

MR Imaging of the Spleen: Spectrum of Abnormalities¹

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LEARNING OBJECTIVES

After reading this article and taking the test, the reader will be able to:

- Discuss the state-of-the-art MR imaging technique for diagnosis of splenic diseases.
- Describe the normal MR imaging features of the spleen.
- Identify the MR imaging appearances of various splenic diseases.

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The spleen has the same relationship to the circulatory system that the lymph nodes have to the lymphatic system. A wide range of diseases can affect the spleen. Pathologic conditions of the spleen can be classified into the following categories: congenital diseases (accessory spleen, polysplenia, and asplenia); trauma; inflammation (abscess, candidiasis, histoplasmosis, and sarcoidosis); vascular disorders (infarction, diseases affecting the splenic vasculature, and arteriovenous malformation); hematologic disorders (sickle cell disease and extramedullary hematopoiesis); benign tumors (cysts, hemangioma, diffuse hemangiomatosis of the spleen, and hamartoma); malignant tumors (sarcoma, lymphoma, and metastases); and other disease processes that affect the spleen diffusely (portal hypertension, Gaucher disease, and sickle cell disease) or focally (Gamma-Gandy nodules). New magnetic resonance (MR) imaging techniques have increased the role of MR imaging in detection and characterization of splenic diseases. MR imaging is an excellent tool for diagnosis and evaluation of focal lesions and pathologic conditions of the spleen.

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Abbreviations: GRE = gradient echo, RARE = rapid acquisition with relaxation enhancement, 3D = three-dimensional, VIBE = volumetric interpolated breath-hold examination

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Introduction

The spleen is the largest ductless gland and the largest single lymphatic organ in the body. It is mesodermal in origin. The spleen is to the circulatory system as the lymph nodes are to the lymphatic system. Splenic functions include immunologic surveillance, red blood cell breakdown, and splenic contraction for blood volume augmentation during hemorrhage. A wide range of pathologic conditions can affect the spleen. With an increasing clinical role, magnetic resonance (MR) imaging is playing an important role in diagnosis and characterization of splenic disease.

The purpose of this article is to demonstrate the MR imaging appearances of various splenic lesions and to illustrate the characteristic MR imaging features. Specific topics discussed are the gross and microscopic anatomy, the MR imaging technique, normal variants and congenital diseases, trauma, inflammation, vascular disorders, hematologic disorders, benign neoplasms or cysts, malignant neoplasms, and diffuse enlargement.

Gross Anatomy

The spleen is an intraperitoneal organ with a smooth serosal surface and is attached to the retroperitoneum by fatty ligaments that also contain its vascular supply. The splenic surfaces are described relative to their locations and are termed the *diaphragmatic* (phrenic) and *visceral* surfaces. The visceral surface is divided into an anterior or gastric ridge and a posterior or renal portion. The splenic hilum is directed anteromedially. The splenic artery and vein emerge from the splenic hilum in the form of six or more branches; the splenic artery is remarkable for its large size and tortuosity. The splenic artery is slightly superior to the vein.

Microscopic Anatomy

The spleen is divided into two compartments, namely, the red and white pulps, separated by the marginal zone. The white pulp is made up of T and B lymphocytes and located centrally, while the red pulp is composed of rich plexuses of tortuous venous sinuses.

MR Imaging Technique

Pulse sequences used for MR imaging of the spleen are similar to those used for standard abdominal MR imaging. Our standard protocol comprises the following sequences: (a) coronal T2-weighted half-Fourier rapid acquisition with

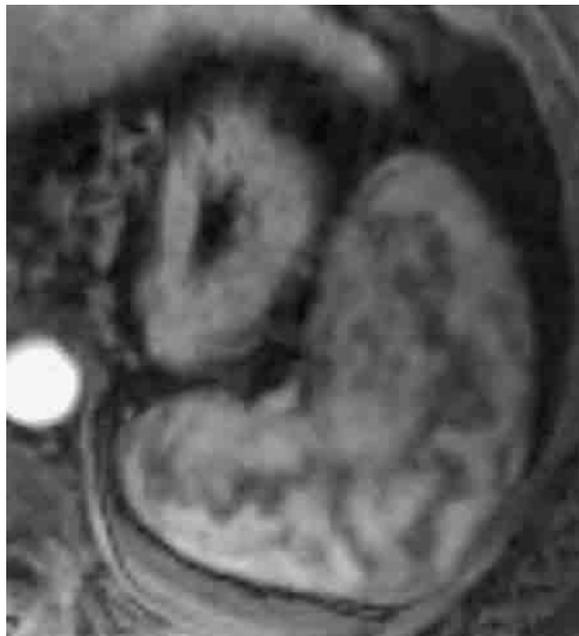
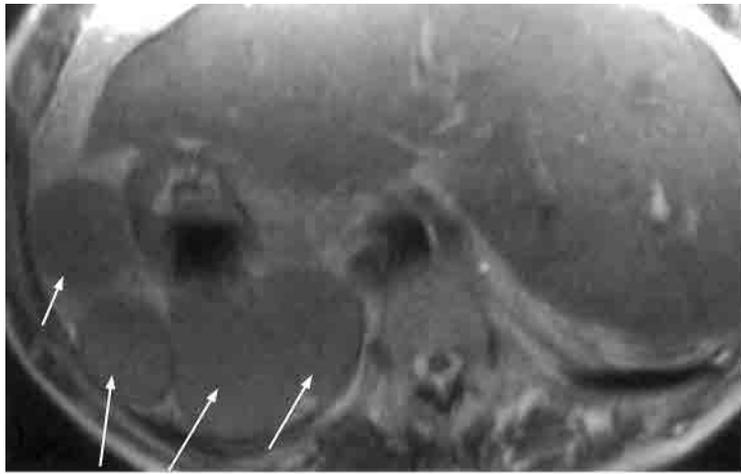


Figure 1. Axial 3D GRE VIBE image obtained immediately after administration of contrast material shows the arciform normal enhancement pattern of the spleen.



Figure 2. Axial out-of-phase image shows an accessory spleen at the hilum (arrow).

relaxation enhancement (RARE) imaging, (b) axial turbo/fast spin-echo T2-weighted or long echo time inversion-recovery imaging performed during a breath hold, (c) axial gradient-echo (GRE) T1-weighted chemical shift in-phase and out-of-phase imaging performed during a breath hold, and (d) an axial three-dimensional (3D) GRE breath-hold sequence such as volumetric interpolated breath-hold examination (VIBE) with pre-contrast and dynamic gadolinium-enhanced imaging.



3.



4a.



4b.

Figures 3, 4. (3) Axial in-phase GRE image shows situs inversus with multiple masses in the right upper quadrant (arrows), an appearance that represents polysplenia. (4) Coronal GRE cine (a) and axial in-phase GRE (b) images show a cardiac anomaly in the form of pulmonary stenosis (arrow in a) and small masses in the left upper quadrant (arrows in b), an appearance that represents polysplenia.

The MR imaging characteristics of the spleen are unique with a large fractional heme content characterized by long T1 and T2 (lower in signal intensity than the liver on T1-weighted images and higher on T2-weighted images) (1,2). Images obtained immediately after gadolinium enhancement usually demonstrate different circulations as regions of alternating high and low signal intensity, resulting in a serpentine or arciform pattern (1–3) (Fig 1). This pattern becomes homogeneous approximately 60–90 seconds after contrast material administration.

Normal Variants and Congenital Diseases

Accessory Spleen

Found in 10% of individuals, accessory spleens may be solitary or multiple and usually measure no more than 4 cm in diameter. The most common location is the splenic hilum (Fig 2). An ac-

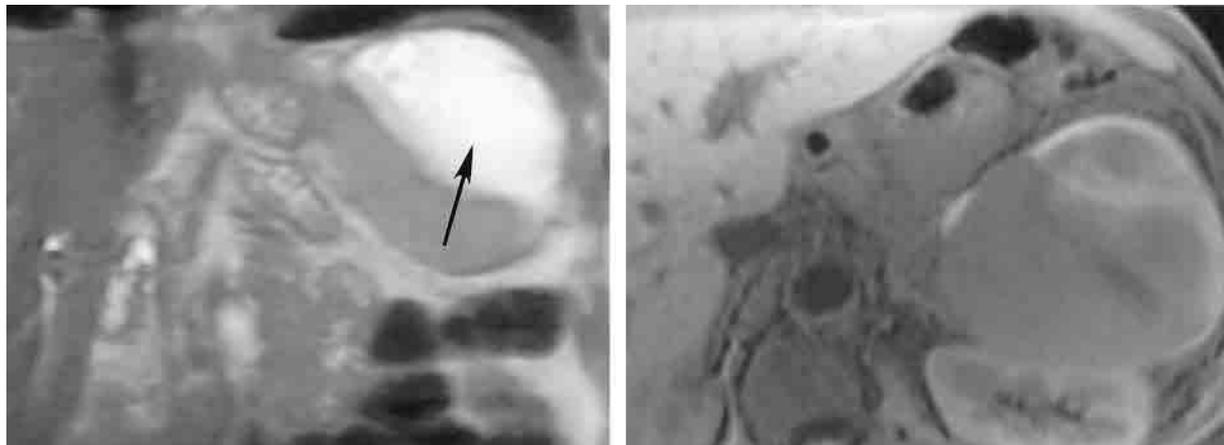
cessory spleen should be distinguished from enlarged lymph nodes, as it follows the signal intensity and enhancement of the spleen on images obtained with various pulse sequences (4).

Polysplenia

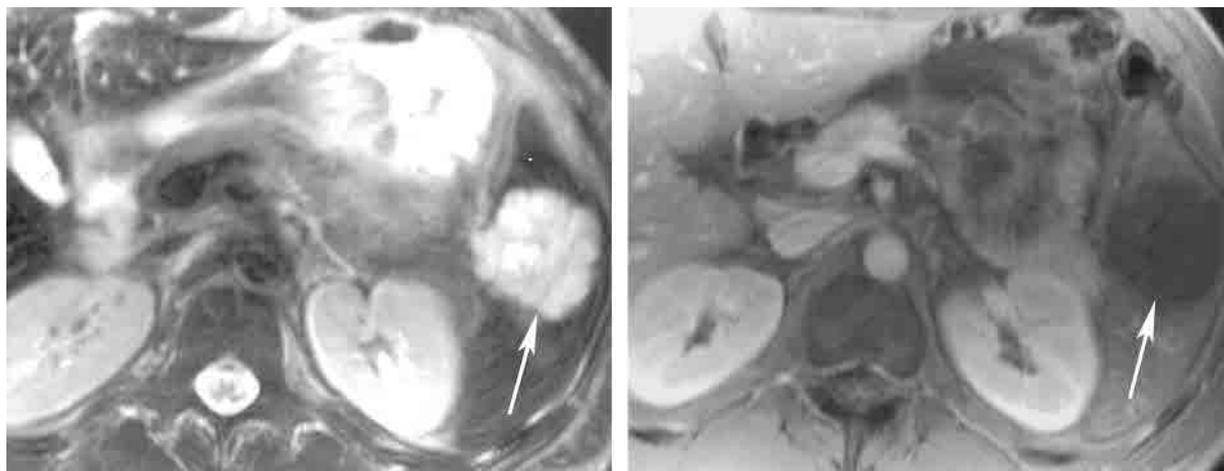
Polysplenia is seen in association with abdominal situs and cardiovascular anomalies. This condition is more common in females. Classically, numerous small splenic masses are seen in the right or left hypochondrium (5,6) (Figs 3, 4).

Trauma

The spleen is the most commonly ruptured intra-abdominal organ in the setting of trauma, being particularly susceptible to injury after blunt trauma due to its complex ligamentous attachments and spongy parenchymal consistency. The MR imaging characteristics of splenic hematomas



a. **b.**
Figure 5. Coronal T2-weighted half-Fourier RARE (**a**) and axial nonenhanced 3D VIBE (**b**) images show an acute or subacute subcapsular hematoma of the spleen (arrow in **a**).



a. **b.**
Figure 6. Axial T2-weighted inversion-recovery (**a**) and gadolinium-enhanced T1-weighted fast multiplanar spoiled GRE (**b**) images of a patient with acquired immunodeficiency syndrome show a splenic abscess (arrow), which is hyperintense on the T2-weighted image (**a**) and hypointense on the T1-weighted image (**b**).

follow those of heme and heme products, with evolution like hematomas in other parts of the body (Fig 5). Compared to splenic signal intensity, acute hematomas demonstrate prolonged T2. Blood products evolve over time into methemoglobin, deoxyhemoglobin, and other paramagnetic degradation products with concomitant signal intensity changes. The evolving concepts in trauma care promoting nonsurgical management of liver and splenic injuries create the need for follow-up cross-sectional imaging studies in these patients (7,8).

Inflammation

Splenic abscesses have been found in 0.14%–0.7% of autopsy cases (9). The prevalence of these lesions has increased due to the increased number of immunosuppressed patients such as those with acquired immunodeficiency syndrome (AIDS). They can be solitary, multiple, or multilocular. MR imaging shows the abscess as a lesion of fluid signal intensity, with low signal intensity on T1-weighted images and high signal intensity on T2-weighted images (Fig 6). There is minimal peripheral enhancement when the capsule develops (10,11).

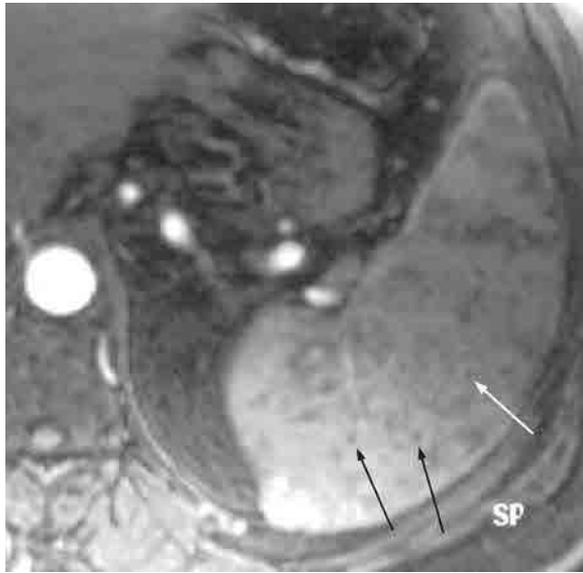
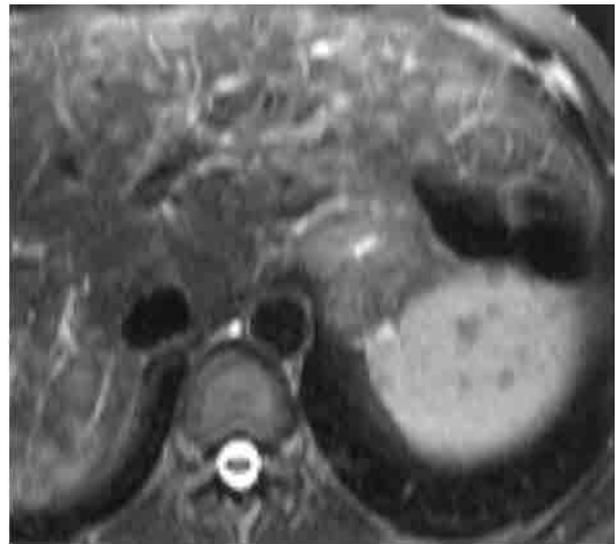
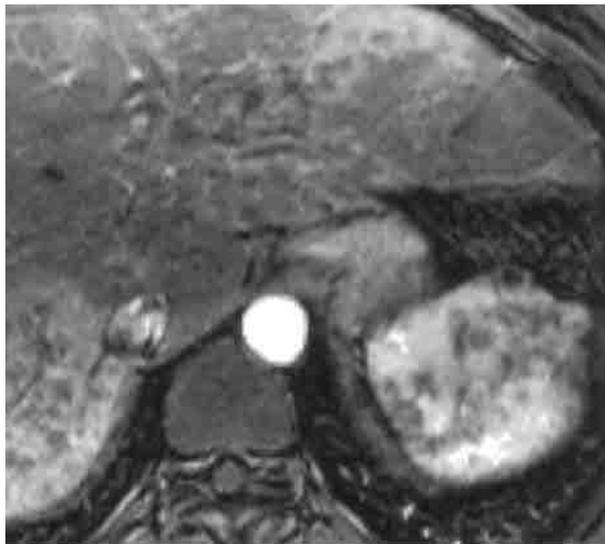


Figure 7. Axial contrast-enhanced 3D VIBE image of an immunocompromised patient shows multiple small, hypointense candidal lesions in the spleen (arrows).



a.

b.

Figure 8. Axial contrast-enhanced 3D VIBE (**a**) and T2-weighted inversion-recovery (**b**) images show scattered low-signal-intensity lesions, which represent infection of the spleen with *Histoplasma capsulatum*.

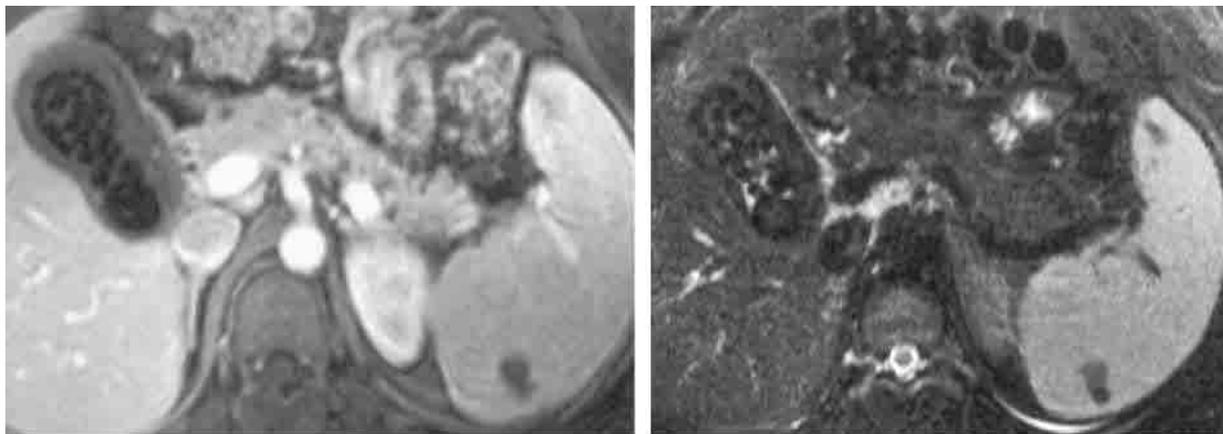
Candidiasis

Candidiasis is the most common infection involving the liver and spleen in immunocompromised patients. MR imaging has been shown to be superior to computed tomography (CT) in detection of microabscesses secondary to candidiasis. These lesions appear as multiple hypointense, ring-enhancing lesions less than 1 cm in diameter on gadolinium-enhanced images (Fig 7) (12).

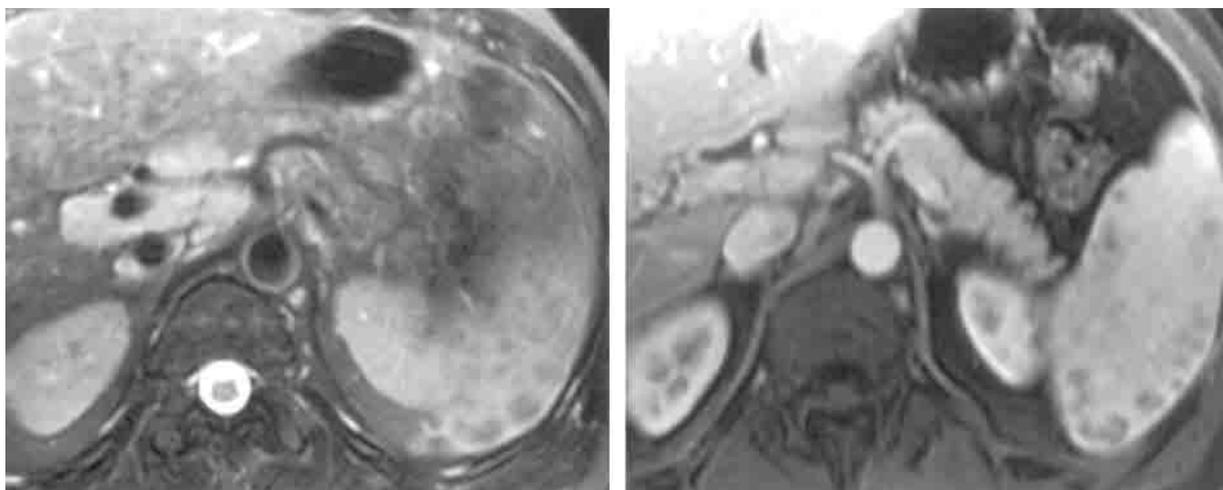
Histoplasmosis

Although seen in patients with competent immune systems, the prevalence of histoplasmosis is

greater in immunocompromised patients. MR imaging demonstrates the acute and subacute phases of this disease as scattered hypointense lesions on both T1- and T2-weighted images (Fig 8). Old granulomas can be calcified, causing characteristic signal intensity changes with blooming artifacts on MR images (13–15) (Fig 9). This appearance is best appreciated on GRE T1-weighted images, especially those obtained with a long echo time.



a. **b.**
Figure 9. Axial T1-weighted (**a**) and T2-weighted (**b**) images show an old calcified splenic histoplasmosis, which appears as a low-signal-intensity lesion with characteristic “blooming.”



a. **b.**
Figure 10. Axial T2-weighted inversion-recovery (**a**), axial arterial phase 3D VIBE (**b**), and coronal delayed phase 3D VIBE (**c**) images show multiple small, hypointense, focal splenic lesions, which represent involvement with sarcoidosis. The lesions do not enhance on the early phase image (**b**) but do enhance on the delayed phase image (**c**).

Sarcoidosis

Sarcoidosis is a granulomatous systemic disease of unknown etiology that can involve numerous sites, infrequently involving the spleen. Nodular sarcoidosis has been reported to demonstrate low signal intensity with all MR imaging sequences. The lesions are most conspicuous on T2-weighted fat-suppressed or early phase contrast-enhanced images. Sarcoidosis lesions enhance in a minimal and delayed pattern (16,17) (Fig 10).



c.

Vascular Disorders

Infarction

Splenic infarcts are seen in the setting of arterial emboli such as in sickle cell anemia, Gaucher disease, hematologic malignancies, cardiac emboli,



Figure 11. Axial contrast-enhanced 3D VIBE image shows a nonenhancing wedge-shaped area of infarction in the spleen (arrow).

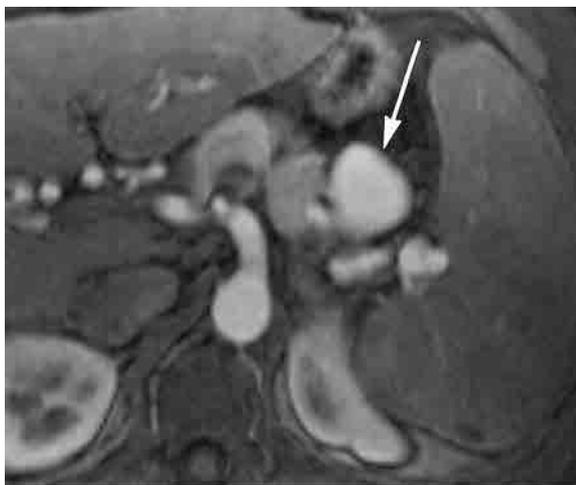


Figure 13. Axial venous phase gadolinium-enhanced 3D GRE VIBE image shows a thrombus filling the splenic vein (arrowheads). The thrombus appears as an area of signal void.

torsion, collagen vascular disease, and portal hypertension. Infarcts are seen as peripheral wedge-shaped defects that exhibit decreased signal intensity on both T1- and T2-weighted MR images and do not enhance after intravenous contrast material administration (Fig 11) (18,19).

Splenic Artery Aneurysm

Splenic artery aneurysms are secondary to multiple causes such as medial degeneration with superimposed atherosclerosis, congenital causes, mycotic causes, portal hypertension, fibromuscular dysplasia, and pseudoaneurysms from trauma and pancreatitis. MR imaging allows effective diagnosis and characterization of these lesions (20).



a.



b.

Figure 12. Axial contrast-enhanced 3D GRE VIBE images show aneurysmal dilatation of the distal end of the splenic artery (arrow).

Three-dimensional GRE sequences such as VIBE or dedicated 3D MR angiographic sequences are the best for evaluating these lesions (Fig 12) (21).

Splenic Vein Thrombosis

Splenic vein thrombosis has multiple causes but is most commonly secondary to pancreatitis. It has been reported in at least 20% of patients with chronic pancreatitis. The usual mechanism is compression and fibrosis caused by pancreatitis. Occasionally, splenic vein thrombosis is produced by erosion of a pseudocyst into the splenic vein. Splenic vein thrombosis may result in gastric varices and at times either esophageal or colonic varices. Splenic vein thrombosis is usually visualized as an intraluminal filling defect after intravenous contrast material administration (Fig 13). Noninvasive contrast-enhanced MR angiography has the potential to replace intraarterial digital subtraction angiography as the standard method of assessing the portal venous anatomy (22).

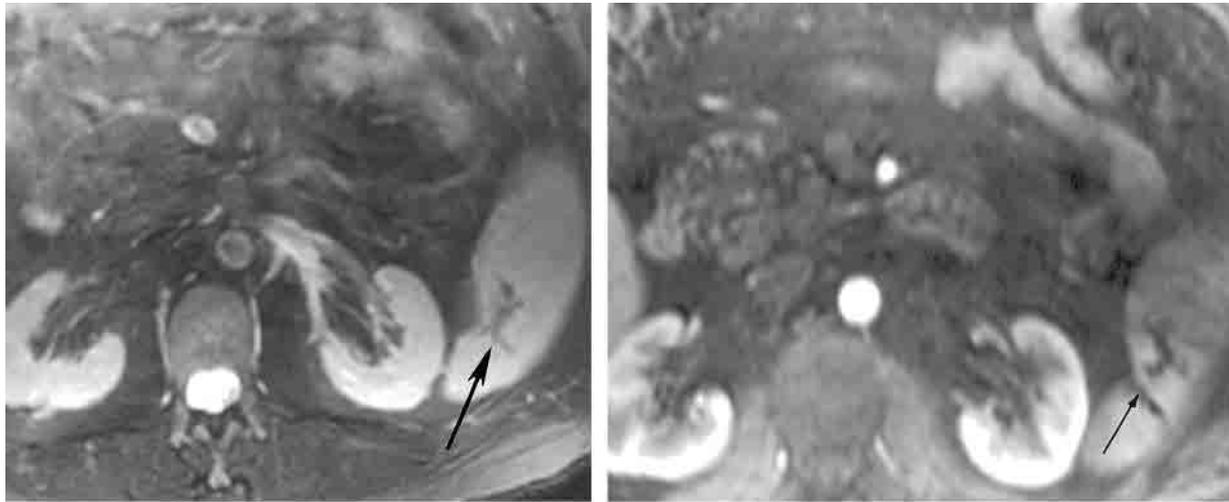


Figure 14. Axial T2-weighted inversion-recovery (**a**) and contrast-enhanced 3D VIBE (**b**) images show a splenic lesion that appears as an area of signal void (arrow). The lesion demonstrates serpentine enhancement on the contrast-enhanced image (**b**) and represents an arteriovenous malformation.

Arteriovenous Malformation

Arteriovenous malformations can occur anywhere in the human body but rarely occur in the spleen. A machinery-type bruit in the upper left abdominal quadrant represents an important and simple diagnostic symptom found at clinical examination during auscultation (23–25). MR imaging can demonstrate arteriovenous malformations as multiple signal voids with all nonenhanced pulse sequences. Arteriovenous malformations demonstrate serpentine enhancement after intravenous injection of gadolinium contrast material (Fig 14).

Hematologic Disorders

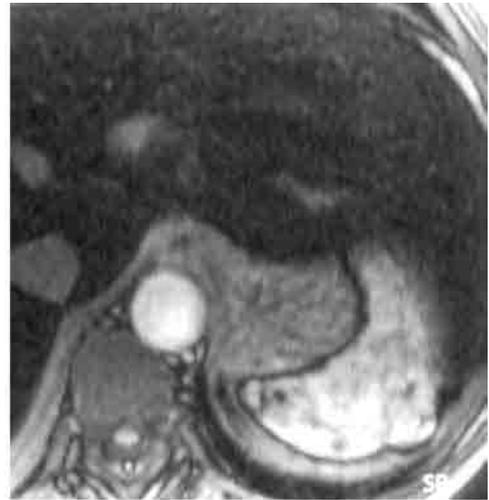
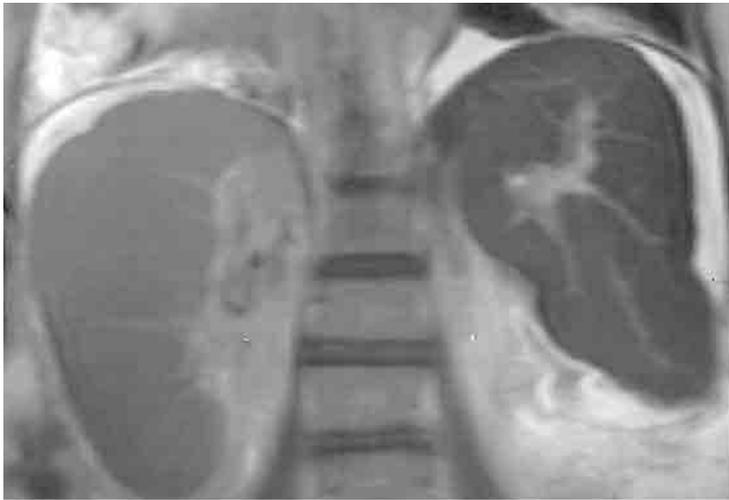
Sickle Cell Disease

Sickle cell disease is common in the black population with a prevalence of 0.2% (homozygous form) and 8%–10% (heterozygous form). The spleen is the organ most commonly involved by sickle cell disease. In patients with sickle cell disease, the spleen appears as a nearly signal void

area due to iron deposition from blood transfusion (Fig 15). Autosplenectomy is often found in patients with homozygous sickle cell disease (Fig 16) (26,27).

Extramedullary Hematopoiesis

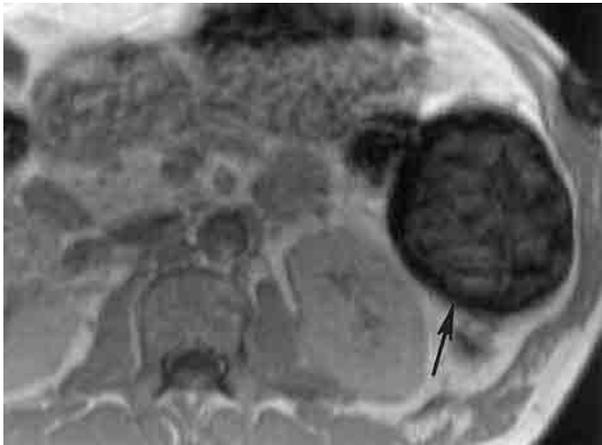
Extramedullary hematopoiesis is a compensatory response to deficient bone marrow cells. It predominantly affects the spleen and liver. Although it usually shows diffuse infiltration microscopically, there may be focal masslike involvement of the liver and spleen. The signal intensity of the mass depends on the evolution of the hematopoiesis. Active lesions show intermediate signal intensity on T1-weighted images, high signal intensity on T2-weighted images, and some enhancement after intravenous contrast medium injection. Older lesions may show low signal intensity on T1- and T2-weighted images and may not show any enhancement. These lesions usually exhibit reduced signal intensity on in-phase T1-weighted GRE images compared with that on opposed-phase images owing to the presence of iron (the opposite of fat on chemical shift images) (Fig 17) (28).



15.

16.

Figures 15, 16. (15) Coronal T2-weighted half-Fourier RARE image of a patient with sickle cell disease shows decreased signal intensity of the spleen. This appearance is due to repeated blood transfusion. (16) Axial contrast-enhanced T1-weighted GRE image of a patient with sickle cell disease shows a very small spleen, which is indicative of autosplenectomy.



a.

b.

Figure 17. Axial in-phase (a) and out-of-phase (b) images show a splenic area of extramedullary hematopoiesis (arrow). The lesion has reduced signal intensity on the in-phase image (a) compared with that on the out-of-phase image (b). This difference is secondary to iron deposition.

Benign Neoplasms or Cysts

Splenic Cyst

True (or primary) splenic cysts are epithelial cell lined, as opposed to pseudocysts. True cysts include epidermoid and parasitic cysts. Their MR imaging characteristics follow those of cysts in other organs of the body, with lack of tissue archi-

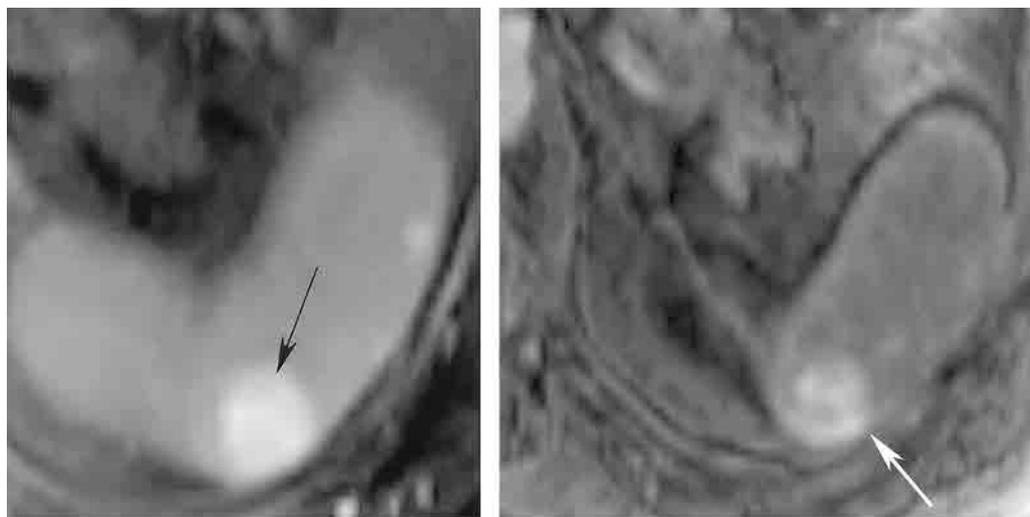
tecture and high water content. These lesions demonstrate longer T1 and T2 relative to normal splenic tissue. There is no enhancement following administration of gadolinium contrast material (Fig 18). MR imaging is useful when ultrasound and CT results are equivocal (29,30).



a.

b.

Figure 18. Axial contrast-enhanced T1-weighted 3D VIBE (a) and T2-weighted half-Fourier RARE (b) images show the typical features of a splenic cyst (arrow).



a.

b.

Figure 19. Axial T2-weighted fast spin-echo (a) and contrast-enhanced 3D VIBE (b) images show the typical MR imaging features of a splenic hemangioma (arrow).

Hemangioma

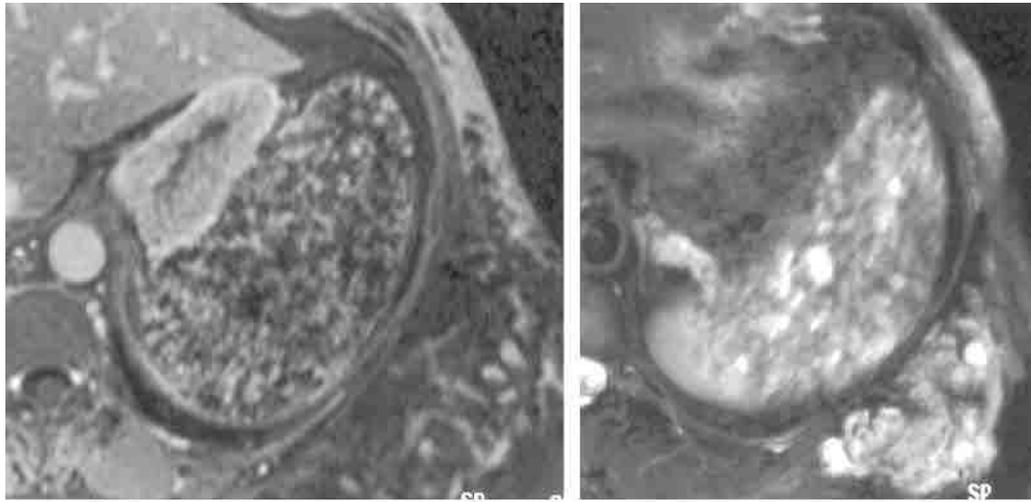
Hemangioma is the most common primary benign neoplasm of the spleen and is composed of endothelium-lined vascular channels filled with blood. Most hemangiomas are hypointense to the spleen on T1-weighted images and hyperintense on T2-weighted images. After contrast material administration, they demonstrate early nodular centripetal enhancement and uniform enhancement at delayed imaging (Fig 19) (31–33).

Diffuse hemangiomatosis of the spleen is a rare benign vascular condition occurring as a manifestation of systemic angiomatosis (associations with Klippel-Trénaunay-Weber, Turner, Kasabach-Merritt-like, and Beckwith-Wiedemann syn-

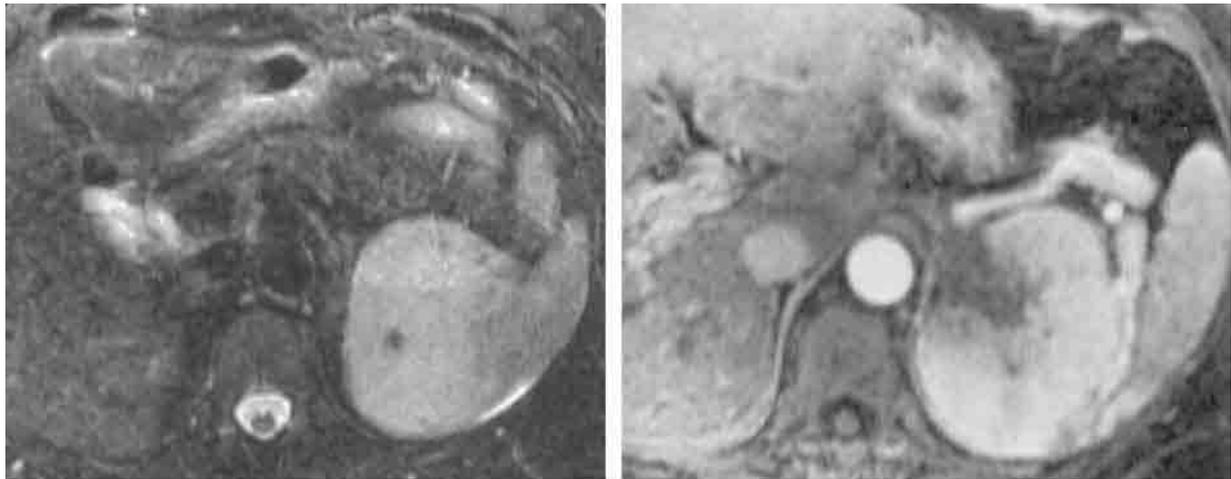
dromes have been reported) (Fig 20) or, less commonly, confined to the spleen. It is sometimes accompanied by severe disturbance of blood coagulation (34,35).

Hamartoma

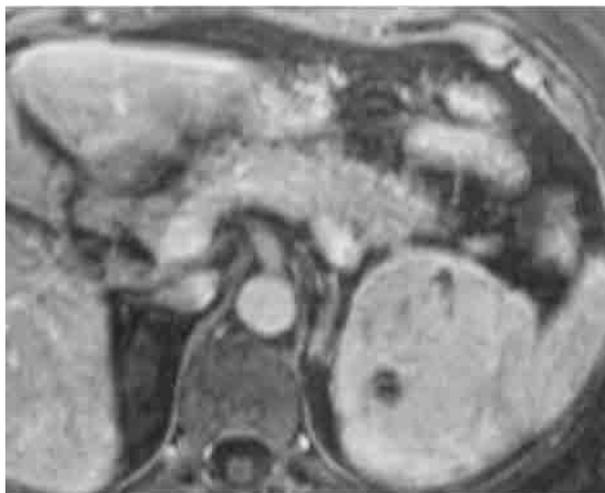
Hamartomas are benign asymptomatic lesions, usually single, composed of a mixture of normal splenic structures such as white and red pulp. These lesions are commonly associated with tuberous sclerosis. Most splenic hamartomas are heterogeneously hyperintense relative to the spleen on T2-weighted images and demonstrate diffuse enhancement on early postcontrast images and more uniform enhancement on delayed images (Fig 21) (31,36,37).



a. **b.**
Figure 20. Axial contrast-enhanced 3D VIBE (**a**) and T2-weighted (**b**) images of a patient with Klippel-Trénaunay-Weber syndrome show diffuse angiomatosis of the spleen and chest wall.



a. **b.**
Figure 21. Axial T2-weighted inversion-recovery (**a**), early contrast-enhanced 3D VIBE (**b**), and late contrast-enhanced 3D VIBE (**c**) images show a splenic lesion with high signal intensity on the T2-weighted image (**a**), low signal intensity on the T1-weighted image (**b**), and more uniform enhancement on the delayed image (**c**). The lesion represents a splenic hamartoma.



c.



a.

b.

Figure 22. Coronal contrast-enhanced 3D VIBE (a) and T2-weighted half-Fourier RARE (b) images show a splenic mass with low signal intensity on the T1-weighted image (a), high signal intensity on the T2-weighted image (b), and heterogeneous enhancement. The mass represents a splenic angiosarcoma.



Figure 23. Axial contrast-enhanced 3D GRE VIBE image shows multifocal involvement of the spleen by multiple hypointense lymphomatous lesions.

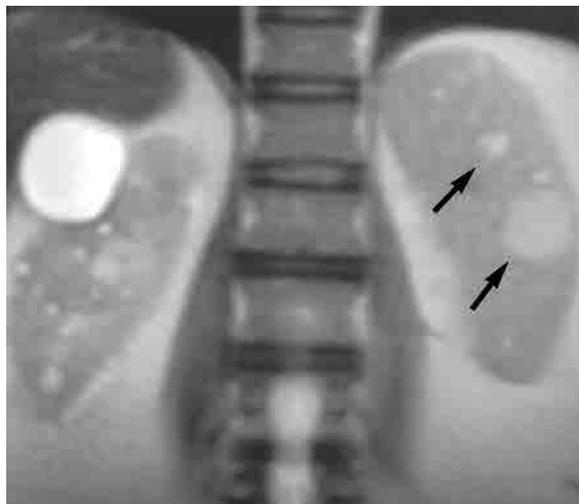


Figure 24. Coronal T2-weighted half-Fourier RARE image of a patient who underwent left nephrectomy for renal cell carcinoma shows hyperintense splenic metastases (arrows).

Malignant Neoplasms

Sarcoma

Primary splenic angiosarcomas are extremely rare tumors with a very poor prognosis. These tumors are highly aggressive and manifest with wide-

spread metastatic disease or splenic rupture. At MR imaging, the spleen is noted to have low signal intensity on T1-weighted images and heterogeneous high signal intensity on T2-weighted images. With the administration of gadolinium contrast material, the lesion demonstrates heterogeneous enhancement with multiple hyperintense nodular foci and hypointense regions (Fig 22). Of



a. **Figure 25.** Axial contrast-enhanced VIBE (**a**) and coronal T2-weighted half-Fourier RARE (**b**) images show hepatosplenomegaly secondary to portal hypertension. Note the diffuse enhancement of the splenic parenchyma in **a** and the collateral veins at the hilum (arrows in **a**).

the many imaging methods, MR imaging seems to be more precise in the overall assessment and staging of this type of tumor and is of particular value for timely diagnosis of this rapidly fatal disease (38–41).

Lymphoma

Lymphoma is the commonest malignant tumor of the spleen. It is important to detect splenic involvement because it can alter the management. Lymphomatous deposits have T1 and T2 similar to those of normal splenic parenchyma. Gadolinium-enhanced sequences are more sensitive for the evaluation of splenic lymphoma. Diffuse involvement may be seen as large irregularly enhancing regions. Multifocal disease is also common and can be seen as multiple focal lesions that are hypointense relative to the uniformly or arciform enhancing spleen (Fig 23) (1,2,30,42).

Metastases

Splenic metastases are relatively uncommon. Although splenic metastases usually occur in widespread disseminated malignancies, isolated splenic metastases have also been recognized. At MR imaging, metastases typically appear as hyperintense masses on T2-weighted images (Fig 24) and hypo- to isointense masses on T1-

weighted images. The degree and characteristics of enhancement depend on the nature and type of the underlying primary neoplasm (43–45).

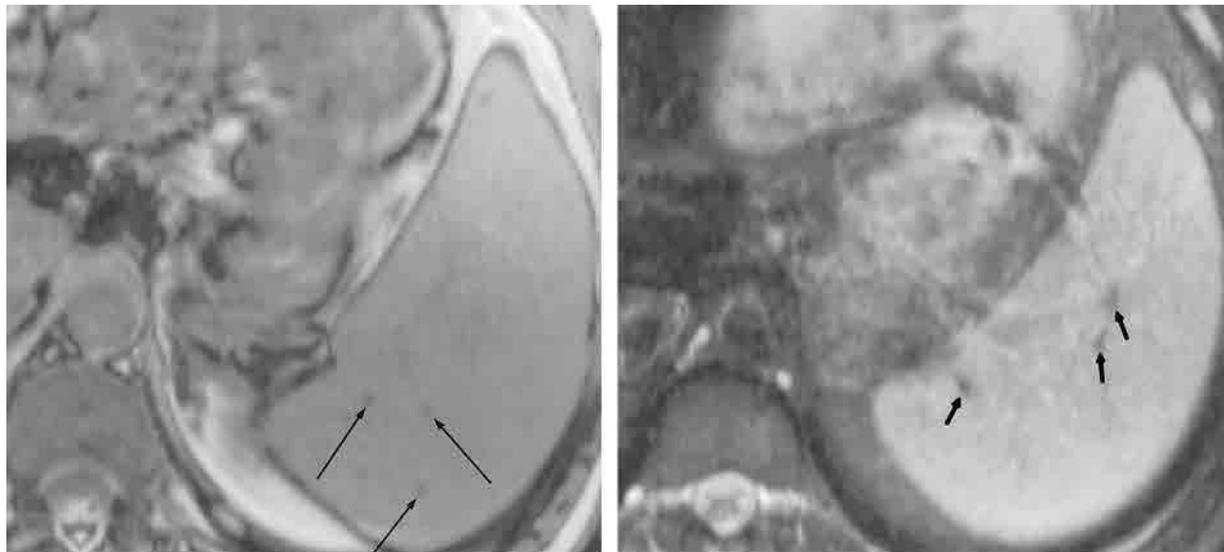
Diffuse Enlargement (Splénomegaly)

Splenic enlargement can be caused by various diseases such as lymphoma, malaria, leukemia, portal hypertension, and metabolic diseases (eg, Gaucher disease).

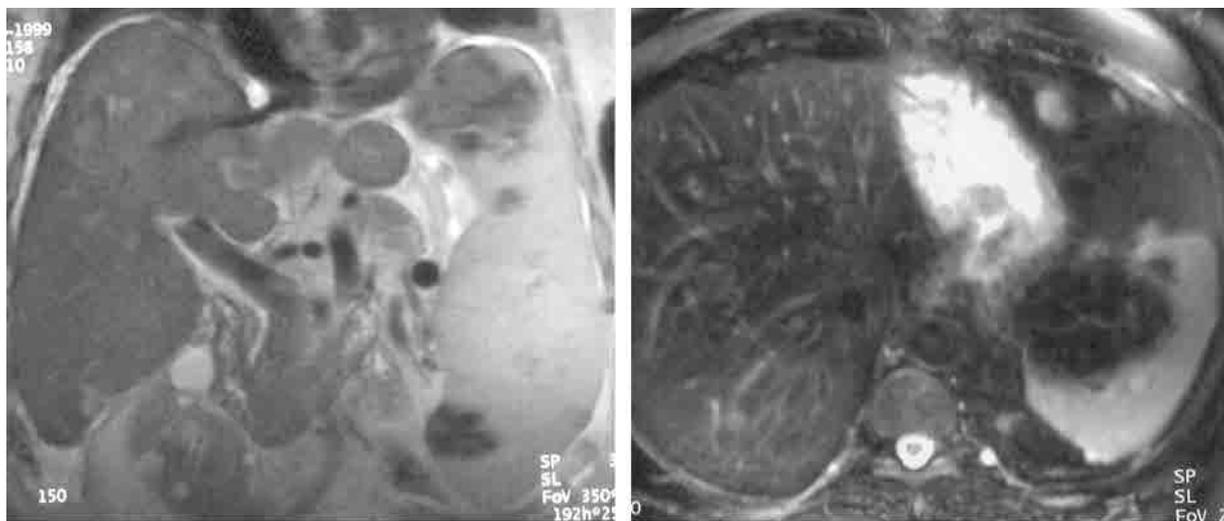
Portal Hypertension

Portal hypertension is considered the most common cause of splenomégaly in the United States. With splenomégaly secondary to portal hypertension, MR imaging often reveals associated signs of hepatic cirrhosis with or without change in the liver size depending on the stage of hypertension. On images obtained immediately after contrast material administration, uniform enhancement is usually seen. Dilated collateral veins may also be demonstrated at the splenic hilum (Fig 25) (46–48).

Foci of hemosiderin deposition are seen in about 9%–12% of patients with portal hypertension. These foci are called *Gamma-Gandy bodies*.



a. **b.**
Figure 26. Axial out-of-phase T1-weighted GRE (a) and T2-weighted inversion-recovery (b) images show multiple tiny hypointense foci in the spleen that represent Gamna-Gandy nodules (arrows).



a. **b.** **c.**
Figure 27. Coronal T2-weighted half-Fourier RARE (a), axial T2-weighted inversion-recovery (b), and axial contrast-enhanced 3D VIBE (c) images show splenomegaly with Gaucher lesions, which are hypointense on both T1- and T2-weighted images.



c.

MR imaging usually demonstrates these foci as multiple tiny foci of decreased signal intensity with all pulse sequences, secondary to iron deposition (Fig 26) (49,50).

Gaucher Disease

Gaucher disease is an autosomal recessive lysosomal disorder secondary to lack of the enzyme glucocerebrosidase, leading to accumulation of glucocerebrosides in the cells of the reticuloendothelial system and causing hepatosplenomegaly (Fig 27). On T1-weighted images, signal intensity is low relative to the normal spleen secondary to glucocerebroside; on T2-weighted images, signal intensity is intermediate except for nodal clusters of Gaucher cells, which appear hypointense on T2-weighted images and isointense to the spleen on T1-weighted images. Splenic infarcts and fibrosis associated with Gaucher disease may exhibit a multifocal pattern (51).

Conclusion

MR imaging is an excellent imaging tool for diagnosis, evaluation, and characterization of various focal splenic lesions and pathologic conditions.

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