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Focal splenic lesions: imaging spectrum of diseases on CT, MRI and PET/CT

Short title: Imaging spectrum of focal splenic lesions

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Abstract

The spleen can be affected by a variety of diseases. Some of them are readily identified as variations of normal or benign diseases on imaging. However, for a substantial number of focal splenic abnormalities, the diagnosis can be difficult so that histopathologic analysis may be required for a definite diagnosis. In this review, the typical splenic abnormalities that can be diagnosed with imaging with a high degree of confidence are illustrated and the complementary role of computed tomography (CT), magnetic resonance imaging and positron emission tomography/CT that help make a diagnostic approach are discussed. Finally, current applications and future trends of radiomics and artificial intelligence for the diagnosis of splenic diseases are addressed.

Index terms:

1. Positron-emission tomography;
2. Tomography, X-ray computed;
3. Magnetic resonance imaging;
4. Splenic diseases;
5. Biopsy

Abbreviations

^{18}F -FDG: ^{18}F -Fluorodeoxyglucose;

ADC: Apparent diffusion coefficient;t

CT: Computed tomography;

DW: Diffusion-weighted;

GBCA: Gadolinium-based contrast agent;

HU: Hounsfield unit;

MRI: Magnetic resonance imaging;

NPV: Negative predictive value;

PET: Positron emission tomography;

PPV: Positive predictive value;

SANT: Sclerosing angiomatoid nodular transformation;

SUV: Standardized uptake value

1. Introduction

The spleen is a lymphatic organ with a mesodermal origin, located under the left hemidiaphragm [1]. The spleen can be affected by a variety of diseases. Some of them are readily identified as variations of normal or benign diseases on imaging [2,3]. However, for a substantial number of focal splenic abnormalities, the actual diagnosis can be difficult so that histopathological analysis be required for a definite diagnosis [4,5].

In this review, we illustrate typical splenic abnormalities that can be diagnosed with imaging with a high degree of confidence and discuss the complementary role of computed tomography (CT), magnetic resonance imaging and positron emission tomography/CT that help make a diagnostic approach.

2. Anatomy

The spleen is an intraperitoneal, encapsulated organ, located in the left upper quadrant, which is attached to the retroperitoneum by gastrosplenic and splenorenal ligaments [1]. Two splenic surfaces are individualized, relative to their locations. The diaphragmatic surface is directly adjacent to the inferior aspect of the left hemidiaphragm and is usually difficult to investigate with imaging. The visceral surface is more favorable to imaging assessment. Microscopically, the spleen is made of two compartments. One is the white pulp containing lymphocytes and centrally located, whereas the other is the red pulp containing tortuous venous sinuses, with a more peripheral location [6]. This specific arrangement has some clinical implications because it is commonly admitted that vascular splenic tumors predominantly develop from the red pulp, whereas, lymphoid tumors predominantly develop from the white pulp [7]. In addition, this arrangement may be responsible for an early heterogeneous enhancement on imaging after intravenous administration of contrast material (**Figure 1**) [8].

Splenic volume may vary among patients and marked variations may be observed in the absence of underlying disease. However, variations may be secondary to an underlying disease. In this regard, patients with celiac disease or adult patients with sickle cell disease

have small spleens [9,10] whereas patients with liver cirrhosis or sinusoidal obstruction syndrome have enlarged spleen secondary to portal hypertension [11].

3. Imaging techniques

3.1. Ultrasound

Ultrasound is a simple imaging technique to provide a first line assessment of the spleen. On ultrasound, the spleen is a homogeneous organ, with a texture similar to that of the liver. Ultrasound is highly specific for the diagnosis of splenic cyst. However, ultrasound has limited specificity for focal splenic lesion characterization and additional imaging test are often needed, when ultrasound shows equivocal findings. Hence, in general, a firm diagnosis of focal splenic lesion is rarely achieved with ultrasound alone [12]. Contrast-enhanced ultrasound is more specific as hypovascularity suggests malignant splenic lesions, while hypervascularity is associated with benign ones [13,14,15].

3.2. CT

CT is commonly used for the evaluation of splenic focal lesions. On CT, the spleen is homogeneous before intravenous administration of contrast material, with median attenuation values of 55 Hounsfield units (HU) [16]. The spleen displays an early and mottled enhancement due to a different flow rate of the red pulp compared to the white pulp. The spleen becomes homogeneous on late and delayed phases of enhancement after intravenous administration of iodinated contrast material. It is recommended to obtain several imaging passes, including unenhanced, arterial (40 s), venous (70 s), late (3 min) and delayed (5 min) phases for optimal lesion characterization [2]. Using multiphase CT, Jang et al. found that 91% (10/11) of malignant focal splenic lesions are hypoattenuating on all imaging phases [17]. On the opposite, hypervascularity on arterial phase is observed only in benign focal splenic lesions [18]. Using unenhanced CT images, the diagnosis of splenic cyst can be made confidently when a focal splenic lesion is homogeneous with internal content attenuation values of 0-20 HU [19].

3.3. MRI

On MRI, splenic parenchyma is hypointense on T1- and hyperintense on T2-weighted images. Enhancement patterns are similar to those observed on CT. Splenic peak enhancement varies as a linear function of the dose of intravenous gadolinium-based contrast agent (GBCA) [20]. Similar to CT, several imaging passes after intravenous administration of a GBCA is needed. In addition, MRI owing to the use of different sequence types help better characterize the internal content of focal splenic lesions. Using MRI, the diagnosis of splenic cyst can be made confidently when a focal splenic lesion is homogeneous with hyperintense internal content similar to that of the cerebrospinal fluid on T2-weighted images [21]. Splenic parenchyma has a spontaneous restricted diffusion, potentially leading to an underestimation of splenic lesions on diffusion-weighted (DW) MRI. DW-MRI is also of value for lesion characterization [17]. The mean apparent diffusion coefficient (ADC) of malignant splenic lesions ($0.73 \times 10^{-3} \text{ mm}^2/\text{s}$) is lower than that of benign ones ($1.21 \times 10^{-3} \text{ mm}^2/\text{s}$) ($P < 0.001$) [17]. Whole-body-DW-MRI- has been reported as an accurate tool to also evaluate splenic involvement in lymphoma when compared with FDG-PET/CT, allowing one to detect the splenic location of disease with sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of 85.7%, 96.5%, 85.7%, and 96.5%, respectively [22].

3.4. PET/CT

^{18}F -Fluorodeoxyglucose (^{18}F -FDG)-positron emission tomography (PET)/CT is a noninvasive imaging modality that allows metabolic assessment of focal splenic lesions [23]. Benign splenic lesions such as hemangiomas or hamartomas do not show ^{18}F -FDG uptake. ^{18}F -FDG PET/CT has a high NPV for the diagnosis of malignant solid focal splenic lesions discovered on ultrasound, CT or MRI [23]. The sensitivity, specificity, PPV, and NPV of ^{18}F -FDG PET/CT in differentiating benign from malignant solid focal splenic lesions in patients with and without malignant disease are 100%, 100%, 100%, and 100% vs. 100%, 83%, 80%, and 100%, respectively. In patients with known cancer, a standardized uptake value (SUV) threshold value of 2.3 allows discriminating benign from malignant focal splenic lesions with sensitivity, specificity, PPV, and NPV of 100%. In patients without known cancer, false-positive findings are due to benign conditions such as granulomatous diseases [24].

3.5. Radiomics

Recent radiomics techniques, such as texture analysis, have demonstrated great potential for the characterization of focal lesions in a variety of organs [25]. Texture analysis consists in the extraction of a large amount of quantitative data from original images, that can be further used to identify specific features and determine the actual nature of given lesion [25]. However, its application to the spleen is still limited to the identification of lymphomatous involvement of the spleen [26].

4. Variations that may simulate disease

The spleen can be subjected to normal variants and congenital abnormalities. The most frequent one is accessory spleen (or splenules) that has an estimated prevalence of 10% [27]. In general, accessory spleen manifests as a single or multiple nodules that have attenuation or signal and patterns of enhancement similar to those of the spleen. Their identification is relatively straightforward on imaging, although they may simulate malignant peritoneal nodules in patients with suspected peritoneal carcinomatosis (**Figure 2**). The absence of an orthotopic spleen on imaging may suggest the diagnosis of accessory spleen, but this condition may affect patients without prior splenectomy or splenic trauma, making differentiation more challenging [28]. Accessory spleen presents as rounded homogeneous peritoneal-based soft tissue nodule with homogeneous enhancement, whereas peritoneal carcinomatosis nodules are often less homogeneous (**Figure 2**) [28]. Rarely, accessory spleens can be located in the liver or the pancreas and pose a diagnostic challenge. The unique low apparent diffusion coefficient (ADC) along with characteristic enhancement patterns allows a confident diagnosis (**Figure 3**) [28, 29].

5. Benign focal splenic lesions

5.1. Splenic cysts

Splenic cyst is the most frequent benign focal splenic lesion [30]. Most of splenic cysts are true cysts (*i.e.*, epidermoid cysts with squamous epithelial cyst lining) [30] and have typical fluid appearance on imaging. On ultrasound, they are well-defined and hypoechogenic intrasplenic masses. Low-level echoes can be observed, due to deposition of cholesterol crystals [31]. On CT, they are homogeneous with attenuation values similar to that of water or

slightly higher, ranging between 0 and 20 HU [19]. MRI may be useful when ultrasound and CT findings are equivocal. Splenic cyst is hypointense on T1- and markedly hyperintense on T2-weighted MR images by comparison with the adjacent splenic parenchyma, without perceptible enhancement on contrast-enhanced images (**Figure 4**). Rarely, they can be pseudocysts, secondary to trauma or acute pancreatitis, with a more heterogeneous content. Pseudocysts are rarely intrasplenic and mostly adjacent to the spleen [32].

5.2. Infectious diseases

Splenic pyogenic abscesses are predominantly due to hematogenous spread of infection [2,3]. They can be solitary, multiple, or multilocular. On ultrasound they are poorly defined, hypoechogenic and may contain internal septations [2,3]. On CT, they are hypoattenuating, with no or moderate enhancement and can be encapsulated, with a peripheral enhancing rim [2,3]. On MRI, they are hypointense on T1-weighted images and hyperintense on T2-weighted images, with peripheral enhancing rim when they are encapsulated [2,3]. On ^{18}F -FDG PET/CT, splenic abscess shows increased uptake of ^{18}F -FDG [23], probably due to the presence of activated leukocytes and locally increased cytokines and growth factors content [33].

In immunocompromised patients, splenic candidiasis presents as small (< 10 mm), multiple, rounded, focal splenic lesions. They are hypoechogenic on ultrasound, hypo enhancing on CT and MRI. They are best visible T2-weighted images as hyperintense foci and on contrast-enhanced MRI [34, 35]. Splenic candidiasis is most often associated with hepatic candidiasis, so that splenic lesions are associated with intrahepatic lesions that display similar pattern on imaging. MRI may suggest the diagnosis when the so-called bull-eye sign is present [36,37].

Splenic hydatid disease is due to the larval form of *Echinococcus granulosus*. Splenic involvement occurs in less than 2% of all patients with hydatid disease and are rarely isolated but observed in association with other locations [38]. Hydatid cysts are usually homogeneous with internal fluid content showing attenuation values similar to those of water. Internal calcification or hyperattenuating foci on CT are due to intracystic debris, hydatid sand, or inflammation. Presence of collapsed membranes within the cyst (*i.e.*, “water lily” sign) is virtually pathognomonic for hydatid disease [39].

5.3. Splenic hemangioma

Hemangioma is the second most common focal splenic lesion and the most common benign splenic tumor [40]. On imaging, most of splenic hemangiomas are < 2 cm in diameter, well-defined and homogeneous. On ultrasound, it is slightly echogenic or hyper echogenic and hypo- or isoattenuating on unenhanced CT [1,2] and may contain punctate or curvilinear peripheral calcification [40]. On MRI, it is hypo or isointense on T1-weighted images, and most commonly hyperintense on T2-weighted images by comparison with adjacent splenic parenchyma [1,2]. On contrast-enhanced CT or MRI, they rarely display peripheral, centripetal and progressive enhancement similar to that of hepatic hemangiomas [1,2]. On delayed MR images, they are generally hyperintense relative to splenic parenchyma [40]. By contrast with hepatic hemangioma, splenic hemangioma usually present with peripheral rim of enhancement with irregular margins without nodular and mottled enhancement (**Figure 5**). Splenic hemangiomas may develop secondary changes and may contain hemorrhage, necrosis, micro-thrombosis and fibrosis manifesting as hypo-enhancing areas [40]. In such situations, the diagnosis with imaging made more difficult. The diagnosis may be difficult to ascertain in patients with a known cancer, because splenic metastases may display very similar features. In this setting, ¹⁸F-FDG PET/CT may be of value as splenic hemangioma does not show uptake of ¹⁸F-FDG (**Figure 5**) [23].

5.4. Littoral cell angioma

Littoral cell angioma is a rare vascular tumor arising from lining (*i.e.*, littoral) cells of splenic red pulp sinuses [41]. This benign lesion is composed of anastomosing vascular channels arranged in cyst-like spaces and lined by tall endothelial cells. However, studies have reported malignant littoral cell angiomias [41]. Littoral cell angioma usually presents as multiple splenic lesions of varying sizes. It is spontaneously isoattenuating on CT, becomes hypoattenuating during the portal phase of enhancement and later isoattenuating relative to adjacent splenic parenchyma [42]. On MRI, littoral cell angioma is hypointense on unenhanced T1- and hyperintense on T2-weighted images, similar to hemangioma. One suggestive feature is the presence of hypointense foci corresponding to hemosiderin accumulation, which are more visible on T2*-weighted images. After contrast material administration, littoral cell angioma displays delayed enhancement with pooling of contrast material [43].

5.5. *Splenic lymphangioma*

Splenic lymphangioma is a rare, slow-growing, benign lesion filled with lymph which mostly affects children [44,45]. In adults, it is usually an asymptomatic, subcapsular lesion that is incidentally identified on imaging.

On ultrasound it presents as a hypoechogenic, cystic lesion. On CT, it is a well-defined, hypoattenuating lesion with few enhancing septa and rarely peripheral calcification [46]. On MRI, splenic lymphangioma usually presents as a well-defined, multilocular cystic lesion with thin septa. It is homogenous and hypointense on T1-weighted images. On T2-weighted images, it is hyperintense when internal hemorrhagic or proteinaceous material is present [47]. Hyperintensity on T1-weighted images can be observed, due to the presence of proteinaceous or hemorrhagic content.

5.6. *Hamartoma*

Splenic hamartoma is a rare, usually asymptomatic, benign lesion, with a prevalence of 0.13% in autopsy series, with a mean diameter of 5 cm (range: 3 mm to 20 cm) [48,49]. It is made of an association of malformed splenic red pulp elements without organized lymphoid follicles [50,51].

On ultrasound, splenic hamartoma usually presents as a well-circumscribed, homogeneous, solid lesion and predominantly hypoechogenic in 67% [52,53,54]. Contrast-enhanced ultrasound reveals increased blood flow [54]. On CT splenic hamartoma presents as an isoattenuating (23%) or hypoattenuating (77%) lesion on unenhanced CT and isointense on T1- and heterogeneously hyperintense on T2-weighted images (**Figure 6**) [48,55,56]. Of note, hyperintensity on T2-weighted images is inferior to that observed in hemangiomas [1,2]. After intravenous administration of contrast material, internal enhancement is observed in 81% of splenic hamartomas, with a “spleen in the spleen” appearance (*i.e.*, heterogeneous enhancement during the arterial phase that becomes homogeneous during portal and late phases), which is a suggestive feature [52]. Small hamartomas display diffuse early enhancement and homogeneous delayed enhancement similar to adjacent splenic parenchyma [55]. Larger lesions may display heterogeneous enhancement with homogeneous and prolonged uptake of contrast material.

Although imaging findings may suggest splenic hamartoma, the diagnosis is often difficult. In addition, tissue samples obtained from percutaneous biopsy are often not specific so that splenectomy may be needed to ascertain the diagnosis [57].

5.7. Angiomyolipoma

Splenic angiomyolipoma is exceedingly rare and usually associated with renal angiomyolipoma or is observed in patients with tuberous sclerosis [52,58,59].

On ultrasound, splenic angiomyolipoma usually presents as a heterogeneously echogenic lesion [1,2]. On CT, angiomyolipoma is markedly hypoattenuating due to fat content and can display areas of marked enhancement [1,2]. Presence of renal angiomyolipoma is of high diagnostic value for suggesting splenic angiomyolipoma in patients with focal splenic lesion. Splenic angioliipoma may rupture resulting in a chronic intrasplenic bleeding and intrasplenic hematoma [60].

5.7. Inflammatory pseudotumor

Inflammatory pseudotumor of the spleen is a rare, benign, well-circumscribed mass, usually solitary, composed of foci of inflammatory cells, mainly plasma cells, and lymphocytes in a fibroblastic stroma [61]. On CT, inflammatory pseudotumor presents as a well-defined, hypoattenuating mass on unenhanced CT that displays delayed, partial, hypervascular enhancement after intravenous administration of iodinated contrast material [18,62,63]. On MRI, inflammatory pseudo tumor shows moderate hypersignal with partial enhancement and peripheral hypointense rim on T2-weighted images. It displays a capsule-like rim of enhancement after intravenous administration of GBCA [61,62,63]. On 18F-FDG PET/CT, inflammatory pseudotumor shows high uptake of 18F-FDG [61]. However, the diagnosis on imaging alone is challenging, because inflammatory pseudotumor may resemble splenic angiosarcoma [61].

5.8. Inflammatory pseudotumor-like follicular dendritic cell tumor

Inflammatory pseudotumor-like follicular dendritic cell tumor is an uncommon, Epstein-Barr virus-associated neoplasm of the spleen, with a low malignant potential [64,65]. This neoplasm is characterized by spindly tumor cells dispersed in a background of small

lymphocytes and plasma cells. It is an exceedingly rare distinctive clinicopathologic variant of the follicular dendritic cell tumor [64,65].

Ultrasound reveals a bulging, heterogeneous, focal splenic lesion. CT shows calcification on unenhanced images and progressive enhancement from arterial to delayed phase [64]. On MRI, the lesion is heterogeneous and hypointense relative to splenic parenchyma on T1- and T2-weighted images with varying degrees of heterogeneity and progressive enhancement (**Figure 7**) [64]. It is assumed that portions that display late enhancement correspond to fibrotic component [64]. ¹⁸F-FDG PET/CT shows uptake of 18F-FDG with maximum standard uptake value of 8.5 in one study [64].

5.9. Sclerosing angiomatoid nodular transformation (SANT) of the spleen

Sclerosing angiomatoid nodular transformation (SANT) is an extremely rare benign vascular splenic tumor of unknown etiology that contains a rich fibrosclerotic stroma [66, 67]. SANT almost equally affects men and women (50–55.7%) with a mean age of 42 years (range: 23–59 years) and found incidentally by imaging in 51-94% of patients [66, 67]. Although a few patients with multiple SANTs have been reported, SANT is a single lesion in 95% of patients [66]. Histopathologically, SANT contains round-shaped vascular spaces lined by endothelial cells. The spaces are further circumscribed by bands of fibrous tissue that join to form a central stellate fibrous scar [68].

On imaging, SANT is a well circumscribed solid lesion, with a mean diameter of 5.7 ± 1.8 (standard deviation) cm (range: 3.5–10.3 cm). On unenhanced CT, a central splenic, hypoattenuating lesion is observed in 88% of SANTS. Internal calcification can be observed in 25% of SANTs (**Figure 8**) [66]. On MRI, SANT presents as a heterogeneous splenic lesion with central scattered hyperintense signal on fat-suppressed T1-weighted images due to hemorrhage and hemosiderin deposits [66]. On T2-weighted images, 88% of SANT display central hypointensity in relation with fibrous content [66]. Hyperintense radiating areas toward the center of the lesion, corresponding to fibrous scars at pathological analysis, are visible in 100% of SANTS (**Figure 8**) [66]. On DW-MRI, SANT is hypointense relative to splenic parenchyma [66]. Liao et al. have showed that SANT is subject to decrease in signal intensity between in- and out-of-phase T1-weighted MR images in 100% of lesions due to the presence of hemosiderin deposition [66]. However, hemosiderin deposition can be found also

in littoral cell angioma and angiosarcoma, so that the discriminating capability of this finding should warrant further investigation.

On contrast-enhanced CT and MRI, SANT shows peripheral enhancement with progressive central filling-in in a radiating fashion on late phase images, displaying the “spoke-wheel pattern” in 78% of lesions. The spoke-wheel pattern on MRI correlates with a fibrosclerotic central scar with spoke-shaped fibrous strands on pathological analysis [68, 69].

Because imaging features are not always typical and also because large SANT may resemble splenic angiosarcoma or lymphoma, SANT is usually resected during splenectomy [69]

5.10. Splenic sarcoidosis

Approximately 6% to 33% of patients with sarcoidosis have splenic involvement visible on imaging, but the prevalence of splenic involvement ranges between 24–59% when histopathological analysis is considered and reaches up to 38–77% in autopsy series [70]. Homogeneously enlarged spleen is the most common manifestation of splenic involvement in sarcoidosis, being present in approximately 40% of patients [70,71]. Focal splenic lesion is an uncommon presentation but the most challenging one.

Focal splenic sarcoidosis lesions are often multiple, with diameters ranging from 1mm to 30 mm. They are rarely visible on ultrasound, but when visible, they are more frequently slightly hyperechogenic [70,71]. On CT, they are typically hypoattenuating on unenhanced CT and up to 16% of them may contain punctate calcifications. On contrast-enhanced CT, splenic nodules are hypoattenuating relative to adjacent splenic parenchyma, without peripheral enhancement. They are hypointense on MRI, with minimal and delayed enhancement [71]. The lesions are better seen on T2-weighted fat-suppressed or early phase contrast-enhanced images [3]. The nodular pattern mimics that of lymphoma or metastatic disease to the spleen. On ^{18}F -FDG PET/CT, active sarcoidosis splenic lesion shows moderate uptake of ^{18}F -FDG.

5.11. Extramedullary hematopoiesis

Extramedullary hematopoiesis is observed in patients with deficient bone marrow cells. In patients with acquired marrow replacement disorders such as myeloproliferative diseases, bone marrow is nonfunctional and extramedullary hematopoiesis can develop in the

liver, lymph nodes and spleen [1]. The more frequent presentation of splenic extramedullary hematopoiesis on imaging is a diffuse infiltration, whereas focal splenic mass is less frequent.

On ultrasound, splenic focal extramedullary hematopoiesis presents as a hyperechogenic mass, with mild vascularization on color Doppler ultrasound [72]. On CT, focal extramedullary hematopoiesis is spontaneously hypoattenuating with moderate, heterogeneous enhancement after intravenous administration of contrast material [71]. On MRI, the lesion is hypo or isointense intense relative to splenic parenchyma on T1-weighted images, hyperintense on T2-weighted images, and displays heterogeneous enhancement after intravenous administration of GBCA [72,73].

6. Malignant focal splenic lesions

6.1. Angiosarcoma

Splenic angiosarcoma is the most common primary non hematopoietic tumor of the spleen [2, 74]. It is a highly aggressive tumor that conveys poor prognosis, with approximately 80% of patients dying 6 months after the initial diagnosis [74]. Clinically, patients with angiosarcoma may present with left upper quadrant abdominal pain, anemia, coagulopathy, or spontaneous splenic rupture in one fourth of patients. Hematogenous metastases at the time of diagnosis are common, and mostly found in the liver [23].

On imaging, splenic angiosarcoma presents as an aggressive splenic mass or masses with associated splenomegaly [3, 75, 76, 77]. On ultrasound, splenic angiosarcoma presents as multiple, complex heterogeneous and echogenic masses involving the spleen, which is often enlarged [2, 78]. On CT, splenic angiosarcoma is heterogeneous, with spontaneously hyperattenuating foci representing acute hemorrhage or hemosiderin deposits [79]. Rarely, calcifications can be observed on plain CT [35, 80]. After intravenous administration of iodinated contrast material splenic angiosarcoma usually presents as multiple, hypervascular splenic masses [79]. Enhancement is variable depending on the degree of internal necrosis [75]. On MRI, angiosarcoma typically appears as multiple, nodular, heterogeneous masses, with variable signal intensity on T1- and T2-weighted images, due to the presence of hemorrhage with different ages, siderotic nodules, and areas of necrosis [75, 78, 79]. After intravenous administration of GBCA, angiosarcoma displays heterogeneous enhancement with multiple, hyperenhancing nodules and hypointense areas [3, 35, 63, 75, 79, 80]. On DW-MRI, angiosarcoma shows low ADC values, consistent with malignant lesion [81].

6.2. *Lymphoma*

Lymphoma is the most common splenic malignancy with secondary involvement representing 99% of all splenic lymphomatous lesions [35]. Splenic involvement in lymphoma predominantly presents as homogeneous splenic enlargement [11], whereas, focal splenic lesions is a less frequent presentation [77,82]. In general, imaging shows associated enlarged lymph nodes in the retroperitoneum or mesentery, which are highly suggestive findings for the diagnosis of splenic involvement [83].

Lymphomatous nodules are hypoattenuating on contrast-enhanced CT (**Figure 9**) [63]. They are mostly isointense on T1- and T2-weighted images, and usually hypovascular and hypointense relative to normal spleen on contrast-enhanced images [77,82]. Although ^{18}F -FDG-PET/CT is more accurate than CT for the diagnosis of splenic involvement by lymphoma, no studies have compared ^{18}F -FDG-PET/CT to MRI so far [84].

Because patients with lymphoma may have an immunocompromised status, they may have intrasplenic abscess, which is a differential diagnosis of secondary lymphoma.

6.3. *Splenic metastasis*

The spleen is a rare site of metastatic disease, as only 7% of patients with advanced cancers have splenic metastases [3,76]. Melanoma and breast cancer are the two most frequent primaries that give splenic metastases, followed by lung cancer and ovarian cancer [82,85]. Splenic metastasis represents the most challenging situation. Due to the variety of primary tumors that can give splenic metastases, the imaging presentation of splenic metastases may greatly vary, depending on the characteristics of the primary tumor but also on the specific treatment given to the patient.

Splenic metastases can be solitary, well-defined or may have a more infiltrative pattern, with variable size. They are usually hypoechogenic on ultrasound, hypoattenuating on CT and hypo- or isointense on T1- and hyperintense of T2-weighted images. They show heterogeneous enhancement, with possibly a peripheral rim. The presence of internal paramagnetic content due to melanin or fresh blood may result in hyperintensity on T1-weighted images and foci with marked hypointensity on T2*-weighted images and suggest melanoma [84]. On ^{18}F -FDG PET/CT, splenic metastases show significant uptake of ^{18}F -FDG [23,86, 87].

In patients with peritoneal carcinomatosis or pseudomyxoma, the spleen can be affected by malignant deposit (**Figure 10**) [88,89]. CT and MRI are especially useful for making the appropriate diagnosis of peripheral involvement, but also to identify intraparenchymal metastases [88].

7. Future trends in splenic imaging

Radiomics and artificial intelligence have been successfully applied to a variety of intraabdominal organs [90, 91, 92, 93]. However their applications in the field of splenic disease have received little attention to date, and mostly restricted to splenic segmentation [94, 95, 96, 97]. Humpire-Mamani et al. have developed a fully automated algorithm for spleen segmentation using CT data, yielding Dice similarity index of 96.2% [94]. Huo et al. used a multi-atlas segmentation approach obtain splenic volume measurement in 55 patients with splenomegaly from MRI data, yielding a Dice similarity index > 90% [95]. Regarding application of radiomics to the spleen, Wang et al. have identified splenic radiomics features on CT that were associated with a better outcome in patients with gastric cancer [98]. Reiner et al. found that texture analysis of CT data allows discriminating between lymphomatous splenic involvement and splenomegaly due to portal hypertension [26]. To date, no studies have assessed the capabilities of artificial intelligence in characterizing splenic lesions.

8. Conclusion

Focal splenic lesions are relatively rare and discovered incidentally on imaging. Most of them display typical features and can be diagnosed using a pattern-based approach. A dedicated imaging protocol may be needed for better characterization. As a rule, most solitary focal splenic lesions in patients with a known cancer are benign, as solitary splenic metastases are rare [99]. In most instances, the combination of ultrasound, CT, MRI and ¹⁸F-FDG PET/CT findings allows reaching high degrees of confidence for lesion characterization. When imaging features, and especially in patients with a known primary cancer, are not specific enough, percutaneous splenic biopsy or splenectomy may be ultimately needed. Further studies are needed to investigate the capabilities of radiomics and artificial intelligence in focal splenic lesion characterization [100].

Human rights

The authors declare that the work described has been carried out in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans.

Informed consent and patient details

IRB approval is not required for review article. The authors declare that this report does not contain any personal information that could lead to the identification of the patients.

Disclosure of interest

The authors declare that they have no competing interest.

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Legends for Figures

Figure 1. 60-year-old man without splenic disease. MRI shows features typical of heterogeneous, splenic enhancement during the arterial phase following intravenous administration of gadolinium-based contrast agent. A, T1-weighted (TR/TE = 4.23/2.03 ms) MR image in the axial plane obtained during the arterial phase of enhancement following intravenous administration of a gadolinium-based contrast agent reveals heterogeneous enhancement of splenic parenchyma (arrow) referred to as “zebra pattern”. B, On T1-weighted (TR/TE = 4.23/2.03 ms) MR image in the axial plane obtained during the portal phase of enhancement, splenic parenchyma is homogeneous. C, On T2-weighted HASTE (TR/TE = 1200/95 ms), MR image in the axial plane, no splenic lesion are present. D, On T2-weighted BLADE (TR/TE = 2360/112 ms) MR image, splenic parenchyma is homogeneous without any focal splenic lesion.

Figure 2. 39-year-old woman with epithelial ovarian carcinoma and peritoneal carcinomatosis. A, CT image in the axial plane obtained after intravenous administration of iodinated contrast material reveals small, enhancing, heterogeneous peritoneal nodule (arrow). B, Diffusion-weighted (TR/TE = 12000/65 ms; b = 1000 s/mm²) MR image in the axial plane confirms nodule with marked restriction (arrow). C, Intraoperatively, the nodule was confirmed as malignant nodule (arrow). D, CT image in the axial plane obtained after intravenous administration of iodinated contrast material reveals small, enhancing, homogeneous peritoneal nodule (arrow). E, Diffusion-weighted (TR/TE = 12000/65 ms; b = 1000 s/mm²) MR image in the axial plane confirms peritoneal nodule (arrow) with marked restriction, but with lower signal intensity than nodule in B and signal intensity similar to that of the spleen. F, Intraoperatively, the nodule was confirmed as benign splenic nodule (arrow).

Figure 3. 64-year-old man with intrahepatic splenosis. A, Fat-saturated T1-weighted (TR/TE = 4/1.5 ms; Flip angle, 15°) MR image in the axial plane obtained during the arterial phase of enhancement following intravenous administration of a gadolinium-based contrast agent shows heterogeneous intrahepatic lesion (arrow) in segment 3 that displays a zebra pattern of enhancement. B, T2-weighted HASTE (TR/TE = 1000/88 ms) MR image in the coronal plane, shows homogeneous, moderately hyperintense intrahepatic lesion (arrow). C, Diffusion-weighted (TR/TE = 7472/66 ms; b = 800 s/mm²) MR image in the axial plane reveals hyperintense hepatic lesion (arrow). Because of prior history of car crash and splenectomy, no comparison with the spleen was possible, making the diagnosis uncertain. Percutaneous biopsy yielded nonspecific tissue sample for a definite diagnosis. D, Photograph shows gross specimen after partial liver resection. Nodule of splenosis (arrows) was histopathologically confirmed.

Figure 4. 66-year-old woman with intrasplenic cyst. A, T1-weighted (TR/TE = 195/4.75 ms) MR image in the axial plane obtained before intravenous administration of a gadolinium-based contrast agent reveals small, hypointense, focal splenic lesion (arrow). B, Fat-suppressed, T2-weighted turbo spin-echo (TR/TE = 5620/88 ms) MR image in the axial plane, shows homogeneous, markedly hyperintense focal splenic lesion with signal intensity similar to that of cerebrospinal fluid (arrowhead). C, Diffusion-weighted (TR/TE = 5236/79 ms) MR image in the axial plane obtained with high b value (b = 800 s/mm²) shows hypointense focal splenic lesion (arrow), indicating no restricted diffusion. D, On T1-weighted (TR/TE = 3.8/1.4 ms; Flip angle, 15°) MR image in the axial plane obtained during the portal phase of enhancement following intravenous administration of a gadolinium-based contrast agent reveals no internal enhancement of focal splenic lesion (arrow).

Figure 5. 78-year-old woman with splenic hemangioma. A, Unenhanced CT image in the axial plane reveals homogenous spleen. No focal splenic lesion is visible. B, CT image in the axial

place obtained during the arterial phase of enhancement following intravenous administration of iodinated contrast material shows focal splenic lesion (arrow) displaying peripheral enhancement. C, CT image in the axial plane obtained during the portal phase of enhancement shows centripetal filling-in of focal splenic lesion (arrow) consistent with splenic hemangioma. D, ^{18}F -FDG PET/CT fusion image shows no uptake of ^{18}F -FDG, indicating no hyper metabolism.

Figure 6. 62-year-old man with splenic hamartoma. A, CT image in the axial plane obtained during the portal phase of enhancement following intravenous administration of iodinated contrast material shows ill-defined intra splenic lesion (arrows), which is slightly hypoattenuating by comparison with normal splenic parenchyma. B, Fat-saturated T2-weighted (BLADE; TR 3000 TE 116 ms) MR image in the axial plane reveals intrasplenic lesion (arrows) with signal intensity similar to that of splenic parenchyma. C, Fat-saturated T1-weighted (TR/TE = 4/1.5 ms; Flip angle, 15°) MR image in the axial plane obtained during the arterial phase of enhancement following intravenous administration of a gadolinium-based contrast agent shows heterogeneous splenic lesion (arrows) that displays a zebra pattern of enhancement. D, Fat-saturated T1-weighted (TR/TE = 4/1.5 ms; Flip angle, 15°) MR image in the axial plane obtained during the portal phase of enhancement shows a more homogeneous pattern of the splenic lesion (arrows), similar to that of the apparently healthy splenic parenchyma. E, Fat-saturated T1-weighted (TR/TE = 4/1.5 ms; Flip angle, 15°) MR image in the axial plane obtained during the late phase of enhancement shows homogeneous splenic lesion (arrows). F, Photograph shows gross specimen after splenectomy, confirming splenic hamartoma.

Figure 7. 80-year-old woman with inflammatory pseudotumor-like follicular dendritic cell tumor. A, CT image in the axial plane obtained during the portal phase of enhancement following intravenous administration of iodinated contrast material shows large, bulging focal splenic lesion (arrow), containing internal calcification (arrowhead). B, T2-weighted HASTE (TR/TE = 1200/95 ms) MR image in the axial plane, shows heterogeneous, moderately hyperintense splenic lesion (arrow). C, Fat-saturated T1-weighted (TR/TE = 6.85/2.39 ms) MR image in the axial plane obtained during the portal phase of enhancement following intravenous administration of a gadolinium-based contrast agent reveals poor enhancement of splenic lesion (arrow). D, Fat-saturated T1-weighted (TR/TE = 6.85/2.39 ms) MR image in the axial plane obtained during the late phase of enhancement (3 min) reveals poorly enhancing lesion, with some foci displaying more prominent enhancement.

Figure 8. 24-year-old woman with incidentally found sclerosing angiomatoid nodular transformation (SANT) of the spleen. A, CT image in the axial plane obtained during the portal phase of enhancement shows large, focal splenic lesion (arrows) containing internal calcification (arrowhead). B, Fat-saturated T2-weighted BLADE (TR/TE = 2100/115 ms) MR image in the axial plane, shows heterogeneous, moderately hyperintense splenic lesion (arrows) containing central hypointensity. C, Fat-saturated T1-weighted (TR/TE = 4.8/2.1 ms; Flip angle, 10°) MR image in the axial plane obtained during the arterial phase of enhancement following intravenous administration of a gadolinium-based contrast agent shows heterogeneous splenic lesion (arrows) with peripheral enhancement. D, Fat-saturated T1-weighted (TR/TE = 4.8/2.1 ms; Flip angle, 10°) MR image in the axial plane obtained during the late phase of enhancement (6 min) reveals central filling-in in a radiating fashion displaying the “spoke-wheel pattern”, which is a highly suggestive of SANT.

Figure 9. 69-year-old woman with splenic involvement by B cell lymphoma. A, Unenhanced CT image in the axial plane reveals relatively homogenous spleen. Focal splenic lesions are hardly visible. B, CT image in the axial plane obtained during the arterial phase of enhancement following intravenous administration of iodinated contrast material shows poorly enhancing focal splenic lesions (arrows). C, CT image in the axial plane obtained during the portal phase of enhancement shows focal splenic lesions with poor internal enhancement (arrows). D, ^{18}F -FDG

PET/CT fusion image shows marked uptake of ^{18}F -FDG, indicating hypermetabolism of splenic lesions.

Figure 10. 59-year-old man with pseudomyxoma from appendicular origin. A, Fat-saturated BLADE (TR/TE = 2800/116 ms) MR image in the axial plane reveals peritoneal involvement (arrows) and intrasplenic involvement (arrowhead) with lesions displaying hyperintense fluid-like signal. B, Diffusion weighted (TR/TE = 6200/54 msec; b = 800 s/mm²) MR image in the axial plane shows hypointense splenic lesions. C, Apparent diffusion coefficient (ADC) map shows hyperintense splenic lesions with ADC value of 2.118×10^{-3} mm²/s suggestive of mucinous content.



















