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Value of CMR for the Differential Diagnosis of Cardiac Masses

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ABSTRACT

OBJECTIVES The goal of this study was to evaluate the diagnostic value of CMR features for the differential diagnosis of cardiac masses.

BACKGROUND Differentiation of cardiac tumors and thrombi and differentiation of benign from malignant cardiac neoplasms is often challenging but important in clinical practice. Studies assessing the value of cardiac magnetic resonance (CMR) in this regard are scarce.

METHODS We reviewed the CMR scans of patients with a definite cardiac thrombus or tumor. Mass characteristics on cine, T1-weighted turbo spin echo (T1w-TSE) and T2-weighted turbo spin echo (T2w-TSE), contrast first-pass perfusion (FPP), post-contrast inversion time (TI) scout, and late gadolinium enhancement (LGE) sequences were analyzed.

RESULTS There were 84 thrombi, 17 benign tumors, and 25 malignant tumors in 116 patients. Morphologically, thrombi were smaller (median area 1.6 vs. 8.5 cm^2; $p < 0.0001$), more homogeneous (99% vs. 46%; $p < 0.0001$), and less mobile (13% vs. 33%; $p = 0.007$) than tumors. Hyperintensity compared with normal myocardium on T2w-TSE, FPP, and LGE were more common in tumors than in thrombi (85% vs. 42%, 70% vs. 4%, and 71% vs. 5%, respectively; all $p < 0.0001$). A pattern of hyperintensity/isointensity (compared with normal myocardium) with short TI and hypointensity with long TI was very frequent in thrombi (94%), rare in tumors (2%), and had the highest accuracy (95%) for the differentiation of both entities. Regarding the characterization of neoplastic masses, malignant tumors were larger (median area 11.9 vs. 6.3 cm^2; $p = 0.006$) and more frequently exhibited FPP (84% vs. 47%; $p = 0.03$) and LGE (92% vs. 41%; $p = 0.001$). The ability of CMR features to distinguish benign from malignant neoplasms was moderate, with LGE showing the highest accuracy (79%).

CONCLUSIONS CMR features demonstrated excellent accuracy for the differentiation of cardiac thrombi from tumors and can be helpful for the distinction of benign versus malignant neoplasms. (J Am Coll Cardiol Img 2014;7:896–905) © 2014 by the American College of Cardiology Foundation.

Although cardiac tumors are rare entities (estimated prevalence at autopsy of 0.02% to 2.3%, and 0.15% in echocardiographic series) (1), their morbidity and mortality rates are high (2). Surgical removal is the treatment option in most cases, although satisfactory results occur only in benign types (3). Thrombi have a higher prevalence, ranging between 3% and 25% (4) and 2% and 50% (5–7) in patients with atrial fibrillation and left ventricular systolic dysfunction, respectively, and justify anticoagulation to prevent embolic events (8,9). Hence, proper differentiation among these entities remains imperative because both prognosis and therapeutic approach vary substantially.

Transthoracic 2-dimensional echocardiography is the most common imaging technique used for cardiac mass evaluation (10), but it is operator dependent, offers poor tissue characterization, and has acoustic window restrictions in a subset of patients. Transesophageal and 3-dimensional echocardiography may overcome some of these limitations (11,12). Computed tomography is also useful for the evaluation of tumors and thrombi (13), although at the expense of radiation exposure. As opposed to these modalities, cardiac magnetic resonance (CMR) has excellent contrast resolution that allows for superior soft tissue characterization. The combined evaluation of morphology, composition, and perfusion makes CMR a useful tool in the assessment of cardiac masses (14–18). However, studies testing the accuracy of CMR in this regard are scarce and have relatively small sample sizes (19–22). The aim of the present study was to determine the ability of CMR features of cardiac masses to differentiate thrombus

ABBREVIATIONS AND ACRONYMS

CMR = cardiac magnetic resonance

FPP = first-pass perfusion

LGE = late gadolinium enhancement

T1w-TSE = T1-weighted turbo spin echo

T2w-TSE = T2-weighted turbo spin echo

TI = inversion time

from tumor and benign from malignant neoplasms in a larger population.

METHODS

We retrospectively reviewed consecutive CMR examinations performed in patients with a definite mass in the heart (including the aortic and pulmonary roots) from January 2005 to March 2013 at Mount Sinai Hospital, New York. Definite thrombus was defined as a noninfiltrating structure that fulfilled any of the following classic criteria: 1) adjacent to an akinetic myocardial segment (often infarcted) or central venous catheter (without clinical signs or symptoms of infection); 2) located in the atrial appendage in patients with documented atrial fibrillation; 3) a significant size reduction occurred with anticoagulation therapy and confirmed on follow-up imaging; and 4) pathological confirmation.

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A mass was considered a definite tumor when it did not meet any of the aforementioned criteria and fulfilled any of the following: 1) was infiltrative (defined as ill-defined borders from normal myocardium and/or invasion of multiple cardiac or extracardiac structures); 2) had typical features of myxoma (noninfiltrating lesion attached to the left aspect of the fossa ovalis), septal lipomatosis (located in the interatrial septum with evident signal intensity reduction on a fat saturation black-blood sequence), or cyst (well circumscribed, spherical or ovoid shape, and high signal intensity on a T2-weighted sequence); and 3) had a pathological diagnosis.

Tumors were classified as malignant or benign on the basis of histology when available or otherwise on imaging characteristics different from the factors tested in the study: infiltrating neoplasms were considered malignant, whereas noninfiltrating tumors with typical features of myxoma, septal lipomatosis, or cyst were classified as benign (Online Figure 1). Clinical charts were reviewed for demographic and medical data collection. In patients undergoing surgery or biopsy, macroscopic and histological findings were also recorded.

CARDIAC MAGNETIC RESONANCE. CMR studies were performed on a 1.5-T (82%; Magnetom Sonata or Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany) or a 3.0-T (18%; Ingenuity, Philips Healthcare, Best, the Netherlands) magnets by using dedicated phased-array surface coils as receivers. Sequences were acquired during end-expiratory breath holds with electrocardiographic or pulse gating. Our typical protocol includes cine and black-blood imaging before contrast, followed

TABLE 1 Baseline Patient Characteristics

	Thrombus (n = 77)	Tumor (n = 39)	p Value	Benign Tumor (n = 16)	Malignant Tumor (n = 23)	p Value
Male	52/77 (68)	17/39 (44)	0.013	4/16 (25)	13/23 (57)	0.051
Age, yrs	58 ± 15	60 ± 15	0.85	60 ± 11	61 ± 18	0.9
Weight, kg	77 ± 17	79 ± 16	0.61	83 ± 15	75 ± 16	0.13
Atrial fibrillation	10/75 (13)	3/39 (8)	0.37	2/16 (13)	1/23 (4)	0.58
GFR, ml/min/1.73 m^2	82 ± 28	94 ± 37	0.39	79 ± 57	97 ± 35	0.54
Hypertension	44/77 (57)	18/38 (47)	0.32	9/15 (60)	9/23 (39)	0.21
Hyperlipidemia	38/77 (49)	13/38 (34)	0.12	8/15 (53)	5/23 (22)	0.045
Diabetes	23/77 (30)	9/38 (24)	0.49	5/15 (33)	4/23 (17)	0.44
Smoking history	23/77 (30)	12/38 (32)	0.85	3/15 (20)	9/23 (39)	0.29
Family history of CAD	14/77 (18)	5/38 (13)	0.5	4/15 (27)	1/23 (4)	0.069
Previous MI	45/76 (59)	1/39 (3)	<0.0001	0/16 (0)	1/23 (4)	0.50
Previous stroke or embolic event	7/73 (10)	4/37 (11)	0.84	3/14 (21)	1/23 (4)	0.14
Previous coronary revascularization	19/77 (25)	3/39 (8)	0.028	2/16 (13)	1/23 (4)	0.56
History of malignancy	15/77 (20)	18/39 (46)	0.03	2/16 (13)	16/23 (70)	<0.0001
Anticoagulation therapy	50/70 (71)	11/34 (32)	<0.0001	4/11 (36)	7/23 (30)	0.99
>1 CMR scan	10/77 (13)	5/39 (13)	0.98	1/16 (6)	4/23 (17)	0.63
Other imaging technique	65/76 (86)	33/38 (87)	0.92	13/15 (87)	20/23 (87)	0.62
LVEF, %	36 ± 16	60 ± 8	<0.0001	60 ± 8	59 ± 8	0.57
Myocardial scar	51/73 (70)	2/39 (5)	<0.0001	1/16 (6)	1/23 (4)	0.41
Pericardial effusion	15/77 (20)	14/39 (36)	0.054	2/16 (13)	12/23 (52)	0.011

Values are n/N (%) or mean ± SD.

CAD = coronary artery disease; CMR = cardiac magnetic resonance; GFR = glomerular filtration rate; LVEF = left ventricular ejection fraction; MI = myocardial infarction.

by first-pass perfusion (FPP), inversion time (TI) scout, and late gadolinium enhancement (LGE) imaging. Cine images were acquired in all patients and LGE sequences in 95% and 100% of patients with thrombi and tumors, respectively. T1-weighted turbo spin echo (T1w-TSE), T2-weighted turbo spin echo (T2w-TSE), FPP, and TI scout sequences were performed more frequently in tumors (100%, 98%, 98%, and 98%, respectively) than thrombi (36%, 54%, 62%, and 74%; $p \leq 0.001$ for all). The mean contrast dose was 0.18 ± 0.03 mmol/kg of gadopentetate dimeglumine. Average scanning time was ~45 min.

Because the objective of the study was to test the ability of CMR for tissue characterization, we did not evaluate the accuracy of infiltration, mass location, or findings in other structures (i.e., myocardial infarction, pericardial effusion), all of which have shown value in the differential diagnosis of cardiac masses (16,21,23). Specific mass imaging features that were analyzed included:

1. Visualization before contrast administration.
2. Morphology (scored as homogeneous or heterogeneous); size, expressed as average diameter (maximum plus minimum diameters divided by 2) and maximal area; and motility (presence or absence) on cine or black-blood images as appropriate.
3. Signal intensity on T1w-TSE, T2w-TSE sequences assessed qualitatively as hypointense/isointense or hyperintense in reference to normal myocardium.
4. Vascularization on FPP imaging after a bolus of a gadolinium-based contrast agent on a saturation-recovery fast gradient-echo sequence.
5. Post-contrast signal intensity, compared with the normal myocardium, on a dedicated TI scout ("Look-Locker") sequence. The TI that nulled the normal myocardium was considered the reference to classify other TIs as short or long. Adhering to previous studies (7), a pattern of hyperintensity/isointensity with short TI and hypointensity with long TI was defined as typical for thrombus.
6. Post-contrast T1 time-derived from T1 mapping in the TI scout using specific software. Only those masses with sufficient size and/or image quality were analyzed.
7. Presence of LGE on an inversion-recovery gradient-echo sequence.

A single investigator reviewed all CMR examinations and subsequently reanalyzed 20 cases for

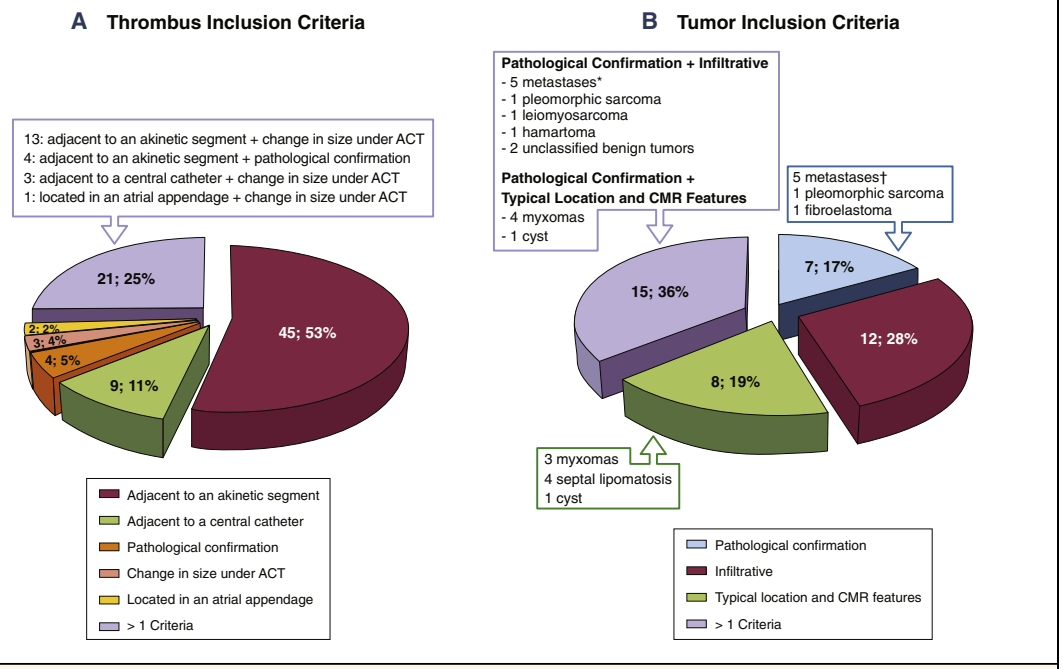

FIGURE 1 Distribution of Inclusion Criteria

(A) Thrombus inclusion criteria. **(B)** Tumor inclusion criteria. *3 lymphomas, 1 multiple myeloma, and 1 liposarcoma. †2 hepatocellular carcinomas, 2 lung carcinomas, and 1 lymphoma. ACT = anticoagulation therapy; CMR = cardiac magnetic resonance.

TABLE 2 Specific CMR Features of Cardiac Masses

	Thrombus (n = 84)	Tumor (n = 42)	p Value	Benign Tumor (n = 17)	Malignant Tumor (n = 25)	p Value
Pre-contrast visualization	65/84 (77)	42/42 (100)	0.001	17/17 (100)	25/25 (100)	NA
Multiple*	7/77 (9)	3/39 (8)	0.8	1/16 (6)	2/23 (9)	0.99
Median diameter, cm	1.6 (1.1–2.3)	3.4 (2.4–4.9)	<0.0001	2.7 (1.6–3.5)	4.3 (2.6–5.7)	0.003
Median area, cm^2	1.6 (0.7–3.3)	8.5 (4.4–20.3)	<0.0001	6.3 (1.8–10.7)	11.9 (5.6–33.4)	0.006
Homogeneous	83/84 (99)	19/41 (46)	<0.0001	6/17 (35)	13/24 (54)	0.23
Motility	11/84 (13)	14/42 (33)	0.007	7/17 (41)	7/25 (28)	0.37
T1w-TSE hyperintensity	5/30 (17)	9/42 (21)	0.62	5/17 (29)	4/25 (16)	0.45
T2w-TSE hyperintensity	19/45 (42)	35/41 (85)	<0.0001	13/17 (77)	22/24 (92)	0.21
FPP (+)	2/52 (4)	28/40 (70)	<0.0001	7/15 (47)	21/25 (84)	0.03
LGE (+)	4/80 (5)	30/42 (71)	<0.0001	7/17 (41)	23/25 (92)	0.001
Typical TI scout pattern†	58/62 (94)	1/41 (2)	<0.0001	1/16 (6)	0/25 (0)	0.39
Post-contrast T1 time, ms‡	477 ± 139	383 ± 84	0.03	370 ± 63	386 ± 91	0.78

Values are n/N (%), median (range), or mean ± SD. *Per-patient analyses. †Hyperintensity/isointensity with short TI and hypointensity with long TI compared with the normal myocardium. ‡Quantified on a post-contrast TI scout sequence in 15 thrombi and 15 tumors (3 benign and 12 malignant).

FPP = first-pass perfusion; LGE = late gadolinium enhancement; NA = not applicable; T1w-TSE = T1-weighted turbo spin echo; T2w-TSE = T2-weighted turbo spin echo; TI = inversion time; other abbreviation as in Table 1.

determination of intraobserver reproducibility. A second investigator re-evaluated the same 20 cases for the assessment of interobserver reproducibility. The study was approved by the local institutional review board with a waiver of informed consent.

STATISTICAL ANALYSIS. Categorical data were summarized as frequencies and percentages, and continuous variables as mean ± SD or median and interquartile ranges. Difference in CMR characteristics between thrombi and tumors and between benign and malignant tumors were compared by using the chi-square test, Fisher exact test, the 2-tailed unpaired Student *t* test, or the Mann-Whitney test as appropriate. Diagnostic performance (sensitivity, specificity, positive and negative predictive values, and accuracy) was calculated for each CMR feature in which a significant difference was found. In the case of continuous variables, the best cutoff values were determined by evaluating the coordinate points of the receiver-operating characteristic curves and selecting those with the highest accuracy according to the Youden index (sensitivity + specificity - 1). Intraobserver and interobserver reproducibility for categorical and continuous variables was assessed with the kappa and intraclass correlation coefficients, respectively. Analyses were performed by using SPSS version 15.0 (IBM SPSS Statistics, IBM Corporation, Armonk, New York).

TABLE 3 Accuracy of CMR Features for the Diagnosis of Thrombus (Versus Tumor)

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Pre-contrast visualization (–)	23	100	100	39	48
Diameter <2.4 cm	84	78	88	72	82
Area <4.1 cm^2	89	80	89	79	86
Homogeneous (+)	99	54	81	96	84
Motility (–)	87	33	72	56	69
T2w-TSE hyperintensity (–)	58	85	81	65	71
FPP (–)	96	70	81	93	85
LGE (–)	95	71	86	88	87
Typical TI scout pattern*	94	98	98	91	95
T1 time ≥422 ms	67	80	77	71	73

*Hyperintensity/isointensity with short TI and hypointensity with long TI compared with the normal myocardium.

NPV = negative predictive value; PPV = positive predictive value; other abbreviations as in Tables 1 and 2.

RESULTS

PATIENT POPULATION. From an initial group of 146 patients with a suspected cardiac mass, 116 (79%) had a definite cardiac mass according to the inclusion criteria and were included in the final analysis. Baseline characteristics of patient subgroups according to mass type are summarized in Table 1.

Compared with patients with a neoplasm, those with thrombi were more often male and more likely to have a previous myocardial infarction and coronary revascularization. As expected, patients with thrombi had lower left ventricular ejection fractions, increased prevalence of myocardial scars on LGE sequences, and were more frequently undergoing anticoagulation therapy. Conversely, a history of malignancy was more common in patients with tumors. Although pericardial effusion was more prevalent in patients with tumors, the difference did not reach statistical significance.

When analyzing the patient characteristics of those with benign versus malignant tumors, there was a trend ($p = 0.051$) for malignancies to occur more frequently in male subjects. Hyperlipidemia was more common in benign neoplasms and a history of malignant disease, and pericardial effusion were more frequent in malignancies.

CARDIAC MASSES. There were 126 masses: 84 thrombi (67%) and 42 tumors (33%). Neoplasms were malignant in 25 (60%) cases and benign in 17 (40%). Seven patients had 2 thrombotic lesions, 2 patients had 2 malignant neoplasms, and 1 patient had 2 benign tumors. Mass types are listed in **Figure 1**. More than one-half of the thrombi were adjacent to an akinetic myocardial segment, which was infarcted in 39 (87%) of 45 cases. There were 20 (48%) primary cardiac tumors, 21 (50%) metastases, and 1 malignant neoplasm of unknown origin (2%).

In terms of location (Online Table 1), most thrombi (68%) developed in the left ventricle, whereas tumors were more heterogeneously distributed. The majority of benign tumors (64%) were found either in the left atrium or the interatrial septum, and 40% of malignant neoplasms involved multiple cardiac chambers.

CMR FEATURES. **Tables 2 to 4** and **Figure 2** summarize CMR findings for thrombi versus tumors and for benign versus malignant neoplasms. Intraobserver and interobserver reproducibility of the assessed CMR parameters was high (Online Table 2).

TABLE 4 Accuracy of CMR Features for the Diagnosis of Malignant (Versus Benign) Tumor

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Diameter ≥4.2 cm	52	100	100	61	73
Area ≥13.4 cm^2	48	100	100	57	69
FPP (+)	84	53	75	67	73
LGE (+)	92	59	78	83	79

Abbreviations as in **Tables 1, 2, and 3**.

Thrombus versus tumor. Tumors were significantly larger than thrombi and more frequently visualized without contrast, whereas thrombi were more frequently homogeneous (**Figures 3A and 3B**) and less mobile. No difference in signal intensity was observed on T1w-TSE; however, hyperintensity compared with the normal myocardium on T2w-TSE was more common in tumors (**Figures 3C and 3D**). FPP and LGE (**Figures 3E to 3J**, respectively) were markedly more frequent in tumors than in thrombi. On the TI scout, the majority of thrombi (94%) showed a typical pattern of hyperintensity/isointensity with short TI and hypointensity with long TI (**Figure 4**); such a pattern was exceptional in tumors (2%; $p < 0.0001$). The aforementioned parameter showed the highest

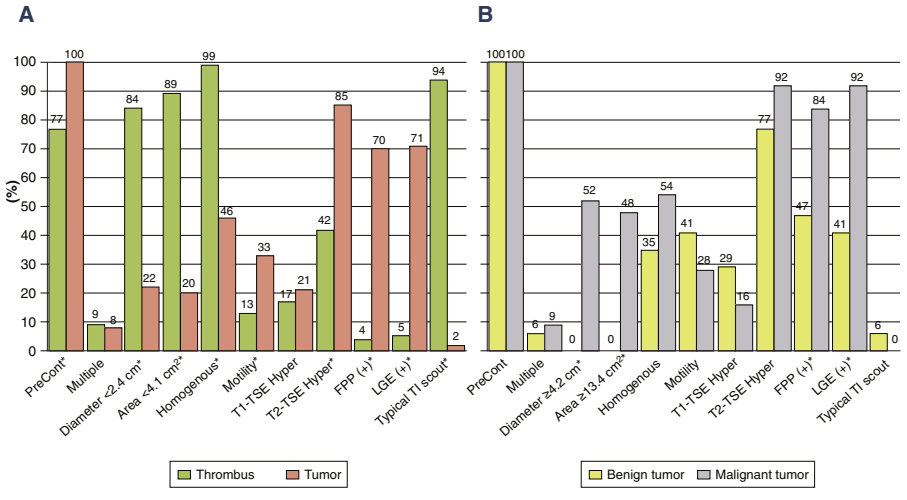

FIGURE 2 CMR Features of Cardiac Masses

(A) CMR features of thrombi and tumors. **(B)** CMR features of benign and malignant tumors. *$p < 0.05$. FPP = first-pass perfusion; LGE = late gadolinium enhancement; PreCont = pre-contrast visualization; T1-TSE Hyper = T1-weighted turbo spin echo hyperintensity; T2-TSE Hyper = T2-weighted turbo spin echo hyperintensity; Typical TI scout = hyperintensity/isointensity with short inversion time and hypointensity with long inversion time compared with the normal myocardium; other abbreviation as in **Figure 1**.

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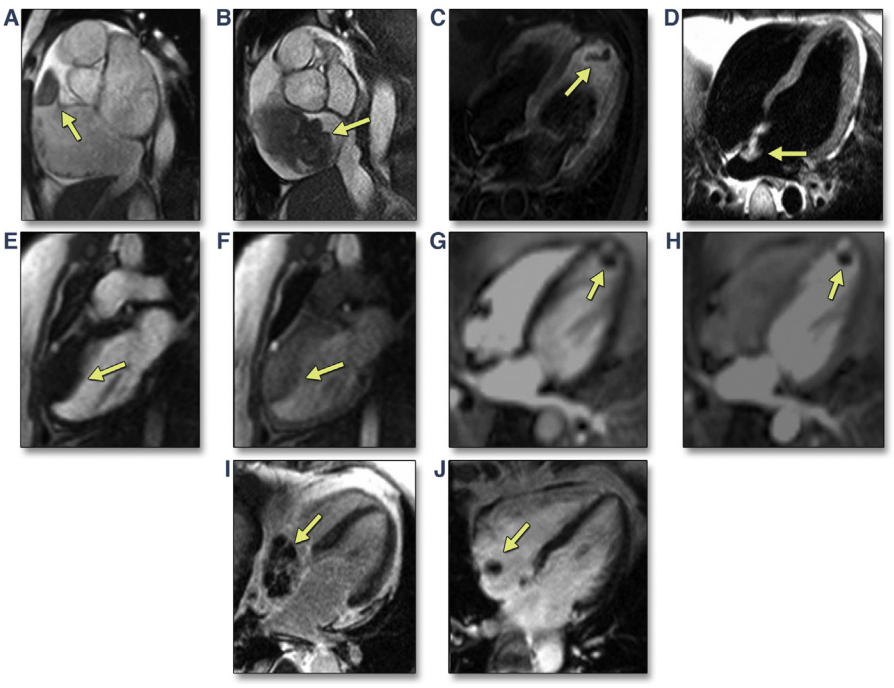

FIGURE 3 Differences in CMR Characteristics Between Thrombus and Tumor

(A and B) Cine sequences. Examples of a homogeneous thrombus **(A, arrow)** and heterogeneous metastatic lung carcinoma **(B, arrow)** in the right atrium. **(C and D)** T2-weighted turbo spin echo (T2w-TSE) sequences. **(C)** Isointense left ventricular thrombus **(arrow)**. There is a hyperintense signal from the slow flow surrounding the mass. **(D)** Hyperintense left atrial myxoma **(arrow)**. **(E through H)** FPP. **(E and G)** Arterial phase. **(F and H)** Myocardial phase. **(E and F)** Markedly perfused mass (hamartoma) in the anterior wall of the left ventricle **(arrows)**. **(G and H)** Absence of perfusion in a left ventricular apical thrombus **(arrows)**. **(I and J)** LGE. **(I)** Presence of LGE in a metastasis of a - hepatocarcinoma in the right atrium **(arrow)**. **(J)** Absence of LGE in a right atrial thrombus **(arrow)**. Abbreviations as in Figures 1 and 2.

diagnostic accuracy (95%) for the differential diagnosis between both types of masses. Adequacy in size for manual tracing and excessive motility restricted T1 time measurement to 15 thrombi and 15 tumors. Post-contrast T1 time was shorter in tumors than in thrombi. A value ≥422 ms showed a sensitivity of 67% and a specificity of 80% for the diagnosis of thrombus (area under the receiver-operating characteristic curve: 0.73 [95% confidence interval: 0.54 to 0.92]; $p = 0.03$).

Benign versus malignant tumors. Benign tumors were significantly smaller than malignancies. No significant difference in black-blood sequences was found between both types of neoplasms, whereas FPP and LGE were more frequent in malignant tumors (an individualized description of each neoplasm feature is provided in Online Tables 3 and 4). Presence of LGE was the feature with the highest accuracy (79%) for the differential diagnosis of both tumor types.

DISCUSSION

The present study demonstrated the diagnostic accuracy of CMR features (the presence of infiltration or other abnormalities such as pericardial effusions was not considered) for the differential diagnosis of thrombi versus tumor and benign versus malignant neoplasms, a critical issue in the clinical management of patients with a cardiac mass. Our results in 116 patients confirm the findings of the few previous studies that had been conducted, which included 22 to 78 patients (19–22).

MOTION, HETEROGENEITY, AND MOBILITY. Most thrombi (80%) fit the profile of small, homogeneous, and immobile lesions. Their median diameter of 1.6 cm and area of 1.6 cm^2 are in good agreement with the median volume of 2.9 cm^3 reported by Weinsaft et al. (7) and mean area of 1.9 cm^2 by Mohrs et al. (23). Of note, widespread use of antithrombotic therapy in most patients (71% in our series) may have

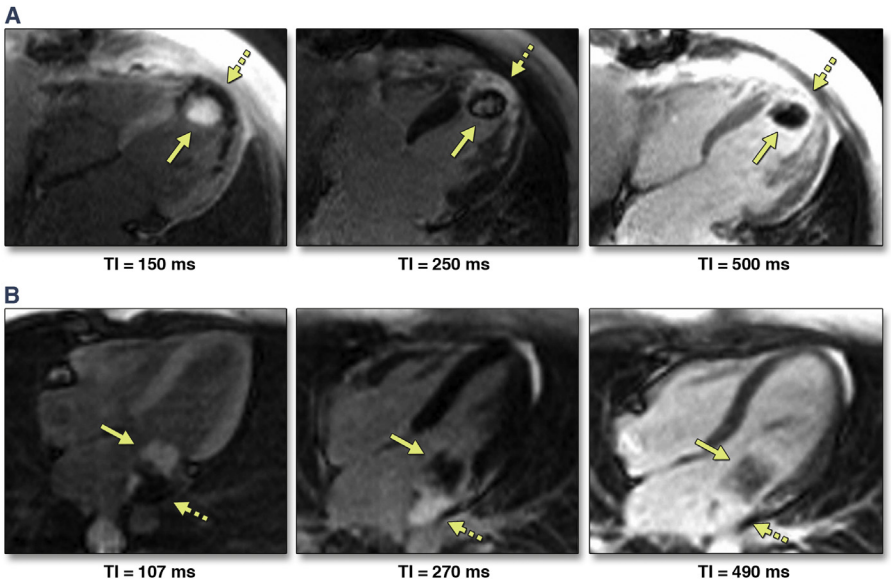

FIGURE 4 TI Scout

(A) Typical appearance of a thrombus: hyperintensity with short inversion time (TI) **(left: arrow)**, "edged" appearance with a hypointense border and a central brighter zone with intermediate TI **(middle: arrow)**, and hypointensity with long TI **(right: arrow)**. Underlying apical infarction is noted **(dashed arrows)**. **(B)** Left atrial pleomorphic sarcoma showing different patterns in 2 distinct tumor regions: hypointensity **(dashed arrow)** and isointensity **(arrow)** with short TI **(left)**, hyperintensity **(dashed arrow)**, and isointensity **(arrow)** with an intermediate TI **(middle)**, and hyperintensity **(dashed arrow)** and isointensity **(arrow)** with long TI **(right)**.

contributed to this small size. With some exceptions (e.g., fibroelastomas [which are typically small]), tumors were larger. Furthermore, malignant neoplasms demonstrated an increased size compared with benign tumors, a finding also consistent with previous studies (24–26). Metastasis, the most frequent malignant neoplasm, can be particularly large, especially those that reach the heart through direct extension from adjacent organs (e.g., lung carcinoma).

Most thrombi (99%) also exhibited a homogeneous appearance that was found in only one-half of the tumors, an observation easily explained by the difference in tissue composition. Although a previous publication identified heterogeneous composition as a sensitive feature of malignancy (19), it has also been frequently reported in benign neoplasms such as myxomas (24), and accordingly it did not emerge as a distinctive parameter between tumor types in our study. Similarly, motility was more frequent in tumors than in thrombi, but this feature was not helpful for the differential diagnosis of benign and malignant tumors.

SPIN ECHO TISSUE CHARACTERIZATION. We found no difference in signal intensity on T1w-TSE imaging between tumors and thrombi, whereas hyperintensity on T2w-TSE sequences was far more common in tumors. Fresh and subacute thrombi can be hyperintense on T1w and T2w imaging due to red blood cell lysis and accumulation of paramagnetic compounds such as deoxyhemoglobin and methemoglobin; chronic thrombi (the suspected form in the majority of our patients) become isointense or hypointense due to the progressive replacement by fibrous tissue (27). Similar to chronic thrombi, and with particular exceptions such as lipomas, most benign and malignant cardiac tumors tend to be isointense or hypointense on T1w imaging but hyperintense on T2w imaging (17).

FIRST-PASS PERFUSION. Most thrombi remained hypointense, likely due to their avascular nature. Interestingly, we observed perfusion in 2 (4%) thrombi, a finding that may be related to the development of neovascularization in the chronic stage (16). Reflecting the sparse vascularization of some benign lesions (e.g., cysts, lipomas) and the dense vascularization of the faster growing malignancies, FFP was more common in the latter, as was also noted in 1 other series (21).

LATE GADOLINIUM ENHANCEMENT. LGE was absent in the vast majority of our thrombi population

(95%). Therefore, after contrast injection, thrombi remained hypointense and easy to differentiate from surrounding bright structures such as blood and/or a scar (14,15). In our series, 19 of 83 cases were only detected after contrast administration, which represents an increase in sensitivity of 23%. Similarly, Mollet et al. (14) and Weinsaft et al. (7) reported detection of only 50% and 67%, respectively, of thrombi before contrast administration. Interestingly, 63 patients (75%) with thrombi had an echocardiogram performed before the CMR scan, and the mass was only noted in 32 (52%). This is in line with the series of 106 pathologically confirmed thrombi reported by Srichai et al. (15), who found high specificity for all modalities but much lower sensitivity for transthoracic and transesophageal echocardiography than LGE-CMR (23%, 40%, and 88%, respectively). Tumors tended to demonstrate post-contrast enhancement, and LGE had 87% accuracy in differentiating both entities.

LGE was also much more common in malignant than in benign tumors (92% vs. 41%). Moreover, the presence of LGE demonstrated the highest accuracy (79%) for neoplasm-type differentiation. The combination of extensive angiogenesis and an expanded extracellular space (necrosis, inflammation) in most malignant tumors, as well as limited vascularization of benign neoplasms, likely explains these findings (17,18).

TI SCOUT AND T1 MAPPING. At the time of LGE sequence acquisition, the amount of gadolinium in the normal myocardium is low but not zero. As a result, its T1 relaxation time and thus the TI needed to null the myocardial signal are expected to be shorter than those of avascular thrombi (7). Although a previous study described the presence of hypointensity with long TI as typical of thrombi, the ability of this feature to differentiate from a neoplastic mass has not been previously evaluated. A TI scout pattern showing hyperintensity/isointensity with short TI and hypointensity with long TI was present in 94% of our thrombi and only 1 (2%) tumor (a simple cyst); it had the highest accuracy (95%) for the differential diagnosis. We have observed a typical "edged" appearance of thrombi using intermediate TI, with a dark rim and a central brighter zone. We speculate that this appearance may be due to different layers within the thrombus, with fresher thrombi (and thus shorter T1) in the periphery.

In addition, we used T1 mapping for objective T1 time quantification. As expected, T1 time was shorter in tumors than in thrombi, although this parameter did not perform better than visual analysis of the TI scout. This may have been influenced by multiple tumor subtypes and small intersubject variations in contrast dose or image timing. No significant differences were noted between post-contrast T1 times of malignancies and benign neoplasms, but the small sample analyzed (3 benign and 12 malignant tumors) and tumor heterogeneity may have contributed to this finding.

STUDY LIMITATIONS. First, the availability of black-blood, FPP, and TI scout sequences was higher in tumors than in thrombi. However, they were frequent enough to identify significant differences between thrombi and tumors in all parameters except for T1w-TSE. Second, the number of tumors included was low; thus, the absence of significant differences in some CMR features between malignant and benign types is possibly related to a low statistical power. In addition, heterogeneity of cardiac tumors precluded comparison between subtypes. Larger studies that allow an adequate subgroup assessment would be desirable; nevertheless, the low prevalence of cardiac tumors makes this goal difficult to achieve. Third, we considered that the 12 masses attached to central venous catheters in the absence of signs of infection represented thrombi and not vegetations. Of these, 3 had a second additional criterion for thrombus (resolution with anticoagulation). Because vegetations are avascular structures, one would expect them to behave similarly to thrombi, particularly in contrast-enhanced sequences, although this remains speculative. Fourth, most CMR features were evaluated from a qualitative instead of a quantitative point of view and, consequently, are influenced by subjectivity. However, interobserver reproducibility was high, and this approach reflects common clinical practice. Finally, the T1 time could only be quantified in a limited number of patients due to small mass size or excessive motility in some cases.

CONCLUSIONS

Only 4 (9%) of 46 thrombi demonstrated either FPP, LGE, or an atypical pattern on the TI scout, exceptions that may be justified by the development of neovascularization in chronic thrombi. A combination of negative perfusion, negative LGE, and a typical thrombus pattern in the TI scout was seen in 1 (2%) tumor, which corresponded to a cyst, an avascular structure that can be diagnosed easily with other sequences such as T2w-TSE imaging. Absence of FPP and LGE was found in 2 (8%) of 25 malignant tumors, which corresponded to lymphomas that showed other malignant features (infiltration).

The etiology of a cardiac mass may be uncertain after routine imaging testing such as echocardiography, and it therefore represents a challenge in clinical practice. In addition to features of malignancy such as infiltration or pericardial effusion, a specific CMR protocol should focus on: 1) morphological evaluation (size, homogeneity, and motility) on cine and black-blood imaging; 2) vascularization assessment with FPP imaging; 3) TI scout pattern; and 4) presence of LGE to differentiate benign from malignant tumors and, particularly, tumors from thrombi with high accuracy.

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APPENDIX For a supplemental figure and tables, please see the online version of this article.

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