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REVIEW

Multimodality imaging of the Meso-Rex bypass

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Abstract
Extrahepatic portal vein obstruction (EHPVO) is the most common cause of upper gastrointestinal bleeding in children. It is defined as thrombosis of the extrahepatic portal vein with or without extension to the intrahepatic portal veins. The Meso-Rex shunt is the gold standard treatment in children with favorable anatomy since it restores physiological portal liver reperfusion. This is achieved by rerouting the splanchnic venous blood through an autologous graft from the superior mesenteric vein (SMV) into the Rex recess of the left portal vein, curing portal hypertension by doing so. General and hepatobiliary radiologists must be familiar with multimodality imaging appearances of EHPVO and with the role of imaging in identifying suitable candidates for Meso-Rex bypass surgery. Imaging might also detect complications of this procedure, some of which might be treated via interventional radiology.

Key words Meso-Rex bypass · Portal vein cavernoma · Portography · Extrahepatic portal vein thrombosis

Introduction

Extrahepatic portal vein obstruction (EHPVO) is defined as thrombosis of the extrahepatic portal vein with or without extension to the intrahepatic portal veins [1]. Portal vein thrombosis might be secondary to sepsis, dehydration, intraabdominal infection (including perforated appendicitis, pelvic inflammatory disease and omphalitis), umbilical vein catheterization, hypercoagulable states, biliary atresia and other chronic liver diseases. The underlying etiology of portal vein thrombosis remains unknown in up to 50% of children and young adults [2–6].

EHPVO is the most common cause of upper gastrointestinal bleeding in children and accounts for almost 70% of cases of chronic portal hypertension in the pediatric population [7]. The impaired physiological hepatopetal

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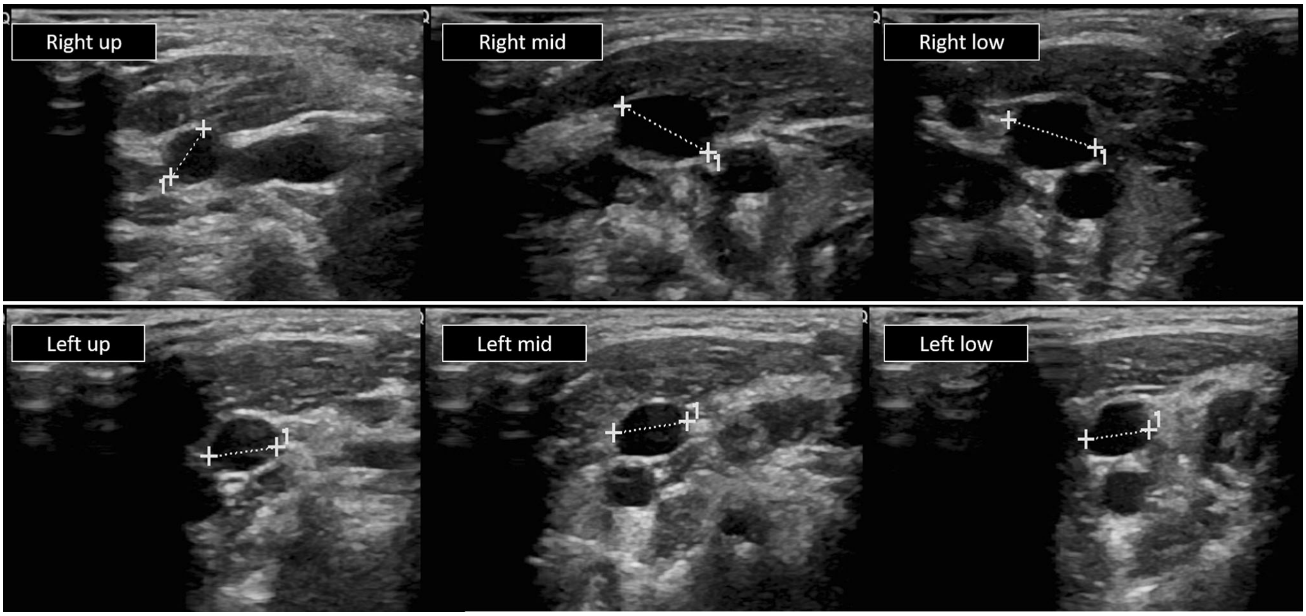

Fig. 1 Ultrasound images show regular patency and size of the upper, middle and lower portions of both internal jugular veins.

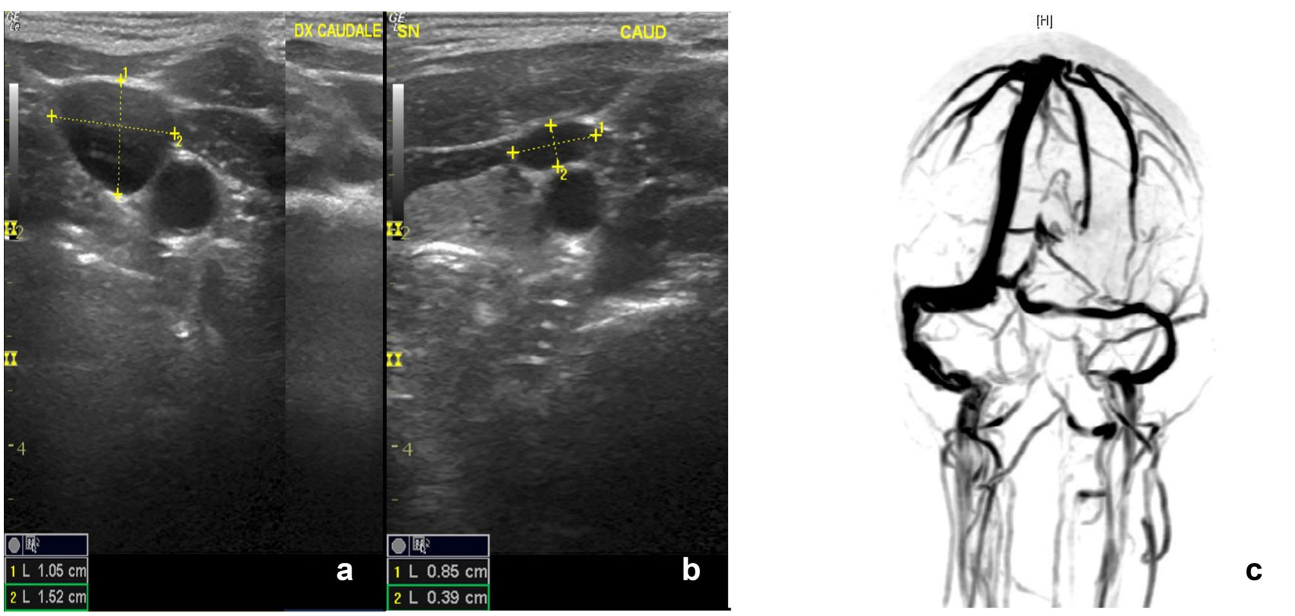

Fig. 2 Ultrasound shows evident asymmetry in the caliber of the internal jugular veins, with hypoplasia of the left internal jugular vein (**a**, **b**). MRI time of flight sequence **c** shows associated hypoplasia of the transverse and left sigmoid sinus.

flow from the superior mesenteric vein and splenic vein is impeded by obstruction of the main portal vein and results in development of pre-hepatic portal hypertension in the presence of an otherwise normal liver and normal liver function [1].

Assessing the portal venous system with high resolution imaging is essential when choosing the adequate type of surgical shunt and also to avoid unnecessary operative exploration. A Meso-Rex shunt or a conventional portosystemic shunt can be proposed depending on the vascular anatomy and residual patency.

Conventional portosystemic shunts include distal or proximal splenorenal shunt, meso-caval shunt, coronario-caval shunt, inferior mesenteric to left renal vein shunt and transjugular intrahepatic portosystemic shunt stent (TIPSS). Conventional surgical shunts have been shown to provide sufficient decompression of the portal system and prevent gastrointestinal hemorrhage, at the expense of

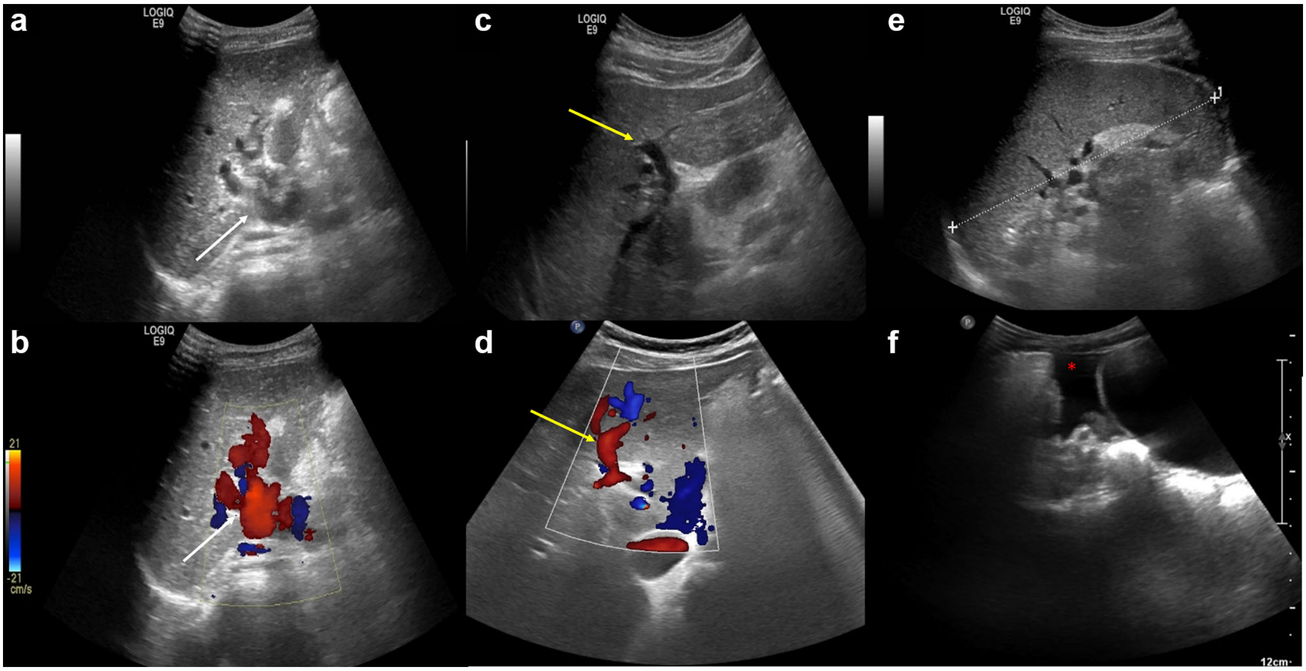

Fig. 3 Ultrasound and color Doppler shows extrahepatic portal vein obstruction (EHPVO) and resultant cavernomatous transformation, with no hepatic parenchymal abnormalities (**a** and **b**; white arrows). Normal flow is seen in the intrahepatic portal venous system in the region of the Rex recessus (images **c** and **d**). Signs of portal hypertension are seen in images **e** and **f**; in particular splenomegaly and ascites (red asterisk).

nonphysiological portosystemic shunting and its complications [8–11].

On the other hand, the Meso-Rex shunt restores physiological portal liver reperfusion by rerouting the splanchnic venous blood toward the intrahepatic portal system, curing portal hypertension by doing so [8]. This shunt is therefore the gold standard treatment in children with favorable anatomy. Complete opacification of the intrahepatic venous portal system, including all segmental portal branches, constitutes favorable (Type A) anatomy, as per the classification of Bertocchini et al. [12].

The Meso-Rex bypass was initially used to treat persistent portal vein thrombosis following pediatric liver transplantation. Subsequently indications rapidly extended to cure idiopathic portal hypertension in children with cavernomatous transformation of the portal vein in the presence of a healthy liver [9–11, 13–15]. It has been shown to reverse complications resulting from chronic portosystemic shunting including the hepatopulmonary syndrome, encephalopathy with improved neurocognitive ability, hyperammonemia and coagulopathy [11]. The Meso-Rex bypass can also prevent formation of large regenerative liver nodules and hepatocellular adenoma. It also improves somatic growth in those patients with growth retardation [11]. For these reasons, the Meso-Rex bypass should be considered the therapy of choice in children with EHPVO secondary to a cavernomatous replacement of the portal vein [11, 16].

The Meso-Rex shunt should be considered, anatomically and physiologically, as a bypass and not a shunt procedure because it restores physiologic, hepatopetal flow into the liver by bridging blood through an autologous graft from the superior mesenteric vein (SMV) into the recessus of Rex of the left portal vein, thereby bypassing the extrahepatic portal venous obstruction [17]. Imaging is essential to provide a road map of portal venous anatomy for surgical planning and also to exclude hepatic venous outflow obstruction and concomitant pathology [11, 16].

Preoperative assessment

The goals of preoperative Meso-Rex bypass imaging are to determine the extent of thrombosis to the splanchnic venous system and intrahepatic portal branches. Patency of the splenic and mesenteric veins must be assessed, as well as that of the recessus of Rex and the intrahepatic portal branches (portography). The internal jugular veins must be checked as they are the preferred material for the bypass. Further vascular assessments include evaluating for the presence of other large collaterals that might be used as alternatives for the Meso-Rex bypass material. Patency of the inferior vena cava (IVC), renal veins and the splenic

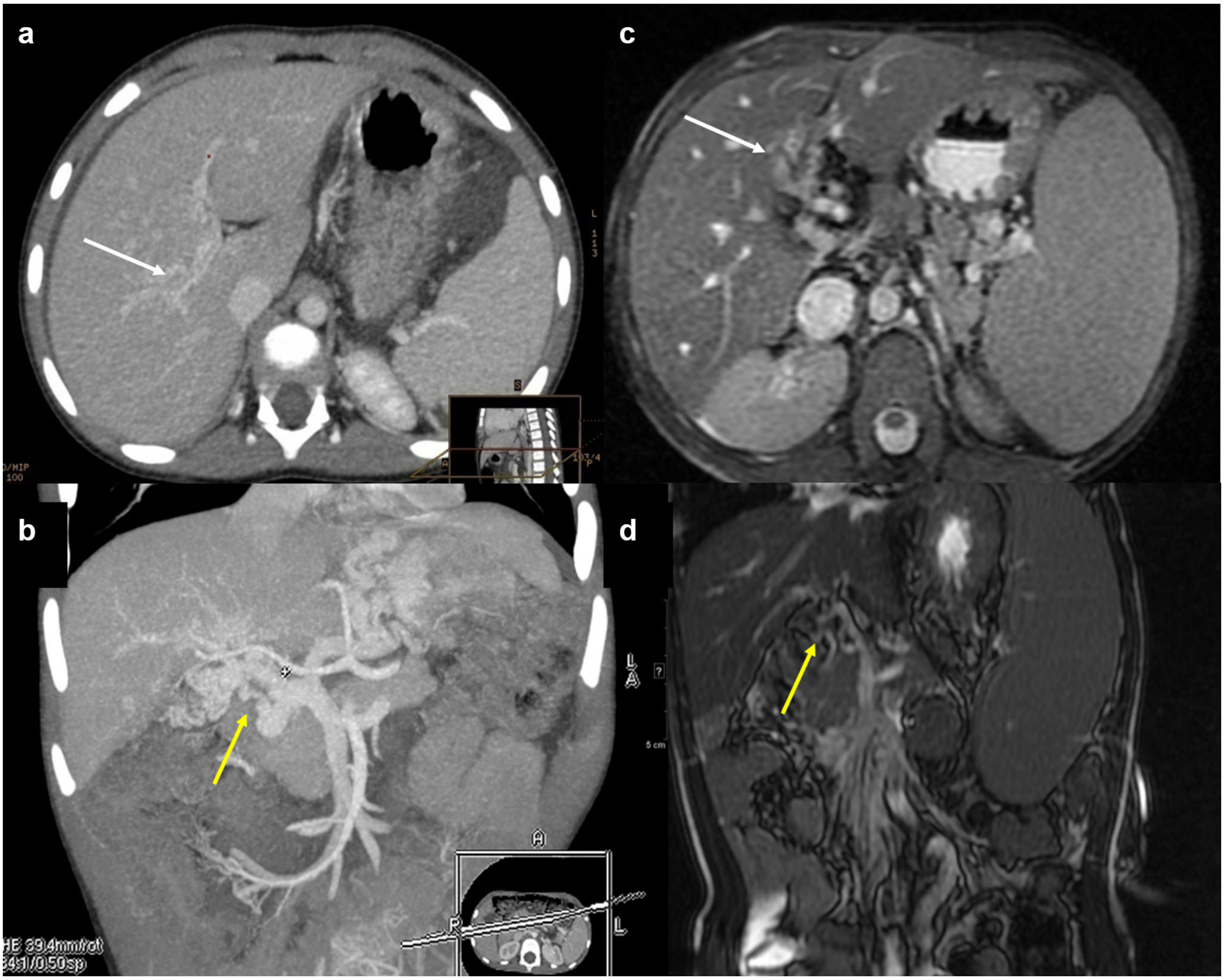

Fig. 4 **a** (CT) and **c** (MR) show cavernomatous transformation of the portal vein (white arrows). **b** (CT) and **d** (MR) show multiplanar images of the cavernomatous transformation (yellow arrows).

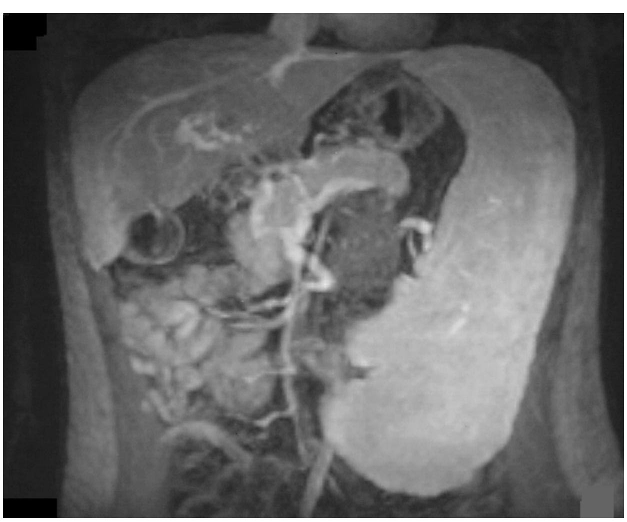

Fig. 5 Coronal post-contrast T1 fat-suppressed image shows liver atrophy and gross splenomegaly in another patient with EHPVO.

vein is also routinely assessed, together with a thorough hepatobiliary assessment [17].

Preoperative assessment: ultrasound and color Doppler

Our ultrasound (US) examination is performed using 6–15 MHz high-frequency linear transducer and 1–5 MHz convex transducer. Neck ultrasound (Fig. 1, 2) assesses both right and left internal jugular veins (patency, symmetry and diameter) [11]. Vein diameter should be ideally 10 mm or more to be adequate for the Meso-Rex shunt.

Abdominal US with Doppler examination (Fig. 3) is used to study the liver parenchyma (morphology; parenchymal echogenicity and nodularity) and to identify the intrahepatic portal branches (mainly the left portal vein and the recessus of Rex). Particular attention should be

Fig. 6 Twelve-year-old child with EHPVO secondary to neonatal umbilical vein catheterization. Endoscopic sclerotherapy and variceal ligation were performed to control variceal bleeding. CT showed large para-esophageal (**a**, white arrow) and peri-gastric collaterals (**b**, yellow arrow), together with gross splenomegaly (red asterisk).

Fig. 7 Four-year-old child with an idiopathic portal vein cavernoma, and a previous history of upper gastrointestinal bleeding. CT shows the portal vein cavernoma (white arrow), gross splenomegaly and portosystemic venous collaterals secondary to severe portal hypertension (yellow arrow).

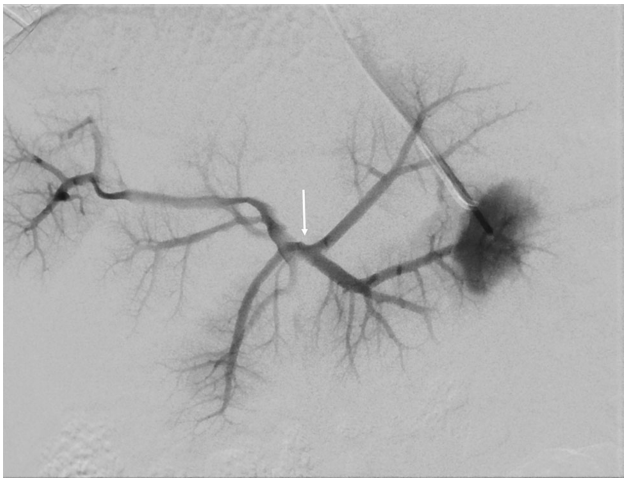

Fig. 8 Same patient as in Fig. 7. Angiographic images show retrograde filling of the intrahepatic portal vessels (including the Rex segment) following wedged left hepatic venography (arrow). Complete opacification of the intrahepatic venous portal system is seen, this includes the segmental portal branches, indicating a favorable anatomy (Type A as per Bertocchini classification). Meso-Rex shunt was performed.

made to the abdominal venous compartment (SMV, splenic vein, splenomesenteric confluence), spleen size and the presence of spontaneous splenorenal shunts (for follow-up purposes). Further findings that might be seen on ultrasound include dilated intrahepatic bile ducts (secondary "portal biliopathy"), gallbladder varices, together with the presence of gallstones and sludge [9, 11].

Preoperative assessment: CT and MR

An abdominal US with Doppler examination of the abdominal vasculature may suffice in the preoperative assessment. However, in our experience and those of other authors, low-dose post-contrast portal venous phase Multidetector CT (MDCT) best depicts the prerequisite vasculature for the mesoportal bypass, particularly the anatomy of SMV and splenic vein, which are commonly obscured by bowel gas if evaluated by US. In addition, 2D and 3D reconstructions might help the surgeon understand the portal vein anatomy in different projections [18–21].

In our protocol, we perform CT examination directly after injection of nonionic contrast medium (Visipaque 320, Iodixanol, GE, USA; 1.5 mL/kg at 0.8–1 mL/s), with arterial and portal phases. The arterial phase timing is determined by smart-prep technique when the contrast reaches the abdominal aorta. Portal venous phase is obtained following a delay of approximately 30 s from the

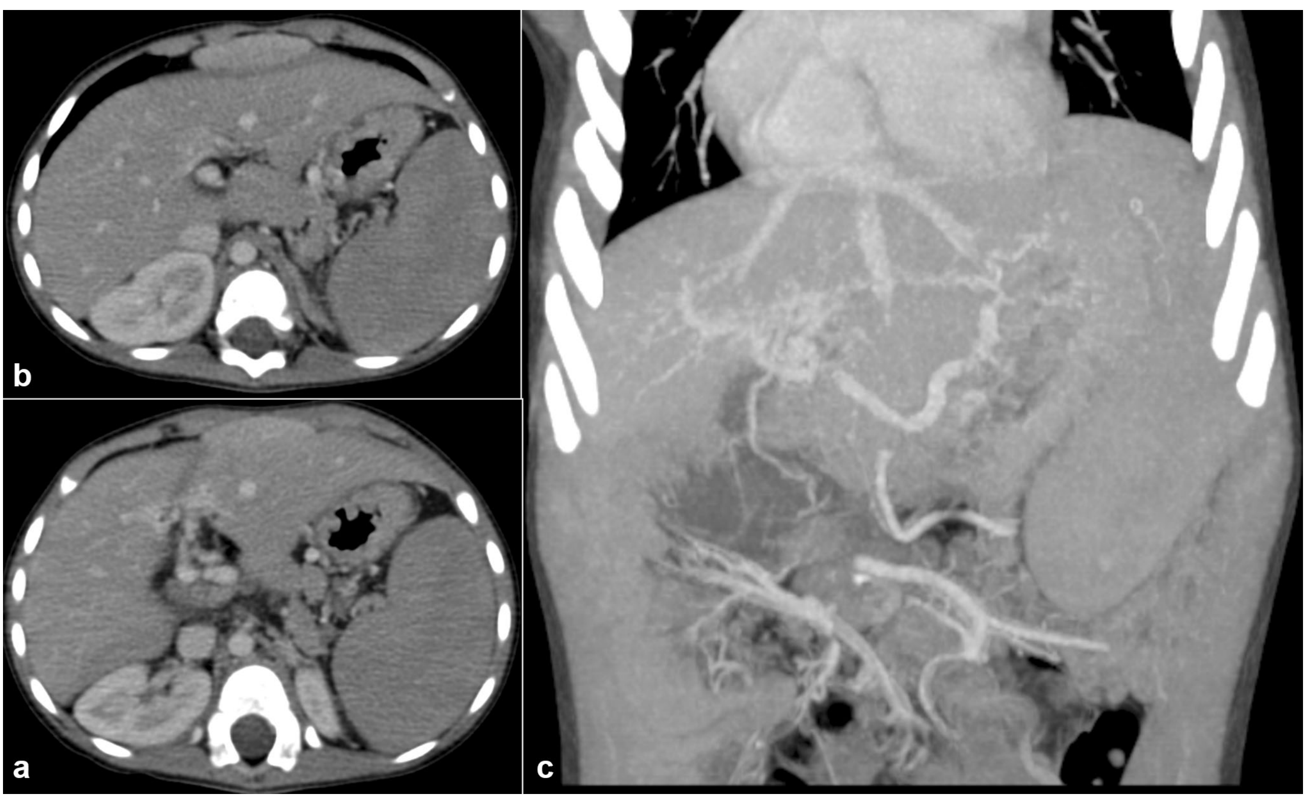

Fig. 9 Three-year-old child with idiopathic portal vein cavernoma. Axial and coronal CT images show a main portal vein cavernoma (**a**) and very thin intrahepatic portal vessels (**b–c**). Gross splenomegaly and portosystemic shunts are also noted.

initiation of arterial phase. Occasionally MR can be used instead of CT. While CT has higher spatial resolution at the cost of using ionizing radiation, MR imaging offers the advantages of multiplanar and multiphase imaging, high contrast resolution and lack of ionizing radiation. The longer acquisitions make MRI more sensitive to motion. Our MR imaging protocol includes T1 and T2 weighted precontrast sequences and a dynamic study with arterial, portal and delayed phases after gadolinium contrast medium administration (Dotarem, gadoterate meglumine, Guerbet, France; 0.2 mmol/kg at 0.8–1 mL/s). The arterial phase timing is determined by real-time fluoroscopic triggering when the contrast reaches the abdominal aorta. Portal venous phase is performed following a delay from the initiation of arterial phase of approximately 30 seconds. Post-contrast fat-saturated T1 coronal and axial images are obtained. Mature and cooperative patients follow breath-holding instructions during the CT and MR examinations. Children who cannot cooperate for the study are examined under sedation or general anesthesia. Sedation is usually sufficient for CT (given the rapidity of this examination). On the other hand, general anesthesia with controlled breath holds could be necessary during multiparametric MRI, given that most sequences are motion sensitive. The main disadvantage to this is that children would be exposed to the risks of sedation and/or anesthesia.

Preoperative imaging in patients with extrahepatic portal vein obstruction can also show the sequelae of portal hypertension. The characteristic finding is replacement of the occluded main portal vein with a cavernoma at the porta hepatis (Fig. 4). Splenomegaly, gastric and esophageal varices and other intraabdominal collaterals may be present (Figs. 5, 6). Collaterals may extensively overshadow the intrahepatic portal system [7].

Cavernomatous transformation may be limited to the liver hilum or extend to variable degrees along intrahepatic branches. In the most severe cases, there is extensive replacement of the entire splanchnic and portal venous system with the complete loss of vascular landmarks [16–21].

Preoperative assessment: wedged hepatic venous portography (WHVP)

Conventional noninvasive imaging (US, CT, MRI) is not very reliable in assessing patency of the intrahepatic portal venous system and/or the Rex segment of the left portal vein, given the hypodynamic circulation in patients with

Fig. 10 Same patient as in Fig. 9. Indirect venography, anteroposterior (**a**) and oblique (**b**) fluoroscopic view. Retrograde filling of intrahepatic portal vessels following left hepatic vein catheterization, showing the recessus of Rex (arrows). Indirect venography results in better visualization of the intrahepatic portal vessels as compared to CT, given the retrograde flow through the hepatic sinusoids that distends the portal radicles. Meso-Rex shunt was performed.

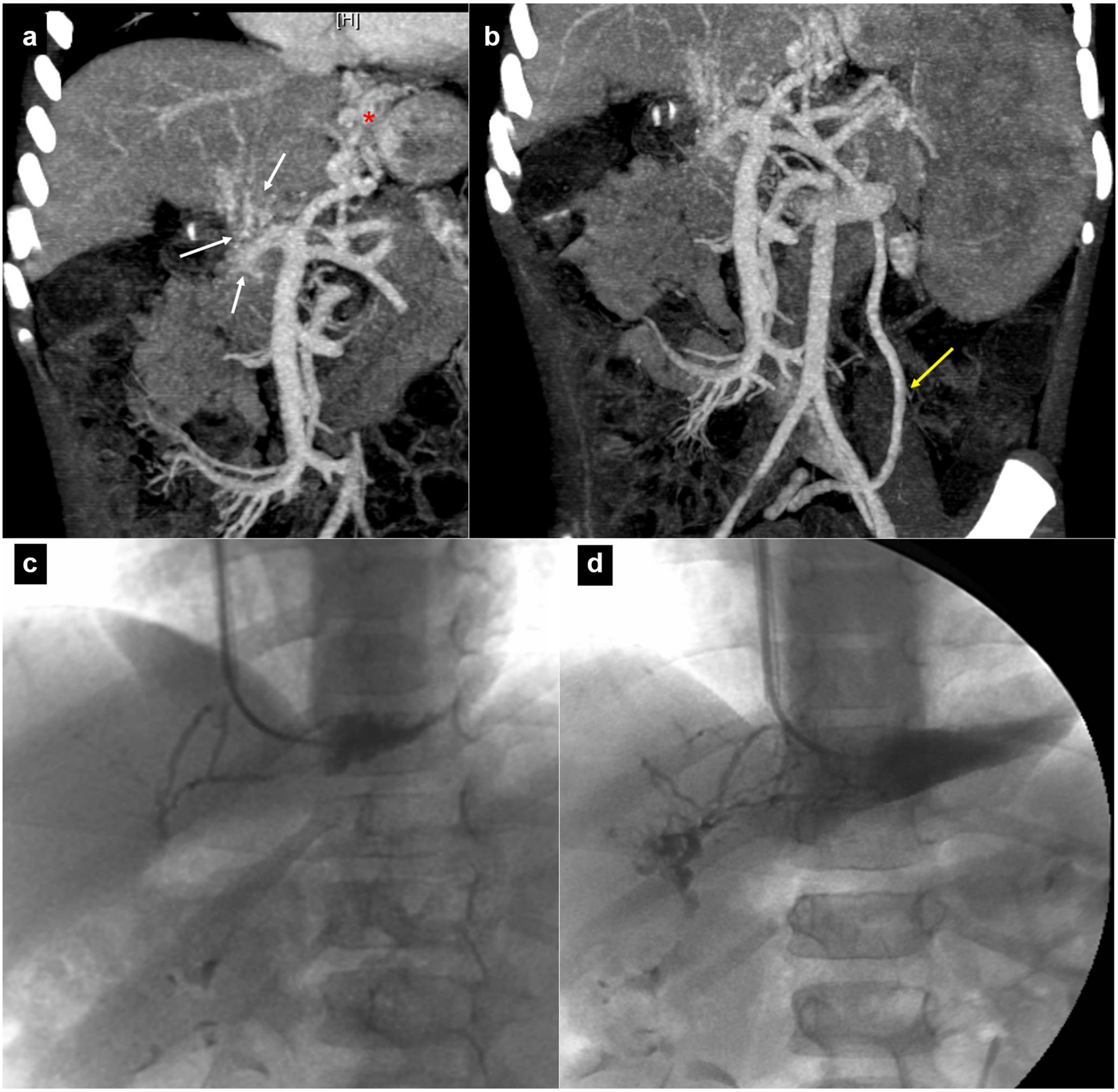

Fig. 11 Six-year-old child with EHPVO secondary to neonatal umbilical vein catheterization. Maximum intensity coronal CT images show a patent superior mesenteric vein and spleno-/mesenteric confluence, a portal vein cavernoma (white arrows) with patent coronary vein and filling of gastroesophageal varices (red asterisk) (**a**). Gross splenomegaly and portosystemic shunting between the inferior mesenteric vein and the left internal iliac vein (yellow arrow) (**b**). The intrahepatic portal branches not clearly visualized. Wedged retrograde portography shows thin intrahepatic portal branches (**c**–**d**), precluding Meso-Rex shunt surgery.

cavernoma. Retrograde portography is considered as being the gold standard imaging technique in these cases [8, 12, 16]. Retrograde filling of the intrahepatic portal veins is achieved via a catheter wedged in the relevant hepatic veins. The procedure is performed in angiosuite under monitored anesthesia care with spontaneous respiration and local anesthesia, or under general anesthesia. The right internal jugular vein is punctured under ultrasound guidance using a 21 Ga needle and a standard micro-puncture set system.

A 5F vascular introducer is placed with distal tip in right atrium. The right or left hepatic veins are catheterized under fluoroscopic guidance with a 5F angled hydrophilic angiographic catheter over a hydrophilic wire. The tip of the catheter is wedged in a peripheral branch of the left hepatic vein. Indirect venography is performed by hand

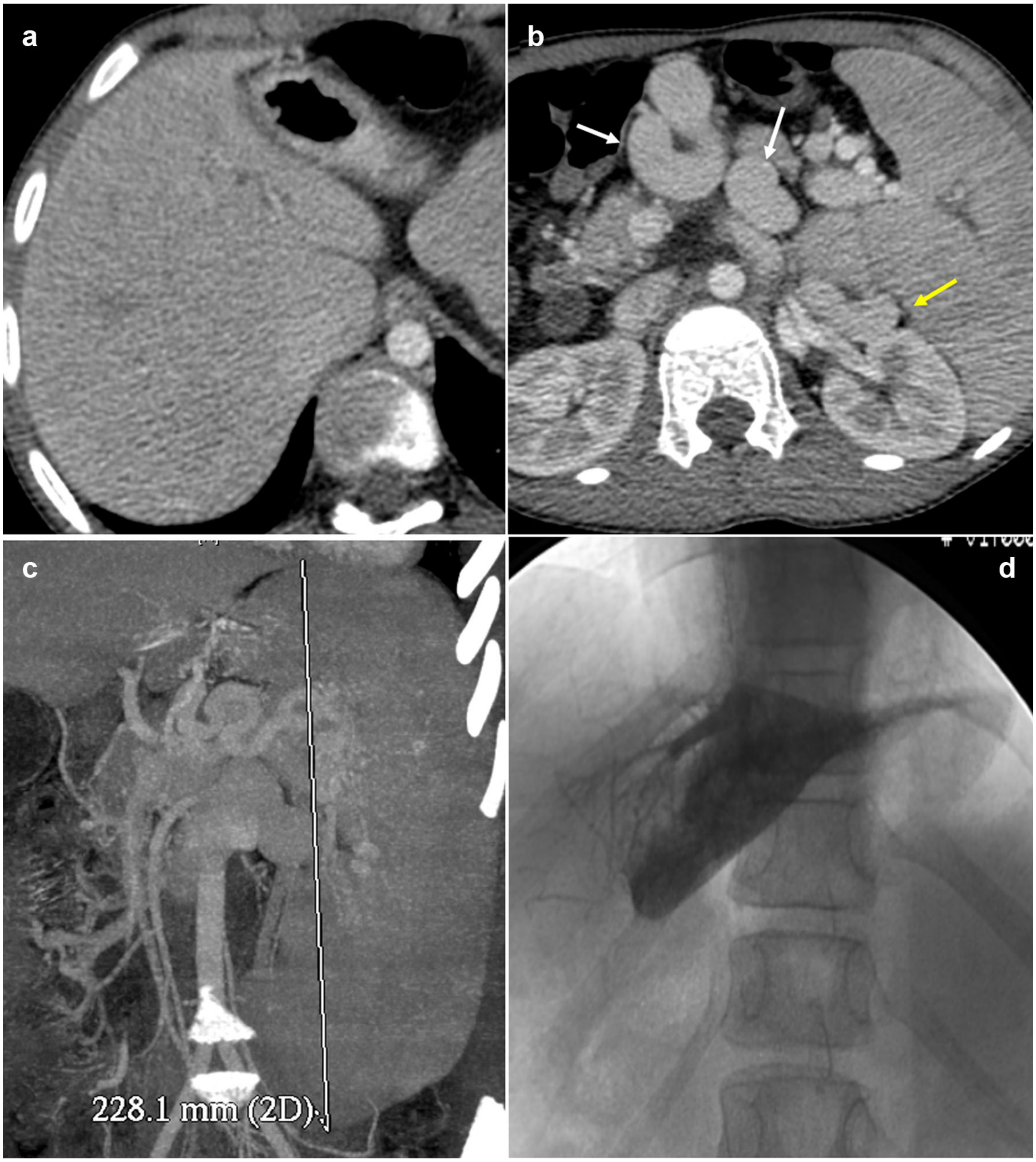

Fig. 12 Thirteen-year-old child with EHPVO secondary to neonatal umbilical catheterization. MDCT showed absence of intrahepatic portal branches (**a**). Large peri-gastric and perisplenic collaterals are seen (white arrows, (**b**); together with a large perisplenic collateral near the left renal vein (yellow arrow). A reformatted coronal image showed gross splenomegaly (**c**). Retrograde wedged portography (**d**) showed very thin intrahepatic portal branches, a splenorenal shunt was performed in this patient.

injections of a small amount (4–8 cc) of iso-osmolar contrast medium. Anteroposterior and right anterior oblique position with cranial and/or caudal angulations are often necessary to depict the Rex segment. The right hepatic vein can also be used; however, this often does not adequately delineate anatomy of the left portal vein [14, 22]. A selected case with anatomy favorable to a Meso-Rex bypass is shown in Figs. 7, 8, 9 and 10, and two cases with unfavorable anatomy are shown in Figs. 11, 12 and 13.

Surgical procedure

In Meso-Rex shunt surgery, an internal jugular vein graft is harvested and used to circumvent the EHPVO by connecting the SMV with the portion of the left portal vein located at the recessus of Rex of the liver (Fig. 14). This Rex portion of the left portal vein is usually not involved by the extensive network of collaterals that may occur in extrahepatic portal venous obstruction and cavernoma

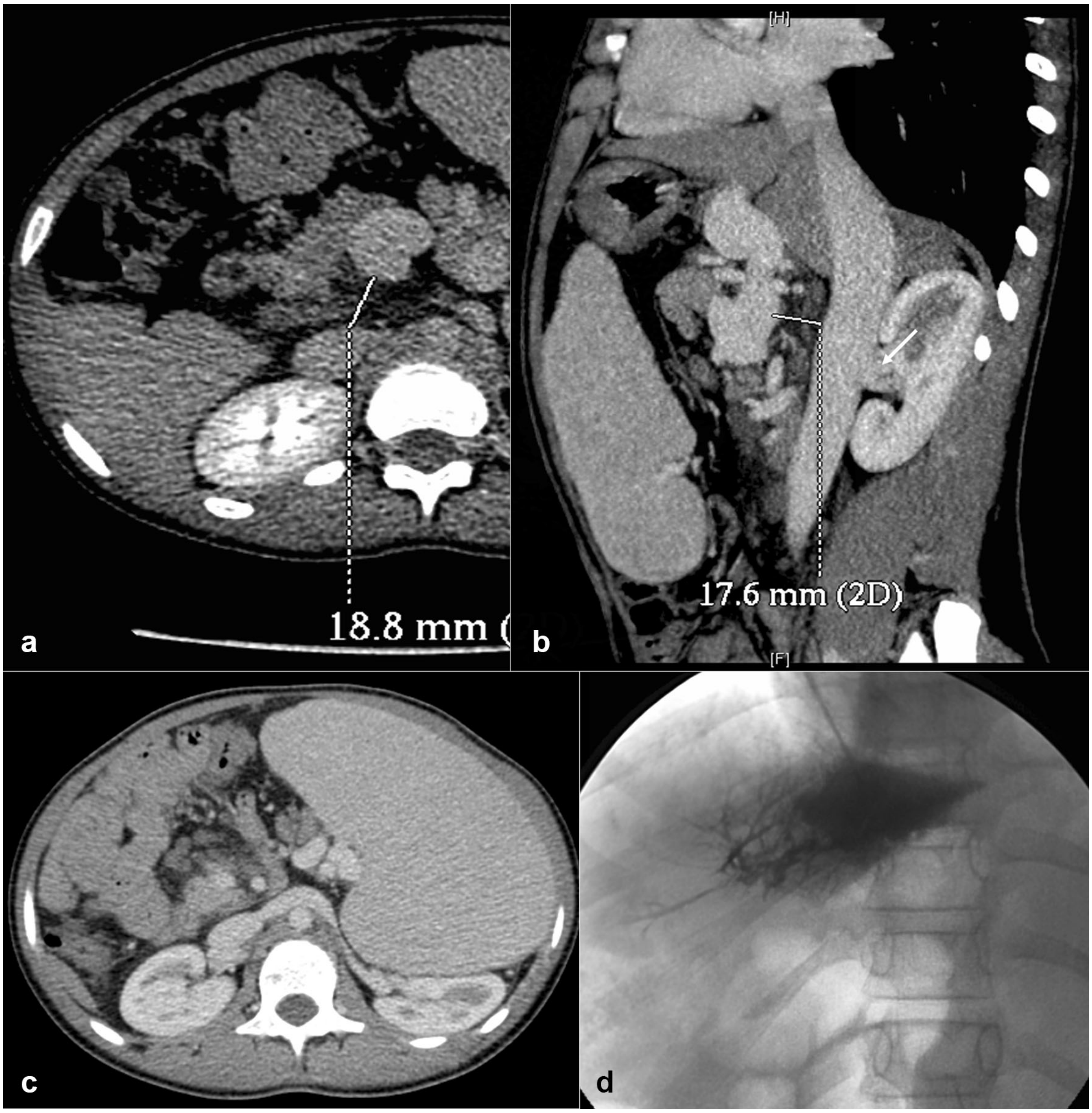

Fig. 13 Twelve-year-old child with idiopathic EHPVO. CT shows a patent splenomesenteric confluence and superior mesenteric vein, in close proximity to the inferior vena cava (**a**–**b**). Caudal displacement and compression of the left renal vein is seen, secondary to gross splenomegaly (**c**). Wedged retrograde portography (**d**) showed very thin intrahepatic portal branches. A meso-caval shunt was preferred.

formation, making it ideal for Meso-Rex bypass surgery [23]. The recessus of Rex is located between hepatic segments III and IV and is identified by following the obliterated umbilical vein (round ligament) to the left portal vein. The graft is anastomosed to the junction of the umbilical remnant and left portal vein via an end-to-side anastomosis and to the SMV by another end-to-side anastomosis (Fig. 15) [9, 11, 23]. Intraoperative ultrasound plays a pivotal role during the procedure. In particular, the shunt is assessed twice by Doppler ultrasound, following intraoperatory unclamping and also after closure of the abdominal incision. A flow rate exceeding 15 cm/s is usually observed. However, this can reach 40 cm/s in some cases and 1 m/s in the small caliber veins around the Rex (Fig. 15) [11].

Post-surgical imaging

Doppler US is utilized as the primary modality both in the early postoperative period and for subsequent follow-up (Fig. 16). During the first week, the flow rate increases

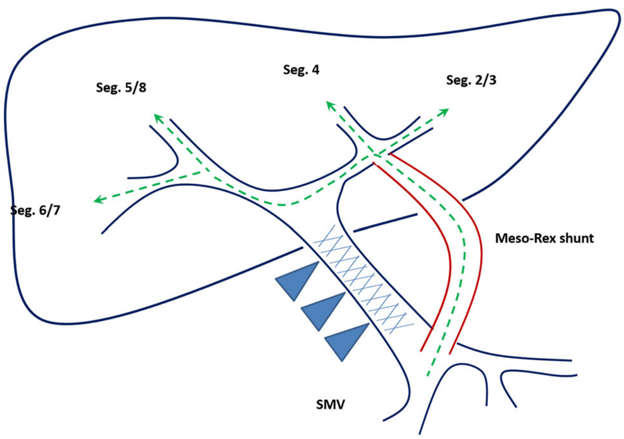

Fig. 14 Schematic illustration of the Meso-Rex shunt. Arrows denote appropriate direction of flow. Arrowheads indicate occluded extra-hepatic portal vein.

rapidly within the bypass and related portal hepatic branches to reach values twice or three times those seen intraoperatively. This is mirrored by a growth in diameter of the intrahepatic portal veins. In our institution, patients are seen after discharge for clinical follow-up and Doppler ultrasound check at 2 weeks, then at 1, 3, 6 months, and yearly in the long term [9].

CT or MRI can be used to depict Meso-Rex bypass anatomy in complex cases where US is inconclusive. Multiplanar and 3-D reconstructions are helpful to illustrate the course and patency of the bypass and the SMV, and the multiple anatomical variations of shunt anatomy can be present (Fig. 17) [16].

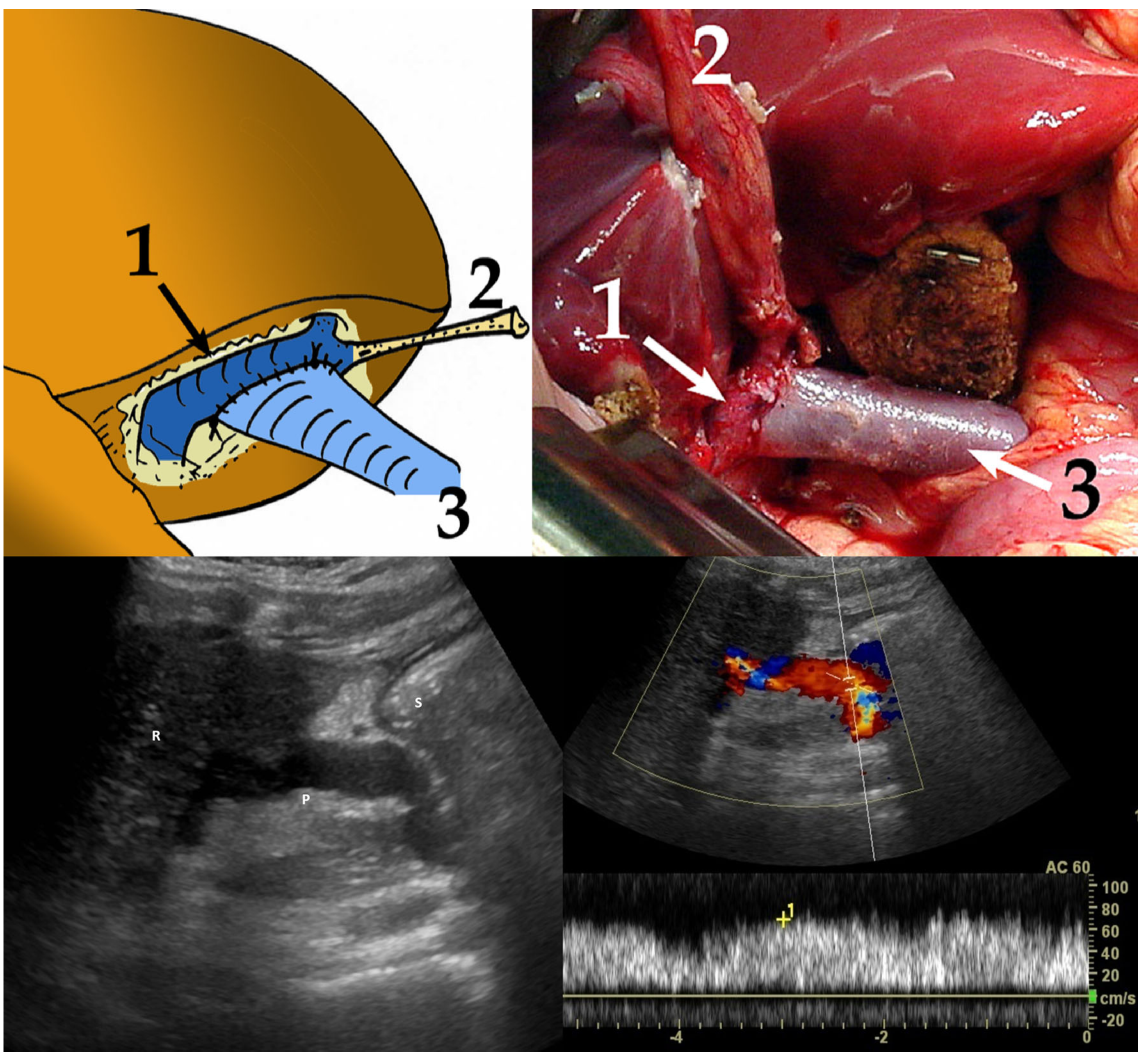

Fig. 15 Schematic drawing and intraoperative photograph (top images) shows the Rex Recessus (1), umbilical ligament (2), and the Meso-rex shunt-upper anastomosis into Rex recessus (3). B-mode and Doppler images of a Meso-Rex bypass, obtained immediately following closure of the abdominal incision. The bypass starts from the superior mesenteric vein to the recessus of Rex (R), lying anterior to the pancreas (P) and posterior to the stomach (S). Doppler analysis confirms excellent flow in the bypass.

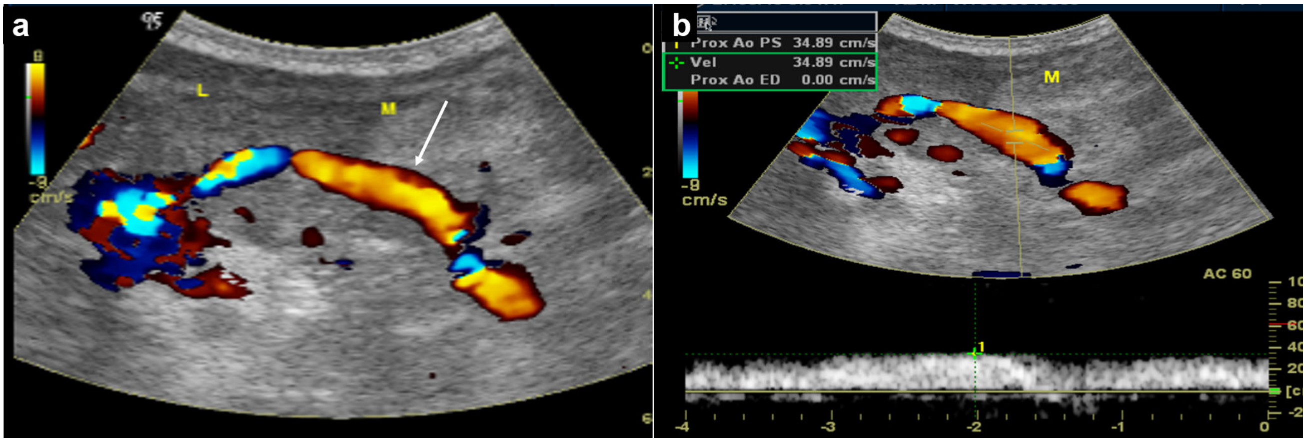

Fig. 16 Follow-up Doppler ultrasound shows patency of a Meso-Rex shunt (arrow) (**a**) with good flow velocity and hepatopetal flow into the intrahepatic portal veins (**b**).

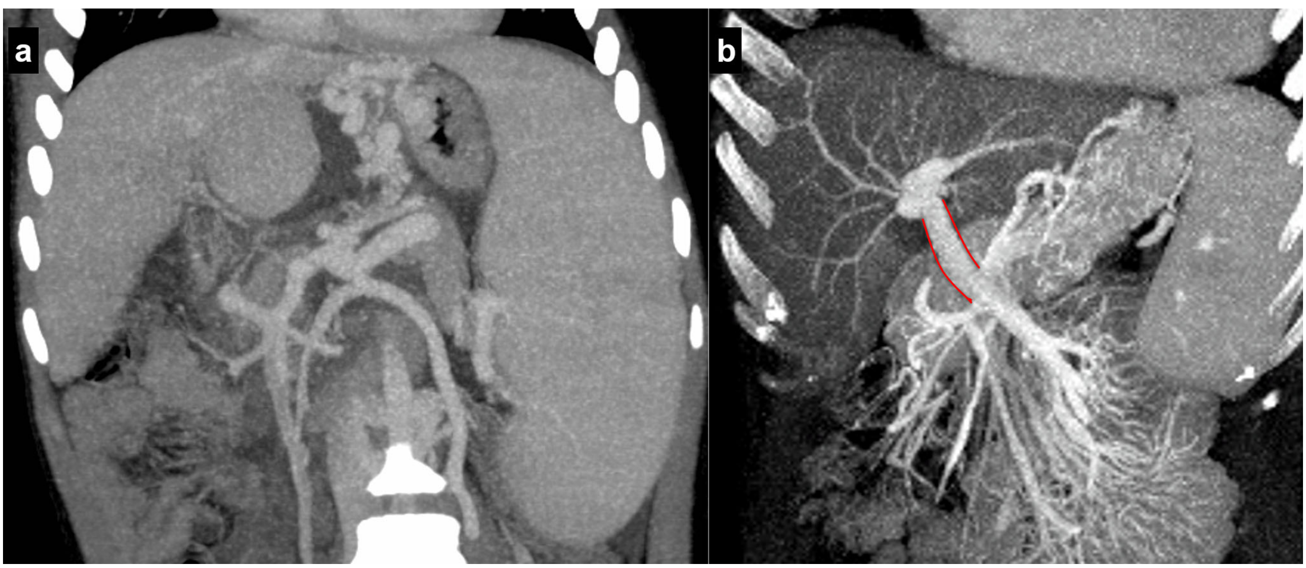

Fig. 17 Coronal CT images prior to, and two years following, Meso-Rex shunt surgery (**a** and **b**, respectively). The portosystemic collaterals visible in (**a**) have resolved post-surgery, given restoration of physiological hepatopetal flow. Liver morphology has normalized and the spleen size has also reduced.

Postoperative complications

Postoperative complications following Meso-Rex bypass surgery include fluid collections, stenosis and thrombosis of the bypass graft. Fluid collections, such as hematoma, seroma or abscess, can be seen immediately after surgery in relation to the shunt (Fig. 18). Stenosis and thrombosis of the bypass graft typically occur weeks to years after surgery and may be clinically evident with recurrence of portal hypertension and elevated ammonia levels [9–11, 15, 16].

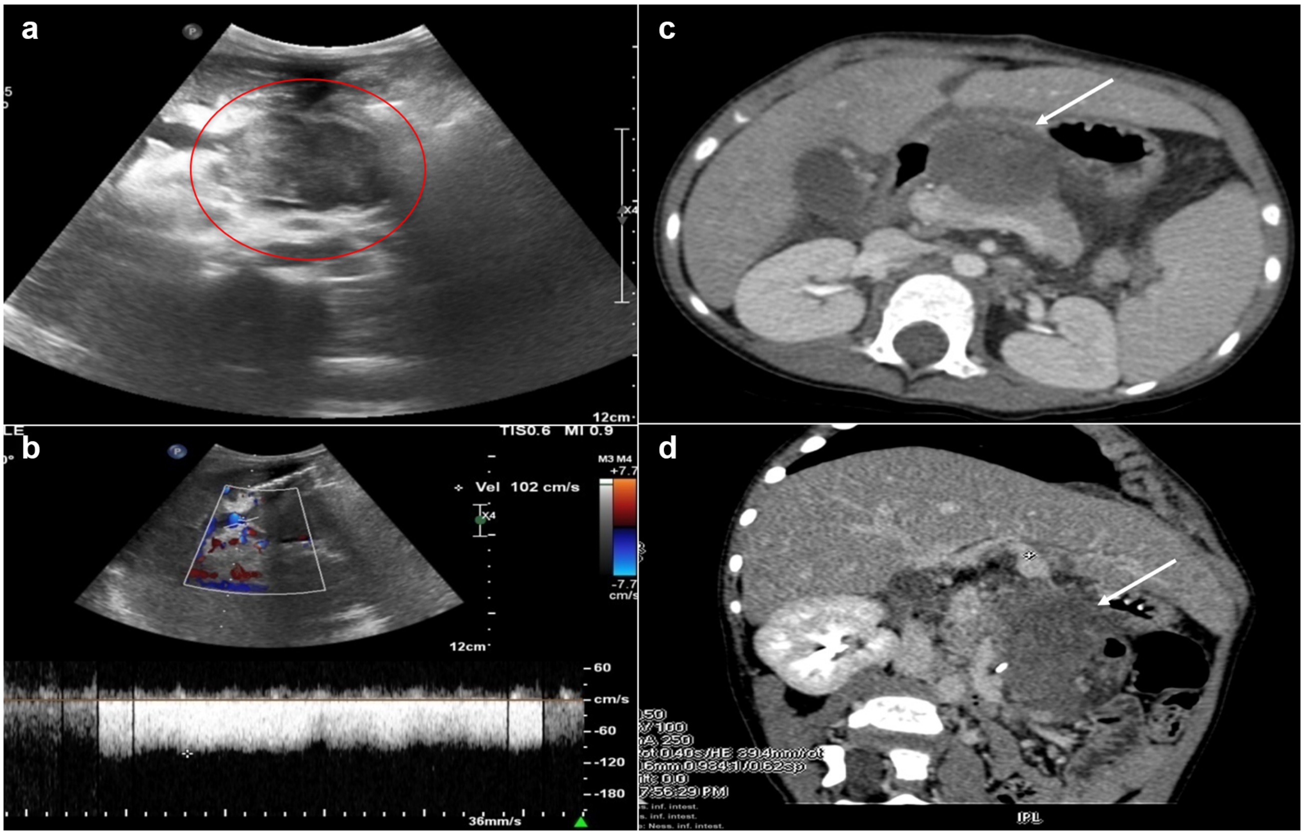

Fig. 18 Ultrasound image **a** shows a hematoma near the Meso-Rex shunt (red circle). This hematoma is causing extrinsic compression of the shunt, as shown by high flow velocity during Doppler examination (**b**). The hematoma is also seen on CT (arrows in **c**, **d**).

Stenosis

Nonocclusive thrombosis or intimal hyperplasia can result in stenosis of the graft bypass. This most commonly occurs in the left portal vein anastomosis. Color and spectral Doppler US will show increased flow velocity with a post-stenotic jet, aliasing and turbulence. A stenotic jet velocity fourfold greater than the flow velocity of the prestenotic portal vein segment is characteristic of stenosis [16]. Stenosis can be treated with transhepatic portography and intervention. Venous pressures can then be measured in the right portal vein and across the Meso-Rex bypass. Sites of stenosis seen on venography or sites of pressure gradients noted by manometry are treated with balloon dilation. In general, balloon dilation can be performed when pressure gradients of greater than 5 mmHg are present or when a radiographically visible stenosis causes flow acceleration (Fig. 19).

Occlusion

Thrombosis or high-grade stenosis represents the main causes of bypass graft occlusion. CT shows a low-density cord, representing the occluded bypass. US can show acute thrombus with a hypoechoic appearance, and color Doppler demonstrates an absence of flow (Fig. 20) [16].

Thrombolysis, with a percutaneous transhepatic approach, can be used to clear the thrombus and re-establish graft bypass blood flow when the diagnosis is made promptly [16].

Further complications

An exceptional case of hepatic artery pseudoaneurysm after Meso-Rex bypass procedure has been observed in our institution, likely secondary to iatrogenic injury during the preparation of the recessus of Rex at surgery (Fig. 21)

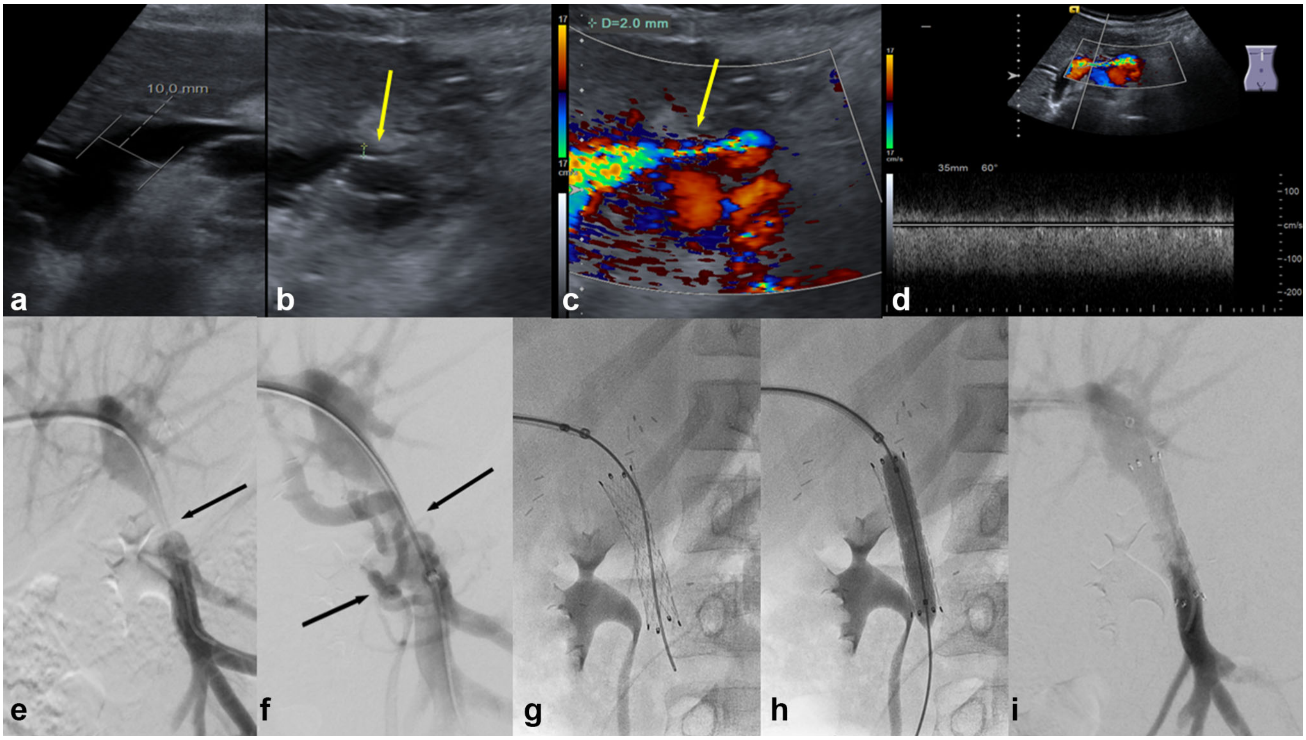

Fig. 19 Stenosis of a Meso-Rex bypass. Ultrasound shows post-stenotic dilatation (**a**) and stenosis (yellow arrow in **b**) of the Meso-Rex bypass, at the point where it joins the left portal vein. Color Doppler US shows turbulent flow as aliasing (yellow arrow in **c**) and high flow velocities in the stenotic segment (**d**). Venogram, obtained via a transhepatic portal venous approach, demonstrates stenosis (black arrow in **e**) of the Meso-Rex to left portal vein anastomosis and filling of venous collaterals (black arrows in **f**). Venoplasty was performed, followed by stenting (**g**, **h**). Post-dilation venography (**i**) demonstrates improved caliber at the stenosis without the appearance of the collateral veins.

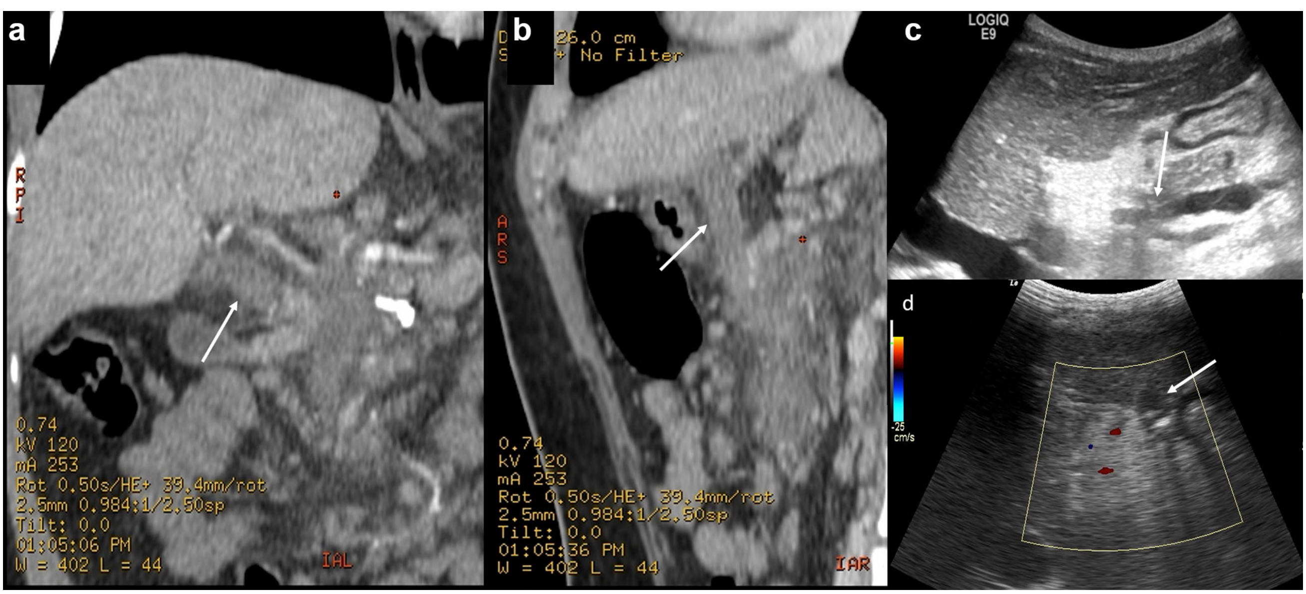

Fig. 20 CT (**a**, **b**) and ultrasound (**c**, **d**) images showing an occluded Meso-Rex shunt (arrows) 5 days following surgery.

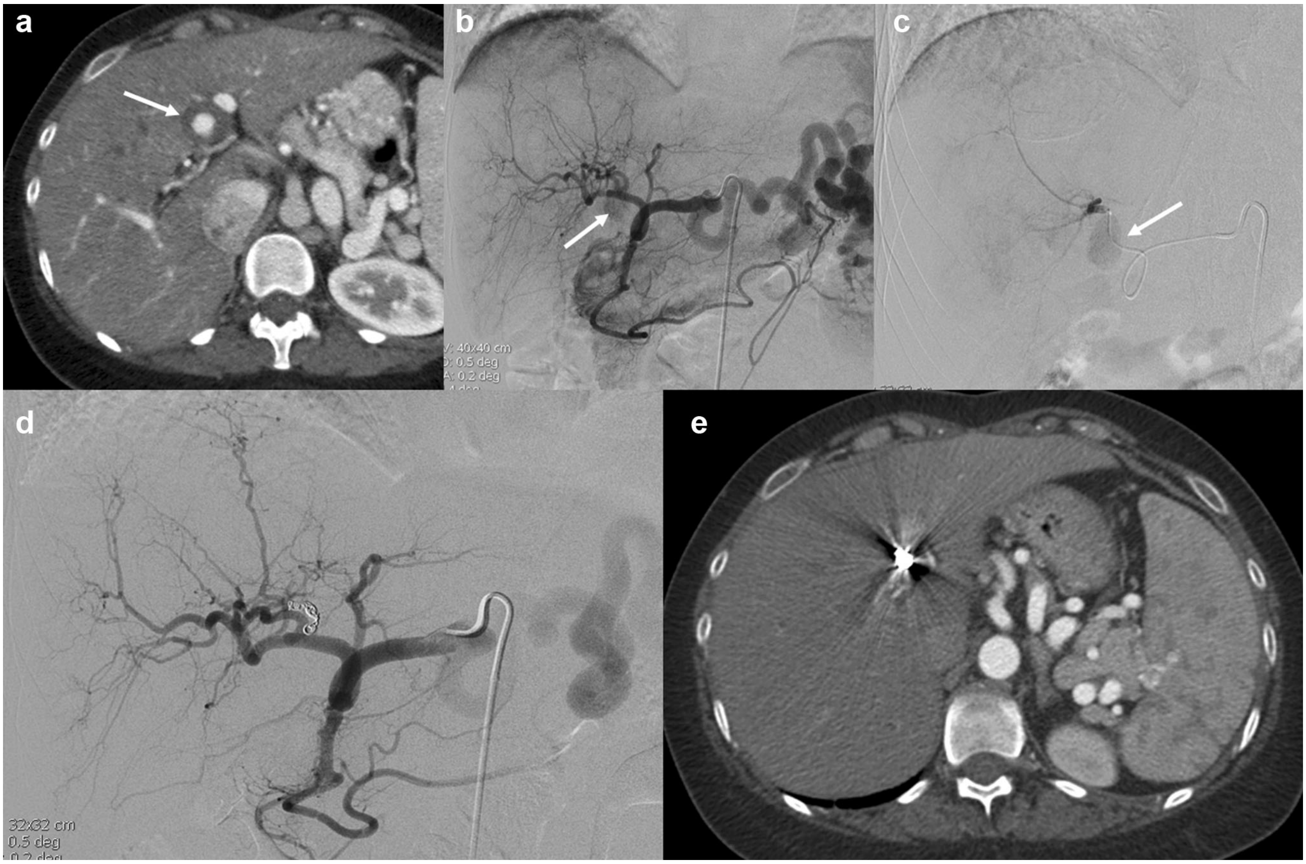

Fig. 21 CT and angiography images (**a**–**c**) show a hepatic artery pseudoaneurysm (arrows) following a Meso-Rex procedure, an uncommon complication. This was successfully managed via coil embolization (**d**, **e**).

Conclusion

The Meso-Rex bypass is nowadays the treatment of choice for EHPVO in pediatric patients given its unique ability to re-establish physiological hepatic portal venous blood flow. Radiologists must become familiar with Meso-Rex shunt anatomy because imaging plays an essential role in the pre and postoperative period to plan and subsequently monitor the Meso-Rex bypass. Imaging might also detect complications of this procedure, some of which might be treated via interventional radiology.

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