4 Imaging of Benign Focal Liver Lesions

4.1 Primary Benign Liver Lesions

Each of the cellular components of the liver - hepatocytes, biliary epithelium and mesenchyme - can give rise to benign tumors.

It is possible to classify these tumors based on their cellular origin:

Hepatocellular Origin
- Hepatocellular adenoma
- Hepatocellular hyperplasia
  - Focal nodular hyperplasia (FNH)
  - Nodular regenerative hyperplasia

Cholangiocellular Origin
- Hepatic cyst
- Simple hepatic cyst
- Congenital hepatic fibrosis or polycystic liver disease

4.1.1 Hemangioma

Hepatic hemangioma is the most common primary liver tumor; the incidence of this lesion in the general population varies in published reports from 0.4% to 20%. Hemangiomas may be multiple in up to 50% of cases, but may also be found in conjunction with other neoplasms. An association with focal nodular hyperplasia occurs in 10-20% of cases [18, 53].

There are two forms of this neoplasm: those that occur in childhood and those that occur in adults. Infantile hepatic hemangioma frequently resolves spontaneously. However, it may also become life-threatening due to arterio-venous shunting and resulting cardiac failure. In such cases, the lesion requires aggressive surgical intervention. Hepangiomas in adults occur most frequently in the fourth and fifth decades of life and there is a much higher incidence in women (about 80%). Estrogen replacement therapy may play a role in the pathogenesis of this type of tumor [24]. Hemorrhage is the most common reason for prophylactic resection, although this occurs relatively infrequently.

Hemangioma, whether solitary or multiple, is a well-defined lesion that ranges in size from a few mm to more than 20 cm. Hemangiomas larger...
than 10 cm are considered “giant” hemangiomas. Microscopically, they are tumors composed of multiple vascular channels lined by a single layer of endothelial cells supported by a thin, fibrous stroma. Large lesions almost always have a heterogeneous composition with areas of fibrosis, necrosis, cystic changes and intratumoral coarse calcifications. In some cases, abundant fibrous tissue completely replaces the lesion [1, 107].

As demonstrated in many studies on the natural history of hemangioma, a large proportion are asymptomatic, and liver function tests are normal. Nevertheless, in some cases, symptoms of liver hemangioma may be misleading. Rarely, patients present with abdominal pain, and in exceptional cases, with fever, leukocytosis, thrombocytopenia, consumptive coagulopathy (Kasabach-Merritt Syndrome) or cholestasis. Occasionally, very large hemangiomas may cause symptoms by compressing adjacent organs [80].

On ultrasound (US) examination, hemangiomas are typically homogeneously hyperechoic with well-defined margins, and may exhibit faint acoustic enhancement. The echogenicity may vary because these tumors may contain cystic and fibrotic regions; this is especially true in large hemangiomas (Fig. 1). Color Doppler US demonstrates filling vessels in the periphery of the tumor but no significant Color Doppler flow deep within the hemangioma itself (Fig. 2).

Power Doppler, however, may detect flow within hemangiomas but the pattern is non-specific and can also be seen in other primary hepatic liver lesions such as hepatocellular carcinoma (HCC) and focal nodular hyperplasia (FNH) [23].

Contrast-enhanced US allows monitoring of the dynamic enhancement behavior of hemangioma. During the arterial phase, both capillary and cavernous hemangiomas generally demonstrate an early and strong peripheral enhance-
ment. In the portal-venous phase, hemangiomas show a tendency for centripetal filling, and during the late phase, the vascular components of both capillary and cavernous hemangiomas tend to appear hyperechoic compared to the surrounding normal liver parenchyma. In the late phase, however, cavernous hemangiomas tend to be more heterogeneous due to incomplete filling of the lesion (Fig. 3) [7, 56].

Hemangiomas typically appear as low density masses on computed tomography (CT) imaging, with well-defined lobulated margins on unenhanced scans. During the arterial phase, hemangiomas demonstrate an initial peripheral nodular enhancement on spiral CT; this enhancement is isodense with the aorta and progresses centrally with time. On delayed scans, the lesion becomes hyperdense or isodense compared with normal liver parenchyma (Fig. 4). The early nodular peripheral enhancement corresponds to large peripheral feeding vessels. The presence of nodular enhancement which is isodense with the aorta has been found to be about 70% sensitive and 100% specific in differentiating hemangioma from hepatic metastases [59]. Although small lesions often fill-in rapidly and completely (Fig. 5), large tumors may show central non-enhanced areas corresponding to scar tissue, myxoid changes or cystic cavities (Fig. 4) [118].

Hemangiomas are revealed as focal defects on both hepatobiliary and sulfur colloid scans against underlying liver which shows normal isotope uptake. Tagged red blood cell scans can be virtually diagnostic of this lesion; there is a defect in the early phases that shows prolonged and persistent "filling-in" on delayed scans [41].

Evaluation of hemangiomas of the liver is one of the major applications of magnetic resonance (MR) imaging, particularly in oncology patients with atypical hemangiomas detected on CT or US examinations (Fig. 6).
On unenhanced T1-weighted MR images, hemangiomas are most commonly visualized as well-defined, typically homogeneous, hypointense masses with lobulated borders. On T2-weighted images they characteristically show marked homogeneous hyperintensity with occasional low signal intensity areas corresponding to areas of fibrosis (Fig. 7) [63, 92].

After administration of an extracellular Gd-agent, or an agent with both extracellular and liver-specific properties, three types of enhancement pattern may be seen, depending on the size of the lesion. The majority of small lesions under 1.5 cm in diameter show uniform early enhancement during the arterial phase at 25–30 sec post-contrast, or peripheral nodular enhancement progressing centripetally to uniform enhancement in the late arterial and portal-venous phases (Fig. 8).

The second pattern is frequently seen in medium-size lesions between 1.5 and 5 cm, but may also be seen in large hemangiomas. These lesions typically show a peripheral nodular enhancement that progresses centripetally to a uniform enhancement in the equilibrium phase at 3-5 min post-contrast. In particular, large hemangiomas may show peripheral nodular enhancement with persistent central hypointensity corresponding to fibrosis and or cystic areas (Fig. 9).

Peripheral nodular enhancement, in particular, detected during the arterial phase of dynamic MR
Fig. 5a-d. Hypervascular hemangioma. On the unenhanced CT scan (a) the hemangioma appears slightly hypodense (arrow). Rapid filling-in is seen in the arterial phase (b), which persists into the portal-venous phase (c). During the delayed phase (d) the hemangioma is isodense with the surrounding liver tissue.

Fig. 6a-d. Atypical hemangioma. Patient with history of renal cell carcinoma. The precontrast CT scan (a) shows a large, slightly hypodense lesion (arrows) located in segment VIII of the right liver lobe. In the arterial phase of the dynamic study after contrast medium administration (b) the hemangioma demonstrates an irregular and marked enhancement with progressive but incomplete filling in the portal-venous (c) and equilibrium (d) phases.
**Fig. 7a, b.** Hemangioma. On the unenhanced GE T1-weighted MR image (a), the hemangioma is seen as a well-defined hypointense mass. Conversely, on the T2-weighted image (b), the lesion (arrowhead) is markedly hyperintense.

**Fig. 8a-d.** Hypervascular hemangioma after Gd-BOPTA. The lesion is markedly hyperintense (arrow) on the Turbo SE T2-weighted image (a) and hypointense on the GE T1-weighted image (b). Rapid enhancement on images acquired during the arterial phase (c) after the bolus injection of Gd-BOPTA is noted, which persists and becomes homogeneous during the portal-venous phase (d).
imaging of the liver, is a very useful discriminating feature for the differential diagnosis of hemangiomas and metastases [59]. The third pattern of enhancement includes lesions that enhance homogeneously and thus may be difficult to differentiate from hypervascular metastases, which may demonstrate similar enhancement behavior. For these lesions, the combination of T2-weighted and serial dynamic post-contrast T1-weighted images facilitates a confident diagnosis of hemangioma (Fig. 10) [94].

Liver-specific contrast agents have also been evaluated for the characterization of hemangiomas. As in the case of purely extracellular Gd agents, a “nodular” centripetal pattern of enhancement on dynamic imaging after Gd-BOPTA and Gd-EOB-DTPA administration is considered highly specific for hemangioma in a manner similar to the finding of rim enhancement in the case of liver metastases. In the delayed liver-specific phase, hemangiomas tend to be isointense or hypointense compared to the surrounding liver parenchyma, and often contain low intensity areas indicative of fibrotic or cystic components. While contrast agent pooling of intralesional components may be seen a peripheral wash-out as observed in metastases is not observed in hemangiomas.

Superparamagnetic iron oxide (SPIO) contrast agents have also been evaluated for the characterization of hemangiomas, especially when these appear atypical on other imaging modalities. After administration of SPIO, hemangiomas appear hyperintense on post-contrast T1-weighted images compared to surrounding liver parenchyma, the reverse of their appearance on pre-contrast T1-
Fig. 10a-e. Capillary hemangioma. On the unenhanced T2-weighted TSE image (a) the capillary hemangioma (arrow) is markedly hyperintense, whereas on the GRE T1-weighted image (b) it is hypointense. During the dynamic study after contrast agent administration, rapid, almost complete filling-in is seen in the arterial phase (c) which persists, completely and homogeneously, into the portal-venous (d) and equilibrium (e) phases.

Fig. 11a, b. Hemangioma after SPIO. On the unenhanced GE T1-weighted image the hemangioma appears hypointense (a). On the post-contrast T1-weighted image after SPIO administration (b) the lesion shows increased signal intensity compared to the surrounding liver tissue (T1 effect).
weighted images. This signal enhancement is caused by a T1 effect due to low SPIO concentration in the vascular channels of hemangiomas. However, this effect can only be observed on T1-weighted delayed phase images, which are not routinely acquired after administration of SPIO (Fig. 11) [35].

With the use of ultrasmall superparamagnetic iron oxide (USPIO) contrast agents, which are ultimately cleared by the reticuloendothelial system but which reside in the intravascular compartment immediately after injection, hemangiomas enhance on T1-weighted dynamic images and appear hyperintense compared with the normal liver parenchyma (Fig. 12). On T2-weighted scans the lesions decrease in signal intensity and, at higher doses of USPIO, may become isointense with the liver [90].

Hemangiomas usually do not contain significant amounts of Kupffer cells or normal hepatocytes and therefore do not take up SPIO particles or Mn"⁺ after the infusion of mangafodipir trisodium. Specifically, on delayed phase T2-weighted images after SPIO administration, hemangiomas appear hyperintense, whereas on T1-weighted images in the hepatobiliary phase after administration of mangafodipir trisodium hemangiomas generally appear hypointense.

4.1.2 Focal Nodular Hyperplasia

FNH is a benign tumor-like lesion of the liver which is considered to be the result of a hyperplastic response of the hepatocytes to the presence of a pre-existing vascular malformation. It is thought that increased arterial flow hyperperfu ses the local parenchyma leading to secondary hepatocellular hyperplasia [111].

In support of this theory, FNH has been found in association with cavernous hemangioma and in some cases FNH has been associated with vascular malformations of various other organs and with neoplasms of the brain (Fig. 13) [111].

In frequency, FNH is the second most common benign hepatic tumor after hemangioma and has been shown to constitute about 8% of primary hepatic tumors at autopsy. It usually occurs in women of childbearing- and middle-age, but cases have been reported in men and children as well. Most investigators agree that oral contraceptives are not the causal agents of FNH [9]. However estrogens could have a trophic effect on FNH by increasing the size of nodules and contributing to the vascular changes [111].

Clinically, this tumor is usually an incidental finding at autopsy, elective surgery or on diagnos-
tic liver imaging performed for other reasons. Less than one third of cases are discovered because of clinical symptoms, usually comprising right upper quadrant or epigastric pain. Although most patients are asymptomatic at discovery, in symptomatic cases pain is usually caused by larger lesions, which expand the Glisson capsule or have a focal mass effect on surrounding organs.

The natural history of FNH is characterized by the absence of complications. Therefore, typical asymptomatic FNH should be managed conservatively in association with the discontinuation of oral contraceptives. Rarely, when symptoms are particularly severe, surgical resection may be indicated.

FNH is usually a solitary, subcapsular nodular mass, but cases with several nodules have been described (Fig. 14). FNH is a homogeneous tumor, which only infrequently demonstrates hemorrhage and necrosis. On cut section the majority of these tumors have a central fibrous scar and although the margin is sharp, generally there is no capsule [19].

Often FNH has a mean diameter of 5 cm at the
time of diagnosis, although sometimes it is possible to find neoplasms that replace an entire lobe of the liver, as in the lobar FNH form.

Currently, FNH is divided into two types, classic and non-classic. Classic FNH is characterized by the presence of abnormal nodular architecture, malformed vessels, and cholangiocellular proliferation. The non-classic type comprises three subtypes: a) telangiectatic FNH, b) FNH with cytologic atypia and c) mixed hyperplastic and adenomatous FNH.

Non-classic FNH may lack the nodular abnormal architecture and malformed vessels, which characterize the classic type, but they always show bile ductular proliferation [73].

The gross appearance of classic FNH consists of lobulated contours and parenchyma that is composed of nodules surrounded by radiating fibrous septa originating from a central scar that contains malformed vessels. A classical form of FNH with a stellate scar is seen in about 50% of cases; however, variant lesions are increasingly being detected. These variant lesions are often small with atypical features, such as the absence of a central scar or telangiectatic changes. The most characteristic microscopic features of classic FNH are fibrous septa and cellular areas of hepatic proliferation. The hepatic plates may be moderately thickened and contain normal hepatocytes. The central scar typically consists of fibrous connective tissue, cholangiocellular proliferation with inflammatory infiltrates and malformed vessels, including tortuous arteries, capillaries and veins.

The arterial blood in FNH, as opposed to that in adenoma, flows centrifugally from the anomalous central arteries. Both classic and non-classic types contain a variable content of Kupffer cells.

In contrast, the gross appearance of non-classic FNH is heterogeneous and globally resembles that of adenoma, with lobulated contours and no macroscopic central scar. The histological findings of non-classic FNH depend on the subtype [9, 73]. The telangiectatic type consists of hepatic plates that frequently appear atrophic. The plates are one cell thick and are separated by dilated sinusoids. Fibrous septa can be found in all cases of telangiectatic FNH that contain some degree of bile duct proliferation. In this type of FNH arteries have a hypertrophic muscular media but no intimal proliferation. In contrast to the classic form, these abnormal vessels drain directly into the adjacent sinusoids, while in classic FNH connections to the sinusoids are almost never seen. Necrotic areas and hemorrhage can be found within telangiectatic FNH; these features are often responsible for the appearance of the tumor and the presence of abdominal pain [73, 111]. FNH with cytological atypia have the gross and histological features of classic FNH but contain areas of large cell dysplasia. The mixed hyperplastic and adenomatous form of FNH has two variants, one resembling the telangiectatic type, the other simulating adenoma [73].

When multiple, FNH lesions tend to be associated with other lesions, such as hepatic hemangioma, meningioma, astrocytoma, telangiectasia of the brain, and systemic arterial dysplasia. FNH has also been described in association with hepatocellular adenoma and liver adenomatosis. In these cases it appears that FNH lesions may be secondary to systemic and local abnormalities of vascular growth induced by oral contraceptives, tumor-induced growth factors, thrombosis or local arteriovenous shunting [9].

On US images, classic FNH appears as a homogeneous well-demarcated nodule which may be hypoechoic, isoechoic or slightly hyperechoic relative to the normal liver parenchyma (Fig. 15). Displacement of contiguous hepatic vessels may be the only detectable abnormality. Some lesions may show a hypoechoic halo surrounding the lesion; this halo most likely represents compressed hepatic parenchyma and is more evident around nodules with fatty infiltration or which are located in steatotic liver tissue.

The central scar and the fibrous septa are often difficult to visualize on US. However, when apparent, the central scar is usually hyperechoic while the fibrous septa are hypoechoic. Characteristic findings at color Doppler US include the presence of a central feeding artery with a stellate or spoke-wheel pattern, which corresponds to vessels running into the radiating fibrous septa from the central scar (Fig. 16). The spectral analysis may show an intratumoral pulsatile waveform with high diastolic flow and low resistive index corresponding to malformed arteries, and a continuous waveform which could represent a draining vein of the neoplasm [112]. US in general is a non-specific imaging method for the characterization of non-classic FNH.

The hypervascularity of the lesion is detected using SonoVue-enhanced US. In the arterial phase of the dynamic study the intralesional vessels are typically of the stellate or spoke-wheel configuration and the lesion appears homogeneously hyperechoic compared to the normal liver parenchyma. In the portal-venous phase, FNH remains hyperechoic and the nodule gradually becomes isoechoic with the adjacent liver in the later phases of dynamic imaging. Conversely the central scar is depicted as a hypo- or anechoic area within the hyperechoic lesion during both the arterial and portal-venous phases, while it shows uptake of contrast in the later phases (Fig. 17) [57].

On unenhanced CT FNH is usually isoattenuating or slightly hypoattenuating. When the lesion is isoattenuating compared to the normal liver parenchyma, it may be detectable only because of
Fig. 14a-j. Multiple focal nodular hyperplasia. Unenhanced axial and coronal T2-weighted images (a, b) reveal several slightly hyperintense liver lesions (arrows) with one lesion in the left liver lobe demonstrating a central scar (arrowhead). On the unenhanced T1-weighted image (c) the lesions are slightly hypointense. Arterial phase images acquired after the bolus injection of Gd-BOPTA reveal strong hypervascularization of all the lesions (d-f), and a central scar in three of the lesions (arrows). In the portal-venous phase (g) the lesions are slightly hyperintense. In the equilibrium phase (h), the central scar of the lesion in the left liver lobe shows late enhancement (arrow). This is typical for FNH in which the central scar is more an arterio-venous malformation than a true scar. T1-weighted images acquired during the hepatobiliary phase (i), show enhancement of the liver lesions. This is more obvious on T1-weighted fs images (arrows) acquired at the same time point (j) and is indicative of the lesions containing functioning hepatocytes that are able to take up Gd-BOPTA. The fact that the lesions enhance to a higher degree than the surrounding liver tissue is indicative of the benign nature of the lesions and of the fact that the biliary system of FNH is malformed, leading to a slowing of biliary excretion.

Fig. 15a, b. Classic focal nodular hyperplasia on US. The ultrasound examination reveals a homogeneous lesion (arrows) that is either hypoechoic (a) or hyperechoic (b) compared to the surrounding normal liver tissue.

Fig. 16a, b. Classic focal nodular hyperplasia on color Doppler US. On ultrasound (a) the lesion (asterisk) is isoechoic and only a displacement of the middle hepatic vein is appreciable (arrowhead). Color Doppler US (b) shows vascularization within the lesion, corresponding to vessels running in the radiating fibrous septa, demonstrating a spoke-wheel pattern.
its mass effect. FNH generally only appears hyper-
attenuating to unenhanced liver when there is he-
patic steatosis or when the liver is otherwise ab-
normally decreased in attenuation. However, in
rare cases FNH may still be isoattenuating or hy-
opattenuating on unenhanced CT in patients with
hepatic steatosis when there is fatty infiltration of
the FNH itself [67]. In a third of cases, a low-densi-
ty central area is seen, corresponding to the central
scar [95].

During the arterial phase of contrast-enhanced
CT, FNH enhances rapidly and becomes hyper-
dense compared to normal liver. The low-attenua-
tion scar appears conspicuous against the hyper-
dense tissue, and foci of enhancement represent-
ating feeding arteries may be seen within the scar. In
the portal-venous phase of enhancement, the dif-
ference in attenuation between FNH and normal
liver decreases and FNH may become isodense
with normal liver parenchyma. The central scar is
almost always seen as hypointenuting to the re-
mainder of the FNH on unenhanced and enhanced
dynamic phase scans. On delayed scans, however,
there is retention of contrast material within the fi-
brous scar, giving it an isodenuating or, more fre-
quently, a hyperattenuating appearance (Fig. 18).
Detection of the central scar is related to the size of
the lesion; while a central scar may be identified in
as many as 65% of larger FNH, it may be seen in
only about 35% of lesions smaller than 3 cm in di-
ameter [15, 19]. 3D multidetector CT angiography
is very useful in demonstrating the intratumoral
vascularization of FNH which is characterized by
hepatic venous drainage and by the absence of
portal-venous supply (Fig. 19) [17].

On MR, FNH are considered classic when they
appear as homogeneously isointense or slightly hy-
perintense on T2-weighted images, and isointense
or slightly hypointense on T1-weighted images be-
fore contrast agent administration. Typical behav-
ior during the dynamic phase of contrast enhance-
ment is marked and homogeneous signal intensity
enhancement during the arterial phase, rapid and
homogeneous signal intensity wash-out during the
portal-venous phase, and signal isointensity (with
the exception of the scar) during the equilibrium
phase (Fig. 20). A typical scar appears as a hyper-
intense central stellate area on T2-weighted images
and as a hypointense area on T1-weighted images.
During the dynamic phase of contrast enhance-
ment a typical scar is hypointense during the arte-
rial and portal-venous phases and slightly hyper-
intense in the equilibrium phase (Fig. 20).

Atypical features of FNH generally consist of le-

Fig. 17a-d. Focal nodular hyperplasia with SonoVue. Precontrast US (a) reveals a well defined isoechoic nodule (arrow) surrounded by a
hypoechoic halo. In the arterial phase (b) after SonoVue administration the FNH (arrow) appears homogeneously hyperechoic compared to
the normal liver parenchyma. Rapid contrast wash-out occurs in the portal-venous (c) and equilibrium (d) phases.
Fig. 18a-d. Focal nodular hyperplasia on CT. On the unenhanced CT scan (a) the FNH (arrows) is isoattenuating to the liver. During the arterial phase (b) after contrast medium administration, the nodule enhances rapidly and homogeneously while the central scar (arrowhead) remains hypodense. In the portal-venous and equilibrium phases (c and d, respectively) the FNH appears isodense compared to the normal liver parenchyma (arrows in c). In the equilibrium phase (d) the central scar is depicted as hyperattenuating (arrow).

Fig. 19. Focal nodular hyperplasia on 3D multidetector CT angiography. 3D multidetector CT angiography shows the intratumoral vascularization, characterized by an arterial vessel leading directly into the lesion (arrowhead) and hepatic venous drainage (arrows).
Fig. 20a-f. Focal nodular hyperplasia. On the Turbo SE T2-weighted and HASTE T2-weighted images (a and b, respectively), the nodule (arrows) is isointense compared to the surrounding liver tissue and possesses a hyperintense “stellate” central scar. On the unenhanced T1-weighted image (c), the FNH (arrows) appears as an isointense lesion with a hypointense central scar. This lesion shows intense and homogeneous enhancement during the arterial phase after contrast agent administration (d) and rapid wash-out in the portal-venous phase (e). In the equilibrium phase (f), the lesion is again isointense. The central scar is typically hypointense during the arterial and portal-venous phases. However, it appears hyperintense (arrow) in the equilibrium phase comparable to that seen in CT imaging.
**Fig. 21a-h.** Atypical focal nodular hyperplasia with Gd-DTPA. On the precontrast HASTE T2-weighted image (a) the nodule (arrow) is slightly hyperintense compared to the surrounding normal liver parenchyma, whereas on the GRE T1-weighted “in-phase” image (b) it appears heterogeneously isointense (arrow). On the GRE T1-weighted “out-of-phase” image (c) it appears heterogeneously hypointense. In the arterial phase of the dynamic evaluation after contrast agent administration (d) the lesion shows marked enhancement, with persistent uptake of contrast material in the portal-venous (e) and equilibrium (f) phases. On late GRE T1-weighted “in-phase” (g) and “out-of-phase” (h) images the nodule appears as a well defined, slightly hypointense lesion. This behavior could be related to sinusoidal dilatation.
sion heterogeneity, hyperintensity on T1-weighted images, strong hyperintensity on T2-weighted images and hypointensity in the portal-venous or equilibrium phases. Hyperintensity on T1-weighted images may be due to different pathologic changes, including fat deposition, copper accumulation, high protein concentration, blood degradation products or sinusoidal dilatation. Persistent contrast agent uptake in telangiectatic FNH could be related to sinusoidal dilatation (Fig. 21).

Other atypical features include the absence of a central scar in a lesion greater than 3 cm in size, scar hypointensity on T2-weighted images and scar hypointensity in the equilibrium phase following injection of contrast agent. Finally, the presence of a pseudocapsule, seen as a complete hyperintense perilesional ring during the equilibrium phase can be considered atypical (Fig. 22) [38]. In rare cases, hemorrhage, calcification, or necrosis can be observed in non-classic forms of FNH.

The use of contrast-enhanced dynamic MR imaging provides the greatest diagnostic sensitivity among the imaging techniques in current use, especially when combined with the information available on precontrast T1- and T2-weighted im-

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**Fig. 22a-e.** Atypical focal nodular hyperplasia. On the unenhanced T2- and T1-weighted images (a and b, respectively), the lesion (asterisk in a) is isointense as compared with the normal liver tissue and is delineated by a thin hypointense rim (arrowheads in b). During the early arterial (c) and portal-venous (d) phases after contrast agent administration, the lesion (arrowheads) is seen as highly vascularized. The lesion remains slightly hyperintense in the equilibrium phase (e) when a hyperintense peripheral rim can also be seen.
Fig. 23a, b. Focal nodular hyperplasia after mangafodipir trisodium administration. On the precontrast T1-weighted image (a), the FHN is seen as isointense with a stellate hypointense central scar. On the delayed image after mangafodipir administration (b), the lesion is again isointense compared to the surrounding parenchyma.

Fig. 24a, b. Atypical focal nodular hyperplasia after Gd-BOPTA. The same case as presented in Fig. 22. On the precontrast T1-weighted image (a) the FHN is isointense to partially slightly hypointense compared to the normal liver tissue. During the hepatobiliary phase 3 h after the bolus administration of Gd-BOPTA (b), the lesion is again isointense to the surrounding liver parenchyma, indicating functioning hepatocytes. This enables the diagnosis of FHN.
ages. However, the high frequency of atypical features does not permit the accurate characterization of FNH in every case. In this regard, diagnosis on dynamic MR imaging with conventional extracellularly-distributed Gd agents relies on the same morphologic and hemodynamic features as helical CT [38].

The availability of liver-specific MR contrast agents increases the potential for accurate lesion characterization. FNH are depicted as either hyperintense or isointense during the delayed phase after administration of Gd-BOPTA, Gd-EOB-DTPA or Mn-DPDP, reflecting the abnormal biliary drainage within the lesion (Figs. 23, 24).

Gd-BOPTA in particular offers both a dynamic and delayed phase imaging capability, thereby permitting both morphological and functional information to be acquired for the characterization of these lesions (Figs. 25, 26) [38].

In the same way, Gd-EOB-DTPA is helpful in the characterization of FNH because FNH contains hepatocytes that take up this agent, resulting in

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**Fig. 25a-f.** Focal nodular hyperplasia after Gd-BOPTA. On the unenhanced T2-weighted HASTE and T1-weighted GE images (a, b) as well as on post-contrast T1-weighted images acquired during the dynamic (c, d, e) and delayed (f) phase after administration of Gd-BOPTA, typical findings of FNH are clearly depicted. Importantly, it is possible to characterize the nodule according to both morphologic and functional criteria.
Fig. 26a-e. Atypical focal nodular hyperplasia after Gd-BOPTA
On the unenhanced SE T2-weighted image (a), the lesion (asterisk) shows lobulated margins, exophytic growth and heterogeneous hyperintensity. On the pre-contrast GE T1-weighted image (b), the lesion appears with heterogeneous hypointensity. During the arterial phase (c) after Gd-BOPTA administration, the nodule shows intense but heterogeneous enhancement. The lesion remains slightly hyperintense during the equilibrium phase (d). The signal intensity and enhancement pattern are not typical for FNH. On the hepatobiliary phase image (e), however, the lesion appears slightly hyperintense due to the uptake of Gd-BOPTA by normal hepatocytes and subsequent impaired biliary excretion. This finding is consistent with the characterization of FNH.
iso- or hyperintensity of the lesion compared with the normal liver parenchyma on delayed T1-weighted images; the enhancement pattern is very similar to that which is observed after Gd-BOPTA administration (Figs. 27, 28) [62].

On delayed phase T2-weighted images after SPIO administration, typical FNH demonstrate a loss of signal due to uptake of iron oxide particles by Kupffer cells within the lesion (Fig. 29) [34]. The degree of signal loss on SPIO-enhanced T2-weighted images is significantly greater than that in other focal liver lesions such as HCC and hepatocellular adenoma; however, overlap may occur due to the lack of function of Kupffer cells in some FNH [75].

In a large series it was demonstrated that only 39% of FNH showed significant signal drop after SPIO. The remaining 61% of nodules did not show significant signal drop and appeared homogeneously, but more frequently heterogeneously, hyperintense on T2-weighted images after SPIO (Fig. 30) [39].

On dynamic T1-weighted images after bolus USPIO administration (SH U 555 A), FNH in many cases demonstrate an initial, moderate signal increase followed by an early decrease of signal intensity due to contrast pooling (Fig. 31). The hypervascularity depicted on arterial phase images is generally inferior compared to that observed on Gd-enhanced arterial phase imaging. On dynamic T2-weighted images after USPIO administration, FNH demonstrate a decrease of signal intensity over time [44].

Fig. 27a-d. Focal nodular hyperplasia after Gd-BOPTA. On the pre-contrast T1-weighted image (a) the FNH is seen as isointense compared with surrounding liver tissue. The intense and homogeneous enhancement seen during the arterial and portal-venous phases (b and c, respectively), as well as the delayed isointensity demonstrated during the hepatobiliary phase (d), is typical for FNH.
**Fig. 28a-d.** Focal nodular hyperplasia after Gd-EOB-DTPA. The same case as shown in Fig. 27. The enhancement pattern after Gd-EOB-DTPA is very similar to that observed after Gd-BOPTA; a slightly hypointense lesion on the unenhanced T1-weighted image (a) demonstrates strong hyperintensity during the arterial phase (b) after the administration of Gd-EOB-DTPA. The subsequent portal-venous phase image (c) reveals persistent enhancement typical of FNH. On the hepatobiliary phase image (d) the lesion demonstrates an iso/slightly hypointense appearance compared with the surrounding parenchyma. With this contrast agent the hepatobiliary phase image was acquired after 20 min.

**Fig. 29a, b.** Focal nodular hyperplasia before (a) and after (b) SPIO administration. After SPIO administration (b), the FNH (asterisk in a) shows significant signal drop compared with that seen on the pre-contrast image (a).
Fig. 30a, b. Focal nodular hyperplasia before (a) and after (b) SPIO administration. The same case as shown in Figure 26. The FNH (asterisk) appears slightly heterogeneously hyperintense on the SE T2-weighted image (a). After SPIO administration (b), the nodule is still heterogeneously hyperintense compared to the surrounding normal liver. Note that compared with the unenhanced image (a), the signal drop in FNH is less pronounced than in normal liver parenchyma.

Fig. 31a-g. Focal nodular hyperplasia after SH U 555 A. On precontrast TSE T2-weighted (a) and T1-weighted (b) images, the FNH (arrows) appears as an isointense nodule compared with the normal liver. The lesion is slightly hypointense using a VIBE sequence (c). During the arterial phase (d), after SH U 555 A administration the nodule shows a moderate uptake of contrast agent which washes out rapidly in the portal-venous phase (e). In the equilibrium phase (f) the lesion appears slightly hypointense. The reticuloendothelial phase (g) reveals a typical, marked signal drop, similar to that observed in the normal liver.
4.1.3 Hepatocellular Adenoma

Hepatocellular adenoma (HA) is a rare benign tumor of hepatocellular origin which is most common in middle-aged women. The term HA is used to describe a spectrum of lesions associated with different pathological and etiological factors that give rise to a variety of histological forms. A new classification of adenomas has been proposed, according to which anabolic steroid-associated type HA is considered separate from the classical form [55]. This is due to its distinct histologic appearance, which often resembles that of hepatocellular carcinoma. An additional separate form is liver adenomatosis (LA) which is characterized by the presence of ten or more adenomas within an otherwise normal liver, without a history of glycogen storage disease or chronic anabolic steroid use.

Typical HA is defined as a tumor composed of hepatocytes arranged in cords, that only occasionally produces bile. The tumor lacks portal tracts and terminal hepatic veins [65]. Although the precise pathogenic mechanism of HA is unknown, the use of estrogen-containing [110] or androgen-containing [98] steroid medications clearly increases their prevalence, number and size within the affected population and often within individual patients. Moreover, this causal relationship is related to dose and duration, with the greatest risk encountered in patients taking large doses of estrogen or androgen for prolonged periods of time [98]. In women who have never used oral contraceptives the annual incidence of HA is about 1 per million. This increases to 30-40 per million in long-term users of oral contraceptives [83]. Withdrawal of estrogen derivatives may result in regression of the HA.

Another risk group for HA are patients affected by glycogenosis, in particular, type I glycogen storage disease. In these patients, the possible pathogenetic mechanisms include glucagon/insulin imbalance, cellular glycogen overload, and protooncogene activation [8]. The adenomas are also more likely to be multiple and to undergo malignant transformation, although the latter is still quite rare. Patients with diabetes mellitus have decreased circulating insulin levels and elevated serum glucose, therefore they share a similar pathogenetic mechanism as patients affected by glycogenosis.

A recognized association is that of congenital or acquired abnormalities of the hepatic vasculature. An association with portal vein absence or occlusion [71] or portohepatic venous shunts [54] has been noted, particularly in patients with LA [37]. Although the adenomas in LA are histologically similar to other adenomas, they are not steroid-dependent, but are multiple, progressive, symptomatic, and more likely to lead to impaired liver function, hemorrhage, and perhaps malignant degeneration [26, 37].

Recently, some authors [11, 22] have suggested a genetic alteration in the origin of HA. Specifically, a combination of a β-catenin mutation and a deletion locus on chromosome 12 was found in patients with HA.

An association with pregnancy has also been described, probably due to increased levels of endogenous steroid hormones [103]. HA occurs sporadically in patients without known predisposing factors and rarely in children and adult males.

Most patients with only one or few HA are asymptomatic and almost invariably have normal liver function and no elevation of serum tumor markers such as α-fetoprotein. Large HA may cause a sensation of right upper quadrant fullness or discomfort. However, the classic clinical manifestation of HA is spontaneous rupture or hemorrhage, leading to acute abdominal pain and possibly progressing to hypotension and even death [58].

HA is solitary in 70-80% of cases, but it is not unusual to encounter two or three HA in one patient, particularly at multiphasic CT or MR imaging [49, 77]. Patients with glycogen storage disease or LA may have dozens of adenomas detected at imaging and even more at close examination of resected specimens [26, 37, 86]. Individual lesions vary in size from less than 1 cm to more than 15 cm. The typical steroid-related adenoma often comes to clinical attention when it reaches about 5 cm in diameter. Large and multiple lesions are more prone to spontaneous hemorrhage [58]. The propensity to hemorrhage reflects the histological characteristics of HA, in which the cord-like arrangement of cells structured in large plates are separated by dilated sinusoids. Because adenomas lack a portal-venous supply, they are perfused by arterial pressure derived solely from peripheral arterial feeding vessels. The extensive sinusoids and feeding arteries contribute to the hypervascular nature of HA, which together with the poor connective tissue support, predisposes the lesions to hemorrhage. Because a tumor capsule is usually absent or incomplete, hemorrhage may spread into the liver or abdominal cavity [65].

Kupffer cells are often found in adenomas, but in some cases can be reduced in number and with little or no function, as reflected by absent or diminished uptake of technetium (Tc)-99m sulfur colloid [89]. A key histological feature that helps distinguish HA from FNH is the notable absence of bile ductules in HA [13]. Adenoma cells are generally larger than normal hepatocytes and may contain large amounts of glycogen and lipid. Intra- and intercellular lipid may manifest as macroscopic fat deposits within the tumor [49] and are responsible
for the characteristic yellow appearance of the cut surface of adenoma. Evidence of lipid at CT or MR imaging can be helpful in diagnosing HA.

In many cases HA is seen as a large, predominantly hypoechoic lesion on US with central anechoic areas corresponding to areas of internal hemorrhage (Fig. 32) [117]. Adenomas may undergo massive necrotic and hemorrhagic changes which give the lesion a complex appearance on US with large cystic components. Non-complicated HA may appear as an iso- or hypoechoic mass with a relatively homogeneous aspect (Fig. 32a). However, fatty components within the lesion may result in focal hyperechogenicity. A peripheral pseudocapsule, which is present in about one third of HA lesions, is seen as a hypoechoic peripheral rim on US.

Color Doppler US reveals peripheral arteries and veins which correlate well with both gross and angiographic findings. In addition, Color Doppler may identify intratumoral arteries. This finding is absent in FNH and may be a useful discriminating feature for HA (Fig. 33) [30]. Contrast-enhanced US allows depiction of the characteristic vascular behavior of HA. During the arterial phase, an early and homogenous enhancement of non-necrotic, non-hemorrhagic portions of the tumor can be seen. Pericapsular feeding blood vessels are best

Fig. 32a, b. Hepatocellular adenoma on US. A small, non-complicated adenoma (a) is shown as a homogeneous, isoechoic nodule (asterisk) with a thin, hypoechoic peripheral rim. Larger adenomas are often heterogeneous in echogenicity (b), with both hyperechoic (arrow) and hypoechoic areas (arrowhead), which correspond to areas of hemorrhage, necrosis and fatty infiltration.

Fig. 33a, b. Hepatocellular adenoma on color Doppler US. Color Doppler ultrasound (a) reveals the intratumoral and peripheral vessels characterizing this lesion as hypervascular. A Color Doppler scan (b) reveals the presence of arterial vessels within the lesion, together with a characteristic arterial Doppler-spectrum.
visualized during the early arterial phase. In the late arterial phase and in the early portal-venous phase, the contrast wash-out of HA is initially faster than the progressive wash-in of the surrounding liver parenchyma; therefore the neoplasm remains slightly hypoechoic. In the late portal-venous and sinusoidal phases, HA generally shows the same behavior as the surrounding liver parenchyma (Fig. 34).

On unenhanced CT, HA may appear as a hypodense mass due to the presence of fat and glycogen within the tumor. However, hyperdense areas corresponding to acute or subacute hemorrhage can be noted frequently in large, complicated lesions (Fig. 35). On contrast-enhanced dynamic CT scanning, non-complicated HA generally enhances rapidly and homogeneously and have increased attenuation relative to the liver. A pseudocapsule is frequently seen in larger lesions as a hypodense and hyperdense rim on non-contrast and equilibrium phase CT images, respectively (Fig. 36) [46]. The enhancement in adenomas typically does not persist because of arteriovenous shunting [88]. Larger or complicated HA may have a more heterogeneous appearance than smaller lesions (Fig. 37) [46].

On MR images, HA frequently show heteroge-
neous hyperintensity on unenhanced T2-weighted images and heterogeneous hypointensity on unenhanced T1-weighted images. Areas of increased signal intensity on T1-weighted images indicate the presence of fat and hemorrhage, while areas of reduced signal intensity indicate necrosis (Fig. 38) [77]. Sometimes HA have a hypointense peripheral rim, corresponding to a fibrous capsule. In most cases, the rim is of low signal intensity on both T1- and T2-weighted images (Fig. 38) [3]. Because non-complicated HA frequently have a homogeneous iso- or slightly hyperintense signal on T2-weighted images and an iso- or hypointense signal on T1-weighted images they may be hard to distinguish from surrounding normal liver parenchyma (Fig. 39). The presence of glycogen in HA may increase the signal intensity on T1-weighted images. Similarly, the homogeneous or heterogeneous appearance of HA may be determined by the presence of intranodular fat (Fig. 40).

Dynamic MR imaging is able to demonstrate the early arterial enhancement that results from the presence of large subcapsular feeding vessels. This finding, however, is not specific for HA; the
Fig. 38a, b. Complicated hepatocellular adenoma. Diffuse intratumoral hemorrhage within the lesion appears heterogeneously hyperintense on the T2-weighted spin-echo image (a) and heterogeneously hypointense on the corresponding unenhanced T1-weighted spin-echo image (b). A peripheral hypointense rim (arrows) representing a fibrous capsule is visible on both images.

Fig. 39a, b. Non-complicated hepatocellular adenoma. A non-complicated HA (asterisk) located in the left lobe of the liver, appears slightly hyperintense on the unenhanced HASTE T2-weighted image (a) and isointense on the corresponding unenhanced GRE T1-weighted image (b).
specific MR appearance of HA is generally that of a fat-containing or hemorrhagic lesion with increased peripheral vascularity. On portal-venous and equilibrium phase images HA generally appear isointense or slightly hypointense, with focal heterogeneous hypointense areas of necrosis, calcification or fibrosis.

On delayed liver-specific phase images after Gd-BOPTA administration, the common appearance is hypointensity of the solid, non-hemorrhagic components of the lesion (Figs. 41, 42). This is one of the main features that differentiates FNH from HA in non-complicated, but also in calcified lesions. The hypointensity of HA reflects the lack of biliary ducts. This enhancement pattern of HA in the liver-specific phase after injection of Gd-BOPTA is opposite to that observed in FNH. The overall difference in enhancement behavior of FNH and HA on hepatobiliary phase images can be ascribed to the different structural and functional features of the lesions; in HA the absence of biliary ductules within the lesion results in altered hepatocellular transport compared with that occurring in normal hepatocytes. Thus, while the mechanism of entry of Gd-BOPTA into the hepatocytes of HA may be unaltered, the absence of the intracellular transport gradient due to the lack of any active transport across the sinusoidal membrane manifests as hypointensity against enhanced normal liver parenchyma on images acquired in the hepatobiliary phase.

A recent study has highlighted the ability of Gd-BOPTA to accurately differentiate of FNH from HA [40]: at 1-3 hours after Gd-BOPTA administration almost all FNH appeared hyper- or isointense, while all HA appeared hypointense.

Conversely, after mangafodipir trisodium administration HA appear iso- or slightly hyperintense, similar to the appearance of FNH (Figs. 41, 42). This limits the possibility to make a correct differential diagnosis.

Dynamic T1-weighted imaging after USPIO administration can reveal slight arterial enhancement which in some cases is better seen at the periphery of the lesion and corresponds to the prominent vascular portion of the adenoma. The uptake of SPIO in the accumulation phase depends on the amount and functional status of the Kupffer cells in the tumor as well as in the periphery of the lesion (Fig. 43) [44].

Adenomas in some cases may take up SPIO, re-
Fig. 41a-g. Hepatocellular adenoma: Gd-BOPTA versus Mn-DPDP. A lesion (arrows) appears isointense compared to surrounding liver tissue with intratumoral hyperintense areas on the HASTE T2-weighted image (a) and heterogeneously isointense on the pre-contrast T1-weighted image (b). During the arterial phase after the bolus injection of Gd-BOPTA the lesion demonstrates heterogeneous enhancement (c). On the subsequent portal-venous and equilibrium phases (d and e, respectively) the lesion appears mainly isointense compared to the liver. In the liver specific phase after administration of Gd-BOPTA (f) the lesion is seen as hypointense but shows some internal hyperintense peliotic areas. This may be caused by reduced uptake of Gd-BOPTA into the hepatocytes in HA as well as by the absence of bile ductules in HA: in normal liver tissue contrast agent in the hepatocytes as well as in the bile ductules contributes to the increased signal intensity. Conversely, on delayed phase images acquired after the administration of mangafodipir (Mn-DPDP) (g) the lesion demonstrates non-specific uptake of Mn^{2+} and thus appears isointense compared to normal liver tissue.
Fig. 42a-i. Complicated hepatocellular adenoma: Gd-BOPTA versus Mn-DPDP. HASTE T2-weighted (a) and Turbo SE T2-weighted images (b) reveal a large heterogeneous hyper-hypointense mass (asterisk) in the right lobe. This lesion is seen as heterogeneously hypointense on the unenhanced GE T1-weighted image (c). T1-weighted imaging during the arterial (d), portal-venous (e) and equilibrium (f) phases after the bolus injection of Gd-BOPTA reveals enhancement only in the periphery of the lesion (asterisks in d); a large hypointense central area corresponding to intratumoral hemorrhage does not show any enhancement. On the delayed hepatobiliary phase image after the administration of Gd-BOPTA (g) the lesion appears hypointense. Conversely, the cellular peripheral component shows enhancement and appears isointense with the surrounding liver parenchyma on delayed phase T1-weighted (h) and T1-weighted fat-suppressed (i) images after mangafodipir (arrows in h, i).
sulting in a decreased signal on T2-weighted images. However the uptake of SPIO is usually poor in HA compared to FNH [108].

LA is a separate clinical entity which is characterized by the presence of multiple (>10) adenoma lesions, by the absence of any correlation with steroid medication, by its equal presence in both men and women, and by abnormal increases in serum alkaline phosphatase and γ-glutamyltransferase levels [26].

The conditions that may predispose patients to LA are poorly understood, although one of the more intriguing speculations is that congenital or acquired abnormalities of the hepatic vasculature may be involved [37]. Other investigators [27, 49] have noted that both FNH and HA occur more often in patients who have coexistent vascular tumors, portal-venous absence or occlusion, or hepatic portovenous shunts. It is thought that a focal disturbance of the hepatic blood supply somehow facilitates the hyperplastic development of these two similar benign liver lesions [37].

Patients with LA are at increased risk for development of HCC, and should be closely monitored with CT or MR imaging and by serum α-fetoprotein or other tumor marker examinations [58, 86].

Clinically, patients with LA can be asymptomatic or have chronic or acute abdominal pain.
The multiple adenomas in LA may have a variety of appearances, but the CT and MR characteristics of individual lesions are similar to those reported for sporadic or solitary HA (Fig. 44) [49, 77]. Management of LA remains difficult because there is no predictive sign of its potential complications other than the size of the individual lesions. Therefore close follow-up is mandatory to evaluate progression. Liver resection is the preferred option because LA is essentially a benign disease that does not impair hepatocellular function. Liver transplantation remains a difficult decision, although it is sometimes the last option in progressive forms, or in liver disease that impairs socio-professional day-to-day life in young patients, particularly in young women trying to become pregnant [4].

4.1.4 Nodular Regenerative Hyperplasia

Nodular regenerative hyperplasia (NRH) of the liver is a condition characterized by diffuse micronodular transformation of the hepatic parenchyma without the formation of fibrous septa between the nodules [115]. The nodules vary in size (0.1 to 3 cm) but are usually smaller than 1 cm. Various systemic diseases and drugs are often associated with NRH: myeloproliferative syndromes (polycythemia vera, chronic myelogenous leukemia, and myeloid metaplasia); lymphoproliferative syndromes (Hodgkin’s and non-Hodgkin’s lymphoma, chronic lymphocytic leukemia, and plasma cell dysplasia); chronic vascular disorders (polycystic kidney disease); rheumatologic disorders (rheumatoid arthritis, Felty’s syndrome, scleroderma, calcinosis cutis, Raynaud’s phenomenon, sclerodactyly and telangiectasia), lupus erythematosus; steroids and anti-neoplastic medication [25, 99, 114].

Disturbance in the hepatic microcirculation is believed to be the primary cause of NRH [115]. Several different combinations of vascular obliteration can lead to a variegated parenchyma with atrophy and secondary hyperplasia [116]. The particular pattern of obliteration determines the size and distribution of the nodules. Uniform small nodules are usually produced by small portal vein obliteration. This commonly occurs because of inflammatory lesions in the small portal tracts, typically in early-stage primary biliary cirrhosis and various rheumatologic conditions. In these two examples, the primary lesion involves small ducts and small arteries, respectively, and the obliteration of the adjacent portal veins is a bystander effect. Because the tissue involvement is patchy, some small portal veins remain patent, giving a variegated pattern of patent and obliterated veins, which explains the presence of both atrophy and hyperplasia. Increased flow through the portal vein in the presence of splenomegaly could exacerbate nodule formation in those acini with a patent portal vein [10]. After thrombosis of large portal veins, there are often large contiguous regions of parenchyma near the hilum that retain portal flow and escape atrophy. This situation also leads to large regenerative nodules (macronodular hyperplasia, partial nodular transformation). This variant is characterized by large nodules several centimeters in diameter near the large portal tracts, and atrophy together with small nodules in peripheral parts of the liver [50, 66, 96, 102].

In addition to this simple response to variegated portal vein flow, secondary arterial hyperemia and arterial growth may enhance the topographic variegation of blood flow. Arterial growth leads to large regenerative nodules that resemble FNH [100]. In non-cirrhotic conditions, the hepatic venules are usually normal despite severe portal vein disease. Nodular hyperplasia may result from primary outflow obstruction with either hepatic vein thrombosis or congestive heart failure [14]. In these situations, the nodules are less uniformly
distributed and are accompanied by sinusoidal congestion and fibrous septation [100, 113].

NRH occurs in all ages with a mean age of 50 years, with no gender predilection. It is rarely reported in childhood but when present, it is associated with portal vascular abnormalities, such as congenital absence of the portal vein (Fig. 45) [36]. It may also occur in the setting of diffuse fatty liver due to toxic or hormonal changes (Fig. 46).

The lesions are frequently found incidentally during surgery or imaging studies. Symptoms and signs, when present, can be divided into the following broad categories:

- symptoms of the underlying disease (Felty’s syndrome, myeloproliferative disorders),
- manifestations of portal hypertension such as esophageal varices, splenomegaly and ascites,
- hepatic failure,
- acute abdominal crisis following rupture of a large nodule with hemoperitoneum,
- symptoms of hypersplenism.

Liver function tests are usually either normal or
Fig. 46a-k. Nodular regenerative hyperplasia in a fatty liver: Gd-BOPTA versus USPIO. Due to diffuse fatty infiltration of the liver, the NRH nodule (arrow) in the right liver lobe appears hypointense on both T2-weighted images (a) and T1-weighted images (b). However, on fat-suppressed T1-weighted images (c), the lesion appears hyperintense. This is more apparent on opposed phase imaging (d), indicating diffuse fatty infiltration of the liver. On contrast enhanced imaging using Gd-BOPTA, strong enhancement of the lesion in the arterial phase can be noted (e). The lesion appears slightly hyperintense in the portal-venous phase due to contrast agent pooling (f). Arterial phase imaging after the bolus injection of USPIO (SH U 555 A) (g) suggests that the lesion is perfused. However, the lesion once again appears hypointense in the portal-venous phase (h). The lesion appears slightly hyperintense on T1-weighted images acquired during the hepatobiliary phase after Gd-BOPTA (i). This is more obvious on T1-weighted fs images acquired at the same time point (j) and is due to the fact that the NRH contains functioning hepatocytes that are able to take up more Gd-BOPTA than the surrounding fatty liver tissue. This behavior clearly underlines the diagnosis of a benign lesion. On T2-weighted images acquired after SH U 555 A injection (k) the lesion is even more hypointense compared with unenhanced images (a). This indicates that the lesion contains functioning Kupffer cells.
may be slightly altered. The most common abnormalities observed are elevation of alkaline phosphatase and $\gamma$-glutamyltransferase (GGT) levels.

In most cases NRH is not visible on US due to the same echogenicity as the surrounding parenchyma. In other cases, well-delineated hypoechoic or isoechoic nodules can be seen (Fig. 47) [76, 105].

Hyperechoic nodules have been reported on very rare occasions [20] while on other occasions, a diffusely heterogeneous hepatic parenchyma can be seen. Color Doppler examination in many cases demonstrates arterial supply within the nodules. On CT imaging, approximately half of the cases appear normal, while the nodules in the remaining cases are typically hypoattenuating relative to the
adjacent normal hepatic parenchyma [25, 78]. Usually the nodules enhance homogeneously to different degrees after the intravenous administration of contrast media (Figs. 48, 49) [16].

On unenhanced T1-weighted MR images the lesions are generally almost isointense or slightly hyperintense compared to the surrounding liver parenchyma, while on unenhanced T2-weighted images the nodules appear iso- or slightly hypointense. A peripheral hypointense rim is often visible in large lesions on T1- and T2-weighted images. On dynamic MR imaging, the nodules are usually hyperintense in the arterial phase, and iso- or slightly hyperintense in the portal-venous and equilibrium phases. In the delayed, liver-specific phase after Gd-BOPTA administration, the lesions may appear isointense or hyperintense since they consist of benign hepatocytes with abnormal biliary system drainage (Fig. 50). The peripheral hypointense rim is better seen in larger lesions, particularly in the liver-specific phase, and probably represents an ischemic perinodular area (Fig. 51) [16].

After injection of iron oxide particles, the lesions usually show a significant uptake of contrast agent due to the presence of abundant Kupffer cells within the nodule (Fig. 52).
Fig. 50a-g. Nodular regenerative hyperplasia after Gd-BOPTA. The same case as shown in Fig. 48. The lesion is isointense compared with normal liver tissue on the pre-contrast T2- and T1-weighted images (a and b, respectively) but is strongly hyperintense on arterial phase images after the bolus injection of Gd-BOPTA (c). The lesion retains a slightly hyperintense appearance during the subsequent portal-venous (d) and equilibrium (e) phase images and is seen as homogeneously hyperintense on the delayed, liver-specific phase image (f). Gross pathology of NRH (g) shows an ischemic perinodular area around the lesion, corresponding to the peripheral hypointense rim.
Fig. 51a-g. Nodular regenerative hyperplasia. T2-weighted TSE images (a) and True FISP images (b) reveal numerous iso- to hypointense nodules (arrows) with some of the nodules demonstrating a hypointense rim. These nodules are homogeneously isointense or slightly hyperintense on unenhanced T1-weighted GE images (c) and show weak enhancement on T1-weighted arterial phase images acquired after the bolus administration of Gd-BOPTA (d). The lesions remain slightly hyperintense on the subsequent portal-venous (e) and equilibrium (f) phase images. The delayed, hepatobiliary phase image (g) reveals numerous hyperintense nodules (arrowheads) with a peripheral hypointense rim. The delayed hyperintensity after Gd-BOPTA reflects abnormal biliary system drainage.
4.1.5 Cysts

Primary hepatic cysts should be distinguished from other cystic masses of the liver. A true cyst of the liver or bile duct is defined by the presence of an epithelial lining on the inner surface of the cyst. A simple hepatic cyst, on the other hand, is defined as a single unilocular cyst with a wall composed of a thin layer of fibrous tissue. If more than 10 cysts are seen, adult polycystic kidney and/or liver disease should be considered. The incidence of simple hepatic cysts is about 15% in autopsy series and they are more common in women than in men. Cysts are usually discovered incidentally, although up to 20% have been reported in surgical series of patients who presented with symptoms caused by mass effect such as abdominal pain, and jaundice [91].

On US examination, uncomplicated simple cysts present as anechoic, round, well-defined lesions with smooth borders, no septations and no mural calcifications. Although there is no acoustic shadow, often an acoustic enhancement can be observed.

On CT uncomplicated hepatic cysts are seen as round, well-defined water attenuation masses with smooth thin walls, and no internal septa or solid nodules. They show no enhancement after administration of contrast medium.

On T2-weighted MR images simple uncomplicated hepatic cysts are extremely hyperintense with a homogeneous appearance. On T1-weighted images they typically have a homogeneous hypointense appearance. However, the intensity of the cysts on T1-weighted images can vary if protein and/or hemorrhage are present within cyst fluid. These materials can shorten the T1-relaxivity and therefore cause a hyperintense appearance.

Congenital hepatic fibrosis is part of the spectrum of hepatic cystic disease, and is characterized by aberrant bile duct proliferation and periductal fibrosis. Cysts are usually not visible due to their very small size in typical congenital hepatic fibrosis (Fig. 53). In polycystic liver disease, numerous large and small cysts coexist with fibrosis. In cases of polycystic liver and/or kidney disease, the liver parenchyma surrounding the cyst is not normal, frequently containing von Meyenburg complexes and increased fibrous tissue (Fig. 54) [55].

Hepatic involvement occurs in approximately 30-50% of patients with polycystic kidney disease. Clinically, the majority of patients present in childhood, when congenital hepatic fibrosis predominates with bleeding, varices and other manifestations of portal hypertension. In patients with predominating polycystic liver disease, the lesions are usually identified incidentally. Approximately 70% of patients with polycystic liver disease also have adult polycystic kidney disease. Congenital hepatic fibrosis is also related to Caroli’s disease. Cross-sectional images reveal multiple cysts in the liver that are often associated with multiple renal cysts [12]. In this clinical setting, the cysts may have variable signal intensity, presumably caused by proteinaceous content within the cysts and/or intracystic hemorrhage.

Acquired hepatic cysts, also called peribiliary cysts, are more conspicuous in the peribiliary tissue, and are associated with chronic diseases such as cirrhosis, ascending cholangitis, obstructive
Fig. 53a-g. Congenital hepatic fibrosis in polycystic kidney disease. In contrast to the situation in adult polycystic kidney disease, the liver is not affected by cysts in congenital fibrosis associated with infantile polycystic kidney disease. Images a-c show fibrosis of the liver with cirrhotic changes and dilatation of the peripheral bile ducts (arrows). Additionally, hypertrophy of Segment 1 and the left liver lobe can be noted. In (c), polycystic kidneys are displayed. These are better appreciated on the coronal image (d). On T1-weighted images (e), the liver has a homogenous signal, however, the bile ducts are irregularly shaped and show dilatation due to fibrosis. In the equilibrium phase after contrast agent injection, the dilated bile ducts appear hyperintense while the liver parenchyma shows homogenous enhancement (f). Due to liver fibrosis and resulting portal hypertension in this 14-year old girl, a splenorenal shunt was initiated. This is demonstrated on contrast-enhanced MR angiography (g) in which early filling of the shunt (arrow) and the renal vein as well as of the inferior caval vein (arrowhead) can be observed. Note additionally, the small caliber of the renal arteries due to polycystic kidney disease.
jaundice, systemic infections and in patients with polycystic liver disease and portal hypertension. Microscopically, acquired cysts are serous or mucinous in content and are caused by periductal gland obstruction.

Peribiliary cysts are generally located near the intra- and extrahepatic main ducts.

Although patients are usually asymptomatic, large lesions can cause biliary obstruction and jaundice (Figs. 55, 56).

Fig. 54a-f. Polycystic liver and kidneys in adult polycystic kidney disease. Both the kidneys and the liver show multiple high signal intensity cysts on T2-weighted images (a–c). On T1-weighted images (d) the liver cysts appear hypointense whereas some of the kidney cysts appear hyperintense due to hemorrhage (arrows). After contrast medium injection, homogenous enhancement of liver parenchyma can be noted in both the arterial phase (e) and portal-venous phase (f). The remaining kidney parenchyma also shows homogenous enhancement. Since the risk of developing renal cell carcinoma is increased in patients with polycystic kidney disease, a very precise evaluation of the renal cysts is necessary.
Fig. 55a-e. Peribiliary cysts on US and CT. On the US scan (a) numerous small, well-defined, hypo- to anechoic lesions (arrows) are demonstrated. On the pre-contrast CT scan (b), the cysts appear as hypodense, round lesions. They do not show significant enhancement after contrast medium administration (c-e). Note the “rosary beads”-like arrangement (arrowheads in c) of the cysts.
Fig. 56a-f. Peribiliary cysts on MR after Gd-BOPTA. On MR imaging, peribiliary cysts are characteristically markedly hyperintense lesions on T2-weighted images (a), and hypointense on T1-weighted GE “in-phase” (b) and “out-of-phase” (c) images. The cysts remain hypointense during the dynamic study after bolus administration of Gd-BOPTA (d, e) and do not show enhancement in the hepatobiliary phase (f) due to the absence of communication between the cysts and the biliary tree.
4.1.6 Miscellaneous Tumors

4.1.6.1 Lipomatous Tumors

Benign hepatic tumors composed of fat cells include lipoma, and combined tumors such as angiomyolipoma (fat and blood vessels), myelolipoma (fat and hematopoietic tissue) and angiomyelolipoma [32].

Grossly, lipomatous tumors are usually solitary, round and well-circumscribed masses occurring in non-cirrhotic livers [31]. They contain variable proportions of adipose and smooth muscle tissue with thick-walled blood vessels. Flow cytometry shows a DNA-diploid pattern consistent with a benign lesion [104]. Hematopoietic foci may be present, and when prominent, the term myelolipoma [74] or angiomyelolipoma is used.

Angiomyolipomas are rare, usually asymptomatic solitary tumors. However, these tumors occasionally bleed, causing abdominal pain. Liver angiomyolipomas usually range in diameter from 0.3 to 36 cm and occur predominantly in women [47].

Liver angiomyolipomas may occur in association with Bourneville-Pringle syndrome. In this clinical setting, the lesions are generally multiple, progressive, and symptomatic.

Angiomyolipomas are often highly echogenic on US and are essentially indistinguishable from hemangiomas, although they may also present a mixed hyper-hypoechoic pattern (Fig. 57) [81].

Density measurements on unenhanced CT are characteristic of fat (–20 to –115 HU). Pure lipomas do not enhance, but variable enhancement occurs in lesions containing angiomatous elements (Fig. 58) [51, 81].

On MR imaging, the fatty and angiomatous components of angiomyolipomas lead to a high signal intensity on both T1- and T2-weighted images [69]. Hepatocellular carcinomas containing fat deposits may have a similar appearance. The early phase of contrast-enhanced dynamic CT or MR imaging may be useful in discriminating between angiomyolipomas and HCC with fat, because the fatty areas of angiomyolipoma are well-vascularized and enhance early. Conversely, the areas of fatty changes in HCC are relatively avascular, and enhancement is less obvious.

MR imaging with fat suppression techniques is useful to characterize hepatic angiomyolipomas, since lipid components show a typical signal drop with these sequences [48]. In contrast to the high signal intensity on T1- and T2-weighted images, the lesions appear hypointense compared to the

Fig. 57. Lipomatous tumors in Bourneville-Pringle syndrome on US. On US, multiple well-defined, hyperechoic (arrows) as well as small hypoechoic lesions (arrowheads) can be seen

Fig. 58a, b. Lipomatous tumor in Bourneville-Pringle syndrome on CT. Pre-contrast CT (a) reveals multiple hypodense lesions (asterisk) and mixed lesions (arrows). The hypodensity of the largest lesion reflects the abundant fatty content. After administration of contrast medium (b), some nodules enhance homogeneously (arrowheads) whereas others enhance heterogeneously (asterisk). Note the presence of angiomyolipomas in both kidneys as well.
normal liver parenchyma on images obtained with fat suppression.

The appearance on contrast-enhanced MR imaging with gadolinium agents may mimic the pattern observed in hemangioma with peripheral nodular enhancement or irregular non-nodular vascular enhancement. However, arterial hyperintensity is also a common pattern of enhancement (Fig. 59).

4.1.6.2 Leiomyoma

This extremely rare lesion is a well-circumscribed smooth muscle tumor arising in the liver [45]. Several cases of leiomyoma have been reported in adults and children infected with the human immunodeficiency virus, suggesting that there may be a clinical association between these two entities [68, 109].

Leiomyoma has non-specific radiological characteristics. On US, leiomyomas may appear solid or hypoechoic with internal echoes [85, 109]. Leiomyomas are of low attenuation relative to normal liver on unenhanced CT scans, but following contrast agent administration, may display two distinct enhancement patterns: either peripheral rim enhancement, similar to that seen in abscesses, or homogeneous enhancement, which may sometimes be delayed [68, 109]. On MR imaging, leiomyomas are hypointense relative to the liver on T1-weighted images and hyperintense on T2-weighted images [85, 109]. Enhancement patterns after contrast agent administration are similar to those described for CT imaging.

4.2 Secondary Benign Liver Lesions

4.2.1 Pyogenic Abscess

Abscesses of the liver may be caused by bacterial, amebic or fungal infections, resulting in the localized collection of inflammatory cells and destruction of the surrounding parenchyma [82]. Hepatic abscesses can develop via five major routes [29]:

- the biliary route, due to ascending cholangitis, benign or malignant biliary obstruction and choledocholithiasis,
- the portal vein route, due to pylephlebitis from appendicitis diverticulitis, proctitis, infected hemorrhoids, inflammatory bowel disease and others,
- the hepatic artery route, subsequent to septicemia,
MRI of the Liver

• the direct extension route, from contiguous organ infections,
• the traumatic route, from blunt or penetrating injuries.

Before the era of antibiotics, pylephlebitis of the portal vein through seeding from appendicitis or diverticulitis was the most common cause of hepatic abscesses. Pyogenic abscesses today are most often associated with benign or malignant obstruction with cholangitis. About 50% of pyogenic abscesses are caused by anaerobic organisms or mixed anaerobic and aerobic organisms. Escherichia Coli is most frequently isolated in adults, while Staphylococci organisms are most often isolated from hepatic abscesses in children. Abscesses of biliary tract origin are multiple and frequently involve both hepatic lobes (Fig. 60). Abscesses of portal vein origin are often solitary and mainly localized in the right lobe.

The clinical symptoms of patients with hepatic abscesses include fever, malaise, abdominal pain in the right upper quadrant, nausea and vomiting. Tender hepatomegaly is the most common clinical sign and leukocytosis, elevated serum alkaline phosphatase levels and hypoalbuminemia are the most common laboratory abnormalities. Generally the onset of symptoms is acute [29].

Ultrasound can detect hepatic abscesses as small as 1.5 cm with a sensitivity of up to 90%. Pyogenic hepatic abscesses are extremely variable in shape and echogenicity and may appear as anechoic (50%), hyperechoic (25%) or hypoechoic (25%) (Fig. 61). Septa and fluid-fluid internal necrosis are frequently seen, while calcifications

Fig. 60a-e. Diffuse biliary abscess formation in ascending cholangitis. Diffusely distributed areas of high signal intensity can be noted on the unenhanced T2-weighted image (a). On the corresponding unenhanced T1-weighted image (b) these areas appear hypointense. During the arterial phase of the dynamic series (c) peripheral hypervascularization of the affected areas (arrows) can be noted. In the portal-venous phase (d), the cystic-appearing regions remain hypointense. On fat suppressed images in the equilibrium phase (e) a hyperintense rim surrounding the affected areas (arrows) is indicative of an inflammatory process
and gas may also be detected. Early lesions tend to be echogenic and poorly demarcated [72].

CT is a valid method for detecting hepatic abscesses with high sensitivity. On CT, hepatic abscesses appear as hypodense lesions with an internal pattern of varying density. The lesions generally appear as rounded masses that show minimal contrast enhancement. Most abscesses have a peripheral rim that shows contrast enhancement predominantly in the equilibrium phase. The “cluster” sign is suggestive for abscesses and represents smaller lesions surrounding a large abscess. Another CT sign, the “double target”, is seen with early abscesses, and represents a hypodense lesion surrounded by a hyperdense rim, and an outer low-density region (Fig. 62). The presence of central gas, either air bubbles or an air-fluid level, is a specific sign of pyogenic hepatic abscess, but is present in fewer than 20% of cases [6, 87].

On MR imaging pyogenic abscess appears as an area of decreased signal intensity on T1-weighted images and increased signal intensity on T2-
weighted images. Perilesional edema, characterized by high signal intensity on T2-weighted images, is seen in one third of cases. The abscess cavity may appear with homogeneous or heterogeneous signal intensity. After administration of contrast material, abscesses typically show rim enhancement followed by a slower increase in signal intensity within the center of the lesion (Fig. 63). Small lesions may enhance homogeneously in a manner similar to that seen with small hemangiomas [5].

Peripheral edema may be seen on delayed phase images as a rim of high signal intensity after administration of contrast agents with hepatobiliary properties. Similarly, decreased signal intensity after SPIO administration may be indicative of peripheral edema due to the high content of Kupffer cells and macrophages.
4.2.2 Amebic Abscess

Amebiasis caused by the parasite *Entamoeba histolytica* is an endemic disease of tropical areas, such as Mexico, Central and South America, Africa and Asia. Amebic liver abscess develops after infestation of colonic mucosa by the parasites, which lodge in the portal system. The liver can be invaded in one of three ways:

- via the portal vein (most common),
- through lymphatics,
- via direct extension through the colon wall into the peritoneum and then through the liver capsule.

Amebic liver abscess is the most common extraintestinal manifestation. Most patients with amebic liver abscesses present with a tender liver and abdominal pain in the right upper quadrant. Amebae are not usually found in the stool of patients with an amebic liver abscess. Because the clinical features and findings of stool examinations for amebae are usually not specific or are negative, serologic tests are helpful in detecting suspected amebic abscess; such tests are positive in about 90% of patients [61, 84].

On US studies, amebic abscesses are usually large, round, sharply-defined, hypoechoic masses with fine, low-level internal echoes at high gain settings (Fig. 64) [64].

The CT appearance of amebic abscess is non-specific and variable; the lesion is usually round or oval and demonstrates peripheral hypodensity. A slightly hyperdense peripheral rim can be seen on unenhanced scans, which generally shows marked enhancement after administration of contrast material (Fig. 65). Lesions may appear as unilocular or multilocular masses, with internal debris and nodularity of the margins [106].

Amebic abscesses are well-defined structures with rim-like areas of varying signal intensity on both T1- and T2-weighted MR images. Within the abscess cavity, the signal intensity is decreased on T1-weighted images compared with the normal hepatic parenchyma. On T2-weighted images the lesion is hyperintense with a homogeneous or heterogeneous appearance and is often surrounded by areas of even higher signal intensity that correspond to edema within the normal liver tissue. No enhancement is seen in the central necrotic area after contrast agent administration, whereas heterogeneous enhancement can be observed at the periphery of the lesion, corresponding to inflammatory tissue. Persistent enhancement on late hepatobiliary phase images can be observed in this inflammatory tissue when contrast agents with hepatobiliary properties are used (Fig. 66). MR also offers the advantage of multiplanar capabilities to clearly depict the extension of the lesion. It is also helpful in follow-up studies to evaluate response to therapy.

![Fig. 64. Amebic abscess on US. The ultrasound scan reveals two large lesions (arrows) with different echogenicity](image1)

![Fig. 65. Amebic abscess on CT. The CT scan reveals hypodense lesions with a thin hyperdense peripheral rim. The hypodense appearance is due to the high liquid content](image2)
Fig. 66a-g. Amebic abscess after Gd-BOPTA. HASTE T2-weighted images acquired in the axial plane (a) and True-FISP images acquired in the coronal plane (b) reveal a large heterogeneous hyperintense lesion (asterisk in a). The lesion is seen as an ill-defined iso- to hypointense mass on unenhanced GE T1-weighted images (c). Enhancement is seen mainly in the periphery of the lesion during the arterial phase (d) after the administration of Gd-BOPTA. This enhancement increases during the portal-venous (e) and equilibrium (f) phases when septations and internal necrosis are depicted more clearly. This is even better demonstrated on the T1-weighted fat-suppressed image acquired during the delayed hepatobiliary phase (g).
4.2.3 Candidiasis Infection

Hepatic candidiasis is relatively frequent in immunocompromised patients and it is found in more than 50% of patients with acute leukemia or lymphoma.

On US scans, three major patterns of candidiasis are seen:
- “wheel within a wheel”, in which a peripheral zone surrounds an inner echogenic area,
- “Bull’s eye”, a lesion with a hyperechoic center surrounded by a hypoechoic rim,
- uniformly hypoechoic, the most common appearance, attributable to progressive fibrosis.

After therapy, the lesions may increase in echogenicity and decrease in size, although in some cases sonographic heterogeneity of the liver may persist for several years after treatment [33].

On CT the abscesses are generally multiple, small round hypodense areas on both pre- and post-contrast images. Calcifications can be seen within the lesions [97].

On MR imaging, candida lesions are generally hyperintense on fat suppressed T1-weighted images and have variable signal intensity on conventional T1-weighted spin-echo images. Contrast agent administration leads to the detection of more lesions, which are mainly round, ill-defined, focal hypointense areas. Frequently, percutaneous needle biopsy is needed to achieve a definitive diagnosis [93].

4.2.4 Echinococcal Cyst

Hydatid disease is caused by the parasite Echinococcus granulosus. The disease is mainly present in rural areas where dogs are used for herding live stock, especially sheep, and occurs frequently in Mediterranean countries, in Australia, and in South America.

Dogs are the normal host for the adult parasite, and hundreds of worms may exist in their intestines. Sheep, cattle, herbivores and humans are intermediate hosts for the parasite and are infected after contact with dog feces. In heavily endemic areas, about 50% of dogs and up to 90% of sheep and cattle are infected with E. granulosus. Eggs are passed by the dogs and can be ingested by intermediate hosts.

Once inside the intermediate host, the parasitic eggs hatch and embryos penetrate the intestinal mucosa to enter lymphatic and venous channels. Most embryos are filtered by the liver and lungs with the remaining parasites reaching other organs, including the brain, spleen, kidneys, and the musculoskeletal system. Viable embryos transform into cysts which grow at a rate of approximately 1 cm per year. The wall of the hydatid cyst is composed of two layers: the endocyst, a germinal layer, and the ectocyst, a proteinaceous membrane. A dense fibrous capsule containing collagen, the pericyst, is formed by the host.

Echinococcal cysts usually develop in the liver (75% of cases) but may occur in any part of the body. The lesions are often asymptomatic for many years and are discovered incidentally on US or CT scans. Hydatidosis can also be detected by serologic tests. Classic symptoms of hepatic hydatid cyst include upper abdominal pain and hepatomegaly [2, 60].

Treatment consists of surgical removal of the cyst or antiparasitic drug therapy. If left untreated, a hepatic hydatid cyst may rupture into surrounding structures such as the liver parenchyma, biliary system, peritoneum, GI tract, or pleura. Hydatid cyst rupture is the major complication of echinococcal disease [2, 21, 87].

On abdominal plain film, curvilinear or ring-like calcifications can be seen in the right upper abdominal quadrant in about 20–30% of cases. However, calcifications do not necessarily indicate death of the parasite.

The appearance of the hydatid cyst on US is variable and depends on the stage of evolution and maturity. The lesion may appear as a well-defined anechoic cyst, as an anechoic cyst except for hydatid sand, as a multisepate cyst with daughter cysts, as a cyst with a floating membrane, or finally, as a densely calcified mass (Fig. 67) [21, 42].

US has also been used to monitor the efficacy of medical antihydatid therapy: positive responses include cyst size reduction, membrane detachment, increased echogenicity and mural calcification.

On CT, hydatid disease appears as unilocular or multilocular well-defined cysts. Daughter cysts are seen as areas of lower density and are usually oriented towards the periphery of the lesion (Fig. 68). Daughter cysts can also float in the lumen of the mother cyst. Curvilinear ring-like calcification or grossly diffuse calcification are also common features. The peripheral walls may show enhancement after contrast medium administration (Fig. 69) [70, 87].

On MR imaging, the cystic component of echinococcal disease is similar to that of other cysts, with long T1 and T2 relaxation times. A low intensity rim around the cyst is present in most cases and is more conspicuous on T2- than T1-weighted sequences. This rim corresponds to the pericyst which is rich in collagen and has a short T2 relaxation time [2]. This rim and a multiloculated or multicystic appearance are distinctive features (Fig. 70). Floating membranes have low signal intensity on both T1- and T2-weighted images (Fig.
Fig. 67a-c. Echinococcal cyst on US. Ultrasound reveals either a well-defined anechoic cystic-like lesion (a), a cystic lesion with a floating membrane (arrow) (b), or a dense and heterogeneous nodule (arrowhead) (c).

Fig. 68. Echinococcal cyst on CT. CT after contrast medium administration reveals a large well-delineated cystic lesion. Peripheral round areas of lower density (asterisks) are indicative of daughter cysts.
**Fig. 69a, b.** Echinococcal cyst on CT. CT after contrast medium administration (a) reveals a multilocular well-defined cystic lesion (asterisk) with thick hyperdense walls and septa. Additional nodules with a heterogeneous appearance and gross calcifications (arrowheads) can be seen around the bigger lesion. The almost complete replacement of the lesion by central calcification indicates the death of the cyst (b).

**Fig. 70a-e.** Echinococcal cyst on MR. T2-weighted images acquired in the coronal and axial planes (a and b, respectively) reveal a large multiloculated hepatic mass. The cystic component is seen as hyperintense with a hypointense fibrous capsule. On the unenhanced T1-weighted image (c), the lesion is mainly hypointense with peripheral hypointense wall (arrows). Slight enhancement is seen in the wall but not in the cystic component on arterial phase images acquired after the injection of gadolinium (d). The cystic mass appears hypointense on the subsequent portal-venous phase image (e).
Small cystic extensions from the main lesion are seen as peripheral areas of increased signal intensity on T2-weighted images and probably represent the active portions of the disease [52, 79].

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