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REVIEW

Magnetic resonance imaging of fibropolycystic liver disease: the spectrum of ductal plate malformations

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Abstract

Fibropolycystic liver diseases, also known as ductal plate malformations, are a group of associated congenital disorders resulting from abnormal development of the biliary ductal system. These disorders include congenital hepatic fibrosis, biliary hamartomas, polycystic liver disease, choledochal cysts and Caroli disease. Recently, it has been thought to include biliary atresia in this group of diseases, because ductal plate malformations could be implicated in the pathogenesis of this disease. Concomitant associated renal anomalies can also be present, such as autosomal recessive polycystic kidney disease (ARPKD), medullary sponge kidney and nephronophthisis. These disorders can be clinically silent or can cause abnormalities such as cholangitis, portal hypertension, gastrointestinal bleeding and infections. The different types of ductal plate malformations show typical findings at magnetic resonance (MR) imaging. A clear knowledge of the embryology and pathogenesis of the ductal plate plays a pivotal role to understand the characteristic imaging appearances of these complex diseases. Awareness of these MR imaging findings is central to the detecting and differentiating between various fibropolycystic liver diseases and is important to direct appropriate clinical management and prevent misdiagnosis.

Keywords Fibropolycystic liver diseases · Ductal plate malformations · Magnetic resonance imaging

Introduction

Fibropolycystic liver diseases represent a complex continuum of pathological abnormalities that are thought to arise from a derangement of embryonic ductal plate development at various stages [1, 2].

These abnormalities include congenital hepatic fibrosis, biliary hamartomas, polycystic liver disease, Caroli disease, choledochal cysts and probably biliary atresia, since ductal plate malformation features have been reported on liver histology in patients with this disease. Ductal plate malformations can exist as individual conditions or in various combinations, suggesting the expression of a common underlying genetic abnormality. The clinical manifestations vary widely and include hepatic fibrosis, cholangitis, portal hypertension and renal anomalies [1, 2].

Magnetic resonance (MR) imaging plays a pivotal role, allowing a noninvasive accurate detection and differentiation of these disorders [3] and facilitating patient management.

The aim of this paper is to show the importance of knowing the embryological aspects of the fibropolycystic liver disease, to describe the MR imaging features of the spectrum of ductal plate malformations and also to discuss the relevant differential diagnosis of these entities.

Ductal plate embryologic development

The ductal plate is a transient structure and consists of a double cylinder of hapatoblasts surrounding portal vein branches, that develops during the embryonic life (Fig. 1). The hepatoblasts are bipotential cells and are capable of differentiating into hepatocytes or cholangiocytes (bile

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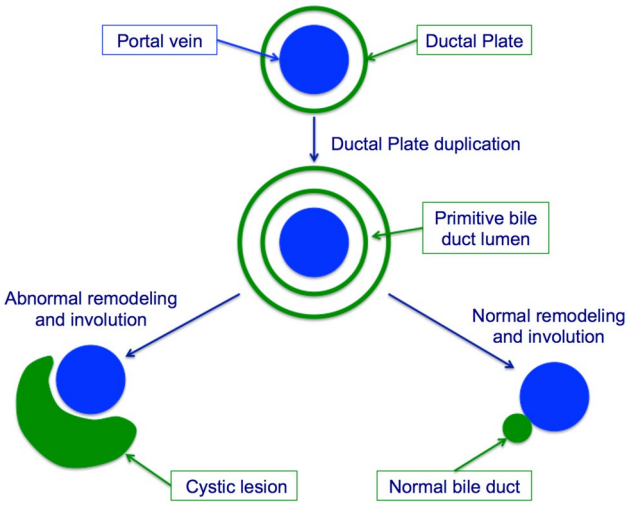

Fig. 1 Biliary ducts embryologic development. The ductal plate is a transient structure and consists of a double cylinder of hapatoblasts (green circles) surrounding portal vein branches (blue circle), that develops during the embryonic life. Biliary ducts are normally formed from remodeling and partial involution of these cylindric ductal plates. The alteration of this process can result in ductal plate malformations

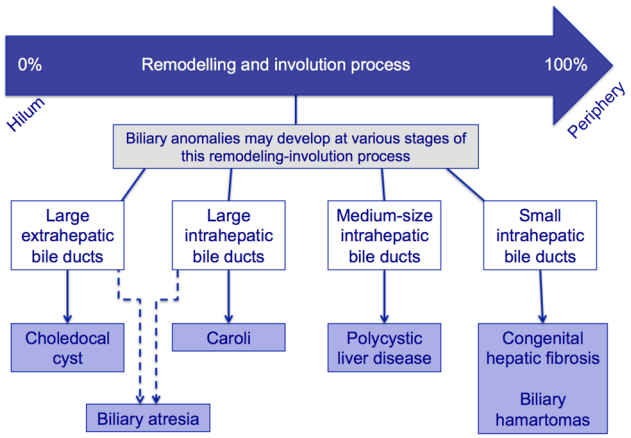

Fig. 2 Etiology of ductal plate malformations. The process of remodeling and partial involution occurs during the embryonic life, beginning from the hilum to the periphery of the liver with successive development of initially the larger ducts, the segmental ducts, the interlobular ducts and finally the smallest bile ductules. The alteration of this process can result in ductal plate malformations and the level of involvement determines the clinical and radiopathological manifestations. Recently, it has been thought to include biliary atresia in this group of diseases, because ductal plate malformations could be implicated in the pathogenesis of this disease

duct cells) [2, 3]. Biliary differentiation occurs when the embryonic cells are in contact with the mesenchyme surrounding the portal vein ramifications. This cell layer joins with a second layer to create a double epithelial cylinder of primitive biliary cells called "ductal plate" [2, 3].

Biliary duct development results from remodeling and partial involution of this ductal plate. In fact, some segments of the cylindrical lumen undergo dilation, forming tubular structures that are gradually incorporated into the portal mesenchyme, and the residual nontubular segments of the ductal plate disappear by apoptosis [2].

This remodeling and partial involution occurs during the embryonic life to form bile canaliculi of various sizes, beginning from the hilum to the periphery of the liver with successive development of initially the larger ducts, the segmental ducts, the interlobular ducts and finally the smallest bile ductules [2–4] (Fig. 2). The alteration of this process can result in ductal plate malformations and the level of involvement determines the clinical and radiopathological manifestations, and also the level of fibrosis, with fibrosis being a dominant feature with small duct involvement.

Malformations of the large extra-hepatic biliary ducts result in choledochal cysts, although controversy remains regarding this pathogenesis.

Caroli disease is characterized by ductal plate malformation of the large intrahepatic bile ducts. Involvement of medium-sized intra-hepatic ducts results in autosomal-dominant polycystic liver disease (ADPLD).

Involvement of small-sized intra-hepatic duct results in biliary hamartomas and congenital hepatic fibrosis. Furthermore, the intra-hepatic biliary duct system is still immature at birth, with final development of the smallest ramifications during the first few neonatal weeks; this condition makes them susceptible to noxious stimuli even during neonatal period [4].

Some authors think that hormones could play a role in this pathological process. Estrogen receptors are expressed in the epithelium lining the hepatic cysts and estrogens stimulate hepatic cyst-derived cell proliferation. This explains why in policystic liver disease the hepatic cysts are more prevalent and hepatic cyst volume is larger in women than in men and why women who have had multiple pregnancies or used oral contraceptive agents or estrogen replacement therapy have worse disease than those who have not [5]. Given that fibropolycystic liver diseases arise from the same pathological process resulting from abnormal embryogenesis of the biliary ductal system, it is important to understand that together these disorders form a spectrum and can exist as an individual conditions or in various combinations in the same patient.

Congenital hepatic fibrosis

Congenital hepatic fibrosis is an autosomal recessive developmental disorder that belongs to the family of hepatic ductal plate malformations and characterized histologically

by a variable degree of periportal fibrosis (Fig. 3) and irregularly shaped proliferating bile ducts, which progresses over time [4, 6, 7]. Clinico-pathologic features of this disorder are non-specific, making radiology an important tool in diagnosing this condition.

Portal hypertension is usually the first manifestations of the disease, with splenomegaly, varices and spontaneous gastrointestinal bleeding.

Onset of disease is variable from early childhood to the 5-6th decade of life, although in most patients the disorder is diagnosed in adolescents or young adults [7]. These patients show liver function tests normal or only modestly elevated. Some radiological findings of congenital hepatic fibrosis are reported [8]. Atrophy of the right lobe and hypertrophy of the left lateral segment and caudate lobe are reported mimicking the morphological changes in patients with advanced viral or alcoholic cirrhosis. However, the medial segment (segment IV) is normal in size or enlarged in congenital hepatic fibrosis while it is small in cirrhotic patients [8] (Fig. 4). This morphologic finding may be useful in distinguishing congenital hepatic fibrosis from cirrhosis. Periportal hepatic fibrosis is seen as high signal intensity among portal branches on T2-weighted MRI images and as hyperechoic periportal thickening on ultrasound [4, 9]. Other features frequently observed in congenital hepatic fibrosis are signs of portal hypertension, such as varices, splenorenal shunt, splenomegaly and ascites [8]. Furthermore, CT and MR findings in congenital hepatic fibrosis include vascular abnormalities and large regenerative nodules. Vascular abnormalities consist of enlarged hepatic artery or a tangle of abnormally numerous arterial vessels at the liver hilum, and portal vein thrombosis with or without cavernomatosis [10, 11]. Large regenerative nodules are the consequence of increased arterialization of the liver [6, 8, 12]. They are often multiple, with a size range of 5–30 mm, homogeneously hyperattenuating on hepatic arterial and portal venous phase without wash-out, and isointense on hepatobiliary phase (Fig. 5), simulating focal nodular hyperplasia (FNH) and regenerative nodular hyperplasia (RNH). Indeed, all together, these lesions show similar findings on imaging and pathology, but FNH occurs in healthy liver and the definition of "nodular regenerative hyperplasia" implies that no fibrosis is present between the nodules [12]. For this reason, in our opinion nodules encountered in patients with congenital hepatic fibrosis are better defined as FNH-like regenerative nodules, owing to the presence of fibrosis in the surrounding liver and the potential progression to cirrhosis [12]. The 50% of patients with congenital hepatic fibrosis had one or more associated biliary abnormalities, given that these conditions arise from the same pathological process [6, 7, 10]. Imaging may demonstrate the association with biliary hamartoma, Caroli disease (Fig. 4d) and choledochal cyst. Thus, magnetic resonance cholangiopancreatography (MRCP) sequences should be utilized to detail the biliary tree and illustrate other associated disorders. Moreover, there is coexistence with renal abnormalities and in particular with polycystic kidney disease and medullary sponge kidney (Fig. 4d). Although imaging can help achieve correct diagnosis noninvasively, definitive diagnosis is only made by liver biopsy [9].

Biliary hamartomas

Biliary hamartomas (BHs), also known as "von Meyenburg complex", are focal disorderly collections of dilated intrahepatic bile ducts, which are lined by a single layer of biliary epithelium embedded within a dense fibrous stroma [4, 12–14]. BHs typically appear as multiple round or irregular focal lesions of relatively uniform size (reported up to

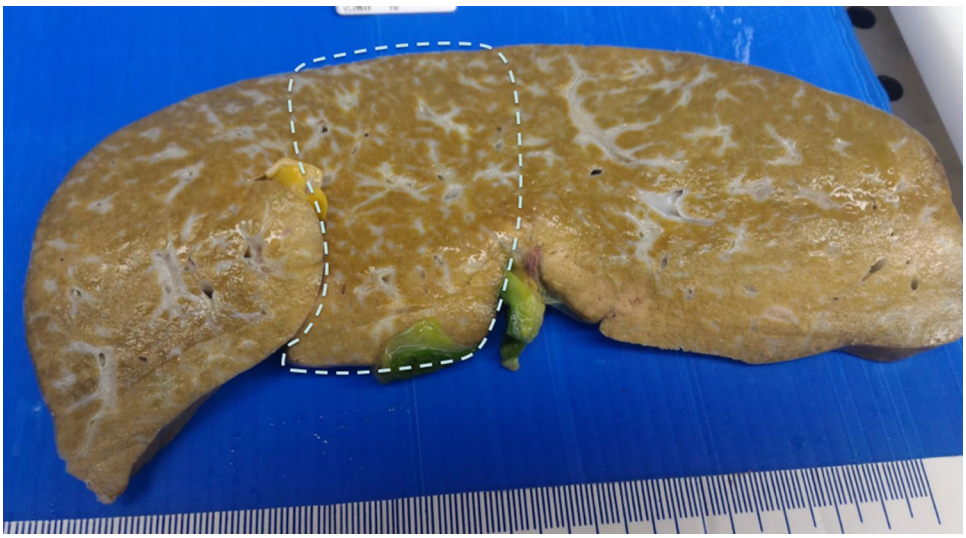

Fig. 3 Congenital hepatic fibrosis. Photograph of hepatic slice from explanted liver after tranplantation, showing diffuse periportal fibrosis (white areas along the portal branches). Notice the enlargement of segment 4 (white line)

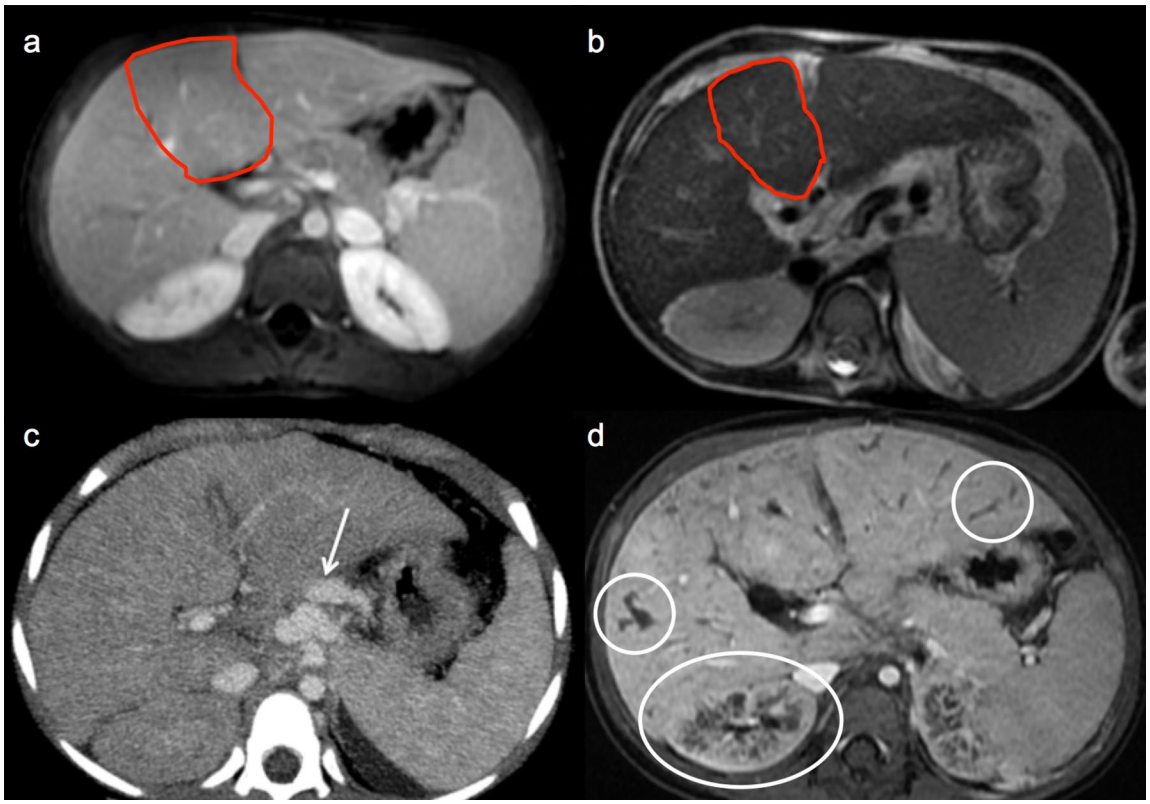

Fig. 4 Congenital hepatic fibrosis. Axial MRI (**a**, **b**, **d**) and CT (**c**) images showing hepatic morphology abnormalities in some cases of congenital hepatic fibrosis. Notice the enlargement of the forth segment (red lines), the hypertrophy of the left lobe and the atrophy of the right liver lobe, the coronary vein (arrow) and the association with Caroli disease and medullary sponge kidneys (white circles)

15 mm) scattered throughout the liver [12]. On ultrasound, biliary hamartomas present as multiple tiny hypoechoic or hyperechoic foci with comet-tail artefacts measuring less than 15 mm and distributed uniformly throughout the liver [4, 15, 16]. CT shows multiple, round, hypoattenuating, non-enhancing lesions [4, 12]. MR imaging is considered the gold standard imaging technique for the diagnosis of biliary hamartomas. On MRI, these lesions are hypointense on T1-weighted and hyperintense on T2-weighted images, equalling to the simple hepatic cysts and cerebrospinal fluid [4, 12, 17–21]. Furthermore, MR cholangio-pancreatography (MRCP) depicts BHs as multiple tiny T2 hyperintense cystic lesions, uniformly distributed in the liver, with no communication with the bile ducts, appearing as ''starry sky'' configuration (Fig. 6) [22]. The lesions do not show contrast enhancement although they may sometimes demonstrate thin rim enhancement with post-contrast imaging, and this is considered to correlate with the compressed liver parenchyma that surrounds the lesions [4, 21]. Hepatobiliary MR imaging is useful because the excretion of the hepatospecific contrast medium into the biliary system demonstrates the lack of communication between the BHs and the biliary ducts.

Biliary hamartomas can coexist with simple hepatic cysts or other fibropolycystic liver disease (Fig. 7). These lesions are often discovered incidentally, are usually clinically insignificant and if the patient has a primary neoplasm they can be mistaken for metastatic disease [12].

The differential diagnoses for BHs include liver metastases, simple hepatic cysts, microabscesses and lymphoma [23]. Biliary hamartomas are usually uniform in size and distribution, whereas liver metastases are usually more heterogeneous in size, distribution and in attenuation or signal intensity [4, 12]. Furthermore, the intensity of BHs similar to the cerebrospinal fluid and the "starry sky" sign on MRCP allow the differentiation from liver metastasis [19, 20]. Compared with biliary hamartomas, simple hepatic cysts are rarely as uniformly small or numerous; where biliary hamartomas coexist with simple hepatic cysts, these latter can be distinguished only by a bigger size. In autosomal dominant polycystic disease, the liver is often enlarged and the cysts are usually larger and more numerous. Microabscesses and lymphoma are usually more heterogeneous in size and in attenuation or signal intensity. In addition, it is reported that biliary hamartomas can be associated with increased risk of cholangiocarcinoma [24].

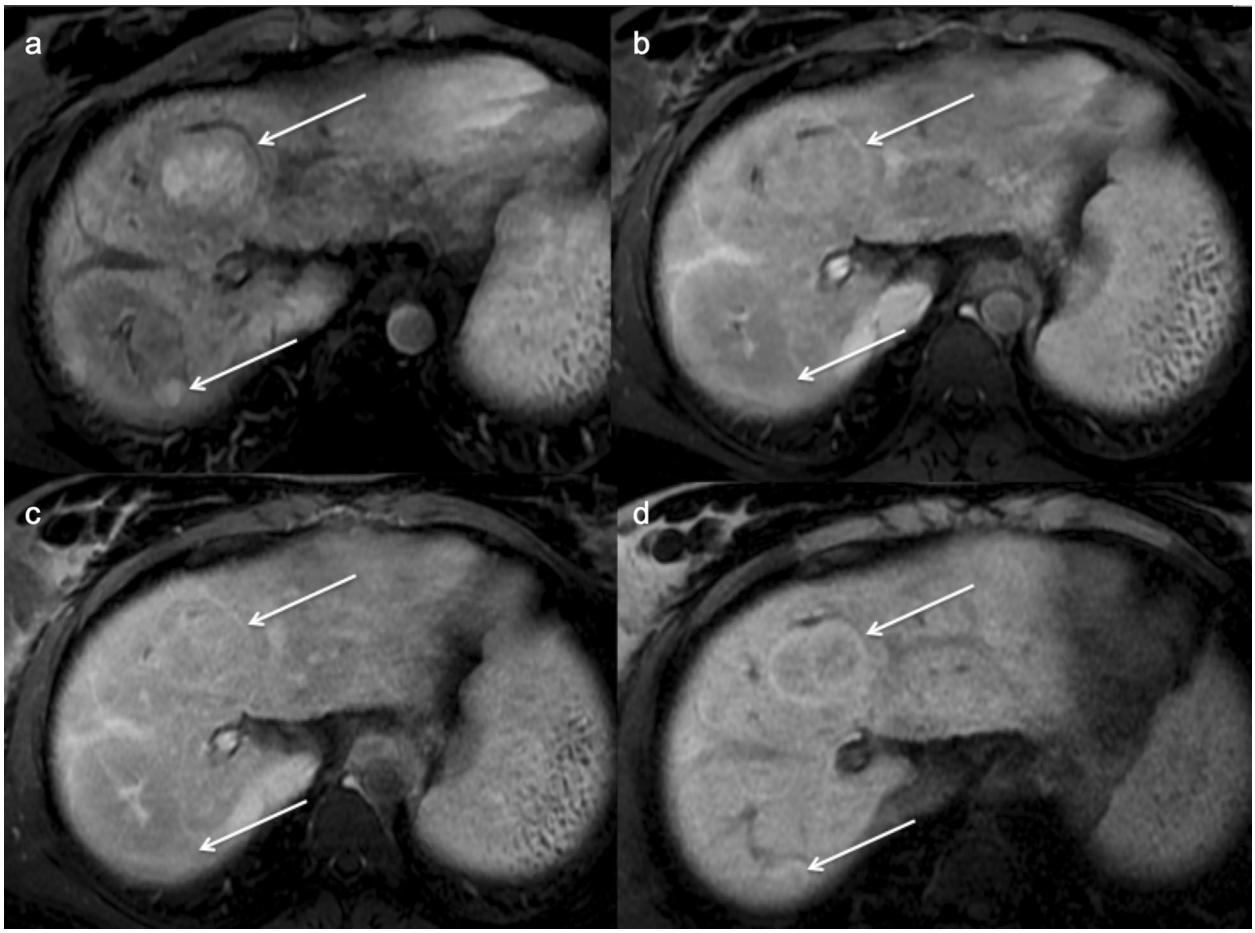

Fig. 5 Congenital hepatic fibrosis. MRI in patient with congenital hepatic fibrosis showing hypervascular regenerative nodules (arrows) on arterial (**a**), portal (**b**), late (**c**) and hepatospecific (**d**) phases. Notice the isointensity on hepatospecific phase (using Gadobenate dimeglumine) demonstrating the regenerative nature of the lesions

Polycystic liver disease

The polycystic liver diseases (PLD) comprise a group of genetic disorders characterized by the progressive growth of cholangiocyte-derived fluid-filled cysts that gradually replace liver tissue (Fig. 8). PLD occurs in combination with two forms of polycystic kidney disease (PKD)—autosomal dominant PKD (ADPKD) and autosomal recessive PKD (ARPKD) as well as alone (autosomal dominant PLD: ADPLD) [25–29].

ADPKD is the most common inherited nephropathy and the second most common inherited syndrome; the estimated prevalence of ADPKD is 1:400 [30, 31]. ARPKD is a childhood-onset disorder that occurs with a frequency of 1:20,000 live births; approximately half of ARPKD neonates die shortly after birth due to pulmonary hypoplasia [32].

ADPLD is characterized by the presence of cysts mainly in the liver with no or very few renal cysts; it is much less common than ADPKD, with a prevalence of 1:100,000. This condition is also a dominant autosomal affection and produces liver cysts identical to those seen in ADPKD. However, the genetic abnormalities in these two disorders are completely different [33]. Hepatic cysts are most commonly associated with ADPKD, where the development of liver cysts lags behind the onset of renal cysts [4]. In patients with ADPLD, the disease rarely presents in childhood and cysts increase slowly in size into adulthood [4].

Hepatic involvement occurs in 30–70% of patients with ADPKD, most of whom are female. The relationship between gender and cyst development is likely explained in terms of hormonal influences.

ADPLD is a milder disease than ADPKD and, unlike the latter, does not lower life expectancy. Renal cysts can occur, but there is no impairment of renal function. At imaging, patients with polycystic liver disease typically show an enlarged liver, with diffuse thin-walled cysts of varying size, ranging from less than 1 mm to 12 cm or more in diameter (Figs. 9, 10) [12, 34]. Two types of cysts may be found, intrahepatic cysts and peribiliary cysts (Fig. 10). The former result from progressive dilatation of the abnormal

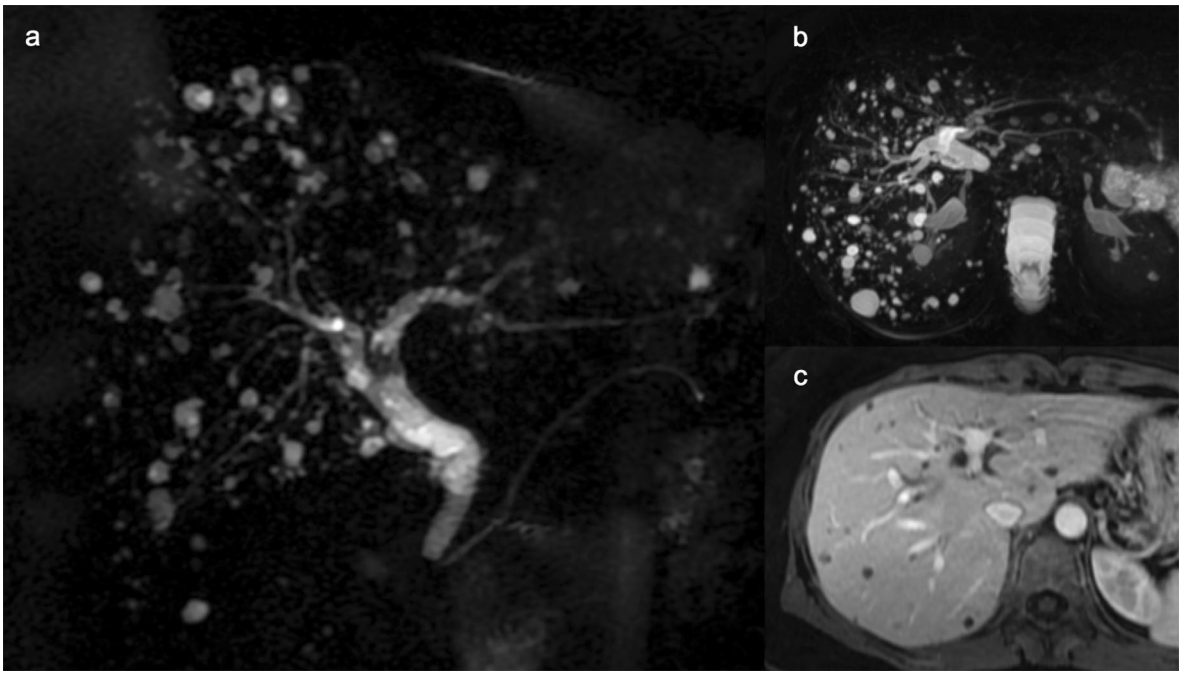

Fig. 6 von Meyenburg Complex. MR cholangiography images on coronal (**a**) and axial (**b**) planes show biliary hamartomas as multiple tiny T2 hyperintense cystic lesions, uniformly distributed in the liver, with no communication with the bile ducts, appearing as ''starry sky'' configuration. After contrast medium administration biliary hamartomas appear as multiple hypointense lesions that can mimick hepatic metastases

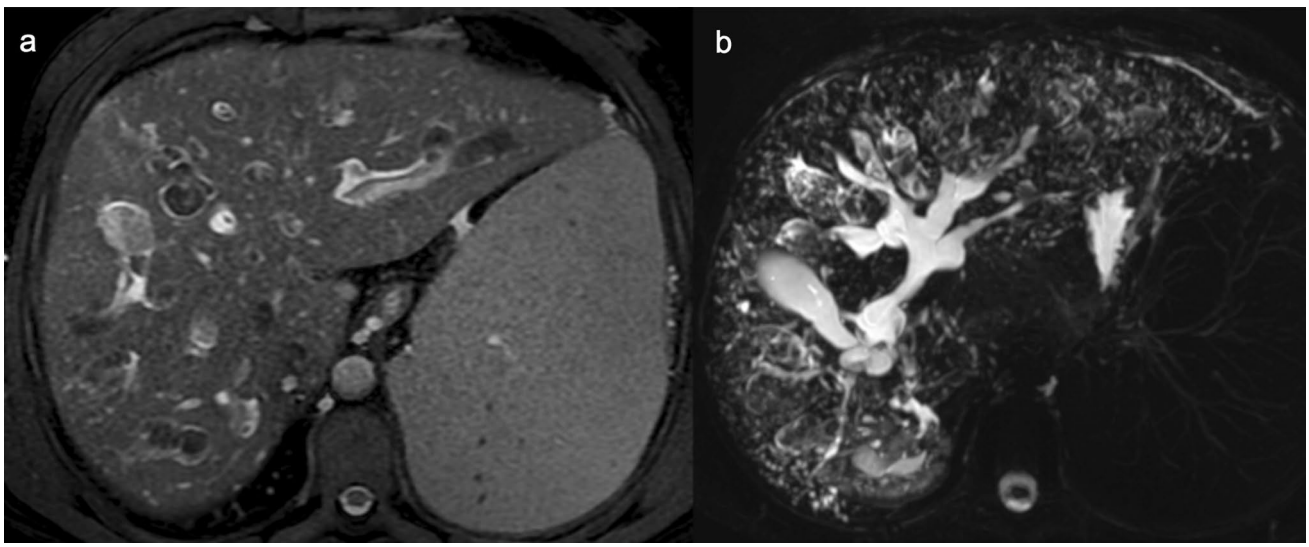

Fig. 7 von Meyenburg Complex. Axial T2-w (**a**) and 3D MRCP Maximum Intensity Projection reconstruction (**b**) MRI images in a patient with coexistence of biliary hamartomas (multiple tiny T2 hyperintense cystic lesions) and Caroli disease (intrahepatic bile ducts dilatation with calculi)

bile ducts in biliary hamartomas within the parenchyma, while the latter are derived from cystic dilatations of the peribiliary glands, which are physiologically distribuited in the connective tissue along the intrahepatic large bile ducts [35]. Intrahepatic cysts are more common, varying in size and mostly peripheral, usually located at a distance from the hilum, classically beyond the third-order branches of the bile tree. Peribiliary cysts are typically less than 10 mm in diameter and appear as either discrete cysts, a string of cysts or tubular structures along the portal vessels, in the perihilar

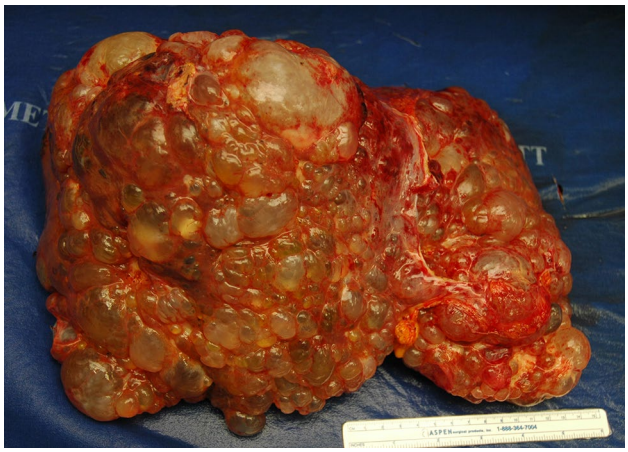

Fig. 8 Polycystic liver disease. Photograph of explanted liver in patient underwent to transplantation, showing numerous cysts that extensively replace the hepatic parenchyma

area and up to the third-order bile duct branches, and developed within the periductal connective tissue.

When associated with PLD, the pathogenesis of peribiliary cysts is congenital. Peribiliary cysts are also associated with chronic liver disease, alcohol use, portal hypertension and portal vein thrombosis; in these conditions, they are related to the altered microenviroment of peribiliary glands and seem retention cysts. Intrahepatic cysts and peribiliary cysts do not communicate with the biliary system but can occasionally cause biliary obstruction or cholangitis. Imaging shows multiple hypoechoic thin-walled cysts on ultrasound, with low attenuation on CT and with signal intensity of fluid-containing lesions on T1-weighted and T2-weighted MR imaging. Most cysts have imaging features of simple fluid, but hemorrhagic cysts and fluid–fluid levels may also be observed.

Cysts complicated by haemorrhage or infection may be seen as increased attenuation on CT and increased T1-weighted signal intensity on MRI [4, 34]. The cystic walls are smooth and usually show no septations or nodularity. Contrast-enhanced MR imaging shows no enhancing mural nodules inside the cysts. Hepatobiliary MR imaging is useful because the excretion of the hepatospecific contrast medium into the biliary system demonstrates the lack of communication between the cysts and the biliary ducts. Thin calcifications of the wall may be seen, as a result of prior hemorrhage and inflammation. In patients with ADPKD, the number and size of cysts increase with advancing age. PLD can coexist with other fibropolycystic liver disease such as Caroli disease (Fig. 10). Despite impressive physical examination and radiologic findings, only a minority of patients with PLD will progress to advanced liver disease or develop complications as a result of massive hepatomegaly. The leading complications in PLD are infection, compression of biliary ducts, bleeding or rupture of the cysts [4, 12]. The differential diagnosis includes simple cysts, biliary hamartoma and hydatid cysts. In PLD, the cysts are typically innumerable and of varying sizes, involving the entire liver; furthermore, cysts can be demonstrated within the kidneys [4]. These features aid the differential diagnosis. PLD typically contain more than 20 cysts, helping differentiate them from nonhereditary multicystic livers, and they generally demonstrate replacement of over 50% of the hepatic

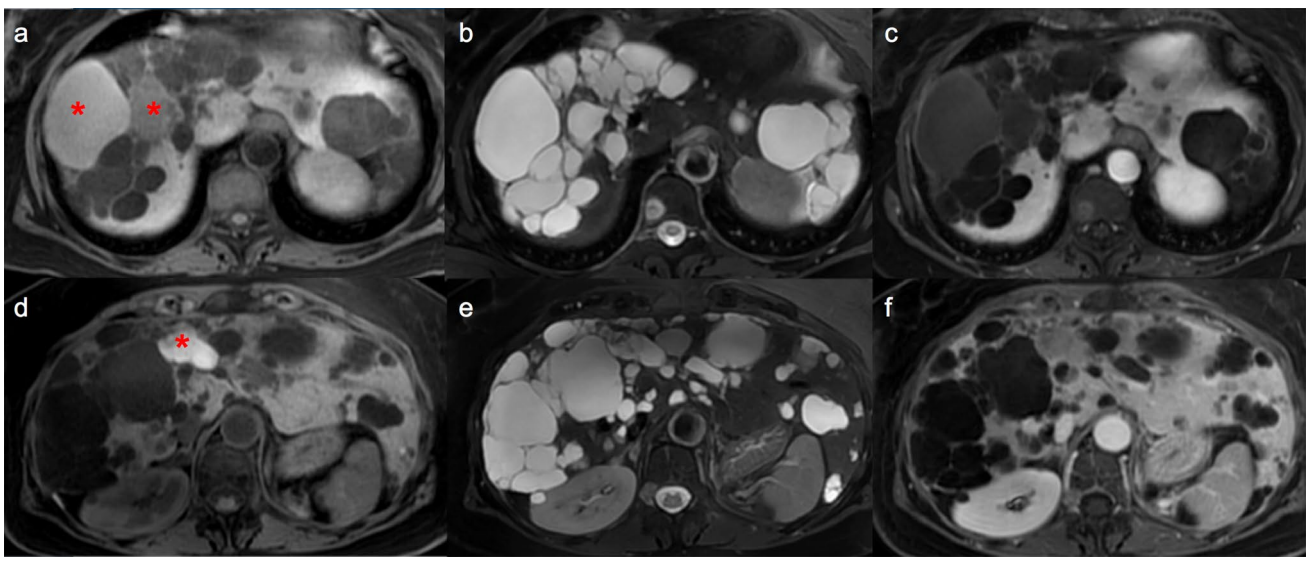

Fig. 9 Polycystic liver disease. Axial T1-w (**a**), T2-w (**b**) and contrast-enhanced (**c**) MR images showing an enlarged liver with multiple diffuse thin-walled cysts varying in size, in patient with ADPLD. Some lesions (red asteriks) show hyperintensity on T1-w images consistent with haemorrhage or infection. Notice the absence of cysts in the right kidney but one of small size

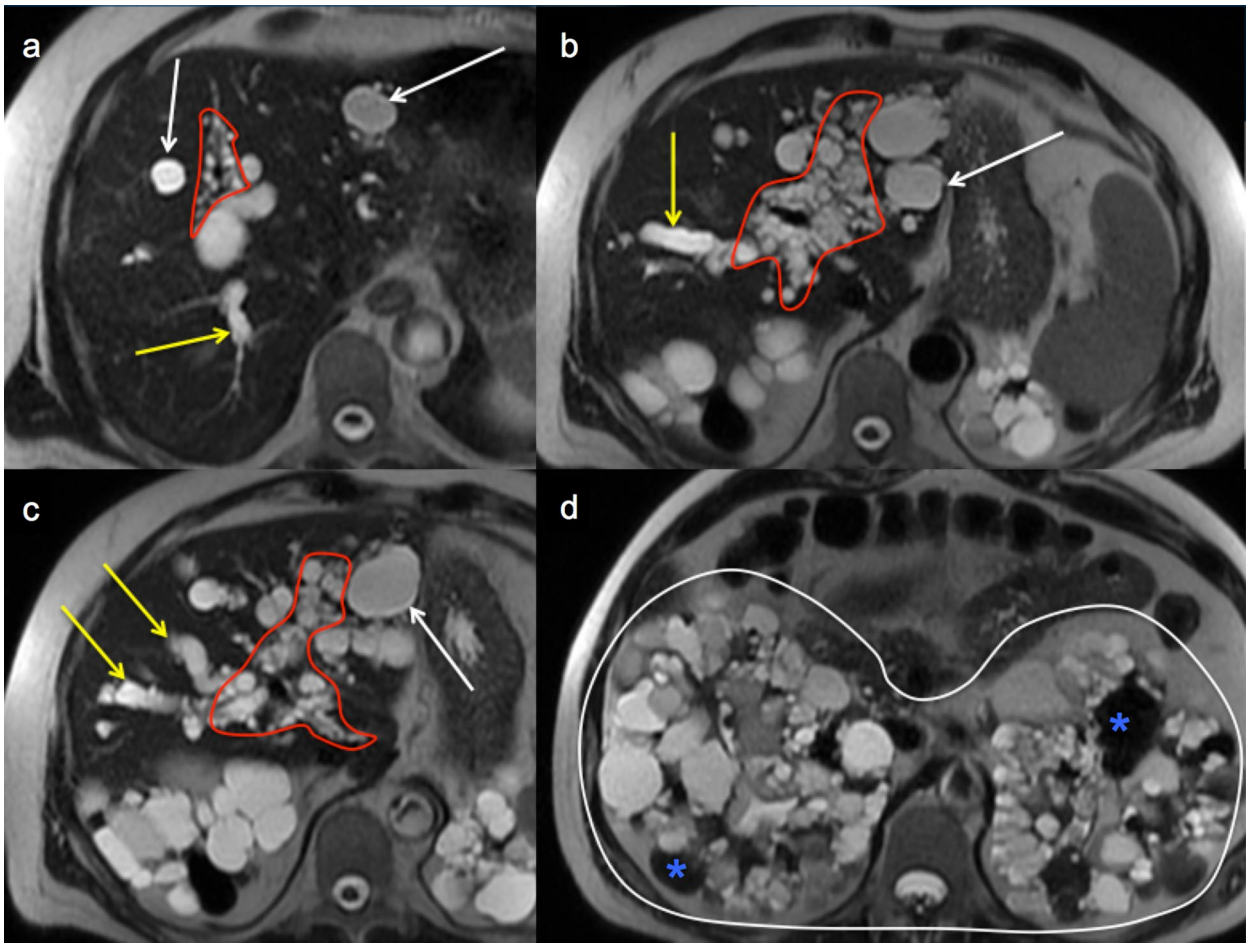

Fig. 10 Polycystic liver disease. Axial T2-w MR images show intrahepatic cysts (white arrows) and peribiliary cysts (red lines) in patient with ADPKD. Notice the coexistence of Caroli disease (yellow arrows) and the presence of polycystic kidney disease (white line) where cysts complicated by haemorrhage or infection are seen as a dark signal on T2-w image on MRI (blue asterisks)

parenchyma by cysts [36]. Liver transplantation has been performed with concurrent kidney transplantation in patients with ADPKD and renal failure who were also symptomatic from massive hepatomegaly.

Caroli disease and caroli syndrome

Caroli disease is defined as a rare autosomal recessive congenital multifocal segmental dilatation of the large intrahepatic bile ducts, which retain their communication with the biliary tree (Fig. 11) [12, 37–40].

Two types of Caroli disease are described in the literature: Caroli disease proper or so-called "pure" form, which is caused by arrested remodeling of the ductal plates of the larger intrahepatic ducts, and the more common Caroli syndrome, in which the arrest of remodeling occurs both in the early and late period of bile duct embryogenesis [12]. In Caroli syndrome, the bile duct dilatation is less marked

Fig. 11 Caroli disease. Photograph of hepatic slice from explanted liver after tranplantation that shows multiple dilated intrahepatic bile ducts containing dark bilirubin casts (white line)

and a variable degree of congenital hepatic fibrosis or other fibropolycystic liver diseases is consistently present. At imaging, Caroli disease typically appears as saccular or fusiform cystic dilatations of the intrahepatic bile ducts up to 5 cm in diameter (Fig. 12), often containing calculi or sludge (Fig. 13) [12].

A finding highly suggestive of Caroli disease is the "central dot sign" [41].

This feature consists of fibrovascular bundles within dilated cystic intrahepatic ducts showing strong contrast enhancement on CT or MR imaging (Figs. 12, 13, 14) [4, 12]. The central dot sign corresponds to a portal-vein radicle and an accompanying hepatic artery branch protruding into the lumen of a dilated bile duct. MRCP shows the entire bile duct tree in fine detail, allowing an evaluation of the severity, distribution, and extent of the abnormalities, and demonstrating the communication between the cystic dilatations and the biliary tree [42]. However, MRCP imaging can fail to demonstrate communication between cystic lesions and draining bile ducts. This problem could be resolved with hepatospecific contrast agents–enhanced MRI, which can demonstrate communications between cystic lesions and draining bile ducts and allows differentiation of Caroli disease from other cystic liver diseases. The clinical manifestations of Caroli disease are produced by bile stasis, which leads to development of stones favoring infections, cholangitis and liver abscesses. By contrast, portal hypertension and hepatic fibrosis dominate the clinical picture in the Caroli syndrome. Secondary biliary cirrhosis can occur due to biliary obstruction [12]. Malignancy has been described and in particular cholangiocarcinomas have also been reported, with a prevalence of 7%, as showed on Fig. 15 [12, 43]. The main differential diagnosis includes polycystic liver disease, primary sclerosing cholangitis (PSC), and recurrent pyogenic cholangitis [4, 12]. In polycystic liver disease, the cysts do not communicate with the biliary ducts in comparison to the duct dilatations of Caroli's disease [4]. In PSC, the duct dilatation is typically more isolated and associated with multiple irregular strictures yielding a "string-of-pearls" appearance [4]. Furthermore, PSC is characterized by pseudotumoral enlargement of the caudate lobe and a lobulated

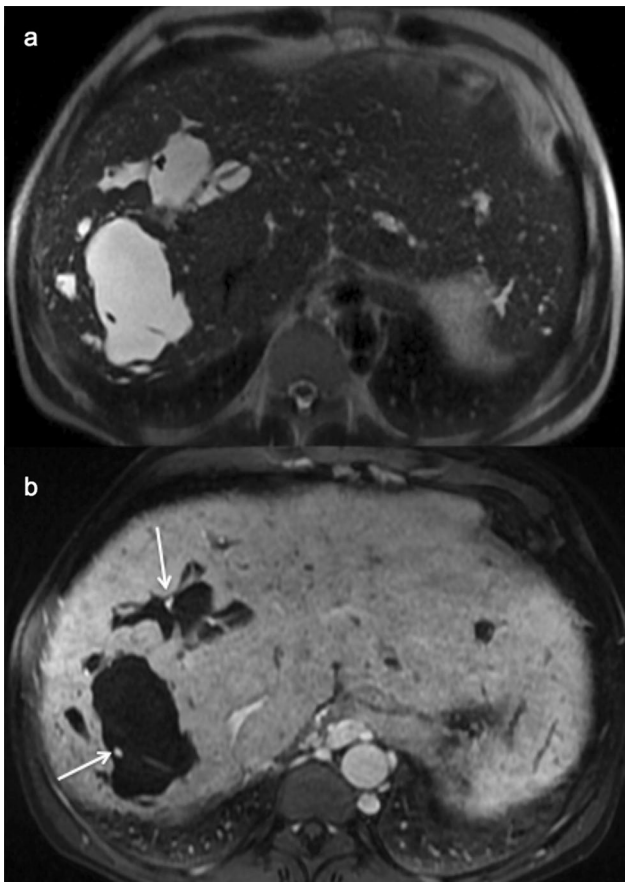

Fig. 12 Caroli disease. Axial T2-w (**a**) and contrast-enhanced T1-w (**b**) MR images show saccular cystic dilatations of the intrahepatic bile ducts associated with "central dot sign" (white arrows)

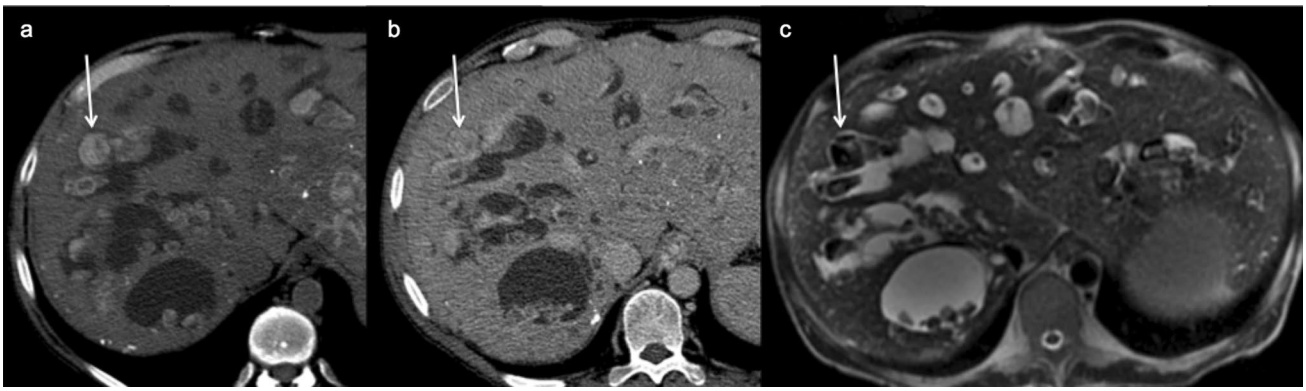

Fig. 13 Caroli disease. Axial unenhanced and contrast-enhanced CT images (**a**, **b**) and axial T2-w MR image (**c**) show multiple saccular cystic dilatations of the intrahepatic bile ducts containing multiple stones (white arrows)

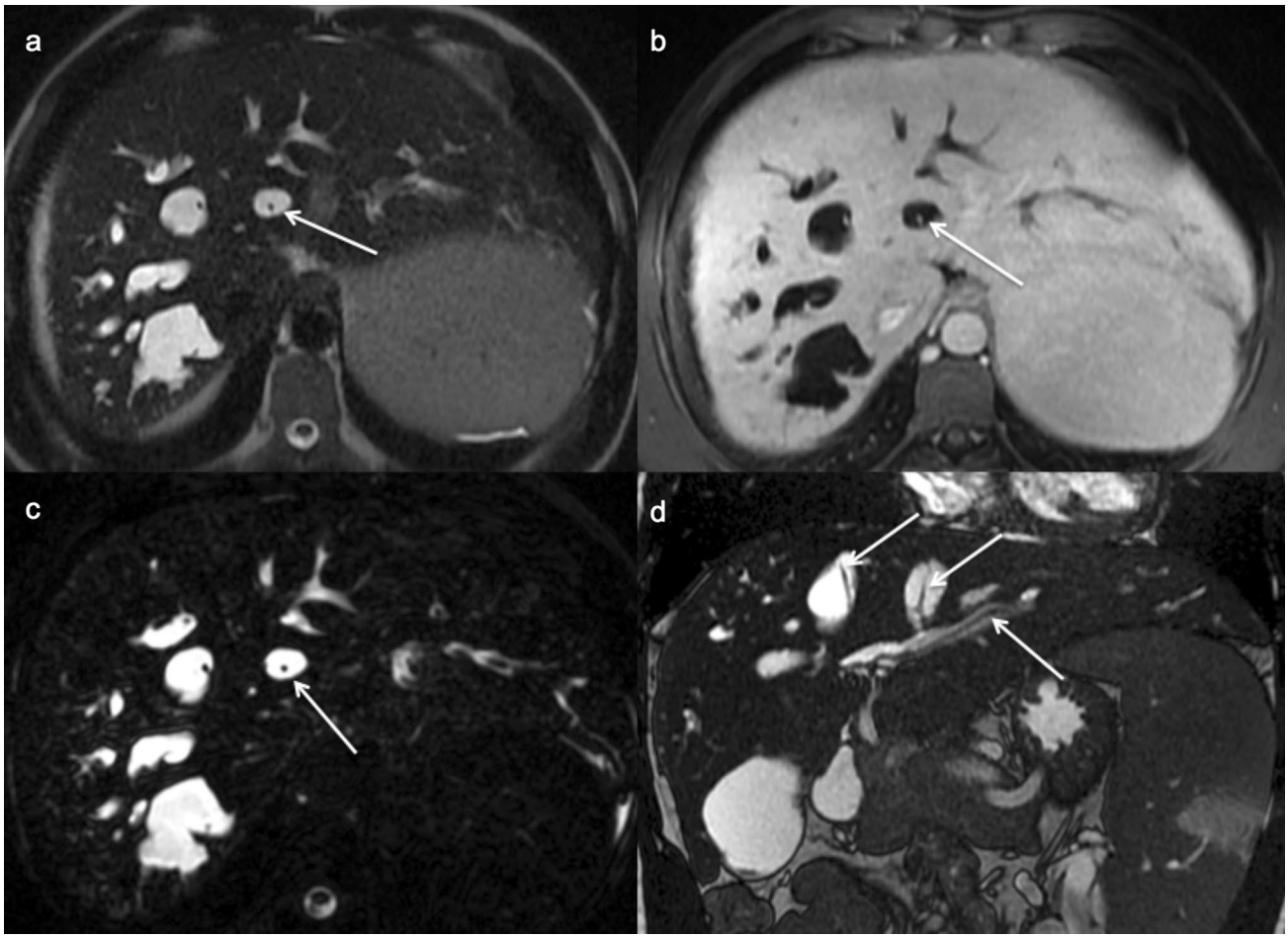

Fig. 14 Caroli disease. MRI showing multiple saccular and tubular cystic dilatations of the intrahepatic bile ducts on axial T2-w (**a**), axial contrast-enhanced T1-w (**b**), axial MRCP (**c**) and coronal MRCP (**d**) images. Notice the "central dot sign" (white arrows) inside the cysts

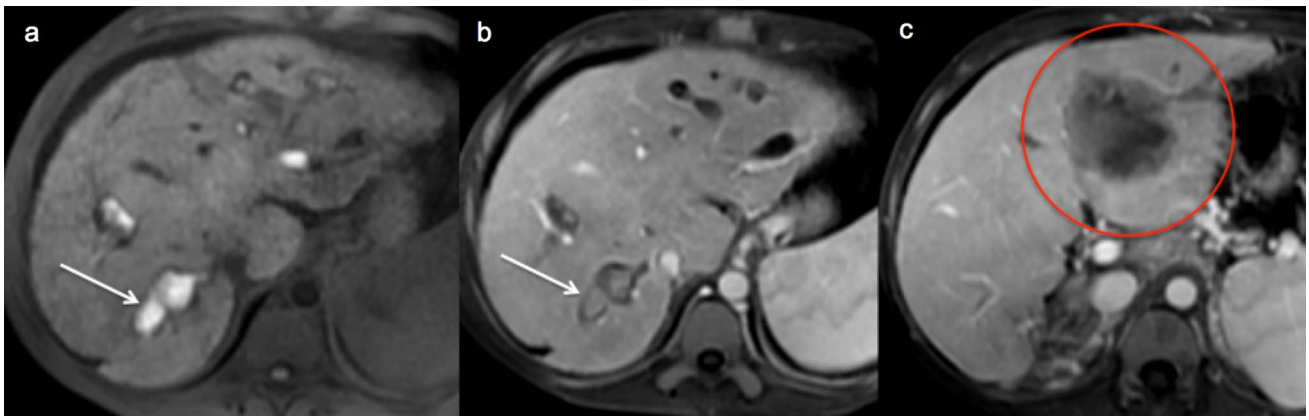

Fig. 15 Caroli disease. MR imaging in patient with cystic dilatations of the intrahepatic bile ducts containing stones on unenhanced T1-w and contrast-enhanced T1-w sequences (**a**, **b**) (white arrows). During the follow-up, the patient showed solid lesions on contrast-enhanced T1-w sequence (**c**) diagnosed as cholangiocarcinoma (red circle)

liver contour [4, 12, 44]. In recurrent pyogenic cholangitis, the dilatation is not saccular and involves both the intra- and extrahepatic biliary ducts [4, 12]. The intrahepatic ducts usually show central dilatation with sudden tapering toward the periphery and are dilated both proximal and distal to the stones [12, 45]. Finally, the central dot sign helps to differentiate Caroli disease from the above-mentioned entities. Liver transplantation is considered in patients with diffuse liver disease associated with frequent cholangitis or secondary biliary cirrhosis [12].

Choledochal cysts

Choledochal cysts are uncommon congenital biliary disorders characterized by dilatation of the intra-hepatic and/or extra-hepatic biliary ducts (Fig. 16). The etiology of choledochal cysts remains controversial, however, two hypotheses exist. One theory is that choledochal cysts are part of ductal plate malformations, supported by the frequent combination of choledochal cysts with other intra- and extrahepatic disorders [1, 12]. Indeed, choledochal cysts are classified into five basic types (Table 1) according to the revised Todani classification [46] and the type V is described as Caroli disease. By contrast, a second hypothesis, which is the most commone one, is based on the presence of a pancreaticobiliary junction anomaly resulting in a common channel that predisposes to the reflux of pancreatic enzymes into the common biliary duct, resulting in progressive bile duct dilatation from inflammatory changes into the biliary wall [4, 12, 47–50]. Choledocal cysts occur more frequently in female and in Asian countries, and 60% of the cases were diagnosed within the first 10 years of life [4]. However, this entity is being diagnosed in adults with increasing frequency. The classic clinical triad consists of abdominal pain, jaundice and palpable mass. At imaging, choledochal cysts appear differently in size and location, according to the five types of the revised Todani classification [46]. Isolated cystic dilatation of the cystic duct is rare, with only several case reports in the literature. It has been suggested to include this form as type VI, although it is not officially part of the revised Todani classification [51]. The type I represents the most common form, and appears as cystic or fusiform dilatation of the extrahepatic bile duct (Fig. 17) that vary from 1 to 10 cm in size [52]. The dilatated system may demonstrate sludge or stones at imaging [4]. MRI with MRCP is the best imaging technique to diagnose the choledocal cyst, demonstrating the communication with the biliary duct, the pancreaticobiliary junction and associated biliary abnormalities. The differential diagnosis includes other cystic lesions, such as enteric duplication cyst, hepatic cyst, pancreatic pseudocyst, and spontaneous perforation of the common bile duct. These disorders can all be differentiated on the basis of clinical information and with the use of MRCP, demonstrating the communication between the choledochal cysts and the biliary system [4]. However, MRCP may fail

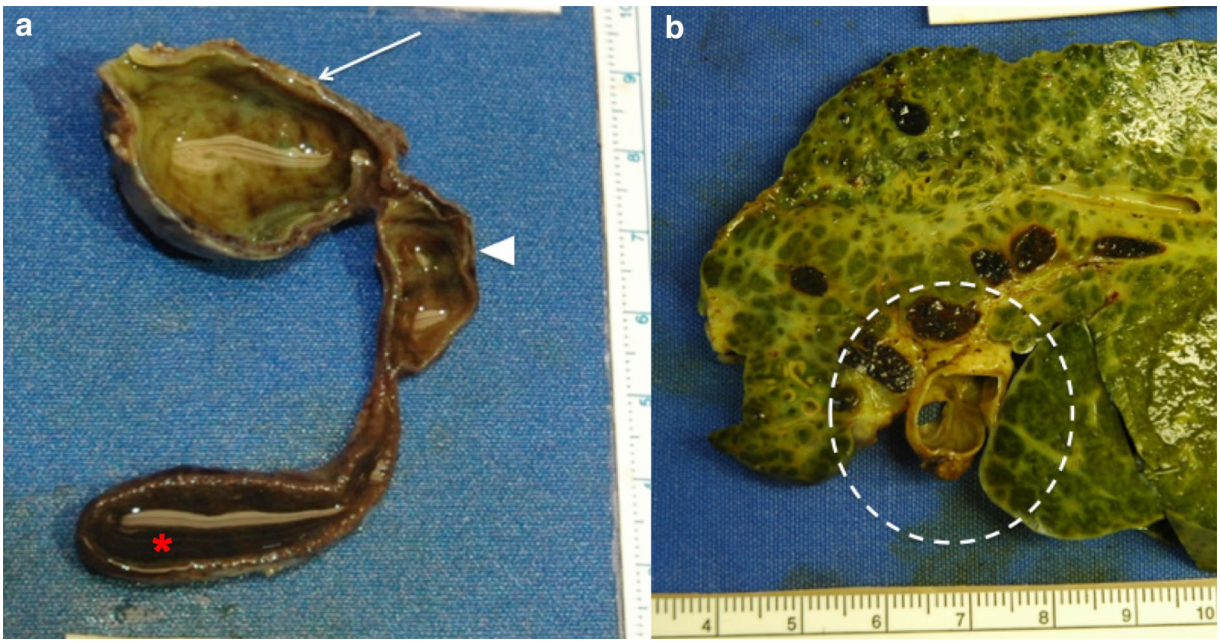

Fig. 16 Choledocal cyst. **a** Photograph of gross specimen showing saccular choledocal cystic dilatation (arrow), fusiform cystic duct dilatation (arrowhead) and gallbladder (asterisk). **b** Photograph of hepatectomy slice from explanted liver after tranplantation in other patient, that shows choledocal cyst (white line) associated with multiple dilated intrahepatic bile ducts containing dark bilirubin casts (Caroli disease)

Table 1 Types of choledocal cysts according to the revised Todani's classification

Todani's classification of choledocal cysts			
Type	Subtype	Description	Incidence (%)
I		Fusiform or saccular dilatation of the extrahepatic bile duct (EBD)	50–90
	Ia	Cystic dilatation with associated APBJ	
	Ib	Focal segmental dilatation (typically distal) without APBJ	
	Ic	Diffuse fusiform dilatation of the EBD with associated APBJ, that can involve the intrahepatic ducts	
II		True choledocal diverticulum	2–3
III		Choledochocele involving only the intraduodenal CBD	1–5
IV		Intra- and extrahepatic duct involvement	30–40
	IVa	Multiple fusiform or saccular dilation of the EBD and the intrahepatic bile ducts (usually associated with APBJ)	
	IVb	Multiple cystic dilatations involving only the extrahepatic bile duct	
V		Caroli's disease	

APBJ abnormal pancreaticobiliary junction

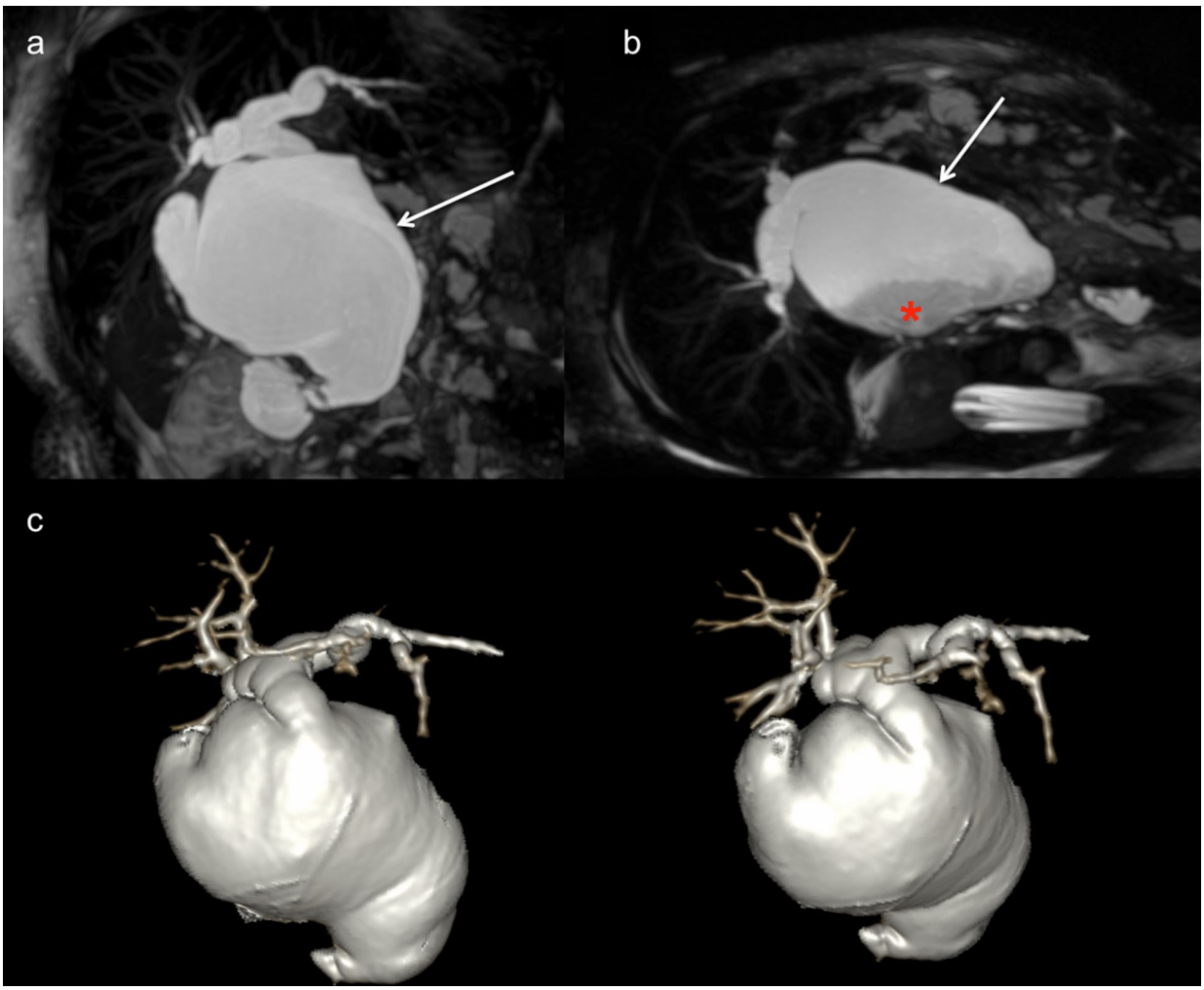

Fig. 17 Choledocal cyst (type Ic). 3D MRCP Maximun Intensity Projection reconstructions on coronal (**a**) and axial (**b**) planes showing a large cystic dilatation of main biliary duct (white arrows), with involvement of cystic duct, gallbladder and intrahepatic biliary ducts. Notice the biliary sludge into the lumen of main biliary duct (red asterisk). The same case of choledocal cyst showed on 3D MRCP Volume Rendering reconstructions (**c**)

to show the communication between the cyst and the biliary tree; for this reason, these patients should be studied in MRI using hepatospecific contrast agents. Hepatobiliary contrast agents offer the opportunity to image both the morphology of the biliary system and also provide functional information provided by excretion of gadolinium into the bile. Indeed, contrast-enhanced images during the hepatobiliary phase are helpful to show excretion of the contrast agent into the biliary system and filling of the choledocal cyst, proving the direct communication between them. Complications reported include recurrent cholangitis, pancreatitis, gallstones and biliary peritonitis secondary to cyst rupture. Choledocal cysts are also associated with biliary malignancy (in particular cholangiocarcinoma), with a reported incidence of approximately 10–30%, that increases with age [52]. Imaging features concerning for cholangiocarcinoma include an irregularly thickened wall and an enhancing mass [52]. Treatment of choledochal cyst consists of complete resection of the cyst and hepaticojejunostomy [12].

Biliary atresia

We mention biliary atresia briefly because ductal plate malformations have also been implicated in the pathogenesis of this disease [53].

Biliary atresia (BA) is a rare disease but is the most common cause of neonatal cholestasis. It is characterized by an inflammatory obstruction of the biliary tree leading to biliary cirrhosis and early death if untreated [54]. Biliary atresia is categorized into two forms, the perinatal form and the fetal-embryonal (or congenital) form. The fetal-embryonal form is the less common variant of the two (20%), with a link to syndromic association such as Biliary atresia Splenic Malformation (BASM). The etiology of BA remains unclear. There are many theories proposed to explain the etiology of BA, including genetic predisposition, abnormal morphogenesis, toxins, virus infection, and autoimmune-mediated processes [54]. However, the presence of ductal plate malformation (DPM) is reported on liver histology in these patients, representing an arrest in normal remodeling of fetal biliary tract, and resulting in an excess of embryonic bile duct structures in the portal tracts [55]. Furthermore, DPM features histology has been considered a marker of early intrauterine onset of disease and an indication of an unfavorable prognosis [56]. Biliary atresia can be classified using macroscopic appearance and cholangiography findings into three main categories according to Kasai's classification (Table 2): atresia of the common bile duct (CBD) (type I), atresia of the common hepatic duct (CHD) (type IIa) or atresia of the CBD and the CHD (type IIb), and atresia of all extrahepatic bile ducts up to the porta hepatis (type III; most common: 90%). Diagnosis is usually performed by ultrasound, hepatobiliary scintigraphy, MRI and liver biopsy (considered as gold standard) and confirmed by surgical colangiography. The typical ultrasound findings of BA include the triangular cord sign, absence or abnormal gallbladder, the presence of hepatic subcapsular flow and the absence of the common bile duct (Fig. 18) [57]. The triangular cord sign represents obliterated extrahepatic bile ducts and appears on US images as an abnormal triangular or tubular echogenic area of more than 4 mm along the anterior wall of the portal vein in the region of the porta hepatis [57]. The triangular cord sign has a sensitivity of 80% and a specificity of 98% [58]. The gallbladder is absent or considered abnormal if it is less than 15 mm long or if there is a lack of smooth and complete echogenic mucosal lining with an indistinct wall or an irregular or lobular contour (so-called "Gallbladder ghost triad") [59]. A hepatic subcapsular flow as a hepatic arterial flow signal continuing to the liver capsular surface on Color Doppler US is suggestive for the diagnostic of BA [57].

Furthermore, the diameters of the hepatic artery and of the portal vein, at the level just proximal to the division of the right portal vein into anterior and posterior branches, can be used for the diagnosis of BA. A hepatic artery diameter of greater than 1.5 mm or a ratio of greater than 0.45 for the diameter of the hepatic artery and the diameter of the portal vein is considered suggestive of BA [57]. Cystic biliary atresia is a relatively uncommon but clinically significant variant of biliary atresia (5–10%) [60]. This variant is characterized by a biliary cystic expansion contiguous with a zone of bile duct atresia. The presence of a cyst in the hepatic hilum or in any part of the extrahepatic biliary tract on imaging in an infant with cholestasis supports the diagnosis of cystic biliary atresia, but can also be seen in patients with a choledochal cyst, the main differential diagnosis in these patients

Table 2 Types of biliary atresia according to the Kasai's classification

Kasai's classification of biliary atresia		
Type	Subtype	Description
I		Obliteration of common bile duct (patent cystic and common hepatic duct)
II	IIa	Obliteration of common hepatic duct (patent cystic and common bile duct)
	IIb	Obliteration of common hepatic duct, cystic and common bile duct
III		Obliteration of left and right main hepatic ducts at the level of porta hepatis (most common: 90%) and of extrahepatic biliary ducts

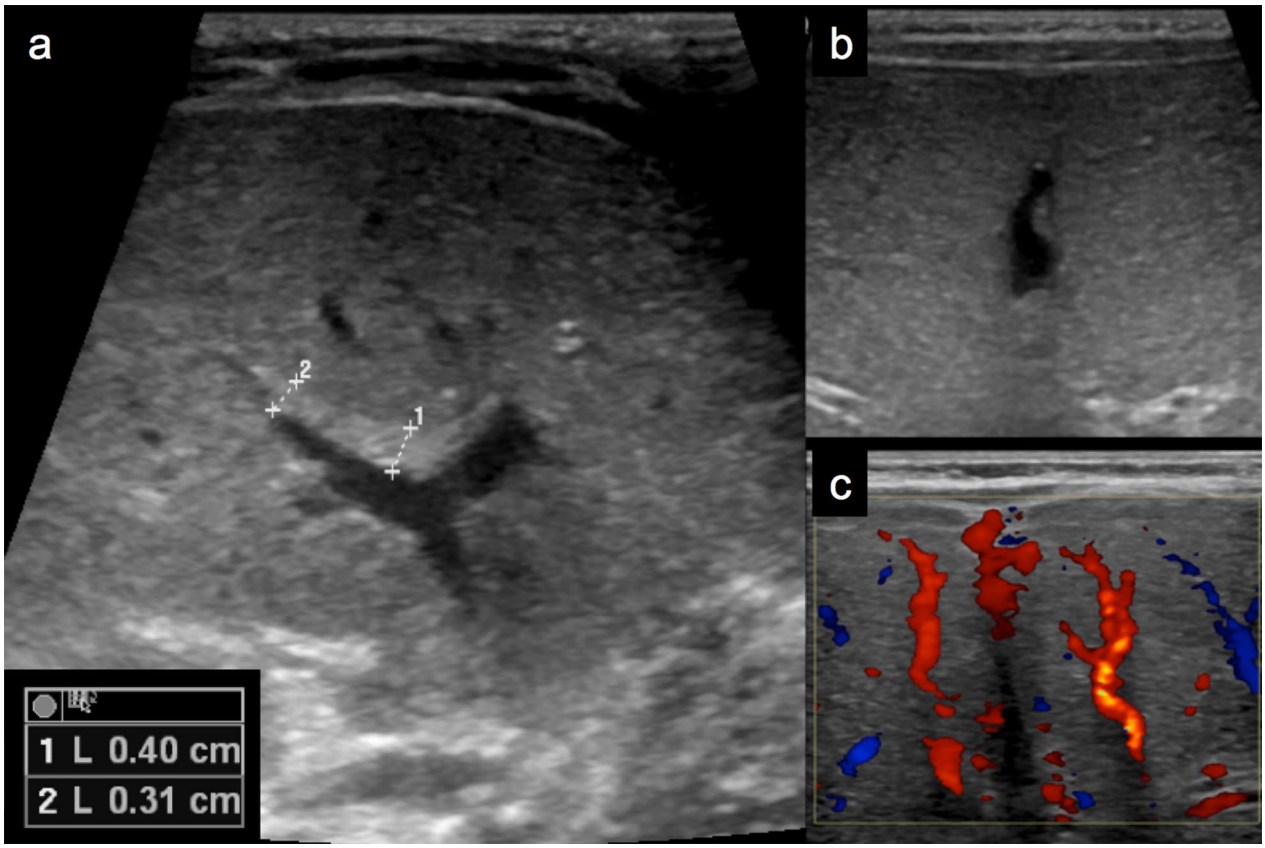

Fig. 18 Biliary atresia. Ultrasound images show the typical findings of BA: triangular cord (**a**), gallbladder ghost triad (atretic gallbladder, irregular or lobular contour and lack of smooth/complete echogenic mucosal lining with an indistinct wall) (**b**) and hepatic subcapsular flow (**c**)

[60]. Imaging findings that help in the diagnosis of cystic biliary atresia are the absence of intrahepatic bile duct dilation (observed in patients with choledochal cyst), the cyst's shape more spherical than fusiform, an absent or irregular gallbladder, the absence of gallstones and sludge within the cyst at the hepatic hilum. These features and the other BA findings above mentioned support the diagnosis of cystic biliary atresia over choledochal cyst and avoid inadequate primary surgical intervention. Biliary atresia leads to biliary cirrhosis and the need for liver transplantation for survival in the majority [54]. An early often palliative treatment involves resection of obliterated extrahepatic bile ducts and creation of a portoenterostomy (Kasai procedure) to restore bile flow [54].

Conclusions

Fibropolycystic liver diseases are caused by ductal plate malformations during the embryologic development. Given that these conditions arise from the same pathological process, it is important to understand that these entities form a spectrum and can exist as individual conditions or in various combinations in the same patient. Although ductal plate malformations are rare, they can be seen in day-to-day practice. Awareness of characteristic imaging features of these diseases is essential in detecting and differentiating between various fibropolycystic liver diseases and other disorders, allowing a correct diagnosis and an appropriate clinical management. Furthermore, when a fibropolycystic liver disorder is suspected, it is important to screen the kidneys for associated renal anomalies.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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