MR Imaging of Cardiac Tumors and Masses: A Review of Methods and Clinical Applications

Cardiac masses are usually first detected at echocardiography. In their further evaluation, cardiac magnetic resonance (MR) imaging has become a highly valuable technique. MR imaging offers incremental value owing to its larger field of view, superior tissue contrast, versatility in image planes, and unique ability to enable discrimination of different tissue characteristics, such as water and fat content, which give rise to particular signal patterns with T1- and T2-weighted techniques. With contrast material–enhanced MR imaging, additional tissue properties such as vascularity and fibrosis can be demonstrated. MR imaging can therefore contribute to the diagnosis of a cardiac mass as well as be used to detail its relationship to other cardiac and extracardiac structures. These assessments are important to plan therapy, such as surgical intervention. In addition, serial MR studies can be used to monitor tumor regression after surgery or chemotherapy. Primary cardiac tumors are very rare; metastases and pseudotumors (eg, thrombus) are much more common. This article provides an overview of cardiac masses and reviews the optimal MR imaging techniques for their assessment.

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Learning Objectives:
After reading the article and taking the test, the reader will be able to:
- Recall the most common cardiac masses and their relative prevalence.
- Outline an MR imaging protocol to assess and characterize a cardiac mass.
- Describe the MR imaging features of thrombus and specific cardiac tumors.

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Cardiac tumors—benign and malignant—are rare, with an estimated prevalence of only 0.002%–0.3% at autopsy (1,2). However, even benign cardiac tumors can exert significant clinical effects by altering cardiac hemodynamics and by acting as embolic or arrhythmia substrates (3). Approximately 75% of all primary cardiac tumors are benign, and the most common in the adult population are myxomas (50%), papillary elastomas (20%), lipomas (15%–20%), and hemangiomas (5%) (4,5). The other 25% of primary cardiac tumors are malignant—95% of these are sarcomas and 5% are lymphomas (Table 1) (4,6). Metastases involving the heart and pericardium (secondary cardiac tumors) from direct invasion or hematologic spread are 20–40 times more common than primary cardiac tumors (3,7). However, the most common type of cardiac mass is in fact “pseudotumors,” such as intracardiac thrombus or misinterpreted normal anatomic variants (Fig 1) (8). Knowledge of the magnetic resonance (MR) imaging features of common cardiac masses is therefore important for establishing an accurate diagnosis and for guiding staging, prognosis, and appropriate therapy in confirmed tumors. In this article we review the role of MR imaging in the assessment of cardiac masses compared with other imaging modalities. We provide a detailed description of a core protocol for the MR assessment of cardiac masses and tumors and illustrate the different imaging characteristics of the most common types of mass, with case examples.

Role of MR Imaging and Other Imaging Modalities

Transthoracic echocardiography is the most readily available noninvasive imaging technique and thus remains the first-line diagnostic test when a cardiac tumor is suspected. Moreover, many cardiac masses are detected incidentally during routine echocardiographic studies for other indications. In many cases, echocardiography demonstrates characteristic anatomic and functional features that already permit a differential diagnosis of a cardiac mass. Three-dimensional echocardiography has further enhanced the role of echocardiography in the assessment of cardiac masses, particularly in terms of anatomic location, morphology, and functional impact (9). Although the widespread availability of echocardiography is a major advantage, there are also several limitations, including operator dependence, a restricted field of view (particularly in patients with pulmonary disease or a large body habitus), and limited imaging of the right heart and mediastinal and extracardiac structures. Where there is diagnostic doubt, transesophageal echocardiography can offer additional imaging planes for further assessment of a lesion—but this is an invasive test. Furthermore, although some tissue characterization is possible with echocardiography (particularly assessment of calcification) and some masses show specific echogenic properties, tissue characterization by means of echocardiography is generally limited outside of advanced imaging techniques such as ultrasonic back scatter or strain rate analysis (10,11).

Cardiac computed tomography (CT) is a commonly used second-line diagnostic modality to assess cardiac masses (12,13). In addition, incidental findings of cardiac masses are becoming more common as CT is increasingly used to evaluate coronary artery disease (14,15). Several recent advances in CT, including submillimeter detector arrays, increased rows of detectors, half-scan postprocessing algorithms, and electrocardiographic gating, have resulted in improved imaging of cardiac structures, including cardiac masses (16,17). CT can also offer information regarding vascularity by means of contrast enhancement, presence of calcification (unlike MR imaging), and presence of fat. Limitations of CT include the exposure to ionizing radiation, lower temporal resolution compared with echocardiography or MR imaging, and lower soft-tissue contrast resolution compared with MR imaging (18).

Positron emission tomography (PET) can also be used to characterize cardiac masses, but its availability remains limited. Additionally, PET has limited spatial resolution and only in combination with the anatomic information of CT has it become a valuable tool for a variety of oncologic indications, including detection, staging, and monitoring of therapy and differentiation of benign from malignant lesions (19).

MR imaging characteristics can be used to predict the likely malignancy of a cardiac mass (20–22) (Fig 2). Hoffman et al (20) used a multiparametric MR imaging protocol to evaluate the signal properties, morphologic characteristics (location, size, infiltrative nature, presence of pleural/pericardial effusions) and contrast enhancement of cardiac tumors in 55 patients. An overall interpretation of the MR imaging features was found to have a diagnostic accuracy of 0.92 (area under the curve) for determining a cardiac mass to be...

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Abbreviations:
EDE = early gadolinium enhancement
FSE = fast spin echo
LGE = late gadolinium enhancement
SSFP = steady-state free precession

Conflicts of interest are listed at the end of this article.
malignant (confirmed at histologic evaluation). Compared with CT, MR imaging offers higher temporal resolution and additional tissue characterization, and MR imaging does not expose patients to ionizing radiation. However, although access to cardiac MR imaging is increasing, it remains less available than echocardiography or CT.

A limitation common to both MR and CT is the need for electrocardiographic gating, which in the presence of significant arrhythmias may lead to acquisition artifacts and image degradation (23). An additional limitation of MR, particularly in very ill patients, is that most cardiac MR sequences generally require breath holds to achieve adequate image quality, but these are becoming shorter as developments in hardware and pulse sequences lead to faster acquisitions. Alternatively, respiratory navigator tracking methods can now be used to acquire good-quality images during free breathing. Perhaps one of the major limitations of MR is the contraindication in patients with pacemakers and intracardiac defibrillators—however, with the correct expertise and precautions, many of these patients can still be safely imaged (24,25). Additionally, there are now a number of MR-compatible implantable devices available (26).

In recognition of its diagnostic capabilities, several consensus statements now position cardiac MR imaging as a primary imaging technique in the work-up of cardiac tumors (27,28). More realistically, the conjugate use of echocardiography and cardiac MR imaging will be used for diagnosis and monitoring of cardiac masses and tumors. Where cardiac MR imaging is not available or is contraindicated and when echocardiography alone has not been sufficient to fully assess a mass, CT offers an alternative second-line imaging strategy.

**Table 1**

<table>
<thead>
<tr>
<th>Tumor Type</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benign</strong></td>
<td></td>
</tr>
<tr>
<td>Myxoma</td>
<td>30%</td>
</tr>
<tr>
<td>Lipoma</td>
<td>10%</td>
</tr>
<tr>
<td>Fibroelastoma</td>
<td>10%</td>
</tr>
<tr>
<td>Rhabdomyoma</td>
<td>8%</td>
</tr>
<tr>
<td>Fibroma</td>
<td>4%</td>
</tr>
<tr>
<td>Hemangioma</td>
<td>3%</td>
</tr>
<tr>
<td>Teratoma</td>
<td>3%</td>
</tr>
<tr>
<td>Other</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>70%–75%</td>
</tr>
<tr>
<td><strong>Malignant</strong></td>
<td></td>
</tr>
<tr>
<td>Angiosarcoma</td>
<td>9%</td>
</tr>
<tr>
<td>Rhabdomyosarcoma</td>
<td>6%</td>
</tr>
<tr>
<td>Mesothelioma</td>
<td>4%</td>
</tr>
<tr>
<td>Fibrosarcoma</td>
<td>3%</td>
</tr>
<tr>
<td>Lymphoma</td>
<td>2%</td>
</tr>
<tr>
<td>Other sarcomas</td>
<td>3%</td>
</tr>
<tr>
<td>Teratoma</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Other</td>
<td>&lt;1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>25%–30%</td>
</tr>
</tbody>
</table>

Note.—Data are compiled based on references cited in the text (3,4,7,31,75,76).

**Figure 1:** Vertical long-axis SSFP image shows a prominent coumadin ridge (CR) between the left upper pulmonary vein (LUPV) and left atrial appendage (LAA). The tip is bulbous, exhibiting the so-called Q-tip sign. Although easily recognized with MR imaging, it can sometimes be misinterpreted as a thrombus with echocardiography.

**Figure 2:** Indicators of malignancy using cardiac MR imaging (3,20,21,88,92).

**Tumor Characteristics**
- Large size—especially if >5 cm
- Irregular, ill-defined borders
- Direct invasion through tissue planes
- Most cardiac tumors involving the right heart are suspicious for malignancy
- Pericardial or pleural involvement—effusions and nodular masses
- Multiple lesions

**Tissue Characteristics**
- Tissue heterogeneity on T1- and T2-weighted images (hemorrhage and necrosis within mass)
- Hemorrhagic pericardial effusion (high signal intensity on T1-weighted images)
- Contrast enhancement
- High T1-weighted with low T2-weighted signal intensity is suggestive of metastatic malignant melanoma
Free-breathing acquisition provides a very rapid overview of the gross anatomy and in large masses can allow tumor localization for the subsequent planning of targeted imaging planes. However, in good breath-holders, a breath-hold FSE sequence with reduced section thickness (example pulse sequence parameters at our institution: 1000/40; flip angle, 90°; section thickness, 4–6 mm, no gap; field of view, 320–400 mm; matrix, 512 × 512) is preferable as it provides high-spatial-resolution anatomic information detailing the precise relationship with surrounding structures and identifying the presence of any local invasion. Use of double-inversion-recovery FSE with nulling of the blood pool signal (“black-blood” imaging) gives additional contrast between the pericardium or pericardial

black-blood T2-weighted imaging, and early and late gadolinium enhancement (LGE) imaging. First-pass perfusion, myocardial tissue tagging, and other methods may complement the acquisition protocol. Figure 4 outlines the important features to include in an MR imaging report for suspicion of a cardiac mass.

**Localization**

_T1-weighted black-blood transaxial stack._—A transaxial stack of T1-weighted images, ideally covering the entire thorax, should be acquired. These may be acquired with a free-breathing single-shot fast spin-echo (FSE) method (pulse sequence parameters at our institution: repetition time msec/echo time msec, 2000/20; flip angle, 90°; section thickness, 8–10 mm, no gap; typically 16–20 sections; field of view, 320–400 mm; matrix, 256 × 256) or, in patients with good breath-hold ability, with a higher spatial resolution method (Fig 3) (29,30).
**Table 2**

<table>
<thead>
<tr>
<th>Cardiac Mass</th>
<th>T1-weighted Imaging*</th>
<th>T2-weighted Imaging*</th>
<th>After Contrast Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudotumor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thrombus</td>
<td>Low (high if recent)</td>
<td>Low (high if recent)</td>
<td>No uptake†</td>
</tr>
<tr>
<td>Pericardial cyst</td>
<td>Low</td>
<td>High</td>
<td>No uptake</td>
</tr>
<tr>
<td>Benign</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myxoma</td>
<td>Isointense</td>
<td>High</td>
<td>Heterogeneous†</td>
</tr>
<tr>
<td>Lipoma</td>
<td>High†</td>
<td>High</td>
<td>No uptake</td>
</tr>
<tr>
<td>Fibroma</td>
<td>Isointense</td>
<td>Low</td>
<td>Hyperenhancement‡</td>
</tr>
<tr>
<td>Rhabdomyoma</td>
<td>Isointense/high</td>
<td>Isointense/high</td>
<td>No/minimal uptake</td>
</tr>
<tr>
<td>Malignant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angiosarcoma</td>
<td>Heterogenous</td>
<td>Heterogenous</td>
<td>Heterogeneous</td>
</tr>
<tr>
<td>Rhabdomyosarcoma</td>
<td>Isointense</td>
<td>Hyperintense</td>
<td>Homogeneous</td>
</tr>
<tr>
<td>Undifferentiated sarcoma</td>
<td>Isointense</td>
<td>Hyperintense</td>
<td>Heterogeneous/variable</td>
</tr>
<tr>
<td>Lymphoma</td>
<td>Isointense</td>
<td>Isointense</td>
<td>No/minimal uptake</td>
</tr>
<tr>
<td>Metastasis‡</td>
<td>Low</td>
<td>High</td>
<td>Heterogeneous</td>
</tr>
</tbody>
</table>

Note.—Table presents typical characteristics, but all tumors can have atypical appearances owing to altered tissue composition.

* T1- and T2-weighted imaging signal intensity is given relative to myocardium.
† Best seen on EGE images (no uptake) 2 minutes after contrast agent administration (Fig 1).
‡ Similar to surrounding fat signal intensity and characterized by marked suppression with a fat-saturation prepulse.
§ However, fibromas are nonenhancing at perfusion imaging because of avascularity.
|| The exception is metastatic melanoma, which has a high T1-weighted and a low T2-weighted signal intensity.

In MR imaging, the relative signal intensity from a particular tissue depends principally on its proton density and the T1 and T2 relaxation times. Different tissues have different T1 and T2 relaxation times owing to different internal biochemical environments surrounding protons. By weighting images to emphasize either T1- or T2-based contrast, MR imaging can exploit differences in signal intensity to discriminate between different tissue types (Table 2). Neoplastic cells tend to be larger than normal cells, contain more free intracellular water, and are usually associated with an inflammatory reaction and increased interstitial fluid. Because water molecules are small and move too rapidly for efficient relaxation, the higher free water content of malignant tissue, as well as the other changes in tissue composition, lead to prolonged T1/T2 relaxation times and thus an inherent contrast between tumors and normal tissue (31,34). In addition, tumors containing fibrotic or lipomatous material show characteristic signal intensity patterns on MR images (Table 2).

**Myocardial tissue tagging: optional.**—Myocardial tissue tagging can be useful in the assessment of cardiac masses to detect more subtle regions of contractile dysfunction due to tissue infiltration (Fig 3). It is often used for the assessment of masses that are localized near to or involve the pericardium. The myocardium normally slips past the adjacent pericardium freely, but can be adherent if a tumor mass involves both myocardium and pericardium or if a pericardial inflammatory reaction is present.

**Tissue Characterization**

In MR imaging, the relative signal intensity from a particular tissue depends principally on its proton density and the T1 and T2 relaxation times. Different tissues have different T1 and T2 relaxation times owing to different internal biochemical environments surrounding protons. By weighting images to emphasize either T1- or T2-based contrast, MR imaging can exploit differences in signal intensity to discriminate between different tissue types (Table 2). Neoplastic cells tend to be larger than normal cells, contain more free intracellular water, and are usually associated with an inflammatory reaction and increased interstitial fluid. Because water molecules are small and move too rapidly for efficient relaxation, the higher free water content of malignant tissue, as well as the other changes in tissue composition, lead to prolonged T1/T2 relaxation times and thus an inherent contrast between tumors and normal tissue (31,34). In addition, tumors containing fibrotic or lipomatous material show characteristic signal intensity patterns on MR images (Table 2).

**T1-weighted imaging.**—Targeted black-blood T1-weighted FSE images (example pulse sequence parameters at our institution: 1000/40; flip angle, 90°; section thickness, 6–8 mm, no gap; matrix, 512 × 512) in the optimal imaging planes defined earlier are acquired to cover the entire mass, with and without a fat saturation prepulse (ie, spectral presaturation inversion recovery [SPIR]). With SPIR techniques, a section-selective fat saturation pulse is applied between the preparatory
inversion pulse and readout resulting in additional suppression of signal from fat. In comparison with standard T1-weighted imaging, the use of SPIR is a highly sensitive method of characterizing fatty tumors such as lipomas. The acquisition of T1-weighted images can be repeated after the intravenous injection of gadolinium-based contrast agent (Fig 3) for further tissue characterization. Strong contrast enhancement on postcontrast T1-weighted images is more suggestive of a malignant, highly vascular lesion, although mild contrast enhancement is still seen in 40%-50% of benign tumors (20). Differential enhancement due to variation in tumor vascularity and altered capillary permeability allows some discrimination between the various tumor types as discussed in their individual descriptions below.

**T2-weighted imaging.**—Prior to the administration of contrast material, T2-weighted images should be acquired in the same imaging planes as T1-weighted images (Fig 3). These T2-weighted FSE images are acquired with breath hold, preferably triple inversion recovery with blood and fat suppression (example pulse sequence parameters at our institution: 2000/100; flip angle, 90°; inversion time, 160 msec; section thickness, 6-8 mm, no gap; matrix, 192 × 192), and can be used to detect regions of edema or liquefactive necrosis in the mass, which have high signal intensity, or regions of coagulative necrosis, which have low signal intensity (29,35). The presence of hemorrhage or thrombus also affects T2-weighted signal intensity (see the diagnosis-specific sections).

**First-pass perfusion imaging: optional.**—A standard rest perfusion sequence with 0.05-0.1 mmol/kg of gadolinium-based contrast agent can help determine the vascularity of a suspected cardiac mass (29). This should be performed in an imaging plane that best demonstrates a large cross-section of the mass. Vascular tumors will show signal intensity enhancement during the arterial phase, as opposed to nonvascular structures, such as thrombus. In addition, first-pass perfusion is useful for demonstrating regions of heterogeneous enhancement due to regional variations in vascularity—for example, regions of necrosis within a tumor.

**EGE imaging.**—EGE imaging is the optimal technique for identifying thrombus, particularly in the context of adjacent regional wall motion abnormalities or scar or as surface thrombus adherent to an irregular tumor. EGE and LGE acquisitions are usually performed following a dose of 0.1-0.2 mmol/kg of gadolinium-based contrast agent, so that a “top-up” bolus may be required if first-pass perfusion imaging is to be performed. EGE imaging is ideally performed within the first 2 minutes of contrast agent administration, with the same segmented double-inversion-recovery FSE as LGE imaging but with a long inversion time of 450-500 msec (29) (example pulse sequence parameters at our institution: 4.5/1.8; flip angle, 15; section thickness, 8 mm, no gap; matrix, 240 × 240). On EGE images, the blood pool and myocardium have intermediate signal intensity, but thrombus has no contrast agent uptake and therefore appears almost black (Fig 5). As with all of the pulse sequences aimed at tissue characterization, EGE imaging should be performed in those imaging planes predetermined to best visualize the tumor—whether standard or nonstandard.

**LGE imaging.**—LGE images are acquired 7-10 minutes after the top-up contrast agent injection, but acquisition may be repeated with a longer delay to enhance the contrast between blood pool and tissues or to highlight abnormalities within tissue (Fig 3). LGE imaging requires selection of the optimal inversion time. If the inversion time is too short, the myocardium is not properly nullled and appears patchy or streaky; if the inversion time is too long, then myocardium appears confluent gray. Therefore a TI-scout or Look-Locker sequence can be performed to formally identify the optimal inversion time (Fig 3). This is then followed by the LGE sequence, the most common of which is a segmented double-inversion-recovery FSE sequence (pulse sequence parameters at our institution: 4.5/1.8; flip angle, 15; section thickness, 8 mm, no gap; matrix, 240 × 240) (Fig 3). Phase-sensitive inversion-recovery methods are available that negate the need for a T1 scout. Generally a complete short-axis stack and one to three sections in both long axes are acquired to ensure complete myocardial coverage for the detection of myocardial scarring or infiltration which may relate to coexisting disease or be part of a neoplastic process; this should then be followed by imaging planes that best demonstrate the mass (if different to the standard planes) to specifically characterize its tissue composition. As gadolinium-based contrast material gradually washes out, the inversion time needs to be increased to maintain optimal image quality as the acquisition progresses—this is generally done between stacks by means of the addition of approximately 10-15 msec for every elapsed minute, but may require a repeat Look-Locker scout.

The principle of LGE imaging, which has mostly been used to detect myocardial infarction, is that over time the contrast agent washes out of normal myocardium but persists in any expanded interstitial space—which can occur due to acute inflammation or fibrosis or following myocardial infarction (36) (Fig 5). Additionally, cellular breakdown in acute myocardial infarction or direct tumor invasion permits gadolinium to become intracellular and therefore also persist in acutely disrupted myocardium. Any combination of these factors can contribute to the hyperenhancement patterns of the various tumor types as described below (Fig 2).

**Masses**

**Pseudotumors**

**Thrombus.**—Thrombus is one of the most common causes of an intracardiac mass and is a frequent differential diagnosis for cardiac tumors. Thrombus is typically found in the left atrium in
association with atrial fibrillation or mitral valve disease or in severely dysfunctional left ventricles following myocardial infarction (Figs 5, 6) (Movie 1 [online]). T1- and T2-weighted signal characteristics vary depending on the age of a thrombus. An acute thrombus usually has intermediate signal intensity on both T1- and T2-weighted images because the hemoglobin content is still in the oxygenated state. In subacute thrombus, the hemoglobin has been metabolized to methemoglobin, which has a different paramagnetic effect (shorter T1 and T2 relaxation times), leading to a lower T1-weighted signal intensity, but T2-weighted signal intensity is usually increased due to the higher water content from lysed red blood cells (37). Over a greater time period, thrombus becomes water-depleted and the cellular debris containing methemoglobin is replaced by fibrous tissue. This change in macromolecular composition with greater fibrin content leads to a lower signal intensity on both T1- and T2-weighted images in chronic organized thrombus (Table 3).

Contrast-enhanced MR imaging with first-pass perfusion, EGE, or LGE imaging enables clear differentiation of thrombus from surrounding myocardium because thrombus is avascular and hence characterized by an absence of contrast material uptake—rarely very chronic, organized thrombus may enhance peripherally due to its fibrous content (37,38). In 24 patients known to have or suspected of having thrombus, Burkhausen et al (39) detected 15 thrombi with EGE imaging compared with only 12 by using a combination of transthoracic and transesophageal echocardiography. In a broad cross-section of 784 consecutive patients with systolic dysfunction, Weinsaft et al (40) found a thrombus prevalence of 7% (n = 55) with LGE imaging, including small intracavitary and small or large mural thrombi missed at cine imaging. They also found a 100% detection rate with LGE imaging among those with thrombus verified at pathologic evaluation (n = 5). Furthermore, the prevalence of thrombus was seen to increase with worsening left ventricular ejection fraction, ischemic etiology, and myocardial scarring. Therefore the established capabilities of cardiac MR imaging in coronary artery disease are of additional value when characterizing suspected thrombus.

Pericardial cysts.—Pericardial cysts are benign congenital fluid-filled structures that are usually located in the right pericardiophrenic angle (4,41). In most cases they are incidental findings, but if very large, as in the example in Figure 7, they can cause symptoms due to compression of adjacent structures. The cysts have a well-demarcated and homogeneous appearance with low or isointense signal intensity on T1-weighted images and very high signal intensity on T2-weighted images (42). There is no contrast agent uptake on LGE images (Fig 7).

Caseous calcification of the mitral valve.—Caseous calcification of the mitral valve is a rare variant of mitral annular calcification that occurs in up to 1% of cases and typically involves the posterior mitral annulus at the atrioventricular groove. Histologic evaluation reveals a necrotic mass containing a mixture of fatty acids, cholesterol, and chronic...
difficult to discriminate from thrombus with echocardiography, versatile imaging planes with MR usually allow full visualization of its characteristic elongated structure with clubbed head and continuity with the left atrial wall (Fig 1) (8). The Eustachian valve, Chiari network crista terminalis, right ventricular moderator band, and false left ventricular tendons are other normal structures that sometimes raise suspicion with echocardiography but are generally easily characterized with MR imaging given the large field of view and high spatial resolution.

Benign Tumors

Myxoma.—Myxomas are the most common type of primary cardiac tumor (25%–50%) and usually occur in the fourth to seventh decade of life (4,45) (Table 1). They are typically solitary, vary in size from 1–15 cm, and have a predilection for the interatrial septum near the fossa ovalis (3). Approximately 75% occur in the left atrium, 20% in the right atrium, and 5% in either ventricle (45) (Fig 6). They are generally well defined, smooth, lobular, or oval and often pedunculated. On MR images, they appear isointense on T1-weighted images and have higher signal intensity on T2-weighted images owing to the high extracellular water content (Fig 8). Regions of acute hemorrhage within myxomas appear hypointense on both T1- and T2-weighted images, and older regions appear hyperintense as the hemoglobin becomes oxidized to methemoglobin (46–49) (Fig 8, Table 2). Cine imaging is very useful in the work-up of myxomas as they are highly mobile, occasionally prolapsing through the mitral valve and causing obstruction. With SSFP cine techniques, myxomas appear hyperintense relative to the myocardium but hypointense relative to the blood pool (Movie 2 [online]). Internally, myxomas may contain cysts, regions of necrosis, fibrosis, hemorrhage, and calcification, which lead to a typically heterogeneous appearance at contrast enhancement (3,50,51). Many myxomas have a layer of surface thrombus, with low signal intensity on LGE images (52). The majority occur

inflammatory infiltrate surrounded by a fibrocalcific envelope (43). The unusual characteristics can lead to misdiagnosis as a cardiac tumor, thrombus, or abscess, and therefore MR imaging can be very useful for tissue characterization. During the early phase, the associated mass is hyperintense at both T1- and T2-weighted imaging due to a high fluid content and liquefactive necrosis (44). Associated regions of calcification within and around the mass appear hypointense but are better characterized with CT. LGE imaging typically shows a peripheral rim of hyperenhancement consistent with a fibrous cap and a dark avascular core of necrotic caseous material (44).

Normal intracardiac structures.—Normal intracardiac structures or embryologic remnants can sometimes be mistaken for tumor or thrombus. The “coumadin ridge” is a normal rim of tissue between the left upper pulmonary vein and left atrial appendage that can sometimes be misinterpreted as thrombus especially if prominent or viewed in cross-section. Although it can be
sporadically but approximately 7% constitute part of an autosomal dominant syndrome known as Carney complex, which is associated with skin lentigines, endocrine tumors, fibroadenomas, and melanotic schwannomas (53). They can be asymptomatic if small, but most patients present with symptoms due to mass effect (eg, inflow/outflow obstruction), embolization, or constitutional symptoms (due to release of IL-6) (54). The treatment is surgical resection with a margin of normal tissue and is considered curative. The overall risk of recurrence after resection is 13% and is much more common with familial myxomas (5).

**Lipoma.**—Lipomas are a common type of benign tumor and account for about 10% of all primary cardiac tumors (4) (Table 1). They are well defined, homogeneous, encapsulated tumors containing neoplastic adipose cells. The majority arise from the epicardial surface and can extend into the pericardial space; subendocardial lipomas are less common and tend to be smaller and sessile (55). Many lipomas are discovered incidentally, and the patients remain asymptomatic without the need for surgical intervention. Rarely, very large lipomas can lead to symptomatic obstruction, especially if they involve the pericardial space (56,57). The key diagnostic finding on cardiac MR images is homogeneous high signal intensity (relative to myocardium) on T1-weighted images that markedly suppresses with the application of additional fat-saturation prepulses (SPIR) (Fig 9). An additional useful clue is the similar signal intensity of surrounding chest wall fat on T1- and T2-weighted images (55). Lipomas are avascular and do not enhance with contrast material (Table 2).

Lipomatous hypertrophy can sometimes be confused with lipomas because both have similar signal characteristics due to their fat content (3,58). However, lipomatous hypertrophy is a benign, nonencapsulated, nonneoplastic condition characterized by adipose cell hyperplasia and associated with older age and obesity (21). It can usually be distinguished from true encapsulated lipomas by its morphologic features—the fatty mass in lipomatous hypertrophy is by definition larger than 2 cm in transverse diameter and classically involves the limbus of the fossa ovalis, sparing the fossa ovalis membrane, giving rise to a bilobed dumbbell shape (31,58,59).

**Fibroelastoma.**—Papillary fibroelastomas are small (usually <1.5 cm), benign endocardial papillomas that predominantly affect the cardiac valves (90%), accounting for 75% of all valvular neoplasms (60,61) (Fig 6). In surgical series they account for approximately 10% of primary cardiac tumors, but their prevalence in the general population is uncertain as they are often asymptomatic and discovered incidentally (62,63) (Table 1). Macroscopically they have a papillary frondlike structure and microscopically they consist of avascular connective tissue lined by endothelium (64). Because of their small size and high mobility they are usually best diagnosed with echocardiography, and MR imaging is rarely additive except in atypical cases (65). Typical MR imaging features are of a small, highly mobile homogeneous valvular mass (usually attached to the downstream side with a small pedicle); hypointense signal intensity and surrounding turbulent flow on cine images; and isointense T1 and hyperintense T2 signal intensity patterns (66,67) (Table 2). The main
REVIEW: MR Imaging of Cardiac Tumors and Masses

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Fibromas are isointense relative to normal myocardium on T1-weighted images and are characteristically hypointense on T2-weighted images (unlike other masses) (20,49) (Fig 10, Table 2) (Movie 3 [online]). They are generally homogeneous unless there is central calcification, which may be seen as patchy central hypointensity. With gadolinium-based contrast agent administration, fibromas generally show no contrast enhancement during perfusion imaging due to their avascularity (Movie 4 [online]). However, 7–10 minutes later, they classically show intense hyperenhancement on LGE images. The explanation of this late hyperenhancement pattern is that microscopically fibromas are a collection of fibroblasts interspersed with large amounts of collagen and
differentials include vegetations and thrombus. Thrombus is easily discriminated with contrast-enhanced tissue characterization as described earlier. Vegetations are usually present in the clinical context of suspected infected endocarditis and cause destruction of valvular leaflets, whereas fibroelastomas are rarely associated with a functional impact on the valve. Clinically, fibroelastomas can be asymptomatic or sometimes associated with systemic embolization from attached thrombi or fragmentation (64). Surgical excision is only recommended in symptomatic patients or in those with larger (>1 cm), highly mobile, left-sided tumors (3).

Fibroma.—Cardiac fibromas are the second most common congenital tumor and typically present in pediatric or young adult life. They are usually solitary tumors (unlike rhabdomyomas) and are most often located intramurally in the ventricles involving the interventricular septum (68). Those associated with polyposis syndromes (eg, familial adenomatous polyposis or Gardner syndrome) occur more commonly in the atria (3,69). Clinically, they can present with syncope, palpitations, sudden cardiac death, chest pain, or cardiac failure as sequelae of mass effects, outflow-tract obstruction, or arrhythmias. Macroscopically, they are solitary, well-defined masses within the myocardium. Microscopically, they are composed of neoplastic fibroblasts without cystic change, hemorrhage, or necrosis but frequently have central calcification, which can help differentiate them from rhabdomyomas. With MR imaging,
need for surgical intervention. With cardiac MR imaging, they appear isointense to normal myocardium on T1-weighted images and hyperintense on T2-weighted images (in contrast to fibromas) (Table 2) (70,71). They typically show minimal or no enhancement with gadolinium-based contrast material (18,70,72).

**Hemangioma.**—Cardiac hemangiomas are vascular tumors that account for 5%-10% of all primary benign cardiac tumors (4) (Table 1). They are typically solitary and found in either ventricle but can be located in any chamber. Histologically they can be capillary, cavernous, or arteriovenous in nature. On cardiac MR images, hemangiomas are typically heterogenous and hyperintense on T1- and T2-weighted images owing to slow blood flow (Fig 4) (70,73). During and after contrast agent administration they are intensely hyperintense due to their vascular content—but there may be regions of inhomogeneity owing to calcification or fibrous septa (73).

**Malignant Tumors**

Malignant primary cardiac tumors are very rare, constituting only 10% of all primary cardiac tumors (Table 1) (7). The majority (95%) of these malignant primary cardiac tumors are sarcomas and the remainder are lymphomas or pericardial mesotheliomas (4). Metastatic cardiac malignancy, on the other hand, is much more common.

**Sarcoma.**—Sarcomas occur mainly in adulthood, usually between the third and fifth decades of life, and carry an extremely poor prognosis (3). Survival after diagnosis rarely exceeds 6 months owing to rapid progression, widespread local infiltration, intracavitary obstruction, or metastases which are often already present by the time of diagnosis (74). There are various histologic subtypes, of which angiosarcomas are the most common (approximately 40%) (4,73). Angiosarcomas are the most common primary cardiac malignancy in adulthood and rhabdomyosarcomas are the most common in childhood (4,76).

Unlike other sarcomas, angiosarcomas typically originate in the right therefore they have a very large extracellular space component. Gadolinium diffuses into interstitial spaces but not across cell membranes and this phenomenon results in a delayed and persistently higher concentration of gadolinium in fibromas at LGE imaging (Fig 10) (18,31,70).

**Rhabdomyoma.**—Rhabdomyomas are the most common primary cardiac tumors in infants and children. They typically present in the 1st year of life and more than 50% are associated with tuberous sclerosis. They arise intramurally in the ventricular myocardium, but unlike fibromas, they are multiple in 90% of cases. Microscopically, they are hamartomas, composed of altered myocytes that are enlarged, highly vacuolated, and laden with glycogen (4). In some cells, eosinophilic septa stretch from the cell membrane to a centrally placed nucleus, giving a spiderlike appearance to the cell. These “spider cells” are pathognomonic for cardiac rhabdomyomas and are thought to represent degenerating rhabdomyocytes (45,63). Macroscopically, they are well circumscribed and vary from a few millimeters to a few centimeters in size. Although rhabdomyomas can protrude into the ventricular chambers, causing obstruction, the majority remain asymptomatic and spontaneously regress before the age of 4 years without the need for surgical intervention. With cardiac MR imaging, they appear isointense to normal myocardium on T1-weighted images and hyperintense on T2-weighted images (in contrast to fibromas) (Table 2) (70,71). They typically show minimal or no enhancement with gadolinium-based contrast material (18,70,72).
atrium and usually present with right-heart failure, hemorrhagic pericardial effusions, or metastases (Fig 6) (Movie 5 [online]) (3). Microscopically, angiosarcomas consist of rapidly proliferating, extensively infiltrating anaplastic cells derived from blood vessels and lining irregular blood-filled spaces, and there are usually large regions of hemorrhage and necrosis within the tumor (75). Macroscopically, there are two morphologic variants: The “focal” variety is typically a well-defined mass protruding into the right atrium, causing serious intracavitary obstruction; the “diffuse” variety is a more extensive mass that rapidly infiltrates the right ventricle and pericardium that manifests with right-sided heart failure or tamponade. These features are reflected at MR imaging, which typically demonstrates a large heterogenous right atrial mass with or without pericardial involvement (thickening, effusion, nodularity, frank disruption of fat planes); heterogenous T1- and T2-weighted signal intensity patterns that reflect tumor tissue, necrosis, and hemorrhage; arterial phase enhancement at first-pass perfusion owing to vascularity (Movie 6 [online]); and heterogenous enhancement at LGE imaging owing to peripheral fibrosis (surface hyperintensity) and focal hypointensity due to central necrosis (Fig 11, Table 2) (31,60,77).

Rhabdomyosarcomas account for approximately 20% of sarcomas and occur most frequently in infants and children (4). They often involve multiple sites within the heart, including the valves—unlike other sarcomas (78). With MR, they are isointense on T1-weighted images, hyperintense on T2-weighted images, and generally demonstrate homogeneous contrast enhancement—occasionally with regions of hypointensity due to central necrosis (45,70).

A cardiac sarcoma with no specific histologic pattern is classified as undifferentiated. Undifferentiated sarcomas account for approximately one-third of all cardiac sarcomas and are therefore the second most common primary cardiac malignancy. Similar to angiosarcomas, they may appear as focal or infiltrative masses with necrosis and hemorrhage, and thus have similar MR imaging features. However, unlike angiosarcomas, which are usually found in the right atrium, undifferentiated sarcomas have a predilection for the left atrium (81%) (79).

Figure 10: Fibroma in a 30-year-old woman who presented with syncope and had unexplained hypertrophy of the anterolateral wall at echocardiography. The mass (arrow) was, A, intramyocardial, with local mass effect (Movie 3 [online]), B, C, isointense (relative to myocardium) on T1-weighted images and, D, hypointense on T2-weighted images. On perfusion images, the mass did not show any substantial contrast enhancement with gadolinium-based contrast agent, suggesting avascularity (Movie 4 [online]). The most characteristic feature was diffuse homogeneous enhancement of the mass on, E, F, LGE images, suggestive of a fibroma, which was confirmed at histologic examination.
The remaining histologic subtypes of sarcomas, including fibrosarcomas, osteosarcomas, leiomyosarcomas, and liposarcomas, are extremely rare and as a result there is insufficient data to permit reliable noninvasive distinction between them. However, even histologic distinction has not been shown to alter their course of treatment or outcome (80). Like the other sarcomas, they generally appear isointense on T1-weighted images, hyperintense on T2-weighted images, and show varying degrees of nonhomogeneous contrast enhancement depending on their exact composition and presence of necrosis or hemorrhage (60).

Primary cardiac lymphoma.—Primary cardiac lymphomas are a rare entity, and cardiac metastases from extracardiac forms of lymphoma are far more common (approximately 25% of patients with lymphoma have cardiac involvement) (6). Nearly all primary cardiac lymphomas are aggressive B-cell lymphomas and they predominantly occur in immunocompromised patients, especially those with HIV infection (Fig 12) (81). They most commonly involve the right side of the heart, particularly the right atrium, but any chamber can be involved and there are frequently multiple lesions (Figs 6, 12) (Movie 7 [online]). There is often pericardial invasion accompanied by large pericardial effusions. Presentation is with rapidly progressive cardiac failure, obstructive symptoms, arrhythmias, or tamponade. By the time of presentation they are usually large, with extensive nodular infiltration of the myocardium (82). Prognosis is invariably poor although there have been reported remissions with early diagnosis and chemotherapy (83). Unlike other malignant tumors, such as sarcomas, lymphomas generally lack regions of central necrosis and hemorrhage (18). As a result, lymphomas are typically homogeneous and isointense on T1- and T2-weighted images, which can be a useful discriminating feature (Fig 12, Table 2) (84,85). Similarly, unlike other malignant tumors, there is generally minimal contrast agent uptake at LGE (18,31). The T1-weighted transaxial stacks should be carefully examined for mediastinal lymph nodes to identify extracardiac involvement and for the purpose of biopsy targets.
Cardiac metastases.—Cardiac metastases are 20–40 times more common than primary cardiac tumors (7). Most patients have no cardiac symptoms and the metastases are discovered at postmortem. In autopsy series, 10%–12% of patients with a primary neoplasm are found to have cardiac metastases (86,87). The most common malignancies to spread to the heart are lung and breast cancers, lymphoma, and malignant melanoma. Metastatic spread to the heart can occur by direct invasion (lung, breast, esophagus), hematogenous (melanoma, lymphoma, leukemia), transvenous via the great veins (renal cell carcinoma, hepatoma), or via mediastinal lymphatics. The most common site of involvement is the pericardium (usually from direct invasion or lymphatic spread) and malignant pericardial effusions are the most common consequence of cardiac metastasis (87). Usually, hemorrhagic and exudative pericardial effusions have high signal intensity on T1-weighted images, whereas benign transudates have low signal intensity. Intramural myocardial metastases tend to be the result of hematogenous spread from melanoma or lymphoma. Transvenous spread leads to intracardiac metastases, such as in the right atrium from renal cell carcinoma via the inferior vena cava. Although cardiac metastases do not have any specific appearances, they generally have low signal intensity on T1-weighted images and high signal intensity on T2-weighted images (Fig 13, Table 2)—with the exception of melanoma metastases, which may appear bright on T1-weighted images, because the amount of melanin pigment directly affects the signal intensity (88,89). The uptake of contrast material in metastases is usually heterogeneous (Fig 13).

Future Developments

As MR imaging continues to develop, further improvements in the characterization of cardiac masses can be expected, for example with T1 and T2 mapping techniques. In parallel, the concept of multimodality imaging by synergizing the advantages of different techniques is continuing and has already led to the development of combined PET/MR imagers, allowing combined high-sensitivity molecular imaging with high soft-tissue contrast and spectroscopic information (90). Beside the potential benefits in myocardial perfusion imaging and assessment of viability, PET/MR might have an important impact on the exact localization and differentiation of tumors.


8. Gupta S, Plein S, Greenwood JP. The cusp–mucoid ridge: an important example of a left atrial pseudotumour demonstrated by planes, superior tissue contrast, and advanced tissue characterization. Cardiac MR imaging features reliably detect thrombus and have been shown to accurately differentiate between benign and malignant tumors. A core protocol of MR sequences as described in this review allows the morphology, anatomy, tissue characteristics, and functional impact of a suspected tumor to be assessed in a single examination.

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References


Conclusion

Although cardiac tumors are rare, they can lead to serious complications, such as intracardiac obstruction and fatal arrhythmias, even when benign. Most cardiac masses are initially detected with echocardiography but cardiac MR imaging is becoming an established method for their further assessment. Cardiac MR imaging provides versatile imaging techniques to diagnose, characterize, and monitor cardiac masses.

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