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Cardiovascular Magnetic Resonance of Primary Tumors of the Heart: A Review

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ABSTRACT

Overall, the prevalence of primary cardiac neoplasms is approximately 0.3% and these masses should be distinguished from the myriad of other primary and secondary processes that can occur in the heart. Tumors within, attached to, or near the heart can cause direct cardiac damage, can result in thrombus formation, can compromise blood flow and can embolize distally. Hence, proper diagnosis is clinically important. It has been suggested that cardiovascular magnetic resonance (CMR) imaging is a useful tool for diagnosing and characterizing cardiac tumors. In this report, we present a case example of a patient with a large, mobile right atrial myxoma imaged by CMR with results of histopathologic analysis after excision. We also demonstrate the utilization of CMR for characterization of cardiac lesions, review the basic characteristics of primary cardiac neoplasms, provide an overview of published cases describing use of CMR, and give suggested guidelines for imaging of cardiac masses with emphasis on diagnosis of cardiac tumors. CMR is an important technique for diagnosing and characterizing cardiac tumors.

CASE EXAMPLE

Overall, at our institution between May 13, 2003 and June 1, 2005, a total of 776 referrals were made for clinical cardiovascular magnetic resonance (CMR) scans with 40 (5%) having an indication to rule out cardiac mass.

We studied CMR in an asymptomatic 66-year-old male scheduled to undergo a routine treadmill test as part of an initial evaluation by a cardiologist/internist. In addition to hypertension, the other coronary risk factors were age, gender, and a family history of early coronary disease. The physician performed a resting echocardiogram prior to treadmill test, which revealed a large mass in the right atrium. The treadmill test was cancelled, and the patient was referred for CMR for further characterization of the lesion.

CMR protocol performed is shown in Fig. 1. Electrocardiographic gating and breathhold acquisitions were used for all images. Axial half-Fourier acquisition single-shot turbo spin echo (HASTE) images continuous throughout the thorax (parameters: FOV 350 × 260 mm, matrix 256 × 184, TE 17 msec, TR 714 msec, slice thickness 7 mm) were acquired. These images revealed a tumor within the right atrium. The mass was 6 × 7 × 5.5 cm, lobulated, pedunculated, and attached by a small stalk to the free wall of the right atrium and to the interatrial septum. The mass had heterogeneous intensities on T1- and T2-weighted imaging. Right and left ventricles as well as the left atrium were normal. Cine images were acquired using a steady-state free precession (SSFP) pulse sequence (parameters: FOV 350 × 260 mm, matrix 256 × 184, TE 1.51 msec, TR 3.1 msec, slice thickness 7 mm). The mass was freely mobile, extended into the inferior vena cava during systole, and partially prolapsed through the tricuspid valve during diastole, as shown in Fig. 2. Gadolinium was injected (0.1 mmoles/kg) to evaluate for enhancement within the mass using inversion recovery SSFP imaging (parameters: FOV 350 × 260 mm, matrix 192 × 128, TE 17 msec, TR 714 msec, TI 290 msec, slice thickness 7 mm) so as to differentiate neoplasm from thrombus. Post-contrast

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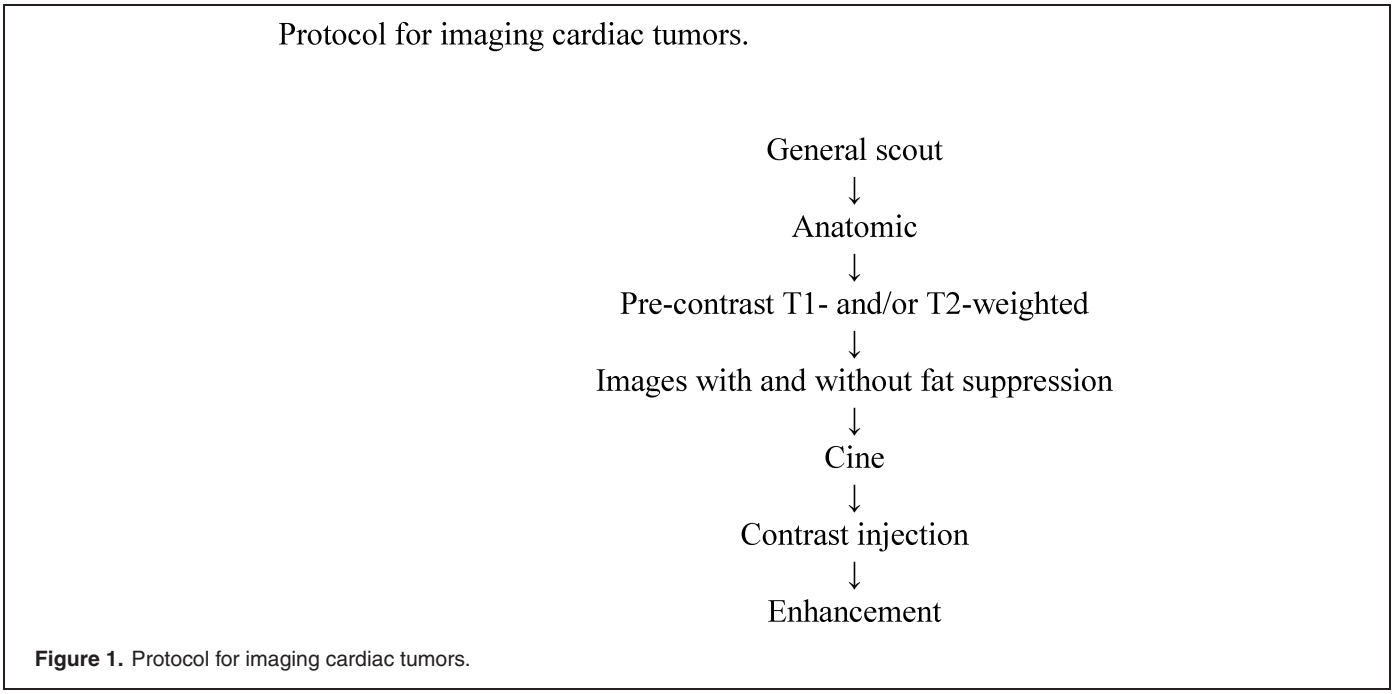

Figure 1. Protocol for imaging cardiac tumors.

images revealed enhancement of the atrial mass, as shown in Fig. 3. These findings were all consistent with diagnosis of myxoma. Late gadolinium enhancement images demonstrated no evidence of prior left ventricular myocardial infarction.

Due to the risk associated with a stress test in the setting of a large atrial mass, coronary angiography was performed that revealed normal coronary arteries and,four days later, the patient underwent atrial mass resection through a median sternotomy. A 70 g multilobular tan-pink to dark purple mass was removed without incident (Fig. 4a). The cut surface of the specimen (Fig. 4b) showed tan-pink focal hemorrhage with fibrosis, calcification and areas of coagulative necrosis. Hematoxylin and eosin stained sections revealed myxoma cells in short cords (Fig. 5a) with an intense lymphocytic infiltrate near the surface (Fig. 5b). A large portion of the mass showed fibrosis with deposition of iron pigments (gamna-gandy bodies, Fig. 5c) and small

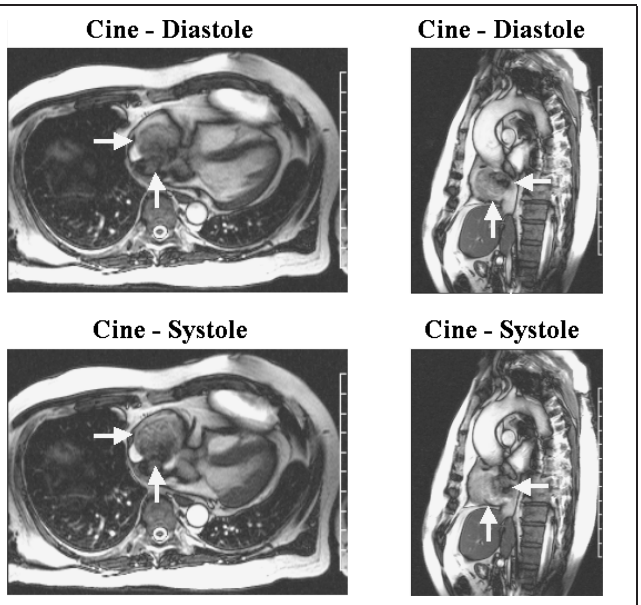

Figure 2. Aortic outflow long-axis and para-sagittal cine CMR showing a pedunculated right atrial mass with two attachments within the right atrium: septum and lateral free wall. The mass also partially enters the inferior vena cava during the cardiac cycle.

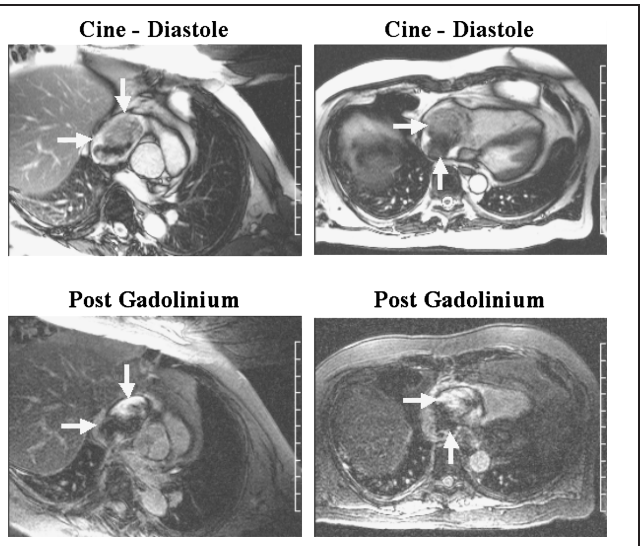

Figure 3. Four-chamber long-axis and short-axis cine CMR (top row) showing partial prolapse of the mass into the right ventricle during the cardiac cycle. Late gadolinium enhancement at corresponding slice positions shows uptake of gadolinium.

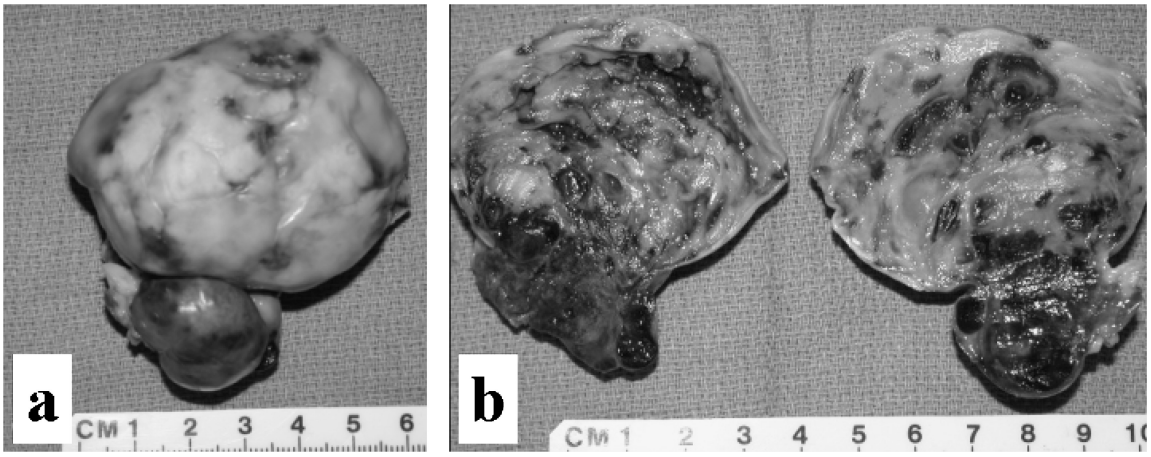

Figure 4. Photograph of myxoma taken at pathology before (left, a) and after (right, b) bisecting the structure.

foci of ossification. These findings were characteristic of a right atrial myxoma (1). The post-operative course was uneventful and the patient returned to full function after 6 weeks.

In this patient, CMR was useful for characterization of the mass and for defining points of attachment. CMR avoided the need for a transesophageal echocardiogram that might have been contemplated prior to operation.

REVIEW OF CARDIAC TUMORS

Cardiac tumors represent a rare but important cause of morbidity and mortality in clinical cardiology and a challenge in diagnostic cardiac imaging (2). The differential diagnosis for cardiac masses is broad and includes primary or secondary neoplasms, thrombus, vegetation, or congenital anatomic abnormality, among other conditions (Table 1). The term cardiac tumor refers specifically to primary cardiac neoplasms and will be the focus of this report (Tables 2 and 3). Establishing whether a given patient has a cardiac tumor is important because these tumors can be lethal if left untreated and cured if excised expeditiously when doing so is indicated (3). The prevalence of primary cardiac tumors is between 0.001 and 0.3%, making them a relatively rare diagnosis (2, 4–6). However, secondary tumors of the heart, due either to distant metastasis or local invasion from chest neoplasm, are at least 20 times more common than primary neoplasm resulting in a larger percentage of patients that have metastatic cancer demonstrating either myocardial or pericardial involvement according to autopsy studies (7–13). Hence, although primary cardiac tumors are rare, the occurrence of primary or secondary neoplasms within the heart is clinically relevant. Therefore, as treatment for different types of cardiac masses differs greatly, it is important to distinguish primary cardiac tumors from other masses that can occur in the heart (Table 1). Although it was previously accepted that the majority of cardiac tumors were discovered at autopsy, modern advances in cardiac imaging have resulted in an increased awareness of masses in or related to the heart, further emphasizing the need for appropriate diagnosis and, where indicated, prompt treatment (5, 8, 9, 14–19).

Table 1. Differential diagnosis of cardiac masses (compiled based on references cited in text)

Cardiac Masses
Cardiac tumor = Primary cardiac neoplasm
Secondary cardiac neoplasm
Thrombus
Vegetation
Abscess
Anatomic variant
(e.g., prominent vein orifice, cardiac varix, pulmonary vein enlargement, Crista terminalis, etc.)
Inflammatory myofibroblastic tumor (also known as inflammatory pseudotumor)
Focal hypertrophy
Rheumatoid nodule
Thrombus within ventricular aneurysm
Intramyocardial hematoma
Non-cardiac tumor (e.g., bronchogenic cyst)
Diaphragmatic hernia
Pericardial Cyst
Lipomatous hypertrophy

Cardiac tumors can lead to a variety of clinical manifestations and/or imaging findings that can be confused with non-neoplastic etiologies such as thrombus (see Fig. 6), bacterial endocarditis vegetations, abscesses, myocarditis, cardiomyopathy, congenital heart disease, pericardial cysts, bronchogenic cysts, diaphragmatic hernias and rheumatic lesions (20). Therefore, accurate diagnosis is important for treatment of patients with suspicious clinical or radiographic findings. Cardiac tumors can be broadly classified according to histopathological subtype (i.e., benign versus malignant), morphology (i.e., pedunculated versus sessile, lobulated, etc.), by location (i.e., juxtacardiac, pericardial, myocardial, intracardiac), and by whether they affect cardiopulmonary blood flow (i.e., obstructive versus non-obstructive). In this review article, cardiac tumors will be

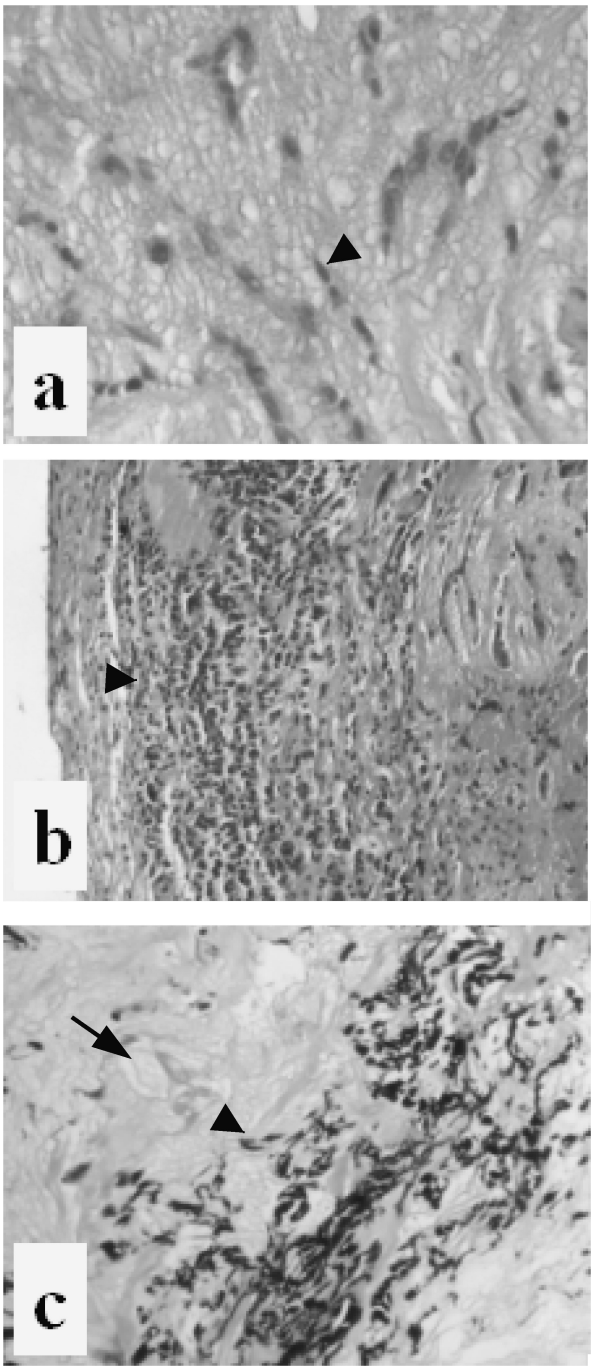

Figure 5. Hematoxylin and eosin stained sections of myxoma showing (top, a) myxoma cells in short cords at the center of the mass, intense lymphocytic infiltrate near the surface (middle, b), and, in general, a large amount of fibrosis with deposition of iron pigments, so-called gamna-gandy bodies (bottom, c), with small foci of ossifications and stromal cells, all typical of and diagnostic for myxoma tumors.

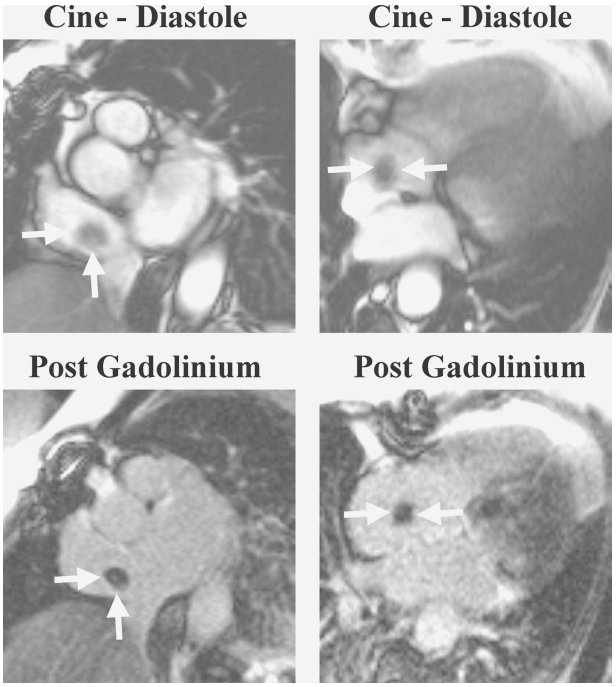

Figure 6. Cardiovascular MR images of a right atrial thrombus in short-axis (left) and 4 chamber long-axis (right) views acquired before (top) and after (bottom) gadolinium administration. Comparison of pre- versus post-contrast images shows no enhancement of the thrombus (arrows).

classified by underlying tissue histology with consideration to other factors (location, morphology, flow limitation, etc.) as they pertain to non-invasive diagnosis.

Benign cardiac tumors comprise approximately 75% of all primary cardiac neoplasms and include (in order of approximate decreasing occurrence) myxomas (see Fig. 2-5), rhabdomyomas (see Fig. 7), fibromas (see Fig. 8), papillary fibroelastomas (see Fig. 9), teratomas (these tumors can also demonstrate malignant features), hemangiomas (21) and lipomas (18, 22–26). Table 2 summarizes features of these tumors. Rare benign tumors of the heart include cystic tumor of the atrioventricular node (also known as polycystic tumor), hamartoma (Fig. 10; this tumor is also known as Purkinje tumor), plasma cell granuloma, neurilemoma (a type of schwannoma), pheochromocytoma (which is a type of paraganglioma and can also be malignant), gastrinoma (this tumor can also be malignant) and histiocytoid tumors (27–47).

Myxomas comprise approximately 50% of primary cardiac tumors and tend to occur inside of the heart chambers (4). Approximately 75% of myxomas are located within the left atrium and occur in association with the fossa ovalis, though right atrial and ventricular myxomas also occur (Fig. 2 and 3). Myxoma tumors tend to be polypoid or oval and consist of collections of stromal cells, variable degrees of hemorrhage, and often have a lymphocytic infiltrate in their border. Myxomas frequently have highly vascular stalks, and the tumors themselves may prolapse into different chambers during the cardiac cycle. Myxomas predispose to turbulent blood flow and have been noted to be a nidus for thrombosis and/or bacterial growth; several cases of distal

Table 2. Typical histopathologic characteristics of common cardiac tumors (compiled based on references cited in text)

Tumor	Type	Size/Location	Number	Histology	Associations
Myxoma	Benign	5-6 cm/Left atrium	Single	Spindle cells	Carney complex
Rhabdomyoma	Benign	2 cm/Myocardium	Multiple	Spider cells	Tuberous sclerosis
Fibroma	Benign	3-10 cm/Myocardium	Single	Connective tissue	Gorlin syndrome
Papillary fibroelastoma	Benign	<1 cm/Valve	Single	Connective tissue	Generalized inflammation
Teratoma	Usually Benign	Varies/Right heart or septum	Single	Three germ-cell layers	None
Hemangioma	Benign	2-4 cm/Varies	Single	Endothelial cells	None
Lipoma	Benign	Varies/Myocardial	Single	Adipose	None
Sarcoma	Malignant	Varies/Right heart	Single	Varied	AIDS
Lymphoma	Malignant	Varies/Varies	Single	Reed-Sternberg cells	AIDS

thrombus and septic embolism have been related directly to cardiac myxomas (4). Myxomas can grow quite large (Fig. 2–4) and are capable of obstructing blood flow in the cardiopulmonary system. Cardiac myxomas may occur in association with the Carney complex, which refers to an autosomal dominant syndrome consisting of cardiac myxomas, pigmented skin lesions, endocrine tumors, and schwannomas (10, 48, 49).

Rhabdomyomas occur most frequently in children, comprise 20% of primary cardiac tumors, are located within the interventricular septal myocardium, occur as several small tumors, and are composed of benign spider cells, which are large polygonal cells that contain myofibrils (5, 17, 50) (Fig. 7). Rhabdomyomas are associated with tuberous sclerosis and may be caused by a defect in cellular apoptosis. Like rhabdomyomas, fibromas also originate within the myocardium but tend to occur in the free ventricular wall and are composed of fibrous connective tissue that may calcify and demonstrate characteristic whorls under light microscopy (51, 52). The Gorlin syndrome is associated with fibromas and is an autosomal dominant disorder that also includes basal cell carcinomas, medulloblastomas, and fibrous histiocytomas. Papillary fibroelastomas are small, fibrous tumors usually associated with the aortic or mitral valve that have frond-like arms emanating from a central core and may be caused by inflammation (53). Teratomas are mixed tumors that arise from all three germ lines and tend to occur in the right heart (5, 17). Of note, 20% of teratomas have malignant features. Hemangiomas are small to moderate sized collections of endothelial cells that often contain areas of hemorrhage (38, 54, 55). Lipomas are relatively common benign tumors of the heart characterized by accumulations of poorly encapsulated fat cells. Lipomas are most commonly interposed between cardiac chambers but can be located intramurally; some case reports of pedunculated lipomas have suggested they can mimic myxomas (56–58).

Regardless of underlying tissue histology, even benign masses can cause significant hemodynamic impairment and sudden cardiac death (17, 59, 60). Histologically non-malignant tumors can be located in an area of the heart that is predisposed to impaired filling, reduced cardiac output, valvular stenosis and/or regurgitation, turbulent blood flow, and increased potential for arrhythmia and/or distal embolization. Therefore, identification and characterization of benign masses is clinically important.

Malignant primary cardiac tumors exhibit invasive local tissue characteristics and/or tend to metastasize and account for

Table 3. Typical CMR characteristics of various cardiac tumors (compiled based on references cited in text)

Tumor	Anatomy	T1/T2	Cine	Base	Enhancement
Myxoma	Within chamber	Heterogeneous/ Bright	±Mobile	Usually Pedunculated	±
Rhabdomyoma	Intramural; multiple masses	Homogeneous/ Bright	—	N/A	±
Fibroma	Next to aortic or mitral valve	Homogeneous/ Dark	±Mobile	Sessile	+
Papillary Fibroelastoma	Intramural	Homogeneous/ Dark	—	Sessile	+
Teratoma	Intramural	Heterogeneous/ Heterogeneous	—	N/A	±
Hemangioma	Intramural	Homogeneous/ Bright	—	N/A	+
Lipoma	Intramural; disappears with fat suppression	Homogeneous/ Dark	Varied	Sessile or Pedunculated	None
Sarcoma	Varies	Heterogeneous/ Heterogeneous	Varied	N/A	±
Lymphoma	Varies	Homogeneous/ Bright	Varied	Sessile	+

T1/T2 indicates T1- and T2-weighted imaged acquired prior to contrast administration. Bright, dark, homogeneous, and heterogeneous indicate relative intensities of cardiac tumors in comparison to remote myocardial tissue. Cine indicates whether the mass is mobile independent of the rest of the myocardium on gated cine images. The symbol ± indicates the result may or may not be present in a given patient.

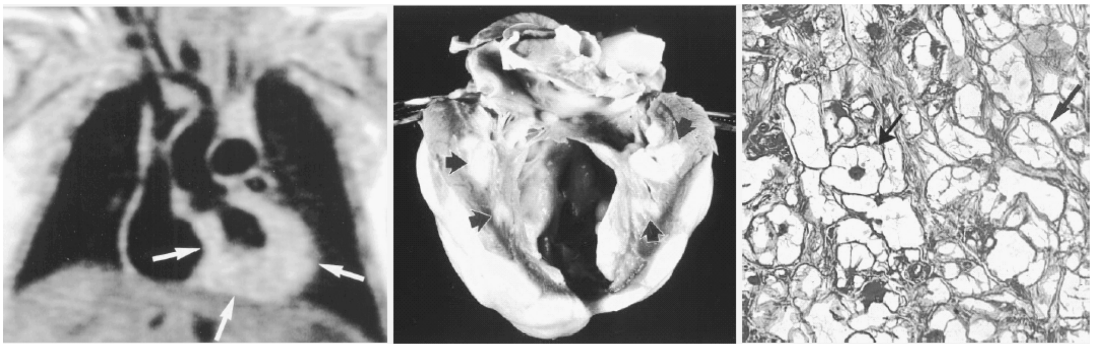

Figure 7. Coronal T1-weighted cardiac MR image (left) of an infant with a rhabdomyoma showing severe thickening of the left ventricular free wall and septum (white arrows). Gross pathology (middle) showed multiple white nodules (black thick arrow) within the myocardium and microscopic histopathology (right, hematoxylin and eosin stain) revealed typical vacuolated cells with cyoplasmic streaming (thin black arrows, "spider cells") characteristic of rhabdomyoma. (Reproduced with permission from Grebenc, et al. *Radiographics*, 2000;20:1073–103.)

approximately 25% of all primary cardiac neoplasms (17). These tumors are clinically more aggressive than benign tumors and may lead to rapid development of heart failure, bloody pericardial effusion, tamponade, superior vena cava syndrome and arrhythmias. Histologically, the majority of malignant primary cardiac tumors are sarcomas (Fig. 11) and lymphomas (Fig. 12); rare malignant neoplasms of the heart include fibrous histiocytomas, osteosarcomas, chondrosarcoma, fibrosarcomas, synovial sarcoma, neurofibrosarcoma, lymphosarcoma, myxosarcoma, reticulum cell sarcoma, undifferentiated sarcoma, and hemangiopericytoma (17, 41, 51, 61–70). Approximately 95% of primary malignant cardiac neoplasms are sarcomas, with the majority of these being angiosarcomas that frequently occur in the right heart and are associated with hemopericardium (71). In general, primary sarcomas of the heart include angiosarcomas, leiomyosarcomas, rhabdomyosarcomas, and liposarcomas (72). Of note, primary cardiac liposarcoma has been documented in several case reports (73–78), and it is important to distinguish this tumor from benign lipomas. Malignant neoplasms of the heart may metastasize by local spread within the thorax or metastasize distantly, most commonly to the spine (41, 51, 61–68). Approximately 50% of right atrial tumors overall have sarcoma histology. Kaposi's sarcoma, seen most often in patients with acquired immunodeficiency syndrome (AIDS), may involve the heart in 12 to 28% of immunocompromized patients (79,80). AIDS can also result in high-grade B-cell lymphomas that occur in the heart (81–84).

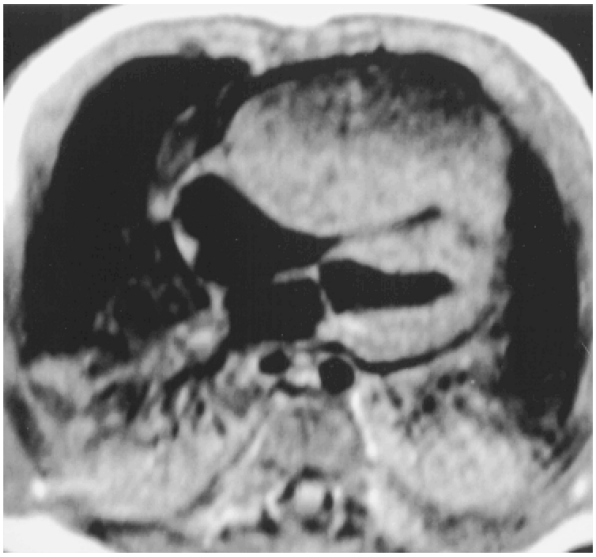

Figure 8. Axial T1-weighted image of a cardiac fibroma associated with the anterior wall of the right ventricle in a newborn. (Reproduced with permission from Grebenc, et al. *Radiographics*, 2000;20:1073–103.)

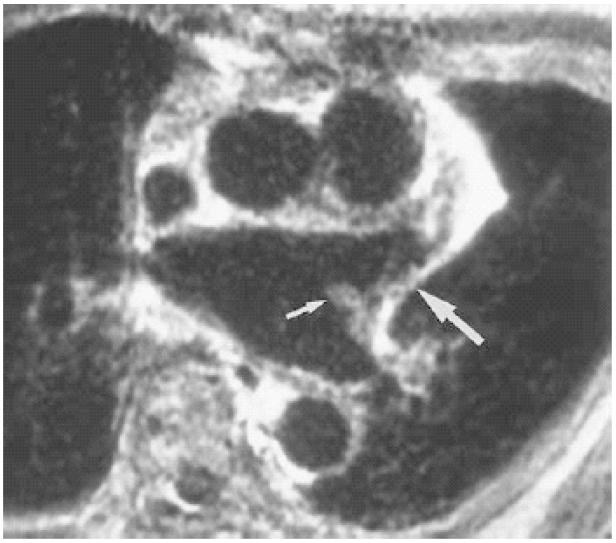

Figure 9. T1-weighted MR image of a left atrial fibroelastoma (arrows) located near the left atrial appendage. (Reproduced with permission from Araoz, et al. *Radiographics*, 1999;19:1421–34.)

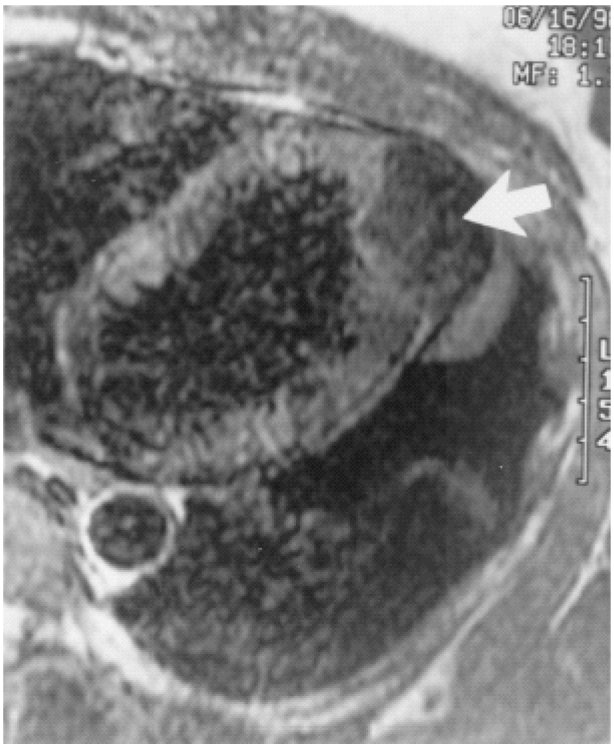

Figure 10. T2-weighted MR image of a cardiac hamartoma (arrow) in the left ventricle measuring $4.5 \times 3.1 \times 4.4$ cm. (Reproduced with permission from Dinh, et al. *Annals of Thoracic Surgery*, 2001;71:1673–5.)

CMR DIAGNOSIS OF CARDIAC TUMORS

Antemortem diagnosis of cardiac tumors was first reported in the 1930s based on physical examination, and the first cardiac tumor was directly imaged in vivo by contrast cardiac angiography in 1952 (3). Today, diagnosis of cardiac tumors has become more standardized. Commonly employed methods for visualizing cardiac tumors include plain film chest x-rays, echocardiography, multi-gated acquisition blood pool scintigraphy, cardiac catheterization, computed tomography (CT), and CMR imaging (85–93). CT and CMR may be useful for diagnosis and characterization of cardiac masses and may be helpful where echocardiographic results are in question. CMR does not suffer from limited imaging windows or require ionizing radiation and, therefore, some investigators have suggested that CMR is the preferred diagnostic modality for evaluation of cardiac tumors (14–16, 89, 94–96).

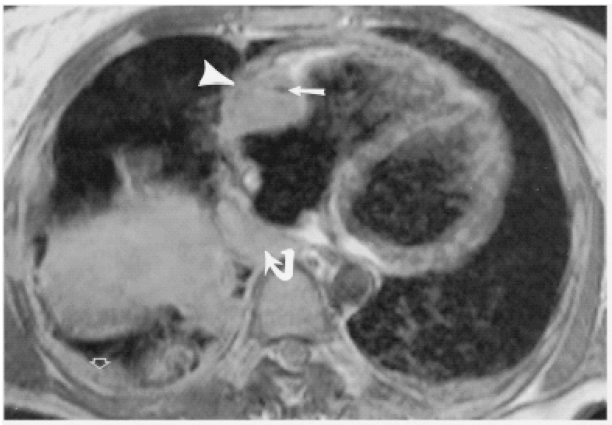

Figure 11. T2-weighted image of a primary cardiac hemangiosarcoma of the right atrium (arrowhead) associated with the right coronary artery (small arrow) and a hemorrhagic pericardial effusion (curved arrow). (Reproduced with permission from Hoffman, et al. *American Journal of Cardiology*, 2003;92:890–5.)

CMR has been used by to image cardiac tumors since the mid 1980s (50, 97–101). Initial reports used single-phase diastolic electrocardiogram-gated (ECG-gated) spin echo images to anatomically characterize structures in the heart (102). Advances in imaging techniques and contrast-enhanced CMR have increased the diagnostic information obtainable in a single examination.

Cardiac myxomas are described in multiple CMR case reports (85, 100, 103–119). Also reported are other less commonly encountered tumors, including: rhabdomyoma, (50, 120–127). fibroelastoma, (53,128) fibroma, (129–132) pheochromocytoma (27, 28, 133–146) hemangioma (37, 54, 55, 147–151), lipoma, (152, 153), mesothelioma (91, 154–156), teratoma (157–159), sarcoma (14, 63, 65, 71, 87, 160–175), lymphoma (14, 81–84, 176–189) as well as several other rare tumors (8, 31, 190–198).

Several case series of patients with cardiac tumors that have been imaged by CMR have been presented. Lund and colleagues performed CMR in 61 patients with suspected cardiac masses and noted that MR imaging provided important diagnostic information that altered clinical management in 53 patients (87%) (176). Sommer and colleagues studied 15 patients by CMR who had echocardiographic findings suspicious for cardiac tumor (199). In this study, T1-weighted, T2-weighted, and cine CMR tumor was used to distinguished tumor from thrombus. Further, tumors were categorized as to whether they were likely to be myxoma versus sarcoma and compared to pathologic analysis of the resected mass. These investigators concluded that myxomas demonstrated several characteristic features on CMR: close relationship to the interatrial septum, high signal intensity on T2-weighted images, and contrast enhancement following gadolinium injection. Funari and Higgins also noted that contrast material aided in diagnosis of cardiac tumors, especially when tissue characteristics of tumor and myocardium were similar before contrast and the tumor was located within the myocardium (200). Paydarfar and colleagues studied 15 patients prior to open heart surgery and noted differential late gadolinium enhancement patterns between avascular thrombi and myxomas within the cardiac chambers, thus providing further basis for distinguishing cardiac masses based on CMR (201). One particularly important application of CMR is distinguishing pericardial cysts from cardiac neoplasms. Pericardial cysts are common, benign, fluid-filled, thin-walled sacs that are lined by epithelial cells and usually occur as one area attached to the pericardium (5). Cysts are often mobile and, while the epithelial lining may enhance

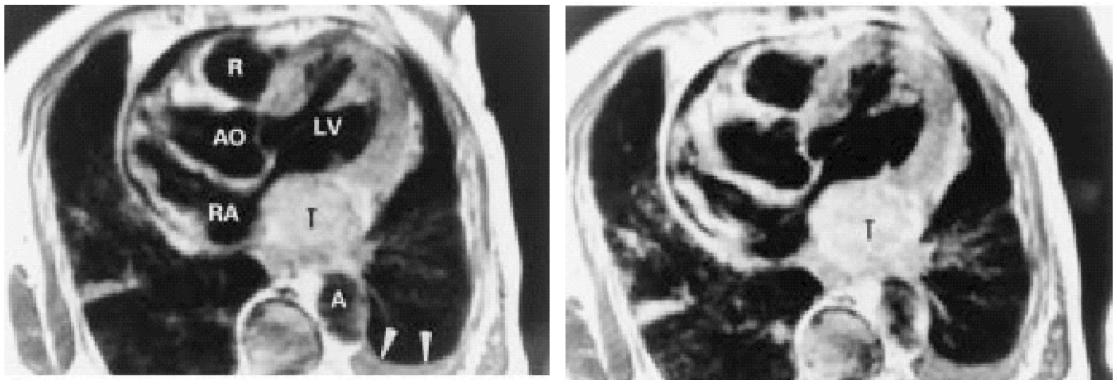

Figure 12. Axial T1-weighted spin-echo cardiovascular MR images of a malignant cardiac lymphoma (labeled "T") of the left atrium before (left) and after (right) administration of gadolinium contrast agent, which revealed vascularity within the tumor. T = tumor, LV = left ventricle, Ao = aorta, RA = right atrium, A = descending aorta (Reproduced with permission from Hoffman, et al. *European Heart Journal*, 1998;19:553–63.)

following contrast injection, the fluid-filled center of a cyst does not typically demonstrate enhancement on CMR images.

Further studies have been conducted to examine the utility of CMR to guide patient management. Grebenc et al. studied 83 patients with myxomas using CT and CMR and suggested that cine imaging in the appropriate orientations provided assessments of the size, location, and point of attachment of a given tumor, all of which were useful for surgical planning (90). Siripornpitak et al. studied CMR characteristics of malignant cardiac neoplasms in 7 patients and suggested that these masses had several important features: wide-based attachment to the myocardium, large size, invasion into more than one cardiac chamber, and central necrosis evidenced by different soft tissue characteristics within the mass (60). Kaminaga et al. studied 25 patients with various benign and malignant primary cardiac neoplasms using CMR and transthoracic echocardiography and found that ECG-gated T1- and T2-weighted imaging before and after gadolinium injection was useful in detection and delineation of tumors in all cases (14). Hoffman et al. studied 55 patients with cardiac masses and suggested that CMR characteristics were useful for distinguishing benign from malignant tumor (area under receiver operator curve was 0.90) based on tumor location, tissue characteristics, and presence of pericardial effusion (202). Finally, Gulatti et al. studied echocardiography and CMR in 28 patient with suspected intracardiac tumors and concluded that: CMR diagnosed masses missed by echocardiography: CMR was more often technically adequate than echocardiography; and CMR was able to correctly distinguish tumor from thrombus (or other vascular lesion) more frequently than echocardiography (75% versus 29% of cases, respectively) in this population (95). These studies provide an important foundation for using CMR as a tool to diagnose and characterize cardiac tumors.

CMR PROTOCOL FOR CARDIAC TUMORS

While the exact CMR protocol that should be used for diagnosis and characterization of cardiac tumors is unclear, the evidence cited above as well as the experience of several centers points to several important parts of an examination. The recommendations for imaging protocols that are provided here come from those found in review articles (4, 16, 56, 59, 60, 68, 86, 163, 202–211) rather than in-depth comparisons of different CMR techniques in a select population with cardiac tumors. Hence, protocols should be tailored to specific patients and may change based on results of future studies. A suggested protocol for acquiring CMR images in patients referred for diagnosis and characterization of cardiac tumors is outlined in Fig. 1. The exact details of particular pulse sequences to image cardiac tumors is covered in the articles referenced within this manuscript.

The CMR protocol for obtaining information relevant to diagnosis of cardiac tumors consists of anatomic tissue characterization, cine for function, and contrast-enhanced imaging for assessment of vascularity. CMR images are improved with use of accurate ECG gating, breathhold and/or multi-averaged imaging (with or without anesthesia, as indicated), patient cooperation, and technical expertise. Following standard coronal, sagital, and axial scout images, breath-held anatomic CMR images of the entire heart and pericardium can be acquired with a variety of techniques (spin echo, fast low angle shot gradient echo, steady state free precession, etc.) in order to fully anatomically characterize both atria, both ventricles, the valves with their respective inflow and outflow tracts, the pericardium, and structures adjacent to the heart. Images should be acquired with satisfactory in-plane and slice thickness dimensions (e.g., voxel size of $1.5 \times 1.5 \times 10$ mm) and should be continuous through the heart and pericardium. If necessary, these images can be acquired over several separate breath-hold acquisitions. Tesoro-Tess and colleagues studied 36 patients with lymphoma and noted that cardiac involvement was common, occurring in 64% of patients, and was more frequently noted on CMR than on echocardiography, emphasizing the importance of high resolution anatomic imaging (184).

Following anatomic images, tissue characterization can be performed with various T1- and T2-weighted images with or without fat saturation. These images may through the entire

volume of the heart or, depending on the quality of the initial anatomic data set, through the mass of interest, if identified. T1- and T2-weighted images are most often used to assess the overall tissue heterogeneity and degree of inflammation and fluid content, respectively, and can be acquired using several pulse sequences (spin echo, steady state free precession, etc.). One relatively commonly employed pulse sequence for T2-weighted CMR imaging is short-inversion-time inversion-recovery (STIR) imaging, which imparts T2 contrast based on a preparation consisting of several short inversion pulses prior to image read-out and demonstrates minimal fat signal (212). Following pre-contrast T1- and T2-weighted image acquisition, images with and without fat suppression pulses should be obtained so that regions of interest that may contain fat may be identified and considered (213, 214).

After tissue characterization, cine images of the entire heart in long- and short-axis views (with other non-standard views to characterize any observed masses, as indicated) should be acquired to ascertain whether a given mass is fixed or freely mobile, and, if mobile, whether it prolapses into other cardiac structures (chambers, valves, veins, outflow tracts, etc.). As with anatomic images, cine images should be acquired such that the entire volume of interest can be considered with sufficient in-plane and slice thickness resolution based on tumor size (Table 2.) Where possible, breath-hold techniques are favored when patients are able; however, in cases where patients cannot hold their breath, imaging may be facilitated by multi-averaged or real-time techniques, as emphasized by Spuentrup and colleagues (215). In addition, it may be that there are areas of the heart where it is unclear whether intramyocardial thickening represents tumor versus myocardium; in cases such as these, Bergey and colleagues noted that cine imaging with myocardial tagging to examine intramyocardial strain patterns may be useful to distinguish between asymmetric myocardial hypertrophy from cardiac tumor (216).

Following functional assessment, gadolinium injection can be used to assess vascularity of the lesion. Necrosis in a tumor can be assessed following gadolinium contrast injection using standard inversion recovery late gadolinium enhancement sequences throughout the region of interest. In cases where tumors may have outgrown their blood supply and thus have underlying tissue necrosis, delayed enhancement imaging may be useful to demonstrate centrally located nonviable tissue or hemorrhage. Semelka studied 15 patients with masses (in 11, tissue was obtained with histopathologic diagnosis) and found that myxomas tended to show low signal intensity on gradient-echo imaging and enhance after gadolinium injection while thrombus showed the opposite findings (54). Matsuoka and colleagues studied four patients with biopsy proven atrial myxomas by pre- and post-contrast T1-weighted CMR and noted that enhancement occurred in post-gadolinium images that matched regions of inflammation on pathologic specimens (217). Alternatively, another approach for distinguishing thrombus from cardiac neoplasm is the use of an inversion recovery (TI) scouting sequence, where thrombus is expected to have a long T1 while tumor would be expected to have a relatively shorter T1. Of note, investigators have documented late gadolinium enhancement in primary cardiac lymphoma (218).

Successful imaging of cardiac tumors depends on several factors, including the experience of the CMR center in acquiring and interpreting images. A thorough knowledge of normal cardiac anatomy on CMR images is therefore required. For interpretation, knowledge of the various characteristics of cardiac tumors as they are seen on CMR images is essential. (See Table 3.) Interpretation of studies should begin with an attempt to discern the location, morphology and extent of any findings suspicious for cardiac tumors. After consideration of anatomy and soft tissue characteristics, cardiac function and the effects of the lesion on function should be carefully evaluated with emphasis on valves, constriction of other cardiac structures, and local wall motion abnormalities. Imaging post-contrast may reveal information about tumor vascularity, evidence of nonviable tissues, and aids in distinguishing mass from thrombus.

CONCLUSION

The ability to correctly diagnose a mass associated with the heart prior to pathologic diagnosis at resection is a challenge in modern clinical cardiac imaging. Despite considerable progress in CMR diagnosis of cardiac tumors, at present there are no definitive ways to diagnose every cardiac mass noninvasively. Important structural and functional information is available using present techniques of CMR. At present, CMR serves as a complementary role to echocardiography in evaluation of cardiac masses; as discussed by Wann et al. either technique can miss significant lesions (93). The outcome of patients with suspected or known cardiac tumors is dependent in part on detection and, if indicated, prompt treatment (195).

CMR offers several distinct advantages in diagnosing cardiac tumors including three-dimensional, multi-planar views and ability to obtain different types of information in one setting (e.g., anatomy, tissue characteristics, function, vascularity, etc.). CMR lacks ionizing radiation, nephrotoxic contrast agents, and imaging windows. CMR can distinguish both thrombotic and cystic structures from cardiac neoplams and offers superior tomographic characterization versus other imaging modalities. Disadvantages at present of CMR include long acquisition times for a single study, contraindication in patients with large body habitus, contraindication in patients have certain metallic implants (pacemakers, insulin pumps, etc.), necessity for skilled technical staff, dependence on ECG gating, and decreased availability compared to echocardiography.

CMR, applied correctly, is a useful technique for identifying and characterizing primary tumors of the heart.

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