Most benign lesions considered unspecific on ultrasound or CT can be identified with great confidence on MRI. Differentiation between benign and malignant liver lesions is essential in patients with extrahepatic malignancies, in whom benign lesions are still more common than metastases. This classification is also crucial in otherwise healthy subjects with incidentally detected liver masses. Most such lesions can be characterized on ultrasound and CT in terms of their tissue character and resectability. Multislice CT, with its superb demonstration of vascular structures, is especially suitable for determining resectability. In some cases, however, the tissue character of a lesion remains problematic. As many as 30% of hemangiomas may demonstrate atypical contrast-enhancement patterns on CT. Additional tissue information that can confirm a lesion's status as malignant or benign may help avoid unnecessary biopsy or surgery. The characterization of lesions depicted in cirrhotic patients (regenerative nodule versus dysplastic nodule versus early hepatocellular carcinoma) is also important but, due to its complexity, beyond the scope of this article. MR imaging has already proved to be an efficient method of detecting focal liver lesions. The sensitivity of contrast-enhanced MRI using superparamagnetic iron oxide particles is reported to be at least equal to that of CT.1 MRI has also emerged as a powerful modality for the characterization of such lesions. Its main advantage lies in the availability of multiple techniques and sequences. Useful parameters include the signal intensity of lesions on moderately and heavily T2-weighted images and on T1-weighted images, including chemical shift (in-phase and opposed-phase gradient-echo) images. Patterns of contrast enhancement following administration of extracellular agents and agents specific to the hepatobiliary and reticuloendothelial systems can also assist diagnosis decision making.2 This opportunity to evaluate diverse and complementary data enables MRI to characterize liver lesions with better accuracy than CT in many instances. CT-based characterization relies mostly on dynamic enhancement patterns.

T1- AND T2-WEIGHTED IMAGING
Evaluation of heavily T2-weighted images is an extremely accurate method of discriminating so-called nonsolid lesions from solid tumors. The most frequently encountered nonsolid lesions contain fluid (cysts, abscesses) or are composed of vascular channels filled with blood (hemangiomas). These features lead to a prolonged T2 relaxation time, and nonsolid lesions have markedly increased signal on T2-weighted MRI (Figure 1). Differences in signal intensity between solid and nonsolid tumors can be enhanced on heavily T2-weighted images (TE > 160 msec). Nonsolid lesions maintain high signal intensity, while the signal intensity of solid masses decreases noticeably. Quantitative analysis of T2 relaxation times, derived from spin-echo, turbo spin-echo, and echo-planar imaging, may also be used to discriminate solid from nonsolid liver lesions. Thresholds of 112 msec to 130 msec have been proposed for turbo spin-echo sequences. These have yielded high sensitivity (94% to 100%) and specificity (91% to 93%).3-7 We use the 116 msec threshold at our institution. The technique proved to be 96% sensitive and 93% specific when applied to a group of 168 patients with 292 focal lesions. Such quantitative analysis is slightly more time consuming than a qualitative assessment of signal intensity from heavily T2-weighted MRI. It is, however, more accurate in differentiating between solid and nonsolid lesions. All calculations can be performed easily on a PC with an Excel spreadsheet. Both quantitative and qualitative analyses enable confident diagnosis of hemangioma and cyst, the two most common benign liver lesions, as well as the less common hepatic abscess.4-7 Making a distinction between nonsolid and solid liver lesions is not the same as identifying a mass as benign or malignant, however. Nonsolid lesions may occasionally be malignant, and some solid tumors are
benign, such as focal nodular hyperplasia and adenoma.

The most important malignant tumors with T2 relaxation times comparable to nonsolid lesions are biliary cystadenocarcinoma and necrotic or hypervascular metastatic lesions. The latter may also exhibit heterogeneous contrast enhancement on arterial phase images, a feature often observed in small hemangiomas. Another pitfall relates to the false characterization of some hemangiomas as solid tumors. This may occur in small hemangiomas due to volume averaging effect. It can also happen with rare, predominantly fibrotic or hyalined hemangiomas that demonstrate decreased signal intensity on T2-weighted MRI. Evaluation of contrast-enhanced images may be helpful in both cases.

Another unique feature of MRI is its ability to identify masses with atypical signal intensity on T1- and T2-weighted imaging. The majority of focal hepatic lesions visible on MRI are hypointense on T1-weighted images and hyperintense on T2-weighted images. Atypical signal intensity of liver lesions (increased on T1-weighted MRI and decreased on T2-weighted images) is rare but may be an important diagnostic clue.

Hyperintensity on T1-weighted MRI can be caused by the presence of fat, melanin, protein (high concentration), extracellular methemoglobin, glucagon, and other compounds with short T1 relaxation times. It may be seen in focal fatty infiltration, which may involve the whole segment or lobe or present as a single or multiple foci. It may also be observed in lipoma, melanoma metastases, and, rarely, metastases from colon cancer, ovarian cancer, and pancreatic mucinous cystic tumor. Hyperintensity is possible in regenerative and dysplastic nodules in the cirrhotic liver as well.8

Focal fatty infiltration occurs infrequently but may still cause diagnostic problems on ultrasound and CT. This is especially true when foci are multiple and scattered. MRI usually provides a confident diagnosis in such cases, due to the characteristic appearance on opposed-phase T1-weighted gradient-echo images. Signal intensity should decrease relative to in-phase images. Fatty infiltration may have similar signal intensity to subcutaneous or retroperitoneal fat on other T1- and T2-weighted sequences. Foci may sometimes not be visible in cases of mild infiltration. Chemical shift imaging is the most sensitive technique for detection of fatty tissue and should be routinely included in a liver imaging protocol.2

Metastatic melanoma is another lesion that usually demonstrates hyperintensity on T1-weighted MRI, including opposed-phase images. This is due to the presence of melanin (Figure 2). Metastases from mucinous tumors are also hyperintense from their retention of high-protein secretions. Diagnosis is often facilitated by identification of hyperintense foci on T1-weighted MR imaging in an otherwise hypointense lesion. This feature is usually related to the presence of fat or hemorrhage, which is most often encountered in primary liver tumors such as hepatocellular carcinoma or adenoma. It is seen rarely in metastatic choriocarcinoma. Decreased lesion signal intensity on T2-weighted MRI is a less frequent finding that may be observed in some metastatic melanomas, though many of them are hyper- or isointense to the liver. It may also be seen in regenerative nodules with iron deposition (siderotic nodules) in patients with cirrhosis, as well as in patients treated successfully with chemoembolization, percutaneous ethanol injections, or radiofrequency ablation.8,9

**CONTRAST OPTIONS**

The technique for assessing liver lesions with intravenous nonspecific extracellular contrast on MRI is similar to that used for CT. Breath-hold scans are first obtained prior to contrast administration using 2D, or preferably 3D, T1-weighted gradient-echo sequences. Further imaging then takes place in the arterial phase (20 to 30 seconds after injection), portal venous phase (50 to 80 seconds after injection), equilibrium phase (90 to 120 seconds after injection), and delayed phase (five minutes after injection).

This technique enables differentiation between hyper- and hypovascular lesions (see table). The liver's blood supply is provided mainly by the portal vein (70% to 75%), with only 25% to 30% coming from the hepatic artery. Focal liver lesions, on the other hand, get their blood supply almost exclusively from the hepatic artery. Hypovascular tumors are thus best appreciated during portal venous phase, when they appear as hypoenhanced lesions surrounded by markedly enhanced liver parenchyma. Hypervascular lesions are best visualized on arterial phase images, when they demonstrate significant enhancement compared with a faintly enhancing liver.10

Dynamic MR studies also mean that lesions with characteristic patterns of contrast enhancement can be identified with confidence. Hemangioma, for example, typically exhibits strong globular and peripheral enhancement on arterial phase images. The rest of the lesion gradually fills with contrast...
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During later phases, enhancement may not reach the center of large (> 5 cm) hemangiomas by the end of the examination. Small hemangiomas (lesser than or equal to 1.5 cm), however, may demonstrate early homogeneous enhancement that is also typical of hypervascular metastases on arterial phase images. Later phases may be evaluated if doubt persists. Hemangiomas tend to retain contrast, whereas enhancement usually decreases markedly and rapidly in hypervascular metastases.

Focal nodular hyperplasia has a characteristic pattern of contrast enhancement as well. This lesion is often difficult to visualize on T1- and T2-weighted MRI, because its signal intensity is similar to that of liver parenchyma. It demonstrates marked homogeneous enhancement on arterial phase images and usually becomes isointense to the liver on portal venous or equilibrium phase scans. Only the central scar seen in up to 50% of cases does not enhance during the early phases. This instead demonstrates increased signal on delayed scans, due to the presence of fibrotic tissue (Figure 3).

Small adenomas and early hepatocellular carcinomas can share similar patterns of dynamic enhancement with focal nodular hyperplasia, in addition to showing similar T1- and T2-weighted imaging characteristics. Larger adenomas and hepatocellular carcinomas usually demonstrate early inhomogeneous enhancement.

Peripheral contrast wash-out can also help in the characterization of liver lesions on MRI. This sign is typical of malignant tumors. Vessel involvement, especially the portal vein and its branches, is most often seen in hepatocellular carcinomas. It may also occasionally be encountered in cholangiocarcinoma. The presence of arteriportal shunts is believed to be typical of hepatocellular carcinoma, though this may also be depicted in some hemangiomas.

One important advantage of MRI over CT is the option of contrast agents specific to the hepatobiliary or reticuloendothelial systems. Both types of media have been shown to increase the sensitivity of MRI in detecting focal liver lesions and the specificity of characterization. These agents enable lesions containing hepatocytes and Kupffer's cells (focal nodular hyperplasia, adenoma, well-differentiated hepatocellular carcinoma) to be differentiated from lesions devoid of these cells. Such a distinction is very helpful when differentiating focal liver lesions, although it cannot predict if a lesion is benign or malignant. Some lesions that do not contain hepatocytes or Kupffer's cells are benign (hemangiomas, cysts, abscesses). Other lesions containing these cells may be malignant (well-differentiated hepatocellular carcinoma) or benign but usually treated by surgical resection (> 3 cm adenomas).

A study published last year showed that delayed-phase MRI, performed one to three hours after administration of gadolinium-BOPTA, differentiated focal nodular hyperplasia from adenomas with 96.9% sensitivity and 100% specificity. Additional diagnostic problems may be caused, however, if contrast is taken up by lesions that do not contain hepatocytes or Kupffer's cells. Such findings have been reported for hemangiomas through retention of contrast in vascular channels, cholangiocarcinomas because of contrast pooling in fibrous tissue, and hypervascular metastases for unknown reasons.

Hepatobiliary contrast may help when examining patients with multiple fluid structures in the liver, as when differentiating between cysts and cystic dilatation of biliary ducts in Caroli's disease. Enhancement is seen in the latter condition after contrast is excreted to the bile. Contrast agents that combine the imaging properties of extracellular and either hepatobiliary or reticuloendothelial-specific contrast offer new diagnostic possibilities. The biphasic effect of these agents enables evaluation of dynamic enhancement after bolus injection and the liver-specific phase during the same examination.

**OPTIMAL PROTOCOLS**

Morphological features should not be forgotten when characterizing liver lesions. The presence of a central scar, for instance, may be an important diagnostic clue. The scar is most often seen in focal nodular hyperplasia, fibrolamellar hepatocellular carcinoma, and cholangiocarcinoma. Hyperintensity on T2-weighted MRI may suggest focal nodular hyperplasia. The scar is usually hypointense in other lesions. Involvement of intrahepatic or hilar biliary ducts is most often seen in cholangiocarcinoma. This finding may also be observed in cases of gallbladder carcinoma and, rarely, in other malignant tumors.

There is no single protocol for imaging of focal liver lesions. Protocols will vary according to equipment availability and individual preference. Experience suggests that a protocol should include the following sequences:
- moderately T2-weighted turbo spin-echo (TE 90 to 100 msec);
- heavily T2-weighted turbo spin-echo (TE > 160 msec);
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- T2-weighted turbo spin-echo with fat saturation;
- T1-weighted gradient-echo imaging, in and out of phase; and

2D or 3D T1-weighted gradient-echo dynamic contrast-enhanced imaging.

We prefer to perform a single dual-echo turbo spin-echo sequence (TE 40 and 120 msec) instead of the moderately and heavily weighted T2-weighted sequences suggested above. This permits quantitative assessment of lesions' T2 relaxation times. Combination of this quantitative data with a qualitative assessment of signal intensity and contrast enhancement has enabled us to differentiate and characterize focal hepatic lesions with a sensitivity and specificity of 92%.15

A steady-state T1-weighted gradient-echo sequence (TrueFISP) may be performed to discriminate small cysts from solid lesions that demonstrate a marked increase in signal intensity on T2-weighted MRI. Additional cholangiographic sequences should be performed if biliary tree infiltration is observed.

MRI provides a more comprehensive characterization of focal liver lesions than any other imaging modality due to its ability to evaluate multiple parameters that are helpful in determining lesion type. The assessment of T1-weighted images, along with moderately and heavily T2-weighted images, often provides important information on lesion morphology. MR contrast can provide information on lesion vascularity and the presence or absence of hepatocytes and Kupffer's cells. The option to use fat-saturated sequences and MR cholangiopancreatography can also be of benefit. MRI should be used routinely to characterize lesions that have an unspecific appearance on ultrasound and CT. Most benign lesions, such as hemangiomas, focal fatty infiltration, focal nodular hyperplasia, and cysts, can then be diagnosed with confidence.

DR. CIESZANOWSKI and DR. PALCZEWSKI are radiologists in the department of clinical radiology at Warsaw Medical University, Poland.

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