MR Imaging of Hypervascular Liver Masses: A Review of Current Techniques

Alvin C. Silva, MD • James M. Evans, MD • Ann E. McCullough, MD • Mashal A. Jatoi, MD • Hugo E. Vargas, MD • Amy K. Hara, MD

Major technologic advances in magnetic resonance (MR) imaging, including the advent of novel pulse sequences (eg, diffusion-weighted and steady-state free precession sequences) and the use of hepatocyte-specific contrast agents, have led to better image quality and shorter acquisition times, resulting in dramatic improvements in the noninvasive detection and characterization of hepatic lesions, particularly hypervascular neoplasms. However, as the role of MR imaging in clinical evaluation of the liver continues to evolve, keeping abreast of new developments can be daunting as well as confusing. A systematic approach that makes use of a simple decision algorithm can help differentiate hypervascular hepatic lesions on the basis of their distinguishing MR imaging characteristics and related clinical information.

Abbreviations: FNH = focal nodular hyperplasia, Gd-BOPTA = gadobenate dimeglumine, HCC = hepatocellular carcinoma, H-E = hematoxylin-eosin, NRH = nodular regenerative hyperplasia, SSFP = steady-state free precession, THID = transient hepatic intensity difference

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Introduction

As a result of major advancements in field gradient technology and multichannel surface coils, magnetic resonance (MR) imaging is playing an increasingly greater role in the accurate, noninvasive detection and characterization of hepatic lesions. Because of its relatively lower cost, shorter acquisition times, and wider availability, computed tomography (CT) has long been the traditional mainstay for clinical hepatic imaging. However, because MR imaging displays the same lesion contrast enhancement patterns as CT, but with superior lesion-to-liver contrast and without the use of ionizing radiation (1–4), there has been increasing interest in and experience with MR imaging in this regard. In addition, the use of newer pulse sequences, such as diffusion-weighted and steady-state free precession (SSFP) (fast imaging employing steady-state acquisition [FIESTA; GE Healthcare, Waukesha, Wis]), balanced fast-field-echo (bFFE; Philips Medical Systems, Best, The Netherlands), true fast imaging with steady precession (TrueFISP; Siemens Medical Solutions, Erlangen, Germany), and true steady-state free precession (TrueSSFP; Toshiba America Medical Systems, Tustin, Calif) sequences, along with hepatocyte-specific contrast agents (eg, gadobenate dimeglumine [Gd-BOPTA {benzyloxypropionitetraacetate} [MultiHance; Bracco Diagnostics, Princeton, NJ]), may facilitate a more specific diagnosis of the lesion in question (5–7).

Because the liver can be primarily or secondarily involved by numerous vascular, metabolic, infectious, and neoplastic processes, the patient’s clinical history can have a considerable impact on the imaging differential diagnosis. For example, primary hepatic malignancies are more common in the presence of chronic diffuse liver diseases such as cirrhosis, hemochromatosis, and steatohepatitis, whereas secondary hepatic malignancies (metastases), especially from gastrointestinal tumors, are more common in the normal liver. Thus, a systematic approach to the diagnosis of focal hepatic lesions includes familiarity with the distinguishing imaging characteristics and knowledge of any preexisting condition. In this article, we discuss and illustrate the most relevant and common MR imaging features of frequently encountered hypervascular liver lesions—including hemangioma, focal nodular hyperplasia (FNH), adenoma, hepatocellular carcinoma (HCC), nodular regenerative hyperplasia (NRH), and hypervascular metastases—with emphasis on the role of advanced MR imaging techniques. In addition, we briefly discuss two potential pitfalls in the evaluation of hypervascular liver masses, namely, treated metastases and variant perfusion (transient hepatic intensity difference [THID]). We also present a simple decision algorithm that can help differentiate hypervascular hepatic lesions at MR imaging on the basis of significant clinical history and the distinguishing imaging characteristics of a given lesion.

MR Imaging Techniques

All MR images were obtained on a commercially available 1.5-T superconducting imager (Signa HDx 14.0, GE Healthcare) with an eight-channel surface coil. In addition to the standard T1- and T2-weighted sequences, SSFP and diffusion-weighted sequences were also performed (Tables 1, 2). For diffusion-weighted imaging, we use a b value of 600 as an optimal compromise between image quality (signal-to-noise ratio) and true diffusion characteristics. For evaluation of known or suspected hypervascular hepatic masses, we perform dynamic contrast material–enhanced imaging at 20 (arterial phase), 60 (portal venous phase), and 120 (equilibrium phase) seconds after the injection of Gd-BOPTA and again at 1 hour after injection.

Hypervascular Liver Masses

Enhancing liver lesions can be characterized as either hypovascular or hypervascular, with the latter group being distinguished by earlier, more intense enhancement relative to normal hepatic parenchyma. Thus, accurate detection of hypervascular liver masses requires dynamic contrast-enhanced imaging during the hepatic arterial phase, whereas characterization of these masses requires imaging during one or more delayed phases.
### Table 1
MR Signal Intensity Characteristics of Hypervascular Liver Masses before and after Gadolinium Administration

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Arterial Phase</th>
<th>Portal Venous Phase</th>
<th>Delayed Phase</th>
<th>Gd-BOPTA (1-hour delay)</th>
<th>T1-weighted</th>
<th>T2-weighted</th>
<th>SSFP</th>
<th>Diffusion-weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>↑↑</td>
<td>↑</td>
<td>↓↑</td>
<td>↑↑ ↑↑ ↑↑↑</td>
<td>↑↑↑</td>
<td>↑↑↑</td>
<td>↑↑↑</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>Hemangioma</td>
<td>↑↑</td>
<td>↑</td>
<td>↑</td>
<td>Variable</td>
<td>↓↑</td>
<td>↓↑↑</td>
<td>↓↑↑</td>
<td>↑</td>
</tr>
<tr>
<td>FNH</td>
<td>↑ (↓)</td>
<td>Iso</td>
<td>Iso (↑)</td>
<td>Iso (↓)</td>
<td>Iso (↑)</td>
<td>Iso</td>
<td>Iso</td>
<td>Iso</td>
</tr>
<tr>
<td>Adenoma</td>
<td>↑*</td>
<td>Iso/↓</td>
<td>Iso/↑</td>
<td>Variable</td>
<td>Variable↑</td>
<td>Variable↑</td>
<td>Variable↑</td>
<td>Variable↑</td>
</tr>
<tr>
<td>HCC</td>
<td>↑*</td>
<td>Iso/↓</td>
<td>Iso/↑</td>
<td>Variable/↓</td>
<td>Variable↑</td>
<td>Variable↑</td>
<td>Variable↑</td>
<td>Variable↑</td>
</tr>
<tr>
<td>Metastases</td>
<td>↑</td>
<td>Iso</td>
<td>Iso</td>
<td>Iso/↑</td>
<td>Iso/↑</td>
<td>Iso</td>
<td>Iso</td>
<td>Iso</td>
</tr>
<tr>
<td>NRH</td>
<td>↑</td>
<td>Iso</td>
<td>Iso</td>
<td>Iso/↑</td>
<td>Iso/↑</td>
<td>Iso</td>
<td>Iso</td>
<td>Iso</td>
</tr>
<tr>
<td>THID</td>
<td>↑</td>
<td>Iso</td>
<td>Iso</td>
<td>Iso/↑</td>
<td>Iso/↑</td>
<td>Iso</td>
<td>Iso</td>
<td>Iso</td>
</tr>
</tbody>
</table>

Note.—Arrows indicate increased (“up” arrow) or decreased (“down” arrow) signal intensity or enhancement relative to the surrounding normal liver. Arrows in parentheses indicate increased or decreased signal intensity or enhancement in an area of central scarring. Double up arrows indicate marked hyperintensity. Iso = isointense or isoenhancing.

*Heterogeneous.

†Lesser degree of change in signal intensity or enhancement.

### Table 2
SSFP and Diffusion-weighted Imaging Protocols

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SSFP</th>
<th>Diffusion-weighted</th>
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<td>Plane/sequence</td>
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<td>Axial/spin-echo</td>
</tr>
<tr>
<td>Options</td>
<td>Sequential, fast, ASSET</td>
<td>Echoplanar imaging, diffusion, ASSET</td>
</tr>
<tr>
<td>Scan timing</td>
<td>Single echo</td>
<td>Single shot</td>
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<tr>
<td>Echo time (msec)</td>
<td>Minimum full</td>
<td>Minimum</td>
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<tr>
<td>Repetition time (msec)</td>
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<tr>
<td>Bandwidth (kHz)</td>
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</tr>
<tr>
<td>Other</td>
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<td>NA</td>
</tr>
<tr>
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<td>Control variable ramp</td>
</tr>
<tr>
<td>Diffusion-weighted imaging</td>
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<td>600 b-value in all directions, optimal echo time = on, spin echo = on</td>
</tr>
<tr>
<td>Scanning range (sections)</td>
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<td>19</td>
</tr>
<tr>
<td>Field of view (cm)</td>
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<td>36</td>
</tr>
<tr>
<td>Section thickness (mm)</td>
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<td>7</td>
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<tr>
<td>Spacing</td>
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</tr>
<tr>
<td>Acquisition time (sec)</td>
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<td>21</td>
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<tr>
<td>Frequency direction</td>
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<td>128</td>
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<tr>
<td>Phase</td>
<td>160</td>
<td>128</td>
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<tr>
<td>Number of signals acquired</td>
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<tr>
<td>Phase field of view (cm)</td>
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<td>Full</td>
</tr>
<tr>
<td>Frequency duration</td>
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<td>Anteroposterior</td>
</tr>
<tr>
<td>Central frequency</td>
<td>Water</td>
<td>Water</td>
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<tr>
<td>Autoshim</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Phase correct</td>
<td>NA</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note.—ASSET = parallel imaging, FIESTA = fast imaging employing steady-state acquisition, NA = not applicable.
Figure 1. Small hemangiomas. (a, b) Axial arterial phase (a) and delayed phase (b) T1-weighted MR images show a small, hypervascular-type hemangioma in the left hepatic lobe (arrow), with persistent enhancement on the delayed phase image. By comparison, another small hemangioma (arrowhead) has the more typical peripheral, nodular, interrupted enhancement pattern. (c) On a T2-weighted MR image, both hemangiomas (arrow and arrowhead) have marked hyperintensity similar to that of fluid. (d, e) SSFP image (d) shows the hemangiomas as well-defined, hyperintense lesions (arrow and arrowhead), whereas a diffusion-weighted image (e) shows the lesions with marked hyperintensity related to T2 shine-through (arrow and arrowhead). (f) Portal venous phase image obtained in a different patient shows a hemangioma (arrow). (g) On a Gd-BOPTA–enhanced 1-hour delayed image obtained in the same patient as in f, the hemangioma is hypointense (arrow). One-hour to 3-hour delayed imaging with Gd-BOPTA is generally not helpful for hemangiomas because they can have a variable appearance that ranges from hypointensity to diffuse or central hyperintensity. (h) Photomicrograph (original magnification, ×40; hematoxylin–eosin [H-E] stain) shows dilated, anastomosing, endothelium-lined blood-filled spaces with occasional fibrous septa (*). Note the adjacent normal liver parenchyma on the left.
**Hemangiomas**

A hemangioma is the most common type of solid, benign hepatic tumor (8). It is a well-circumscribed mass of blood-filled spaces lined by endothelium on a thin, fibrous stroma. Thrombi, calcification, fibrosis, and scarring are variably present. Hemangiomas occur more frequently in women, are generally asymptomatic, and are discovered incidentally. However, patients with giant hemangiomas (>4–6 cm in diameter) can present with abdominal symptoms related to mass effect on the hepatic capsule or adjacent abdominal structures.

MR imaging is arguably the most sensitive and specific diagnostic study for hemangiomas, with one series demonstrating a specificity of 100% in the differentiation of hemangiomas from metastases (9). On T1-weighted images, hemangiomas are hypointense relative to the liver (Fig 1a, 1b), whereas on T2-weighted images, they are markedly hyperintense, nearly cystlike in signal intensity (Fig 1c). With SSFP sequences, hemangiomas demonstrate well-defined hyperintensity similar to that of the hepatic vasculature (Fig 1d) (6). At diffusion-weighted imaging, hemangiomas are hyperintense, not because of restriction, but rather because of T2 shine-through (Fig 1e) (5). Three distinct enhancement patterns that follow the intravenous administration of contrast material have been described. Pattern 1 is characterized by immediate uniform enhancement (small capillary hemangiomas <1.5 cm). Pattern 2, the most common of the three patterns (77% of cases), characteristically appears as a well-circumscribed hepatic mass with peripheral, nodular, and interrupted enhancement that can be greater than or equal to that of the blood pool (10–12) and progresses centripetally to uniform enhancement. Pattern 3 is characterized by peripheral nodular enhancement with centripetal progression but persistent central hypointensity (giant hemangiomas >5 cm).

Hemangiomas are more T2 hyperintense than are most metastases, although hypervascular metastases can mimic hemangiomas because of their marked T2 hyperintensity. Delayed (>5 minutes) contrast-enhanced images are helpful in these cases because small, uniformly enhancing hemangiomas retain contrast material and remain hyperintense, whereas hypervascular metastases will show “washout” of contrast material. In general, 1-hour delayed postcontrast imaging with Gd-BOPTA may not be helpful, since hemangiomas can have a variable appearance that ranges from hypointensity (Fig 1g) to diffuse or central enhancement (13).

**Focal Nodular Hyperplasia**

FNH is a benign tumor that is thought to represent a hyperplastic response of the hepatic parenchyma to a preexisting arterial malformation (14). It is most common in women of reproductive age but can occur, albeit rarely, in men and children. FNH is the second most common benign liver tumor after hemangioma and is usually asymptomatic. On rare occasions, however, it can be symptomatic, possibly owing to blood flow variations and liver capsule distention or mass effect on adjacent organs that requires resection for relief of symptoms (15). These lesions have a mean diameter of 4 cm and are solitary in 80%–95% of patients (16). To our knowledge, malignant transformation has not been reported. Pathologic findings for FNH include hyperplastic hepatocytes and small bile ductules surrounding a central fibrous scar (17). Kupffer cells are also present in relatively high numbers compared with hepatic adenomas and HCCs.

At MR imaging, FNH is generally isointense to slightly hypointense relative to the liver on T1-weighted images and isointense to slightly hyperintense on T2-weighted images (Fig 2) (18). A central scar is classically present and is T1 hypointense and T2 hyperintense because of the presence of blood vessels, bile ductules, and edema within myxomatous tissue. The central scar usually shows delayed enhancement (19). On SSFP and diffusion-weighted images, FNH is generally isointense relative to adjacent liver parenchyma.
Figure 2.  FNH. (a) Axial arterial phase T1-weighted MR image shows a homogeneous, hypervascular mass (arrow) with a hypoenhancing scar (arrowhead). (b) On a delayed phase MR image, the mass (arrow) has “faded” (ie, has become isointense relative to adjacent liver), with delayed enhancement of the scar (arrowhead). (c, d) T1-weighted (c) and T2-weighted (d) MR images show the mass (arrow) with an intensity similar to that of the adjacent liver. The scar is hypointense on the T1-weighted image (arrowhead in c) and hyperintense on the T2-weighted image (arrowhead in d). (e, f) Arterial phase (e) and Gd-BOPTA–enhanced 1-hour delayed (f) MR images obtained in a different patient show a hypervascular mass (arrow) that remains hyperintense relative to the liver, a finding that is consistent with FNH. (g) Gd-BOPTA–enhanced 1-hour delayed MR image obtained in a third patient shows how FNH can also have a peripheral ring-type, delayed enhancement pattern (arrow). (h) Photomicrograph (original magnification, ×100; Masson stain) of a core needle biopsy specimen shows benign hepatocytes with radiating fibrous septa, a few larger vessels, and shrunken bile ducts (arrow).
On dynamic contrast-enhanced images, FNH shows marked, homogeneous arterial phase enhancement that becomes isointense during the portal venous phase (20). Lesions may occasionally be slightly hyperenhancing on equilibrium phase images. If a liver mass is indeterminate for FNH, MR imaging with a hepatocyte-specific contrast agent may help confirm the hepatocellular origin of the mass. With Gd-BOPTA, FNH will appear iso- to hyperintense on 1-hour to 3-hour delayed images in over 96% of cases (Fig 2f) (18). FNH can also have a peripheral, ring-type delayed enhancement pattern on delayed images obtained 1 hour after Gd-BOPTA administration (Fig 2g). In contrast, in a study by Grazioli et al (18), no adenomas were reported to be iso- or hyperintense relative to the liver on delayed images obtained 1–3 hours after Gd-BOPTA administration.

**Hepatic Adenoma**

Hepatic adenoma is a benign neoplasm that is most commonly seen in women taking oral contraceptives (21). The prevalence of hepatic adenoma increases with the duration of oral contraceptive use and the size of the estrogen dose. Although adenomas are typically solitary, they are multiple in up to 21% of cases, with multiple adenomas being more often associated with glycogen storage disease or use of anabolic steroids (22). Liver adenomatosis, a rare (but possibly distinct) entity of unknown cause, has been defined as 10 or more adenomas in a patient without the typical risk factors associated with hepatic adenoma (23,24). Adenomas are more often symptomatic than FNH, with patients presenting with abdominal pain, a palpable mass, or abnormal liver function test results. Complications, particularly in lesions greater than 5 cm, include hemorrhage (with possible hepatic rupture) and, rarely, malignant transformation to HCC. Hemorrhage is likely related to infarction as the tumor outgrows its blood supply. Adenomas can range from 1 to 19 cm in diameter (mean, 3–5 cm).

Pathologic analysis shows adenomas to be benign hepatocytes arranged in large plates or cords without acinar architecture. The hepatocytes are separated by dilated sinusoids, which may be the cause of the hypervascularity in adenomas. Hepatic adenomas contain intracellular glycogen and lipid. Although Kupffer cells may be present, they are generally fewer in number, with reduced or insignificant function. Bile ducts are absent, which is an important histologic means of distinguishing adenomas from FNH (23).

In clinical terms, the management of hepatic adenoma requires accurate diagnosis because of the tendency of the lesions to spontaneously rupture or hemorrhage, as well as the potential for malignant transformation (25). If the lesion is less than 5 cm and the patient has a normal serum α-fetoprotein level, one recommendation is cessation of oral contraceptives and use of serial imaging. Classically, a hemorrhagic liver mass in a young woman taking oral contraceptives is highly suggestive of an adenoma.

At MR imaging, adenomas have variable signal intensity but can show hyperintense foci secondary to hemorrhage or intracellular lipid on T1-weighted images (Fig 3) (26). Depiction of intralesional fat with fat-suppressed or opposed-phase T1-weighted sequences helps distinguish adenomas from FNH. At T2-weighted imaging, these lesions have variable signal intensity but are often mildly hyperintense relative to the liver. With SSFP sequences, adenomas have a variable appearance that depends on the presence of fat or blood. On diffusion-weighted images, these lesions demonstrate variable signal intensity depending on the presence of blood or necrosis; in our experience, however, they are more often slightly hyperintense relative to the liver than is FNH (Fig 3e).

On dynamic contrast-enhanced images, adenomas show heterogeneous hypervascularity during the arterial phase but are typically not as vascular as FNH (27). These masses often demonstrate delayed contrast material washout (hypointense relative to the liver) with or without a delayed-enhancing pseudocapsule. Adenomas are hypointense on 1-hour to 3-hour delayed images obtained with Gd-BOPTA (Fig 3f) (18).
Figure 3. Hepatic adenoma. (a) Axial arterial phase T1-weighted MR image shows a hypervascular mass in the periphery of the right lobe (arrow). (b, c) In-phase (b) and opposed-phase (c) T1-weighted MR images show the mass (arrow) with relatively lower signal intensity on the latter image, a finding that indicates the presence of intraluminal fat and helps identify the mass as an adenoma rather than FNH. However, smaller adenomas uncomplicated by hemorrhage or fat may mimic FNH at imaging. (d, e) Postcontrast arterial phase (d) and diffusion-weighted (e) MR images obtained in a different patient show a hypervascular mass in the right lobe (arrow) with subtle, mild hyperintensity on the diffusion-weighted image. The mass was occult with other sequences. (f) On a Gd-BOPTA-enhanced 1-hour delayed MR image, the mass (arrow) is hypointense relative to normal liver. Fine-needle aspiration biopsy of the mass was performed because adenomas and a minority of FNHs (<4%) can manifest in a similar fashion. (g) Photomicrograph (original magnification, ×100; H-E stain) of a biopsy specimen reveals bland hepatocytes without normal bile duct structures or fibrous septa, findings that confirm the diagnosis of hepatic adenoma.
Hepatocellular Carcinoma

HCC is the most common primary malignancy of the liver (28). It is most commonly associated with underlying hepatic cirrhosis, a premalignant condition that is the irreversible sequela of various hepatic insults including inflammatory-infectious (hepatitis), toxic (alcohol), and metabolic (eg, hemochromatosis, Wilson disease, α1-antitrypsin deficiency syndrome) processes (29). Cirrhotic nodules range from “benign” regenerative to premalignant dysplastic and frankly malignant HCC (30–32). Accurate differentiation among these cirrhotic nodules can be challenging because of considerable overlap in imaging and histologic features. Nevertheless, because patients with untreated disease have a median survival time of only 6–9 months, early liver transplantation provides the only opportunity for cure for HCC (33). Thus, radiologic imaging plays a pivotal role in making an early diagnosis and in subsequent management and prognosis.

With T1-weighted MR imaging, HCC lesions less than 1.5 cm are often isointense, whereas larger lesions may be hyperintense secondary to lipid, copper, or glycogen (Fig 4) (34). Note that fatty metamorphosis in a cirrhotic nodule is suspicious for HCC (26,35). At T2-weighted imaging, most HCC lesions are hyper- or isointense,
although hypointensity can be seen with more well-differentiated tumors. In cirrhotic patients, a hypervascular mass with increased T2 signal similar to that of the spleen is suspicious for HCC (36). With SSFP sequences, these lesions are generally isointense (occasionally hypointense if fat is present) but can have increased signal intensity (Fig 4c). At diffusion-weighted imaging, they have a variable appearance that depends on their histologic make-up. Well-differentiated tumors are often isointense, whereas moderately to poorly differentiated tumors are more often hyperintense (Fig 4d) (37).

At dynamic contrast-enhanced imaging, lesions less than 2 cm in diameter can demonstrate homogeneous intense enhancement during the arterial phase, whereas larger lesions more often demonstrate heterogeneous enhancement (38). During the portal venous and equilibrium
phases, HCC will show rapid loss of enhancement, becoming iso- or hypointense relative to the liver. Venous washout, defined as a hypervascular mass that becomes hypointense relative to adjacent parenchyma on delayed postcontrast images, has been reported as an imaging finding that increases the specificity for HCC, since regenerative and dysplastic nodules do not typically display this finding (39,40). A surrounding tumor capsule can be identified in lesions of any size, but because of increasing capsule thickness with increasing tumor size, capsules can be better seen with larger HCCs (41). Capsules have been observed in 10%–78% of lesions in various series (41,42). They are typically thin and discontinuous, are hypointense with both T1- and T2-weighted sequences, and show progressive delayed enhancement (Fig 4b, 4e).

Nodular Regenerative Hyperplasia
NRH is an uncommon benign hepatic entity defined as diffuse nodularity of the liver produced by multiple regenerative nodules. This condition is associated with various diseases such as Budd-Chiari syndrome, myeloproliferative syndromes, lymphoproliferative syndromes, and collagen vascular disorders, and with drugs such as immunosuppressive or antineoplastic medications (43). The pathogenesis of the nodules has not yet been determined; however, increased resistance to sinusoidal hepatic blood flow (with resultant portal hypertension) and a decrease in portal venous inflow or hepatic venous outflow (as seen in right-sided heart failure, passive hepatic congestion, and pulmonary hypertension) have been cited as possible factors (44,45). In Budd-Chiari syndrome, progressive thrombotic occlusion of the hepatic vein branches and chronic hepatic sinusoidal congestion lead to prolonged exposure of hepatocytes to blood-borne hepatopoietins, thus stimulating nodular hepatocellular regeneration (46). At pathologic analysis, these lesions often resemble FNH (47,48).

At MR imaging, NRH is iso- to hyperintense on T1-weighted images and iso- to hypointense on T2-weighted images (Fig 5). Nodules can range from 0.1 to 4 cm in size. At SSFP and diffusion-weighted imaging, these nodules are generally isointense relative to the liver.

On dynamic contrast-enhanced images, multiple small, similar-sized enhancing nodules are demonstrated during the hepatic arterial phase. These nodules then fade to isointensity, a finding that helps distinguish them from HCC, which shows rapid washout (hypointensity) during the portal venous and equilibrium phases (47). Similar to FNH, NRH is predominantly hyper- or isointense on delayed images obtained 1–3 hours after Gd-BOPTA administration (Fig 5d) (47,48).

Hypervascular Metastases
Metastases are the most common malignant hepatic tumor, occurring up to 18 times more frequently than primary neoplasms (49). These tumors most commonly manifest as multifocal, discrete lesions but sometimes manifest as a solitary mass or confluent masses. The imaging appearance depends on the degree of underlying hepatic arterial supply. Hypovascular metastases show decreased enhancement relative to normal liver and are most conspicuous on portal venous phase images. In contradistinction, hypervascular metastases enhance earlier, are best seen on arterial phase images, and show washout on delayed images (50). These metastases typically arise from primary neuroendocrine tumors (eg, pancreatic islet cell tumor, carcinoid tumor, or pheochromocytoma), renal cell carcinoma, thyroid carcinoma, choriocarcinoma, melanoma, and sarcomas.

Hypervascular metastases are moderately hypointense on T1-weighted MR images (Figs 6–8); however, hemorrhagic metastases (eg, lung, kidney, testicle; melanoma) can demonstrate T1 hyperintensity (Fig 7c) (51). In addition, perilesional fat deposition (Fig 6) has been specifically described with hepatic metastases from a primary pancreatic insulinoma and is thought to be related to the effects of insulin, that is, the inhibition of fatty acid oxidation and the promotion of hepatocyte triglyceride accumulation (52,53). On T2-weighted images, hypervascular metastases are usually markedly hyperintense and may be cystic or necrotic (54). On SSFP (Fig 6d) and diffusion-weighted (Fig 7b) images, these lesions are hyperintense (55,56).
Figure 6. Hypervascular metastases (insulinoma). (a) Axial arterial phase T1-weighted MR image shows a small, hypervascular mass in the right hepatic lobe (arrow) with surrounding hypointensity (arrowheads). (b, c) In-phase (b) and opposed-phase (c) images show the mass surrounded by an area of mild hyperintensity (arrowheads in b) and hypointensity (arrowheads in c), respectively, findings that confirm the presence of perilesional fat. (d) SSFP image shows hypervascular metastases with marked hyperintensity that mimics the signal intensity of cysts or hemangiomas. Because SSFP sequences are performed with a short echo time (1.2 msec), perilesional hypointensity (arrowheads) similar to that depicted at opposed-phase T1-weighted imaging is again seen (cf c). (e) Photomicrograph (original magnification, ×200; H-E stain) of a fine-needle aspiration biopsy specimen reveals rare clusters of loosely cohesive, cytologically low-grade cells with round nuclei that stain strongly for synaptophysin, a neuroendocrine marker.

On dynamic contrast-enhanced images, the arterial phase enhancement of hypervascular metastases may be uniform, peripheral-rim, or heterogeneous (50). The “peripheral washout sign” is a specific but insensitive sign for both metastases and HCC (57). This sign refers to contrast material preferentially washing out from the periphery of a hepatic mass on delayed scans, which thus appears hypointense relative to the center of the lesion. It is thought to be related to the degree of tumor vascularity, with increased vascularity peripherally (viable tumor) and decreased vascularity centrally (necrotic or fibrotic region). Metastases are hypointense relative to the liver or demonstrate a “target” appearance on delayed images obtained 1–3 hours after Gd-BOPTA administration (Fig 8b) (58,59).
Figure 7. Hypervascular metastases (melanoma). (a) Axial arterial phase T1-weighted MR image shows multiple hypervascular masses (arrows). (b) Diffusion-weighted image better delineates the masses (arrows). (c) On a precontrast T1-weighted image, two of the masses are hyperintense (arrows), a finding that suggests hemorrhage or melanin. (d) Photomicrograph (original magnification ×40; H-E stain) of a fine-needle aspiration biopsy specimen helps confirm the presence of melanoma metastases (*). Photomicrograph obtained at a higher magnification (×600) with H-E stain (inset) shows an epithelioid tumor with the dusty brown cytoplasmic pigment, prominent nucleoli, and intranuclear vacuolation typical of melanoma.

![Image of Figure 7](image1.png)

Figure 8. Hypervascular metastases (rectal adenocarcinoma). (a) Axial arterial phase T1-weighted MR image shows a heterogeneous, peripherally hypervascular mass (arrow) in the left hepatic lobe. (b) On a Gd-BOPTA–enhanced 1-hour delayed T1-weighted MR image, the mass (arrow) is hypointense relative to the liver. (c) Photomicrograph (original magnification, ×40; H-E stain) shows multiple foci of malignant adenocarcinoma (*) in fibrous stroma that replaces the hepatic parenchyma.

![Image of Figure 8](image2.png)
Pitfalls
Two potential pitfalls in the evaluation of hypervascular liver masses are treated metastases and THID.

Treated Metastases
After the initiation of chemotherapy, metastases can exhibit a less aggressive enhancement pattern that mimics hemangiomas, including early peripheral nodular enhancement and delayed retention of contrast material. This appearance has been postulated to be the result of chemotherapeutically treated metastases is an early, intact peripheral rim of enhancement (Fig 9) unlike the discontinuous peripheral enhancement seen in hemangiomas (60).

Transient Hepatic Intensity Difference
Transient areas of liver parenchyma enhancement (eg, THID), from either nontumorous arterioportal shunts or obstruction of distal parenchymal portal venous flow, can cause homogeneous nodular enhancement caused by altered vascularity and the retention of contrast material on the 10-minute delayed postcontrast images reflecting an enlarged extracellular space or decreased venous drainage (60). A key distinguishing feature of chemotherapeutically treated metastases is an early, intact peripheral rim of enhancement (Fig 9) unlike the discontinuous peripheral enhancement seen in hemangiomas (60).

Figure 9. Treated metastases mimicking hemangiomas in a patient who was undergoing chemotherapy for metastatic breast cancer. (a) Axial arterial phase T1-weighted MR image shows multiple lesions, two of which are hypervascular (arrows) and two hypovascular (arrowheads). (b) Portal venous phase image shows persistent enhancement of the hypervascular lesions (arrows) and peripheral nodular enhancement of the hypovascular lesions (arrowheads), findings that incorrectly suggest hemangiomas. (c) T2-weighted MR image shows marked hyperintensity of the lesions (arrows and arrowheads), a finding that again incorrectly suggests hemangiomas. (d) Follow-up T2-weighted MR image obtained 7 months later shows dramatic improvement in the burden of metastatic disease (arrow and arrowhead).
arterial phase enhancement that may mimic an underlying mass (61). Clues to the diagnosis include peripheral location, geographic or wedge shape, and nondisplaced internal vasculature. Serial follow-up imaging can also be helpful because these lesions will invariably no longer be visible (Fig 10).

**Decision Algorithm**

Table 1 shows the various categories of liver masses and their signal intensity characteristics with pre- and postgadolinium-enhanced MR imaging sequences.

As shown in Figure 11, evaluation of a hypervascular liver lesion should first involve the determination of any underlying chronic liver disease (by either correlation with clinical history or identification of specific hepatic morphologic changes or sequelae of portal hypertension).

**Normal Liver**

If the liver is normal, the most common causes of hypervascular liver lesions are hemangioma, FNH, adenoma, and hypervascular metastases.

**Hemangioma.**—The key characteristic of hemangioma is that the early-enhancing type will also show persistent delayed hyperenhancement. Of the more frequently encountered lesions, hemangioma
is the only hypervascular mass that is hyperintense both early and late; other lesions in the differential diagnosis will fade or wash out (12).

**Focal Nodular Hyperplasia.**—If no classic central scar is present, FNH will typically show iso- or hyperenhancement on delayed images obtained 1–3 hours after Gd-BOPTA administration, a finding that helps distinguish FNH from adenoma (hypointense). Absence of “light bulb bright” T2 signal and lack of restricted diffusion also help differentiate FNH from hypervascular metastases and hemangioma.

**Adenoma.**—Adenoma is a relatively heterogeneous lesion compared with FNH. The presence of fat, blood, and heterogeneous hypervascularity are additional helpful distinguishing signs. Although venous washout is generally worrisome for malignancy, adenoma may also display this feature and, in fact, is the only “benign” hypervascular mass that may do so. In comparison, FNH generally fades to isoenhancement relative to background liver or shows subtle hypoenhancement. Adenomas are also hypointense on 1-hour to 3-hour delayed images obtained with Gd-BOPTA.

**Hypervascular Metastases.**—Hypervascular metastases classically show marked T2 and restricted diffusion compared with FNH and adenoma, and will wash out on delayed enhanced images, unlike hemangioma. Identification of ring-type hypervascularity or peripheral washout in a patient with known hypervascular primary malignancy can also be helpful. Hypervascular metastases will show hypoenhancement on 1-hour to 3-hour delayed images obtained with Gd-BOPTA. Note that periportal fat can be specific for insulinoma metastases.

**Chronic Liver Disease**
If chronic liver disease is present, the differential diagnosis includes mimics, HCC, and NRH.

**Mimics.**—Regenerative nodules, dysplastic nodules, small hemangiomas, and variant perfusion are the more common lesions that require differentiation from HCC in chronic liver disease. Regenerative nodules are typically isointense or isoenhancing relative to the liver with all sequences. Dysplastic nodules may show hypervascularity without washout or a capsule (unlike HCC) and are generally T2 hypointense rather than hyperintense. Small hemangiomas show marked T2 hyperintensity and persistent delayed enhancement rather than washout. Variant perfusion (THID) is hypervascular, geographically shaped, typically peripheral in location, and occult with all other sequences.

In general, we manage these lesions as follows: For lesions less than 2 cm in size, serial follow-up is suggested to evaluate for interval growth or the development of signal intensity or enhancement characteristics of frank HCC. If the imaging features are not definitive for HCC, but the lesion is 2 cm or larger, or if there is a high clinical degree of suspicion for HCC (elevated α-fetoprotein level), biopsy can be considered.

**Hepatocellular Carcinoma.**—In cirrhotic patients, a hypervascular mass showing washout and a delayed-enhancing capsule may be the most specific sign for HCC. The presence of fat, increased T2 signal, restricted diffusion, or increasing size at serial follow-up examination can also be helpful in differentiating HCC from THID, regenerative nodules, and dysplastic nodules. Note that hepatic adenoma and HCC, which is histologically an adenocarcinoma, can have similar imaging characteristics.

**Nodular Regenerative Hyperplasia.**—NRH is an uncommon entity that is seen in patients with Budd-Chiari syndrome or hepatic vascular disorders. T2 hypointensity and delayed isoenhancement help differentiate NRH from HCC (T2 hyperintensity and washout with a capsule). Like FNH, NRH will show isoenhancement or hyperenhancement on 1-hour to 3-hour delayed images obtained with Gd-BOPTA.

**Conclusions**
As the role of MR imaging for clinical hepatic imaging continues to evolve, keeping abreast of newer pulse sequences and contrast agents can be daunting as well as confusing. Thus, a systematic approach that makes use of a decision algorithm based on the presence or absence of chronic liver disease and the distinguishing imaging characteristics of a given lesion should prove helpful in formulating a more specific diagnosis for a hypervascular liver mass.

**References**
2. Semelka RC, Martin DR, Balci C, Lance T. Focal liver lesions: comparison of dual-phase CT and multisquence multiplanar MR imaging including


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Hemangiomas are more T2 hyperintense than are most metastases, although hypervascular metastases can mimic hemangiomas because of their marked T2 hyperintensity. Delayed (≥5 minutes) contrast-enhanced images are helpful in these cases because small, uniformly enhancing hemangiomas retain contrast material and remain hyperintense, whereas hypervascular metastases will show "washout" of contrast material.

With Gd-BOPTA, FNH will appear iso- to hyperintense on 1-hour to 3-hour delayed images in over 96% of cases.

Venous washout, defined as a hypervascular mass that becomes hypointense relative to adjacent parenchyma on delayed postcontrast images, has been reported as an imaging finding that increases the specificity for HCC, since regenerative and dysplastic nodules do not typically display this finding.

Hypovascular metastases show decreased enhancement relative to normal liver and are most conspicuous on portal venous phase images. In contradistinction, hypervascular metastases enhance earlier, are best seen on arterial phase images, and show washout on delayed images (50). These metastases typically arise from primary neuroendocrine tumors (eg, pancreatic islet cell tumor, carcinoid tumor, or pheochromocytoma), renal cell carcinoma, thyroid carcinoma, choriocarcinoma, melanoma, and sarcomas.

A key distinguishing feature of chemotherapeutically treated metastases is an early, intact peripheral rim of enhancement (Fig 9) unlike the discontinuous peripheral enhancement seen in hemangiomas.