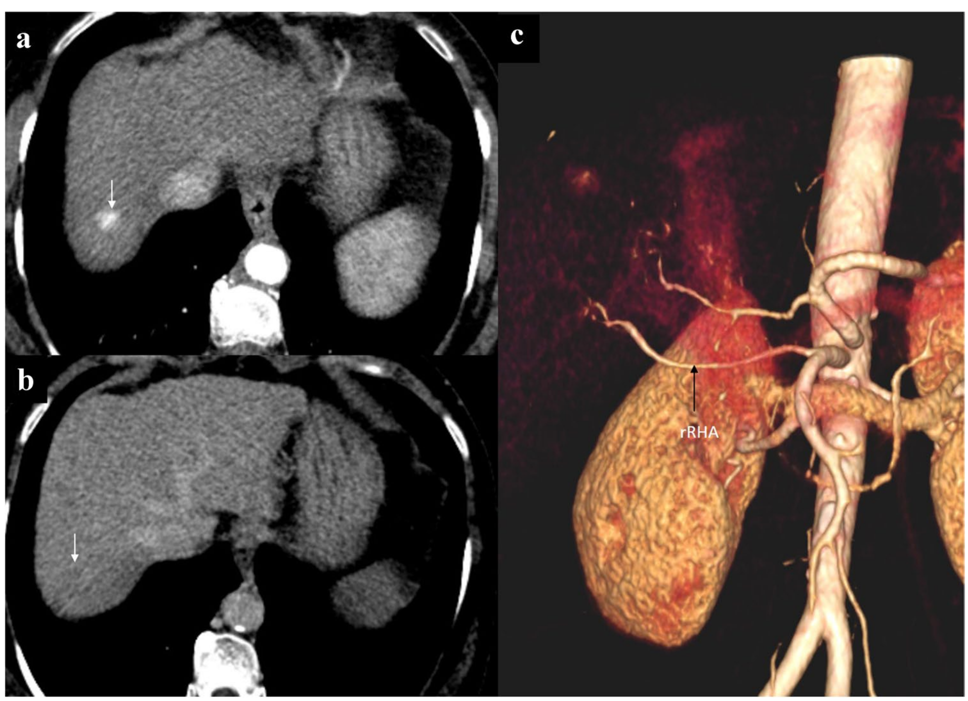

Fig. 4 **a**–**c** Michel's type-III anatomy (replaced right hepatic artery arising from the superior mesenteric artery) in a 45-year-old man with heptaocellular carcinoma (HCC). **a**, **b** Axial arterial and delayed phase images showing well-defined arterially enhancing lesion in the Seg. VII of the liver which is showing washout in the delayed phase (white arrows). **c** Coronal volume-rendering technique (VRT) image showing replaced right hepatic artery (rRHA) (black arrow)

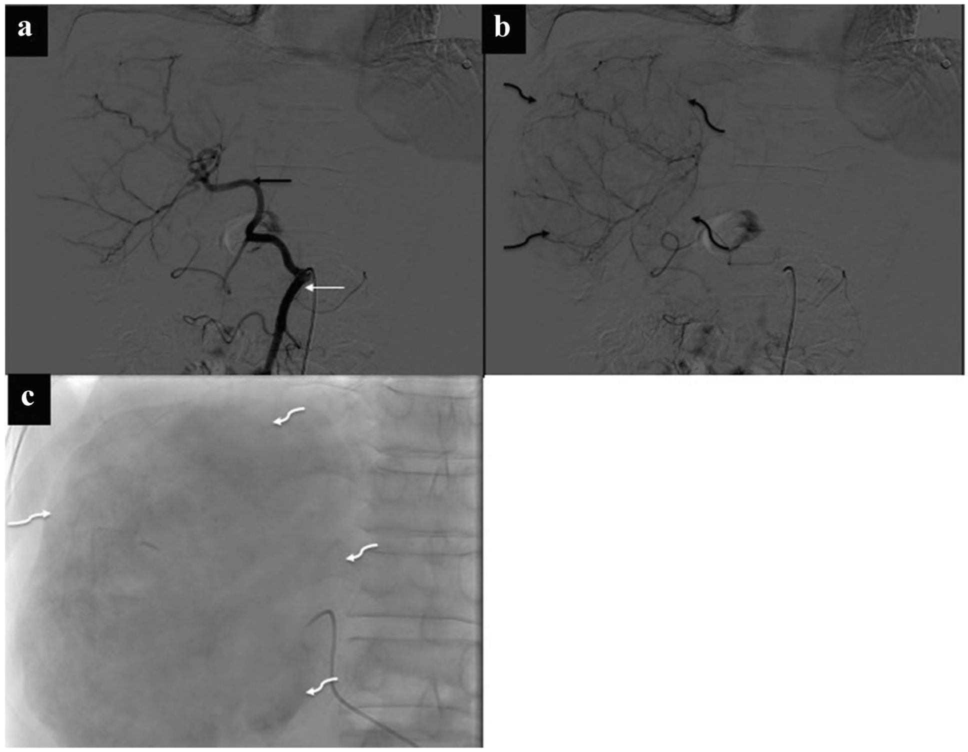

Fig. 5 **a**–**c** Michel's type-III anatomy (replaced right hepatic artery arising from the superior mesenteric artery) in a 61-year-old man with heptaocellular carcinoma (HCC). **a** Coronal digital subtraction angiography (DSA) image showing replaced right hepatic artery (black arrow) arising from the superior mesenteric artery (white arrow) supplying HCC in right lobe of liver. **b** Multiple arterial feeders and tumoral blush can also noted (curved black arrows). **c** Post procedure coronal image showing lipidol deposition in the HCC (curved white arrows)

despite initial damage control laparotomy, the patient continues to bleed [22]. In the DSA, an abdominal aortogram is a critical first step before selective hepatic angiography, especially when CT abdominal angiogram was not done. This allows for a step-wise progression closer to the target vessel and avoids the pitfall of missing a significant bleed from an unexpected anatomic variant [23]. Knowledge of the hepatic vascular variants is essential to prevent missing injured variant branches and to ensure that the entire organ has been examined (Figs. 6 and 7) [10]. In addition to major trunk variants, several accessory hepatic arteries are commonly found [24].

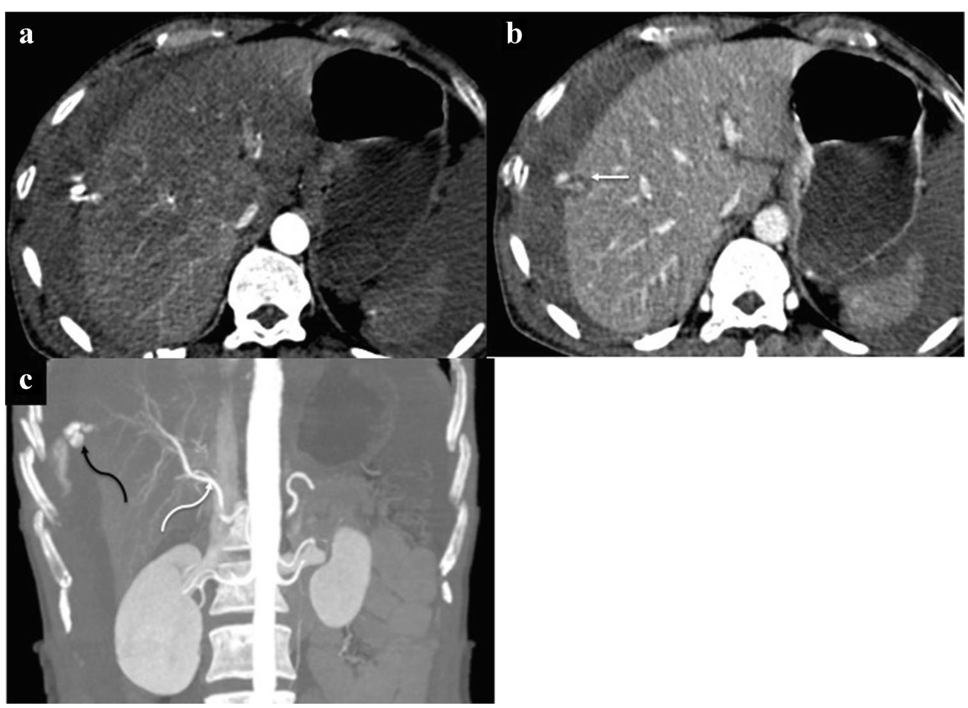

Fig. 6 **a**–**c** Accessory right hepatic artery from the aorta in a 37-year-old male with grade-I hepatic injury after the road traffic accident. **a**, **b** Axial arterial and venous phase image showing small laceration (white arrow) in the peripheral portion of the Seg. V of the liver with the overlying multiple rib fractures. Despite small laceration, there is gross hemi-peritoneum seen. **c** Coronal maximum intensity projection (MIP) image showing active contrast extravasation (curved black arrow) from the peripheral branch of the accessory right hepatic artery which is originating from the aorta (curved white arrow)

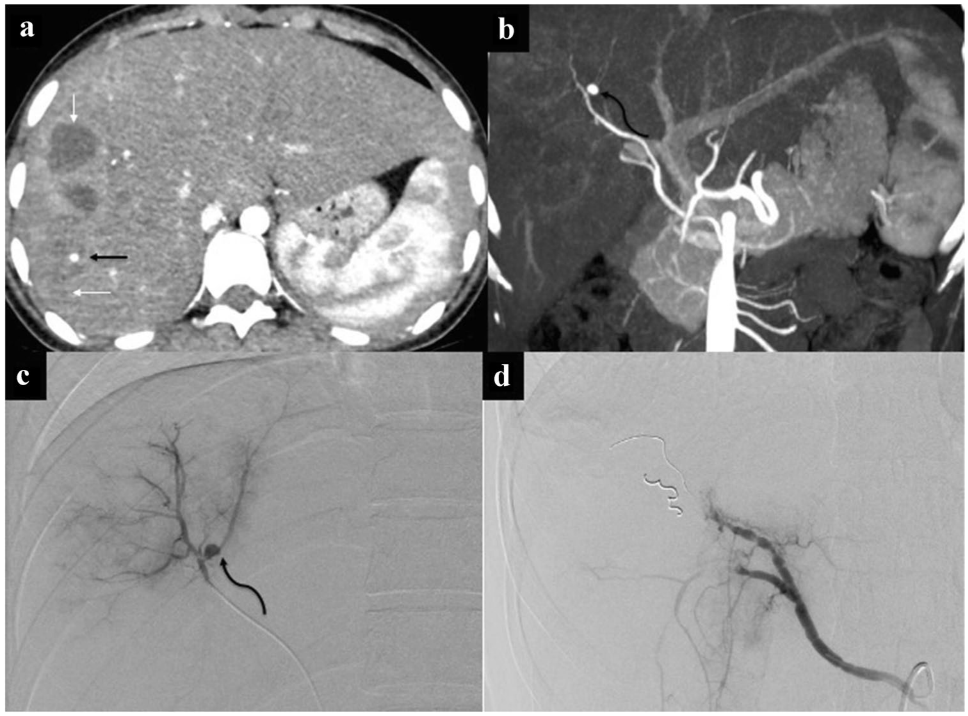

Fig. 7 **a**–**d** Michel's type-III anatomy (replaced right hepatic artery arising from the superior mesenteric artery) in a 16-year-old female with liver abscess. **a**, **b** Axial arterial phase image showing multiple ill-defined peripherally enhancing lesions in the Seg. VII and VIII of the liver (white arrows). In addition, pseudoaneurysm is seen in the center of the lesion in Seg. VIII (black arrows). **c** Coronal digital subtraction angiography (DSA) image showing pseudoaneurysm arising from the anterior branch of the replaced right hepatic artery (rRHA) (curved black arrow). **d** Post embolization DSA image shows complete occlusion of the anterior branch of the replaced right hepatic artery

Splenic trauma

Most commonly injured organ in blunt abdominal trauma is the spleen [25]. Patients with splenic injuries who are hemodynamically unstable have features of peritonitis or have additional significant intra-abdominal injuries that require operative management [26]. Non-operative measures are kept for isolated low-grade splenic injury. Watchful observation with serial physical examination and hematocrit-level monitoring may be useful in stable patients [27]. Splenic artery intervention such as embolization is done for high-grade splenic injuries or in the case of vascular injuries such as active contrast extravasation, pseudoaneurysm and arteriovenous fistula [28]. Splenic artery embolization is of two types: proximal and distal. Grades 4 and 5 splenic injuries require proximal splenic artery embolization. Distal embolization usually is done in cases of vascular injuries. Distal splenic artery embolization is time-consuming and difficult due to the tortuous pathway of the splenic artery [29, 30]. More than 75% of the patient's splenic artery origin from the celiac trunk and in the remaining 25% patients it can originate from the hepato-splenic trunk, aorta and spleno-gastric trunk [31] (Fig. 8).

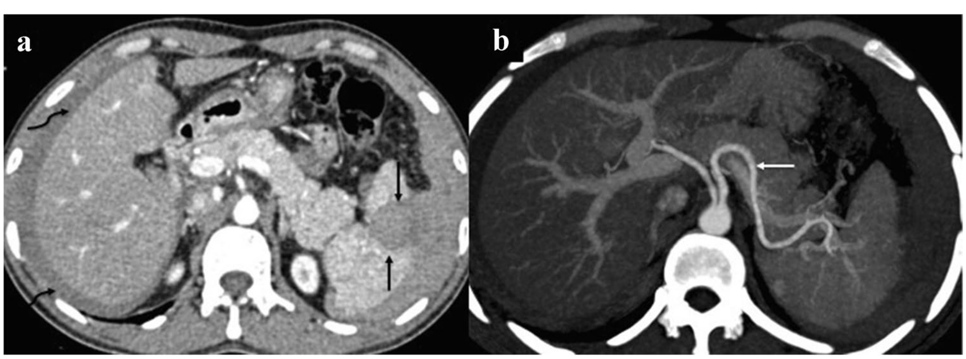

Fig. 8 **a**, **b** Splenic artery from the aorta in a 16-year-old female with grade IV splenic injury after the road traffic accident. **a** Axial venous phase image showing lacerations (black arrow) in the inter polar region of the spleen with surrounding peri-splenic hematoma and hemoperitoneum in the peri-hepatic region (curved black arrow). **b** Axial maximum intensity projection (MIP) image showing origin of the splenic and common hepatic artery separately from the aorta (white arrow)

Liver transplantation

Cadaveric, living donor liver transplant and split liver grafting are the three types of liver transplant done in clinical practice. Acute liver failure and chronic liver disease are the most common indications of liver transplant [32, 33]. Tsang et al. study quoted that 62.3% of the potential donors excluded from the transplantation because of various reasons, out of which 4% are excluded because of the presence of the arterial variations in the donor [34]. Pre-operative imaging of both donor and recipient is needed to identify the anatomical arterial variations. CT angiography and DSA provide adequate vascular road map before taking a patient for liver transplantation and for vascular reconstruction. All hepatic arterial variants are not surgically important. The significance of particular arterial variant depends on whether they are present in the donor or recipient [35].

Arterial variants significant in the donor

The medial segment of the left hepatic lobe can be supplied by the RHA, LHA and CHA. The important arterial variant is RHA hepatic artery supplying medial segment of the left lobe of the liver in the donor who requires full arterial supply to the left hepatic lobe because the plane of the hepatectomy resection would cross the arterial supply to this segment [36, 37].

Arterial variants significant in the recipient

Michel type IX variant, i.e. common hepatic artery (CHA) arising from the SMA having retro-portal course, is a significant arterial variant in recipient because it changes the sequence of vascular reconstructions. Another significant variant for the recipient is Michel type II and V variants (replaced or accessory LHA, respectively). In these recipients, during the native liver removal, this artery should be ligated at its origin from the LGA artery to prevent inadvertent hemorrhage [35].

Arterial variants significant in both — donor and recipient

Replaced RHA branching from the SMA, i.e. Michel type-III variant, affects both recipient and the donor. Due to the resultant small diameter of CHA, the chances of hepatic artery thrombosis increase [3]. Replaced hepatic artery is good for living donor because it provides a longer and larger graft as compared with the normal right hepatic artery. Small diameter is avoided and chances of hepatic artery thrombosis will be less and thereby reducing mortality and morbidity in patients with the liver transplant [38]. Multiple vascular anastomoses are done in the case of accessory hepatic arteries; therefore, it requires particular attention while hepatic resection and anastomosis. Post-operative complications such as acute liver failure and necrosis of liver parenchyma are more common if proper anastomosis is not done. Patient mortality and morbidity will ultimately increase [39].

Bile ducts are completely and solely supplied by hepatic arteries, unlike liver parenchyma. Inadvertent arterial injury can result in biliary strictures, cholangitis and in a few cases graft failure, too. The main reason for this complication is an excessive dissection of RHA which can occur in variant arterial anatomy. The presence of arterial variant in one candidate should prompt a closer look for a similar or additional variant in genetically related candidates [35].

Hepatic tumor resection

Primary and secondary hepatic tumors significantly decrease the life span of patients. Sometimes, hepatectomy is the procedure of choice for tumors. Proper understanding helps in complete resection of tumor and reduces recurrence. Multiplanar reformation (MPR) and VRT are very useful tools to demonstrate the relationship of the tumor to surrounding vessels. Any arterial anatomical variants may complicate the procedure. Surgical techniques need to be modified in such cases for complete resection of the tumor. Injury to arterial variants may lead to severe bleeding and hepatic infarction and biliary strictures [40, 41]. If accessory right hepatic artery is present and right hepatectomy is planned, then prior identification and ligation of the accessory right hepatic artery are a must. This will prevent injury and bleeding if proper care is taken. Surgical techniques need to be modified to prevent ischemia if replaced right hepatic artery is present [35]. The inference is the presence of replaced hepatic arterial variants warrants modification in the surgical technique to avoid iatrogenic vascular injury with resultant ischemia and accessory arteries warrant ligation to prevent excessive hemorrhage [3] (Figs. 9, 10, 11, and 12).

Pancreatic surgeries

Adenocarcinoma of the pancreas is one of the leading causes for cancer deaths in the world [42]. Surgical resection is the treatment of choice, but it is possible only in localized tumors [43]. Vascular involvement may pose difficulty to the surgeon while resection. During the extended pancreaticoduodenectomy and extended distal pancreatectomy, a wide peri-aortic dissection is needed for the removal of the adjacent malignant lymph nodes and for getting tumor-free margins. Normal vascular anatomy is a key to the successful outcome of surgery. If anatomical variations are present and encased by the tumor itself, then the line of management may change and the surgeon may find it difficult to resect the tumor. Arterial injuries can happen in pancreatic tumor surgeries. Pre-procedure assessment of arterial anatomical

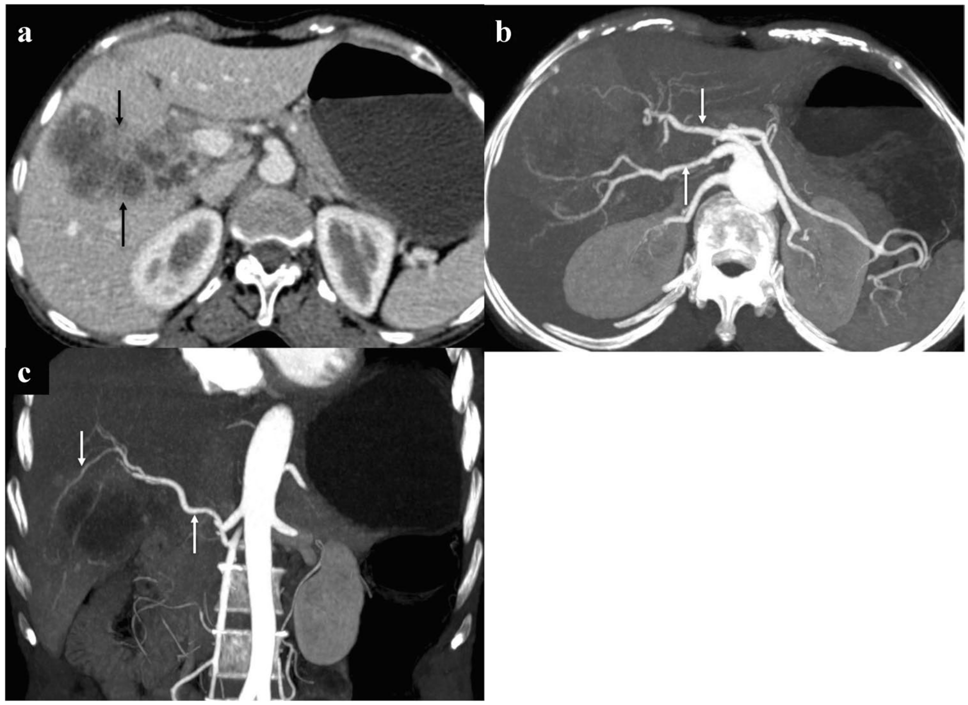

Fig. 9 **a**–**c** Michel's type-III anatomy (replaced right hepatic artery arising from the superior mesenteric artery) in a 50-year-old female with carcinoma gall bladder. **a** Axial venous phase image showing heterogeneously enhancing mass lesion infiltrating into the Seg. V of the liver (black arrows). **b**, **c** Axial and coronal maximum intensity projection (MIP) images showing replaced right hepatic artery and its major branches are involved by the lesion (white arrows)

Fig. 10 **a**–**c** Celiaco mesenteric trunk in a 36-year-old female with carcinoma gallbladder. **a** Axial venous phase image showing heterogeneously mass lesion involving the Seg. V of the liver (white arrows). There are multiple enlarged peri-portal and celiac axis lymph nodes that are also seen (curved black arrow). **b** Coronal maximum intensity projection (MIP) image showing narrowing of the common hepatic artery by the enlarged peri-portal and celiac axis lymph nodes (black arrows). **c** Volume-rendering technique (VRT) image showing origin of the celiac trunk and superior mesenteric artery from the aorta as a common trunk (curved white arrow)

variants is necessary for the surgeon before the surgery to prevent vascular injuries [44]. The most common and most important variation in these patients is the presence of a replaced RHA originating from the SMA. Replaced right hepatic artery may be involved in pancreatic head and uncinate process tumors, which increases chances of hepatic arterial variants injury and precluding surgical resection. If it is not involved, then surgeons must take proper precautions to prevent injury. Intra-operatively, it is difficult to identify replaced RHA because of two reasons. First, normal RHA courses anterior to the right portal vein, while the replaced RHA courses posterior to the main portal vein in the portacaval space and ascends postero-lateral to the common bile duct (CBD) and can get injured easily. The second palpation

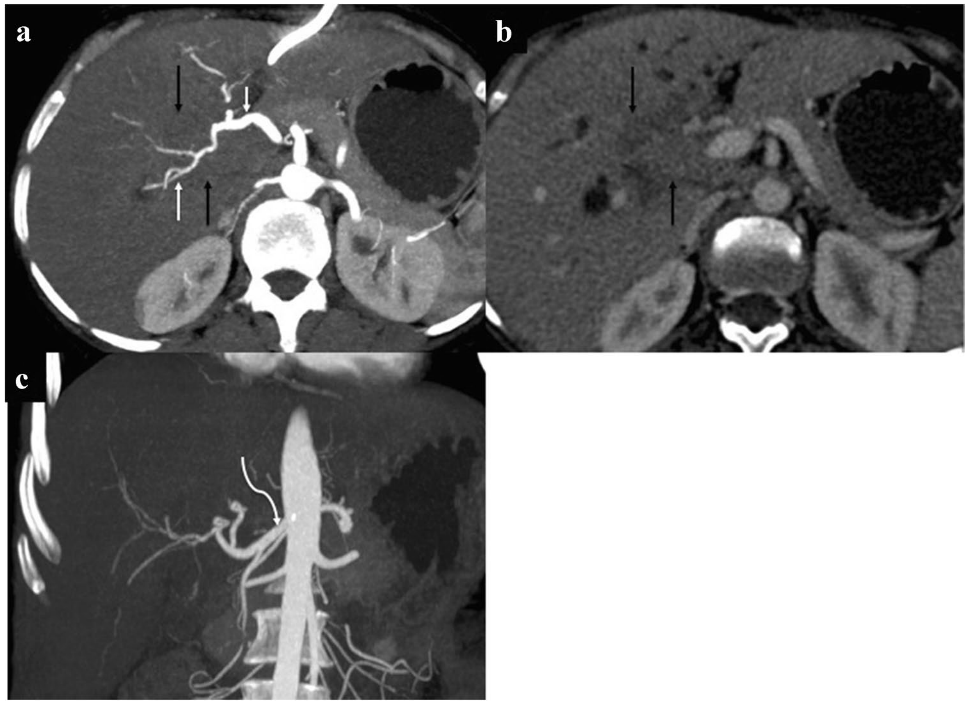

Fig. 11 **a**–**c** Common hepatic artery arising from the aorta in a 52-year-old female with hilar cholangiocarcinoma. **a**, **b** Axial arterial and venous phase images showing heterogeneously enhancing mass lesion in the region of the hilum causing blockage of the primary confluence (black arrows); in addition, lesion is causing narrowing of the hepatic artery proper and the right hepatic artery (white arrows). **c** Coronal maximum intensity projection (MIP) images showing common hepatic artery arising from the aorta (curved white arrow)

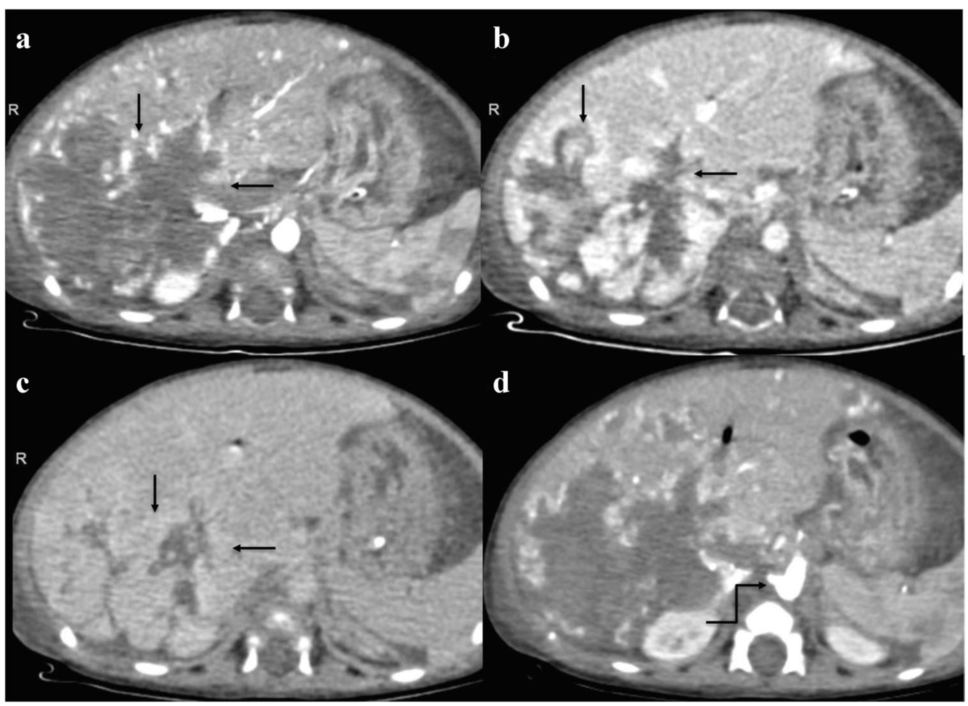

Fig. 12 **a**–**d** Accessory right hepatic artery from the aorta in a six-month-old infant with infantile hemangioendothelioma (IHE). **a**–**c** Axial arterial venous and delayed phase images showing relatively well-defined lesion in the Seg. VI and V of the liver, which is showing peripheral enhancement in the arterial phase and progressive filling in the venous and delayed phase (black arrows). **d** Axial arterial phase image showing an accessory right hepatic artery from the aorta, which is supplying the lesion (curved black arrow)

of replaced RHA becomes difficult when there are enlarged peri-portal lymph nodes and portal inflammation is present. In patients with jaundice posted for pancreatic duodenectomy, it is important to do percutaneous biliary drainage procedure first in replaced RHA cases [45]. Another important arterial variant in patients with pancreatic cancers is the origin of CHA from SMA. It is uncommon and when pancreaticoduodenectomy is performed, it should be preserved. Dissection should be done to its origin from SMA. CT angiography is necessary by delineating arterial anatomical variants [40] (Fig. 13). MDCT also helps in characterizing surrounding tumor invasion and adjacent arterial status. Multiplanar reformation (MPR) and VRT help in determining the exact site and extent of vascular invasion

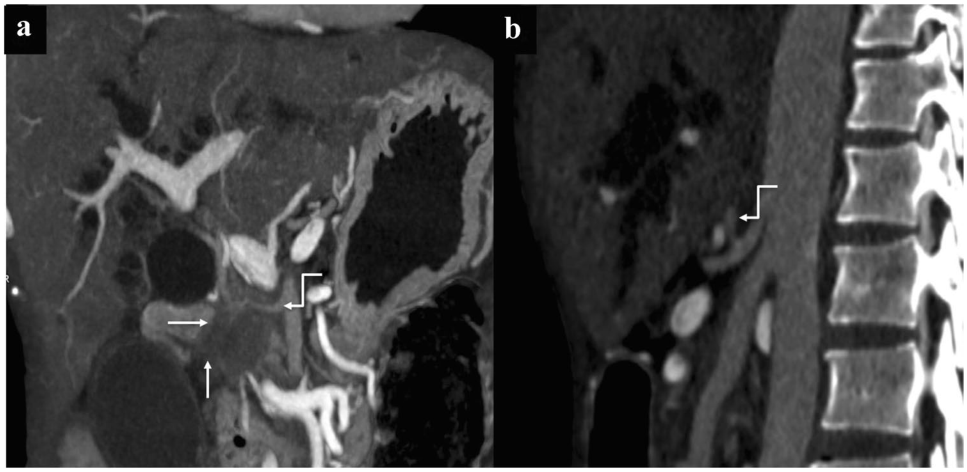

Fig. 13 Michel's type-IX anatomy (common hepatic artery arising from the superior mesenteric artery) in a 48-year-old female with pancreatic carcinoma. Axial pancreatic phase image showing hypo enhancing mass lesion (white arrows) in the head of the pancreas causing narrowing of the common hepatic artery (curved white arrows)

[46, 47]. If the hepatic artery is arising directly from the aorta, it increases the chance of surgical resection, while if the hepatic artery is arising from the SMA, then chance of successful resection is very less because it will be coursing through the retroperitoneal soft-tissue margin and likely involved by the lesion.

Gastric cancer surgery

The second most common cause for cancer-related deaths is gastric cancer [48]. Resection is the only treatment of choice. Gastrectomy with D2 lymph node dissection is widely accepted as a standard treatment in locally advanced gastric cancer patients [49]. D2 group of lymph nodes is present along LGA, CHA, celiac trunk, splenic artery and at the splenic hilum. D2 resection is important to prevent recurrence. These vessels should be considered a landmark for lymph node dissection. Therefore, the identification of these vessels is important. In cases of variations in arterial anatomy, this might be difficult and may lead to iatrogenic injury to arterial variants [50]. CT angiography helps in delineating various arterial variations. Precise knowledge of these various anatomical variations is necessary to prevent injury to these arterial variants and helping in lymph nodal resections thereby decreasing recurrence and morbidity. Accessory or replaced LHA arises from the LGA and supplies a part of or the whole left lobe (Fig. 14). During a curative gastrectomy, LGA is usually ligated and divided

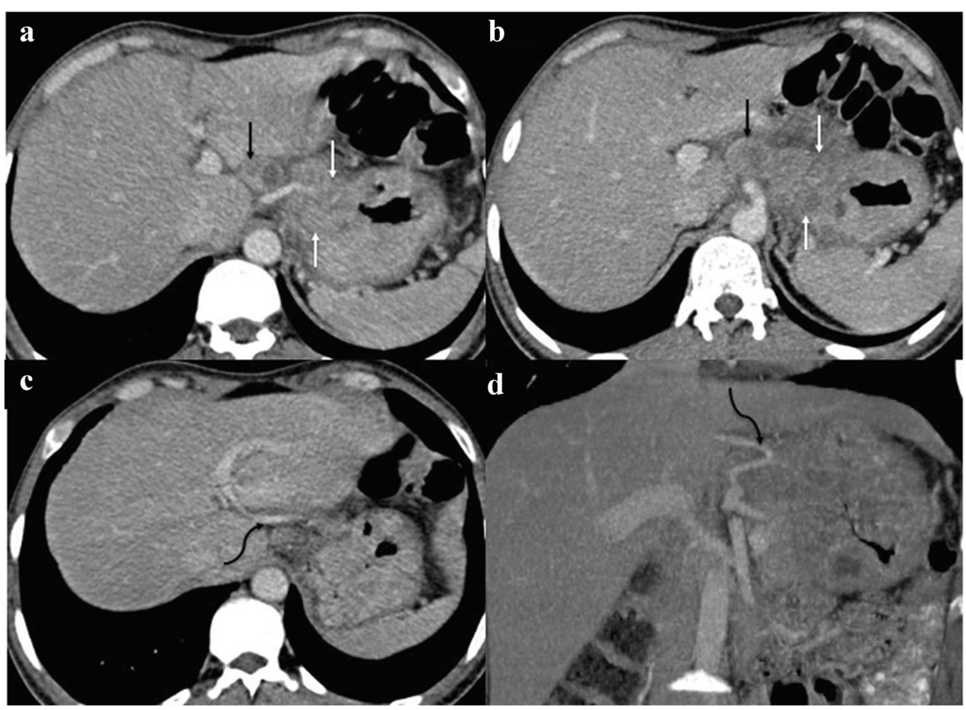

Fig. 14 **a**–**d** Michel's type-IV anatomy (replaced left hepatic artery arising from the left gastric artery) in a 38-year-old male with carcinoma stomach. **a**, **b** Axial venous phase images showing heterogeneously enhancing thickening of the wall of the antaro-pyloric region of the stomach with the infiltration of the surrounding tissues (white arrows) and enlarged celiac lymph node (black arrows). **c**, **d** Axial and coronal images showing replaced left hepatic artery coursing through the lesion (curved black arrows)

at its origin for the complete dissection of the lymph nodes. Inadvertent ligation or injury to a replaced LHA may cause liver dysfunction and liver infarct. Dangerous complications could be liver necrosis and death of the patient in the post-operative period. Therefore, pre-operative assessment of the presence of a replaced or accessory LHA is extremely useful for planning of gastrectomy.

The inference is that the variations of celiac and hepatic arterial anatomy are common and CT angiography along with DSA can be used to identify both common and rare arterial variants. MDCT also helps in vascular mapping and staging of hepatobiliary and pancreatic tumors. Pre-operative assessment is necessary to decrease morbidity by avoiding iatrogenic injury to hepatic arteries.

Author contribution All authors have contributed in case collection, manuscript preparation and write up. In addition, Pawan Kumar contributed significantly in editing and finalization. Corresponding author S H Chandrashekhara in addition contributed in conceptualizing, editing and preparing the final draft.

Data availability Yes.

Declarations

Competing interests PK, AS, GST, SHC, SG and VN declare no competing interests.

Ethical approval and consent to participate Yes.

Consent for publication Yes.

Human ethics Not taken as it is a pictorial review.

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