Cirrhosis: CT and MR imaging evaluation

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Abstract

In this article, we present the CT and MR imaging characteristics of the cirrhotic liver. We describe the altered liver morphology in different forms of viral, alcoholic and autoimmune end-stage liver disease. We present the spectrum of imaging findings in portal hypertension, such as splenomegaly, ascites and varices. We describe the patchy and lacelike patterns of fibrosis, along with the focal confluent form. The process of hepatocarcinogenesis is detailed, from regenerative to dysplastic nodules to overt hepatocellular carcinoma. Different types of non-neoplastic focal liver lesions occurring in the cirrhotic liver are discussed, including arterially enhancing nodules, hemangiomas and peribiliary cysts. We show different conditions causing liver morphology changes that can mimic cirrhosis, such as congenital hepatic fibrosis, “pseudo-cirrhosis” due to breast metastases treated with chemotherapy, Budd-Chiari syndrome, sarcoidosis and cavernous transformation of the portal vein.

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1. Introduction

Cirrhosis is the final result of chronic damage to the liver from various etiologies, characterized by parenchymal injury leading to extensive fibrosis and nodular regeneration. The result is a diffuse disorganization of hepatic morphology with progressive loss of liver function. Although the mortality rate has been reduced by about 30% in the last few decades, within the European Union cirrhosis is still one of the leading causes of death and serious morbidity. Cirrhosis is most commonly the result of hepatitis B and C virus infection or chronic alcoholism; other causes are biliary, cryptogenic and metabolic. Usual clinical manifestations result from portal hypertension, portosystemic shunting and hepatic insufficiency. Common complications are ascites, gastrointestinal bleeding, encephalopathy and coagulopathy.

In this review, we present the CT and MR imaging findings in the cirrhotic liver.

2. Liver morphology

At an early stage of cirrhosis, the liver may appear normal on cross sectional imaging. With disease progression, heterogeneity of liver parenchyma and surface nodularity are observed. Caudate lobe hypertrophy is the most characteristic morphologic feature of liver cirrhosis (Fig. 1). A ratio of transverse caudate lobe width to right lobe width greater than or equal to 0.65 constitutes a positive indicator for the diagnosis of cirrhosis with high level of accuracy [1]. A modified caudate lobe width to right lobe width ratio, using the right portal vein instead of the main portal vein to set the lateral boundary has recently been proposed [2]. Other regional changes in hepatic morphology typically seen in advanced cirrhosis are segmental hypertrophy involving the lateral segments (II, III) of the left lobe (Fig. 2), and segmental atrophy affecting both the posterior...
Fig. 1. Typical cirrhotic morphology at MR imaging. Transverse T2-weighted fat-suppressed turbo spin-echo MR image (A) shows enlarged caudate lobe, mildly lobulated liver margins (arrowheads) and regions of high attenuation (arrow) of hepatic parenchyma caused by patchy fibrosis. Gadolinium-enhanced T1-weighted fat-suppressed gradient-echo MR image (B) obtained during portal venous phase shows inhomogeneous liver enhancement and caudate to right lobe ratio of 1.80.

segments (VI, VII) of the right lobe and medial segment (IV) of the left lobe [3] (Fig. 2). Alteration of blood flow is the likely explanation for these morphologic abnormalities. Enlargement of hilar periportal space, the notch-sign [4] (Fig. 2), an expanded gallbladder fossa (Fig. 2) [5] and generalized widening of the interlobar fissures are also considered typical findings of cirrhosis.

Primary sclerosing cholangitis and primary biliary cirrhosis have some distinctive features in comparison to other types of cirrhosis. In primary sclerosing cholangitis induced end-stage cirrhosis, pseudotumoral enlargement of the caudate lobe is observed in virtually all patients, along with atrophy of the peripheral hepatic segments resulting in a lobulated liver contour (Fig. 3A and B). Concomitant multiple irregular strictures of the intra- and extrahepatic bile ducts are also observed (Fig. 3C) [6]. Primary biliary cirrhosis typically produces early signs of portal hypertension while the liver is enlarged, along with prominent “lacelike fibrosis,” regenerative nodules, and lymphadenopathy (Fig. 4) [7]. Late-stage primary biliary cirrhosis results in morphologic changes including a shrunken, fibrotic liver, that is indistinguishable from other etiologies.

3. Portal hypertension and mesenteric edema

In chronic liver disease, progressive hepatic fibrosis leads to increased vascular resistance at the level of the hepatic sinusoids. The increased pressure gradient is defined as portal hypertension, and causes complications such as ascites and the development of engorged and tortuous collateral vessels that typically develop at the lower end of the esophagus (Figs. 3C and 5A) and at the gastric fundus (hypertensive gastropathy) (Fig. 5B) [8]. The paraumbilical veins (Fig. 5C) and the left gastric vein, both draining into the portal vein, also reopen to form portosystemic shunts. Other shunts between the portal and the systemic circulation include splenorenal collaterals (Fig. 5B), hemorrhoidal veins, abdominal wall (Fig. 5D) and retroperitoneal collaterals.

Increased venous pressure is also responsible for the prominent mesenteric edema and stranding occurring in 86% of patients with cirrhosis [9]. It can occur in mild, moderate or severe form with pseudonodules surrounding mesenteric vessels and mimicking enlarged lymph nodes (Fig. 6).
Fig. 3. Primary sclerosing cholangitis at CT. (A) Nonenhanced CT shows severe lobulation (arrows) of the hepatic contour and compensatory hypertrophy of the caudate lobe (arrowheads). The peripheral areas of the liver are hypodense due to atrophy. The phenomenon of segmental hyperplasia associated with atrophy of other parts of the liver is known as the atrophy–hypertrophy complex. (B) In the portal venous phase, the attenuation difference between the caudate and the liver is lost. (C) Portal venous phase CT scan in a different patient with primary sclerosing cholangitis shows irregular dilatation of the intra-hepatic bile ducts (arrowheads). Note esophageal varices (arrow) due to portal hypertension.

Fig. 4. Primary biliary cirrhosis at CT. (A) Transverse nonenhanced CT scan (narrow window setting) shows lacelike pattern of low-attenuating fibrosis surrounding subcentimeter regenerative nodules that are hyperattenuating to normal liver or spleen. (B) On portal venous phase CT scan obtained at the same level as A, regenerative nodules are not easily recognized. Splenomegaly and enlarged porta hepatis and portacaval lymph nodes (arrows) are also noted.

4. Fibrosis

Fibrosis is an inherent part of hepatic cirrhosis, and is typically detected as patchy fibrosis (Fig. 1A), as a lacelike pattern, or as a confluent mass. The lacelike type of fibrosis is best described as thin or thick bands that surround regenerative nodules. This pattern is best visualized on nonenhanced CT (Fig. 4A), and is usually not well visualized on portal venous phase images (Fig. 4B) [10]. It is seen in about one-third of patients with primary biliary cirrhosis [7], regardless of stage.
Focal confluent fibrosis is observed in end-stage liver disease and is usually a wedge-shaped lesion located in the subcapsular portion of segment IV, V or VIII, with associated capsular retraction [11,12] (Fig. 7). In those rare cases in which the lesion shows enhancement on arterial dominant phase, it may be mistaken for hepatocellular carcinoma. Delayed, persistent contrast enhancement, however, is typically observed, and is due to the retention of contrast by the fibrotic tissue (Fig. 7D). This feature, along with the characteristic capsular retraction and typical location and shape help to distinguish confluent fibrosis from hepatocellular carcinoma.

5. Regenerative nodules

In the cirrhotic liver, regenerative nodules are macronodular (≥9 mm), as usually seen in chronic hepatitis B, or micronodular
Fig. 6. Mesenteric edema in cirrhosis. Contrast-enhanced CT scan shows increased attenuation of the fat (arrows) around the mesenteric vessels due to congestion and edema caused by portal hypertension. Mesenteric edema in this case mimics the appearance of lymph-nodes.

(3–9 mm), as seen in other causes of cirrhosis. Most regenerative nodules are difficult to detect at CT or MR because they are too small or are too similar to surrounding liver parenchyma [13]. Computed tomography detects regenerative nodules when they are surrounded by hypodense fibrotic bands on nonenhanced CT (Fig. 4A) or when they accumulate iron (siderotic nodules) [14]. Siderotic regenerative nodules are typically hyperattenuating to liver on nonenhanced CT and are isodense to liver, and therefore difficult to detect, after contrast injection.

MR imaging demonstrates regenerative nodules with greater sensitivity than any other imaging modality. They usually appear isointense (Fig. 8A) to hypointense on T2-weighted MR images relative to the surrounding inflammatory fibrous septa and isointense (Fig. 8B) to hyperintense relative to background liver parenchyma on T1-weighted sequences [13]. The accumulation of iron within regenerative nodules may cause hypointensity on T2-weighted images (Fig. 9A) because of magnetic field inhomogeneities, and marked hypointensity on T1-weighted gradient-Echo MR images (Fig. 9B), usually best visualized using TEs greater than 10 ms. Due to their portal venous supply, regenerative nodules usually enhance to the same degree than the background liver.

6. Dysplastic nodules

Dysplastic nodules are regenerative nodules containing atypical cells without definite histological signs of malignancy, and
Fig. 8. Cirrhosis and multiple regenerative nodules at MR imaging. Transverse T1-weighted gradient-echo MR image (A) shows multiple subcentimeter isointense nodules (arrows), surrounded by diffuse lacework of low-intensity fibrosis. On transverse T2-weighted fat-suppressed turbo spin-echo MR image (B), nodules (arrows) are still isointense and surrounded by thick hyperintense septa of lacelike fibrosis. Arterial dominant phase (not shown) failed to show enhancement of nodules, consistent with diagnosis of regenerative nodules.

Fig. 9. Cirrhosis and siderotic regenerative nodules at MR imaging. Transverse T2-weighted fat-suppressed turbo spin-echo MR image (A) shows multiple hypointense nodules (arrowheads). On transverse T1-weighted gradient-echo breath-hold MR image (B), nodules are hypointense.

Fig. 10. Cirrhosis and dysplastic nodule at MR imaging. Transverse T2-weighted fat-suppressed turbo spin-echo MR image (a) shows irregular liver margins, perihepatic ascites (a) and 1 cm hypointense mass (arrow). On transverse T1-weighted gradient-echo breath-hold MR image (b), the mass is hyperintense (arrow). Arterial dominant phase (not shown) failed to show enhancement of nodule.
Fig. 11. Cirrhosis and typical hepatocellular carcinoma at MR imaging. Transverse T2-weighted half-Fourier acquired single-shot turbo spin-echo MR image (A) shows 2 cm mildly hyperintense lesion (arrow) in right hepatic lobe. On T1-weighted gradient-echo MR image (B), lesion is hypointense in comparison to background liver. Gadolinium-enhanced T1-weighted gradient-echo MR image obtained during arterial dominant phase (C) shows marked enhancement of lesion (arrow) with central hypointense area due to necrosis. On gadolinium-enhanced T1-weighted gradient-echo MR image obtained during portal venous phase (D), lesion becomes hypointense to surrounding parenchyma. Note hyperintense capsule (arrowhead) surrounding lesion.
Fig. 12. Cirrhosis and large hepatocellular carcinoma with mosaic appearance at MR imaging. Transverse T2-weighted fat-suppressed turbo spin-echo MR image (A) shows large tumor (arrows) in right lobe of the liver that is slightly hyperintense to surrounding nontumorous parenchyma and heterogeneous due to presence of some hypointense areas. Gadolinium-enhanced T1-weighted fat-suppressed gradient-echo MR image obtained during arterial dominant phase (B) shows that only peripheral portion of tumor enhances (arrow), while remaining part is hypointense. Gadolinium-enhanced T1-weighted fat-suppressed gradient-echo MR image obtained during portal venous phase (C) shows washout of tumor portion that enhanced in arterial dominant phase. The fibrotic capsule (arrows) surrounding lesion is well seen because of contrast retention. Mosaic appearance is caused by areas of different intensity level and results from peculiar growth pattern of hepatocellular carcinoma, which contain small viable nodules with interspersed areas of necrosis, fibrosis, and cystic or fatty degeneration. Capsule and mosaic pattern are seen more frequently with increasing tumor diameter.

Fig. 13. Cirrhosis and benign arterially enhancing nodule at CT. (A) Arterial dominant phase CT scan of the liver shows small enhancing lesion (arrows). (B) On portal venous phase CT scan obtained at same level as A, lesions are minimally hyperattenuating to isodense compared to surrounding liver.
are considered an intermediate, premalignant step along the hepatocarcinogenesis process. Malignant transformation within a dysplastic nodule has been identified as early as 4 months after the first detection of the dysplastic nodule [15]. Dysplastic nodules are found in 15–25% of cirrhotic livers at the time of transplantation and are subclassified on the basis of the degree of cellular abnormalities: low-grade (containing hepatocytes with mild atypia) and high-grade (when the degree of atypia is moderate, but insufficient for the diagnosis of malignancy) [16].

As with regenerative nodules, dysplastic nodules receive predominantly portal venous flow, and do not usually demonstrate bright enhancement on arterial phase CT or MRI. Therefore, marked arterial phase enhancement should suggest hepatocellular carcinoma rather than dysplastic nodule, but there is much overlap in imaging features between regenerative nodules, dysplastic nodules and well-differentiated hepatocellular carcinoma. Dysplastic nodules typically appear hypointense to the background liver parenchyma on T2-weighted images (Fig. 10a), and show hyperintensity on T1-weighted images (Fig. 10b), quite in contrast to typical findings for hepatocellular carcinoma. Arterial phase enhancement should suggest development of a focus of hepatocellular carcinoma within a high-grade dysplastic nodule, the so-called “nodule within a nodule” appearance on MR imaging [17].

Dysplastic nodules are detected and characterized better by MR than by CT; however, accurate diagnosis may be made in only about 15% of cases [18].

7. Hepatocellular carcinoma

Hepatocellular carcinoma typically occurs within the cirrhotic liver. As the degree of (de-differentiation) malignancy increases, portal blood supply decreases, whereas nontriadal arteries (i.e., unaccompanied by portal venules and biliary ducts) develop to feed the nodules. The presence of early arterial enhancement with rapid washout during the portal venous phase should be regarded as highly suspicious for the presence of hepatocellular carcinoma. Characteristically, hepatocellular carcinoma is hypovascular to liver on unenhanced CT, and

![Fig. 14. Transient hepatic attenuation difference due to portal vein thrombosis in cirrhosis at CT. (A) Arterial dominant phase CT scan shows hyperattenuation of the right lobe of the liver (arrowheads) in comparison to normal left liver due to thrombosis of the anterior branch of the right portal vein (arrow) and increased arterial flow. (B) Delayed phase contrast-enhanced transverse CT scan demonstrates isovascularization of right liver to the normal parenchyma. Note splenomegaly.](image)

![Fig. 15. Cirrhosis and multiple hemangiomas at MR imaging. Transverse T2-weighted fat-suppressed turbo spin-echo MR image (A) shows two hemangiomas (arrows) as strongly hyperintense in comparison to liver parenchyma. (B) Transverse T2-weighted fat-suppressed turbo spin-echo MR image through the same level obtained 2 years later. The cavernous hemangioma in the right lobe is much smaller (arrow), while the cavernous hemangioma in the left lobe is no longer visible.](image)
manifests as a heterogeneous, moderately enhancing lesion during the arterial phase, with washout on portal venous and delayed phase [19,20]. Similar features are evident on MR imaging, and hepatocellular carcinoma is usually hypointense to liver on T1-weighted imaging and hyperintense on T2-weighted imaging (Fig. 11) [21]. Other useful characteristics of hepatocellular carcinoma are heterogeneity, mosaic appearance (Fig. 12), multiplicity, encapsulation (Figs. 11D and 12C), and portovenous or hepatovenous invasion.

Both CT and MR are quite accurate in diagnosis of hepatocellular carcinoma nodule ≥2 cm in diameter [18,22]. Smaller lesions are more challenging, but these are the goal of surveillance programs in which patients with cirrhosis have imaging evaluation at intervals of 6–12 months or less [23,24]. Accurate detection of small hepatocellular carcinomas is especially important because it offers the chance of curative therapy by percutaneous ablation, surgical resection and liver transplantation.

In patients with hepatocellular carcinoma, an expert panel from the European Association for the Study of the Liver (EASL) distinguishes between lesions measuring less than 2 cm and those with larger diameters [25]. According to their guidelines, imaging detection of a liver nodule 2.0 cm or smaller should always be confirmed with needle biopsy, and in case of negative result, should be subjected to an increase in the frequency of US surveillance. For a mass greater than 2.0 cm, the coincident findings of characteristic arterial vascularization that is seen on at least two imaging techniques (e.g., multiphasic CT and MRI), or hypervascularity in one imaging technique associated with washout in the portal venous and/or delayed phase may be used to confidently establish the diagnosis without biopsy [26].

Distinction among regenerating nodules, dysplastic nodules, and hepatocellular carcinoma with varying degrees of differentiation requires an assessment of the hemodynamic nature of the mass. In evaluation of the cirrhotic liver, whether by CT or

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**Fig. 16.** Cirrhosis and peribiliary cysts at MR imaging. Transverse T2-weighted half-Fourier acquired single-shot turbo spin-echo MR image (A) shows organized cluster of high-intensity cysts (arrows) close to each other in left liver lobe. Gadolinium-enhanced T1-weighted fat-suppressed gradient-echo MR image (B) obtained during portal venous phase shows collection of discrete low intensity cysts (arrows) close to each other, separated by thin walls and lying along enhancing left portal vein. Thick slab MR cholangiography (C) shows multiple peribiliary cysts at hepatic hilum and in left liver lobe. Note other single high intensity areas (arrowheads) in right liver lobe, likely representing biliary hamartomas.
MR, it is essential to obtain multiple phases of imaging before and during the rapid (>4 ml/s) IV administration of contrast medium. Unenhanced images are followed by dynamic acquisition of images during the arterial, and portal venous phases of enhancement. With MR, we add an equilibrium or delayed phase acquisition as well [27].

8. Arterially enhancing nodules and perfusion anomalies

With the increasing use of thin section CT and MR imaging and the rapid bolus injection of contrast, small enhancing nodules and perfusion anomalies are increasingly being observed in the cirrhotic liver [28,29]. Both nodules and perfusion anomalies are likely due to intrahepatic shunts between a hepatic arterial branch and the portal venous system. These pseudolesions may simulate a hypervascular hepatic lesion on the arterial dominant phase, and are not detectable on portal venous and delayed phase (Fig. 13). Lack of growth, or even disappearance on subsequent imaging is the key to diagnosis of these vascular entities. Perfusion anomalies can also result from occlusion of a portal venous branch with compensatory increased arterial flow causing arterial phase hyperenhancement (Fig. 14) [30]. These perfusion pseudolesions can usually be distinguished from tumor by their peripheral location, wedge shape, lack of mass effect, and isoattenuation with liver on all other phases. Conversely, spherical shape or central location are features that may require close imaging follow-up (e.g., 4–6 months) to exclude malignancy.

9. Hemangiomas

In the cirrhotic liver, hemangiomas are more difficult to recognize radiologically and pathologically. Progressive fibrosis alters the blood supply of the liver and causes loss of some identifying characteristics of hemangiomas, such as nodular peripheral enhancement and isoattenuation to blood vessels. Usually, however, the characteristic feature of high signal intensity on heavily T2-weighted images remains, helping to distinguish hemangioma from hepatocellular lesions. Fibrosis also causes progressive diminution in size, ultimately resulting in obliteration of the hemangioma (Fig. 15) [31]. In some instances, capsular retraction develops over those hemangiomas that regress in size.

10. Peribiliary cysts

Peribiliary cysts are cystic lesions typically found on both sides of the intrahepatic portal venous branches. These lesions may have variable size and morphology: linear and confluent “tube-like” aspect, coursing adjacent to right or left portal vein, simulating dilated bile ducts, or linear cluster (“string of beads”) of cysts, with a prominent involvement of the left-sided intrahepatic ducts. They represent cystic dilatation of the extramural glands in the periductal connective tissue, and may increase in size and number as the cirrhosis progresses. Peribiliary cysts show the same imaging findings as simple cysts, i.e., low attenuation at CT, low signal intensity on T1-weighted MR sequences and high signal on heavily T2-weighted MR sequences, with no contrast enhancement [32] (Fig. 16).

11. Diseases that mimic cirrhosis

Several disease processes may result in distorted hepatic morphology that might be misinterpreted as cirrhosis on imaging. In congenital hepatic fibrosis, the liver generally shows variable segmental hypertrophy or atrophy, with caudate lobe and left lateral segment enlargement and right lobe atrophy observed.

Fig. 17. Congenital hepatic fibrosis at CT. CT scan obtained during the portal venous phase in a 16-year-old male with congenital hepatic fibrosis shows an enlarged liver. An abnormal network of small vessels representing a collateral circulation is seen running parallel to the intrahepatic portal veins (arrow). This network likely represent an hypertrophied peribiliary vascular plexus due to presinusoidal portal hypertension. Note splenomegaly.

Fig. 18. Pseudocirrhosis at CT. Portal venous phase CT scan in a woman with metastatic breast carcinoma to the liver. The liver shows nodular contours (arrowhead) and a pseudocirrhotic appearance. There is subtle capsular retraction adjacent to some of the lesions (arrow).
However, as opposed to cirrhosis, the left medial segment is of normal size or enlarged (Fig. 17). This morphologic finding has been considered useful in distinguishing patients with congenital hepatic fibrosis from those with cirrhosis [33,34].

Patients with liver metastases from breast carcinoma treated with chemotherapy often develop retraction of the capsular surface with segmental volume loss, lobular hepatic contour and enlargement of the caudate lobe, a pattern that has been described as “pseudo-cirrhosis” (Fig. 18) [35].

Budd-Chiari syndrome is characterized by hypertrophy of the caudate lobe and variable atrophy/hypertrophy of the remaining portions of the liver, along with heterogeneous liver enhancement, ascites and splenomegaly. Sometimes, large hypervascular regenerative nodules can be mistaken for hepatocellular carcinoma (Fig. 19) [36–38].

Sarcoidosis is a multisystem granulomatous disease that affects the liver in 24–79% of patients, and may result in hepatic injury that simulates or causes cirrhosis. Multifocal nodular hypoenhancing lesions in the liver (and spleen) are typical findings, but widened fissures, splenomegaly and upper abdominal lymphadenopathy are features seen in cirrhosis and hepatic sarcoidosis, requiring liver biopsy for further evaluation (Fig. 20) [39].

In those patients with cavernous transformation of the portal vein, serial cross sectional studies have demonstrated hypertrophy of the central zones of the liver (segment 1 and 4) and hypotrophy of the left and right lobes due to the portal hypopfusion of these peripheral areas (Fig. 21) [40].

**12. Summary**

Both CT and MR provide valuable insights into the extent of hepatic injury from cirrhosis and complications including por-
tal hypertension. Distinction among small hepatic focal lesions remains challenging, while both CT and MR are quite accurate in detection and characterization of larger (>2 cm) lesions, including hepatocellular carcinoma. Attention to scan technique is key, including the use of multiphasic imaging with a rapid IV bolus of contrast medium.

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