



Contribution and performance of multimodal imaging in the diagnosis and management of cardiac masses

Maëva Lemasle^{1,2,3} · Yoan Lavie Badie^{1,2,3,4} · Eve Cariou^{1,2,3} · Pauline Fournier^{1,2,3} · Jean Porterie^{1,3,5} · Hervé Rousseau^{2,5} · Antoine Petermann² · Anne Hitzel^{2,4,5} · Didier Carrié^{1,2,3,5} · Michel Galinier^{1,2,3,5} · Bertrand Marcheix^{1,3,5} · Olivier Lairez^{1,2,3,4,5}

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Abstract

To evaluate the contribution and performance of multimodal imaging in the diagnostic and therapeutic management of cardiac masses. We carried out a monocentric retrospective study on patients referred for cardiac mass assessment between 2006 and 2019, and analyzed the respective contribution of transesophageal echocardiography (TEE), cardiac computed tomography (CT), cardiac magnetic resonance (CMR) and ¹⁸F-fluorodeoxyglucose positron emission tomography coupled with CT (¹⁸F-FDG PET-CT). For each test, we determined strategy before and after its completion (need for another imaging or decision-making) as well as result on benign, malignant or indeterminate nature. For the 119 patients included, all imaging modalities increased decision-making rates, which rose from 2 to 54%, 23 to 62%, 31 to 85% and 49 to 100% before and after TEE, CT, CMR and ¹⁸F-FDG PET-CT, respectively ($P < 0.001$ before vs. after). TEE was particularly efficient for atrial masses, especially for the left atrium, with a decision rate rising from 0 to 74% ($P < 0.001$). ¹⁸F-FDG PET-CT was the most efficient to differentiate benign and malignant etiologies (area under the curve 0.89 ± 0.06 and 0.94 ± 0.05 for benign and malignant, respectively, $P < 0.001$). A benign or undetermined result on each modality was associated with a good prognosis, compared to malignant. All modalities studied are useful for cardiac mass decision-making. First-line TEE is particularly efficient for atrial masses, whereas CT and CMR are useful for ventricular masses or suspicion of malignancy. A benign or malignant result for each modality is correlated to survival and ¹⁸F-FDG PET-CT is the most effective to define it.

Keywords Cardiac mass · Transesophageal echocardiography · Cardiac computed tomography · Cardiac magnetic resonance imaging · Positron emission tomography · Benign · Malignant · Survival

Abbreviations

AUC Area under the curve
CMR Cardiac magnetic resonance
CT Computed tomography
ECG Electrocardiogram

FDG Fluorodeoxyglucose
PET Positron emission tomography
¹⁸F-FDG PET-CT ¹⁸F-fluorodeoxyglucose positron emission tomography coupled than tomography
ROC Receiver operating characteristic
TCB Transcatheter biopsy
TEE Transesophageal echocardiography
TTE Transthoracic echocardiography

✉ Maëva Lemasle
mae.lemasle@orange.fr

¹ Department of Cardiology, Rangueil University Hospital, Toulouse, France

² Cardiac Imaging Center, Toulouse University Hospital, Toulouse, France

³ Heart Valve Center, Toulouse University Hospital, Toulouse, France

⁴ Department of Nuclear Medicine, Toulouse University Hospital, Toulouse, France

⁵ Medical School, Toulouse III Paul Sabatier University, Toulouse, France

Introduction

Cardiac masses are rare: a large autopsy series reported an incidence of 0.056% for primary masses and 1.23% for secondary tumors [1]. They represent a heterogeneous group including benign, malignant and non-tumoral masses. Malignant tumors can be divided into primary or secondary

(metastasis or local invasion) neoplasms, but metastases are much more frequent [1, 2]. Among primary tumors, benign masses are the most common. The most frequent non-tumoral masses are thrombi or prominent anatomical structures (prominent crista terminalis, lipomatous hypertrophy of the atrial septum) [1].

Diagnosis may be difficult and there are no guidelines on the diagnostic algorithm. The gold standard for diagnosis is histological evidence, which requires surgery or biopsy and can be difficult to perform. Consequently, initial assessment is usually based on non-invasive tools including clinical history, laboratory tests and cardiovascular imaging. Several imaging modalities can be used, with echocardiography, transthoracic (TTE) and then transesophageal echocardiography (TEE) at the forefront. Then come cardiac computed tomography (CT) and cardiac magnetic resonance (CMR), which cannot be performed at the patient's bedside, followed by positron emission tomography with computed tomography using ^{18}F -fluorodesoxyglucose (^{18}F -FDG PET-CT), which is performed by tertiary centers. TTE is usually the first-line test performed to characterize the lesion and seek a hemodynamic repercussion. Regarding the use of other tests, the strategy is adapted on a case-by-case basis, without diagnostic algorithm guidelines due to the lack of performance data in the context of rare diseases. Multidisciplinary management is always required to decide therapeutic management and before any invasive action.

The main aim of our study was to evaluate the performance and the decision-making impact of multimodal imaging, including TEE, cardiac CT, CMR and ^{18}F -FDG PET-CT among patients with cardiac masses.

Methods

Study population

Consecutive patients referred to the Toulouse University Hospital, Toulouse, France, for diagnostic workup or management of a cardiac mass from 2006 to 2019, were retrospectively included. Two distinct databases were crossed to select patients referred for diagnostic assessment or surgical management of cardiac mass (diagnosis related groups of cardiac mass): hospital electronic health record and hospital echocardiographic report database. Patients with valve tumors or infectious endocarditis were then excluded. Obvious thrombi, including masses on central catheter, were also excluded because they presented the least diagnostic challenge.

All the data were collected as part of the standard diagnostic workup. The investigation conforms to the principles outlined in the Declaration of Helsinki. All patients were informed on admission that their clinical data could be used

for research purposes and all gave their consent. In accordance with applicable standards in France, this study has received ethics committee approval from the French Data Protection Authority and has been approved by our institutional review board (MR 004-no. 2019-69).

Demographic, clinical and biological data

Patient electronic and paper records were consulted and the following parameters were extracted: age, gender, history of malignancy (active or in remission), cardiovascular risk factors, drugs (anticoagulation, antiplatelet therapy, chemotherapy, radiotherapy), presence or absence of electrocardiographic abnormalities, laboratory results (hemoglobin, creatinine, C reactive protein, natriuretic peptides, troponin), symptoms (asthenia, heart failure, chest pain, palpitations, syncope) and the therapeutic decision.

Cardiac imaging tests

For each patient, all cardiac imaging tests performed including TEE, CMR, CT and ^{18}F -FDG PET-CT, were collected and analyzed for final interpretation and positioning in the diagnostic workup. TTE was considered as the first-line test performed for all patients and was not analyzed. TEE was considered as the second-line test. CT and CMR were considered as the third-line tests, followed by ^{18}F -FDG PET-CT. This choice to prioritize the tests was made with regard to clinical practice, the availability of the tests and in such a way as not to introduce any bias in the analysis, since in many cases, all the tests were carried out together regardless of their mutual results.

Strategy before and after each test was determined as follows: need for further cardiac imaging modalities or decision-making, which could be: biopsy, surgery, anticoagulation, anti-neoplastic treatment (radiotherapy/chemotherapy) or medical follow-up. These options could be associated.

Finally, data on the ability of the test to classify into benign, malign or indeterminate was collected. The benign or malignant nature of the mass on the basis of each modality results was based on the anatomy and signal/density/contrast enhancement of the mass and local–regional extension. For ^{18}F -FDG PET-CT results the benign or malignant nature of the mass was based on radiotracer uptake intensity using qualitative assessment (mass uptake intensity as compared to liver uptake intensity) and presence of other lesion in another localization. All indeterminate results were discussed by expert consensus.

Only masses with a definitive diagnosis have been selected to evaluate the capacity of each imaging modality to determine the benign or malignant nature of the mass.

Gold-standard diagnosis

For each imaging modality, the histological result was considered as the gold standard for the definitive diagnosis. Tissue samples were analyzed in the Department of Pathology of the Toulouse University Hospital, Toulouse, France. Diagnostic doubt and sarcomas were re-analyzed by an expert center and/or reference network.

For suspected thrombus, a compatible aspect with disappearance after a period of anticoagulation was considered as a definitive diagnosis. Concerning lipomas and lipomatous hypertrophy of the atrial septum, in the absence of histological analysis, we considered that a typical aspect on CT and/or CMR was pathognomonic and was a reference diagnosis equivalent.[3]. The same attitude was adopted concerning typical prominent crista terminalis.

Outcome assessment

Follow-up was assessed by electronic chart review or by phone interview of the patient's general practitioner/cardiologist, patient or family for the clinical endpoint of all-cause mortality. Follow-up was terminated at 100 months. No patient was lost to follow-up.

Statistical analysis

Continuous variables were expressed as mean \pm standard deviation. Nominal values were expressed as numbers and percentages. Association between the mean values of continuous variables was compared using the Mann–Whitney rank sum test. Nominal variables were investigated by the Fisher exact test. The accuracy of imaging measures for predicting benign or malign etiologies was assessed by computing the areas under the receiver operating characteristic (ROC) curves and the best cut-off value was defined as the point with the highest sum of sensitivity and specificity. Finally, all-cause mortality was summarized using Kaplan–Meier survival curve with the cut-off of imaging measures previously retained and log rank test was used for initial comparisons. Differences were considered statistically significant for P-values of < 0.05 . All analyses were performed using standard statistical software SPSS version 20 (SPSS Inc., Chicago, Illinois).

Results

Baseline characteristics and epidemiology

One hundred and nineteen patients with cardiac masses were retrospectively included. Baseline characteristics of the whole population and according to the benign or malignant

etiology are presented in Table 1. There were 70 (59%) men and mean age was 58 ± 15 years. Histopathology was available for 96 (81%) patients, through surgery procedure ($n = 77$, 65%) or transcatheter biopsy ($n = 19$, 16%). Final diagnosis was obtained for 112 (94%) patients and was divided into 78 (70%) and 34 (30%) benign and malignant etiologies, respectively. The 7 (6%) remaining patients without definitive diagnosis were due to premature death or contraindication for more invasive investigations (patient refusal or comorbidities making exploration unreasonable). Distribution according to the mass etiology is represented in Fig. 1. Among the 78 benign masses, there were 61 (78%) tumors, including 52 myxomas, the most prevalent mass, and 17 non-tumoral masses, mostly thrombi (18%). Among the 34 malignant masses, there were 15 (44%) metastases, 18 (53%) sarcomas and 1 (3%) lymphoma. The primary location of metastases is shown in Table 2.

Localizations of the masses within the heart are shown in Fig. 2. Most of the masses were in the left atrium (50%).

Finally, 77 (65%) patients had surgery (4 patients were contraindicated for intervention and 2 patients refused the operation).

Impact of cardiac imaging tests on decision-making and management

Among the 119 patients, 63 (53%), 71 (60%), 72 (61%) and 43 (36%) underwent TEE, cardiac CT, CMR and ^{18}F -FDG PET-CT, respectively. Cardiac imaging tests performed according to benign and malignant etiology are shown in Table 3. Nine patients had none of the imaging modalities studied: 4 due to surgical emergency, 1 for early death and 4 patients received elective surgery without further imaging examination.

Before- and after-test decision-making rates for TEE, cardiac CT, CMR and ^{18}F -FDG PET-CT were 2 and 54% ($P < 0.001$), 23 and 62% ($P = 0.017$), 31 and 85% ($P < 0.001$), and 49 and 100% ($P < 0.001$), respectively. Before and after cardiac imaging test decision-making is presented in Fig. 3. In case of decision-making, before- and after-test management strategy for each test is shown in Fig. 4.

For atrial masses, before- and after-test decision-making rates for TEE, cardiac CT, CMR and ^{18}F -FDG PET-CT were 2 and 58% ($P < 0.001$), 29 and 76% ($P < 0.001$), 38 and 92% ($P < 0.001$), and 59 and 100% ($P < 0.001$), respectively. TEE was the most effective for left atrium masses, allowing an increase of before- and after-test decision-making rates from 0 to 74% ($P < 0.001$). For right atrial masses, cardiac CT allowed an increase of before- and after-test decision-making rates from 4 to 61% ($P < 0.001$), whereas the difference between before- and after-test decision-making rates for TEE was not significant (5 versus 20%, respectively; $P = 0.250$).

Table 1 Population Demographics

	All patients (n = 119)	Benign masses (n = 78)	Malignant masses (n = 34)	P
Baseline characteristics				
Age, years	58 ± 14	58 ± 13	55 ± 16	0.317
Male, n (%)	70 (59)	44 (56)	23 (68)	0.265
History of malignant disease, n (%)	28 (24)	9 (12)	15 (44)	<0.001
Active malignant disease, n (%)	21 (18)	6 (8)	13 (38)	<0.001
Smoking, n (%)	34 (29)	25 (32)	8 (24)	0.363
High Blood Pressure, n (%)	44 (37)	32 (41)	9 (27)	0.141
Dyslipidemia, n (%)	25 (21)	22 (28)	3 (9)	0.024
Diabetes, n (%)	9 (8)	8 (10)	1 (3)	0.272
Anticoagulation, n (%)	22 (19)	17 (22)	4 (12)	0.211
Antiplatelet therapy, n (%)	21 (18)	18 (23)	2 (6)	0.029
Chemotherapy, n (%)	15 (13)	6 (8)	8 (24)	0.029
Radiotherapy, n (%)	5 (4)	0 (0)	4 (12)	<0.001
Morphologic characteristics				
Larger diameter (mm)	41 ± 19	35 ± 17	53 ± 18	<0.001
Orthogonal diameter (mm)	29 ± 14	26 ± 14	34 ± 15	0.002
Intramycardial n (%)	16 (13)	9 (12)	7 (21)	0.244
Pedunculated, n (%)	63 (53)	53 (68)	10 (29)	<0.001
Sessile, n (%)	33 (28)	16 (21)	17 (50)	0.002
Left atrium, n (%)	59 (50)	50 (64)	8 (24)	<0.001
Right atrium, n (%)	34 (29)	17 (22)	14 (41)	0.035
Left ventricle, n (%)	16 (13)	10 (13)	4 (12)	0.735
Right ventricle, n (%)	11 (9)	3 (4)	7 (21)	0.008
Ascending aorta, n (%)	1 (1)	0 (0)	1 (3)	0.304
Pulmonary artery, n (%)	2 (2)	0 (0)	2 (6)	0.090
Clinical data				
Asymptomatic, n (%)	23 (19)	18 (23)	3 (9)	0.076
Embolism, n (%)	36 (30)	28 (36)	7 (21)	0.108
Asthenia, n (%)	10 (8)	2 (3)	7 (21)	0.003
Symptomatic pericardial effusion, n (%)	7 (6)	0 (0)	6 (18)	0.001
Heart failure, n (%)	15 (13)	7 (9)	7 (21)	0.120
Chest pain, n (%)	17 (14)	14 (18)	3 (9)	0.216
Palpitations, n (%)	14 (12)	11 (14)	2 (6)	0.338
Syncope, n (%)	6 (5)	5 (6)	1 (3)	0.666
Extrinsic compression, n (%)	7 (6)	2 (3)	5 (15)	0.026
ECG abnormality, n (%)	20 (17)	12 (15)	8 (26)	0.205
Laboratory data				
CRP, mg/L	18 ± 27	10 ± 13	35 ± 40	0.001
Hemoglobin, g/dL	13.3 ± 1.7	13.6 ± 1.4	12.3 ± 2.1	0.002
Creatinine, µmol/L	81 ± 23	82 ± 25	78 ± 18	0.402
Increased BNP, n (%)	24 (49)	10 (40)	11 (58)	0.239
Increased troponin, n (%)	17 (49)	6 (35)	11 (69)	0.022
Management				
Indication to surgery, n (%)	83 (70)	61 (78)	18 (53)	0.007
Follow up, n (%)	28 (24)	18 (23)	4 (12)	0.166
Chemotherapy, n (%)	26 (22)	0 (0)	26 (77)	<0.001
Radiotherapy, n (%)	6 (5)	0 (0)	6 (18)	<0.001
Anticoagulation, n (%)	26 (22)	12 (15)	11 (32)	0.041

BNP brain natriuretic peptide, CRP C reactive protein

Fig. 1 Etiologies distribution among the whole population

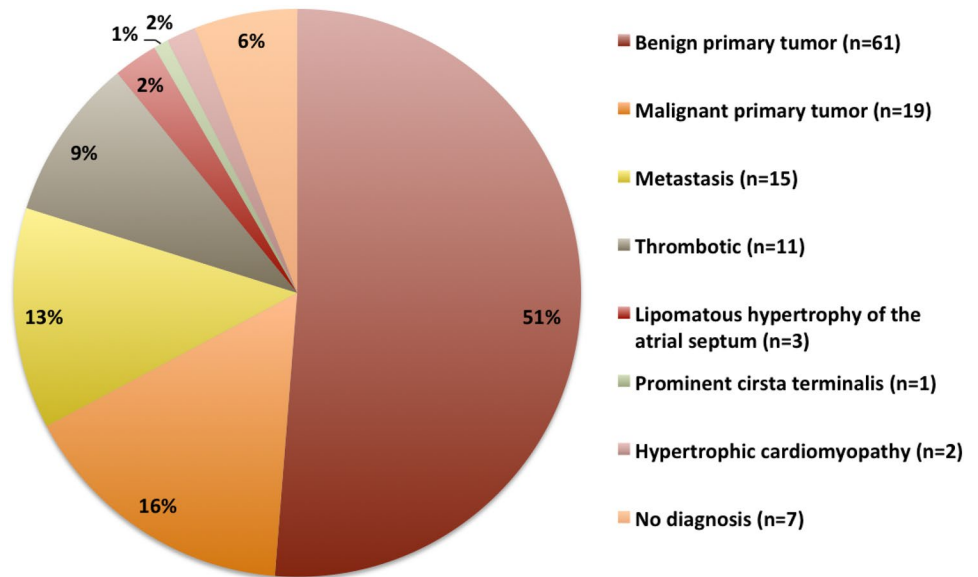


Table 2 Metastases origin

Primary location of metastases	n (%)
Melanoma	3 (20)
Bronchopulmonary	3 (20)
Sarcoma	3 (20)
Esophageal	1 (7)
Hepatocellular	1 (7)
Colorectal	1 (7)
Urothelial	1 (7)
Neuro-endocrine	1 (7)
Thymoma	1 (7)

For ventricular masses, before- and after-test decision-making rates for TEE, cardiac CT, CMR and ¹⁸F-FDG PET-CT were 0 and 25% ($P < 0.001$), 10 and 39% ($P = 0.07$), 14 and 68% ($P < 0.001$), and 45 and 100% ($P < 0.001$), respectively. TEE was not useful for right ventricle masses (0%) and only once for left ventricle masses (33%). For ventricular masses, CMR allowed an increase of before- and after-test decision-making rates from 13 to 67% ($P = 0.008$), whereas the difference between before- and after-test decision-making rates for CT was not significant (17 versus 33%, respectively; $P = 0.625$). For right ventricle masses, cardiac CT and CMR allowed an increase of before- and after-test decision-making rates from 0 to 44% ($P < 0.001$) and 14 to 71%, respectively.

Finally, ¹⁸F-FDG PET-CT allowed the after-test decision-making rate to reach 100%, whatever the localization, with a before-test decision-making rate of 42%, 80%, 38% and 50% for right atrium, left atrium, right ventricle and left ventricle, respectively. Before- and after- cardiac imaging test decision-making, according to mass localization is presented in Fig. 5.

Performance of cardiac imaging in diagnosing benign or malignant masses

Conclusions of each imaging modality according to the final diagnosis are presented in Table 4. The performances of cardiac imaging techniques in diagnosing benign or malignant masses are presented in Table 5. Based on ROC curves, ¹⁸F-FDG PET-CT had the best areas under the curve, which were at 0.89 ± 0.06 and 0.94 ± 0.05 respectively for the diagnosis of benign and malignant tumors. Imaging was not contributive to determining benign or malignant nature for

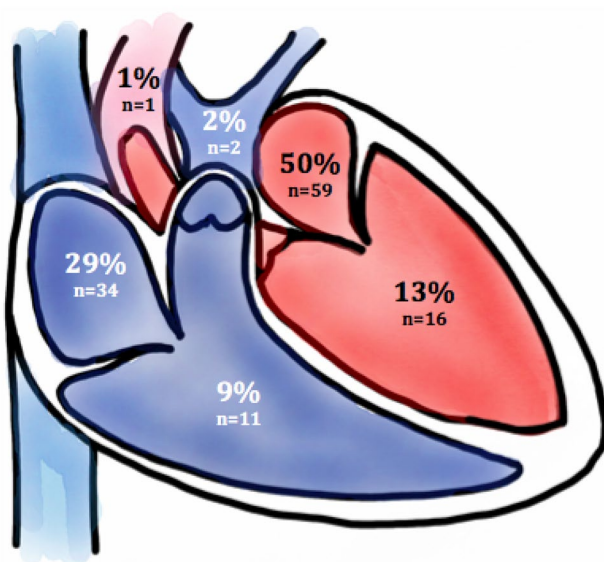


Fig. 2 Mass localizations

Table 3 Imaging data for total population, benign masses and malignant masses

	All patients (n = 119)	Benign masses (n = 78)	Malignant masses (n = 34)	P
Imaging data				
TEE, n (%)	63 (53)	47 (60)	14 (41)	0.062
Cardiac CT, n (%)	71 (60)	41 (53)	24 (71)	0.076
CMR, n (%)	72 (61)	49 (63)	18 (53)	0.327
¹⁸ F-FDG PET-CT, n (%)	43 (36)	22 (28)	16 (47)	0.053

Cardiac CT cardiac computed tomography, CMR cardiac magnetic resonance, TEE transesophageal echocardiography, ¹⁸F-FDG PET-CT ¹⁸F-fluorodesoxyglucose positron emission tomography coupled with computed tomography

Fig. 3 Before- and after- cardiac imaging test decision-making. *P ≤ 0.001, after versus before. Cardiac CT cardiac computed tomography, CMR cardiac magnetic resonance, TEE transesophageal echocardiography, ¹⁸F-FDG-PET ¹⁸F-fluorodesoxyglucose positron emission tomography

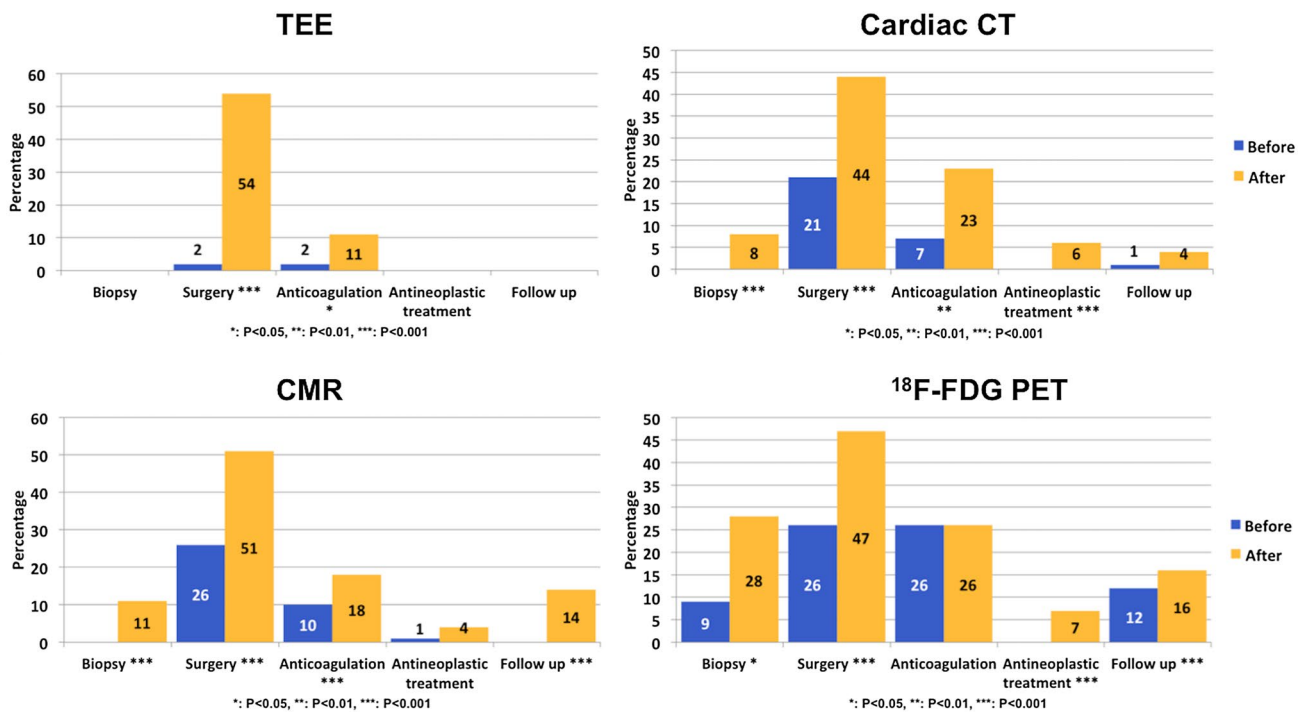
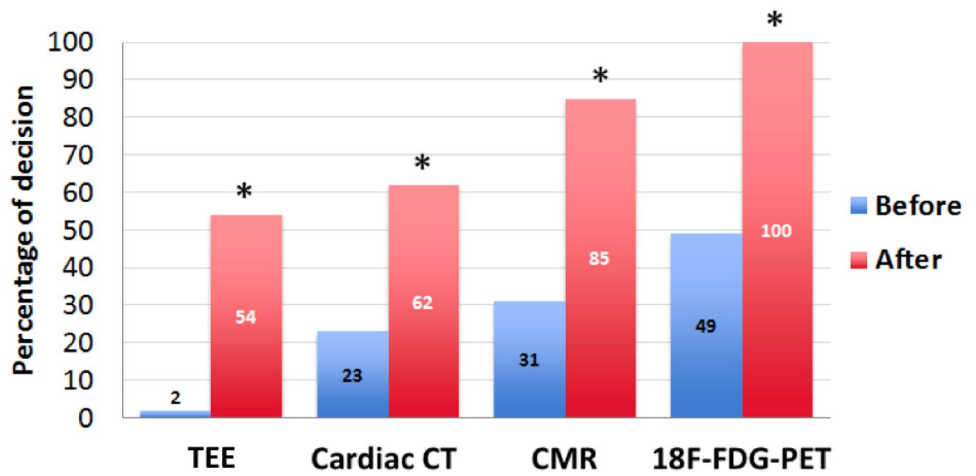
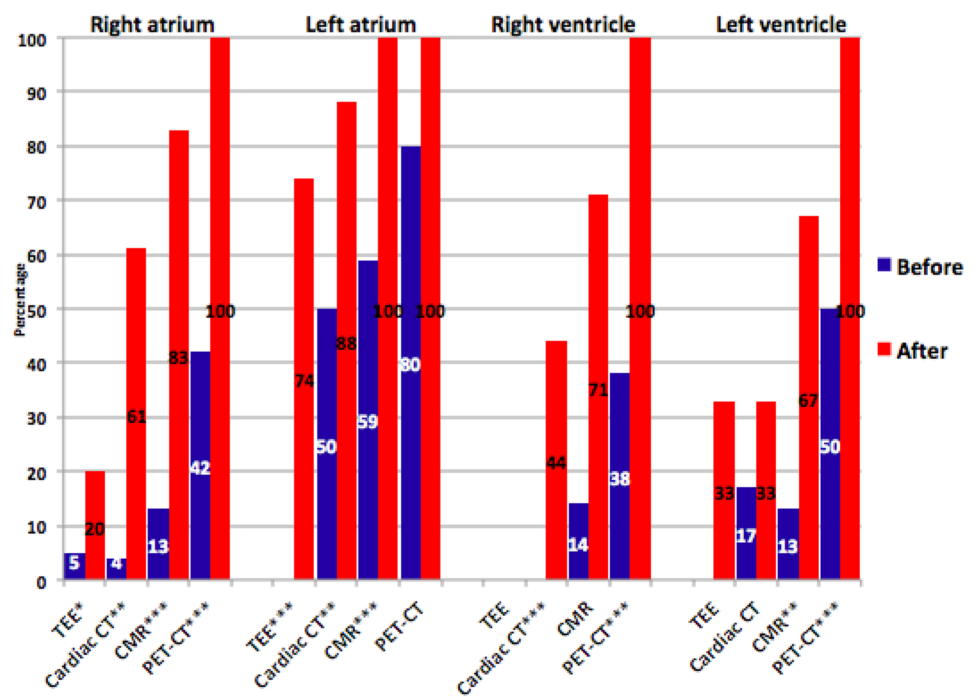


Fig. 4 Before- and after-test management strategy for each cardiac imaging modality. *P < 0.05; **P < 0.01; ***P < 0.001 after versus before. Antineoplastic treatment chemotherapy and/or radiotherapy,

Cardiac CT cardiac computed tomography, CMR cardiac magnetic resonance, TEE transesophageal echocardiography, ¹⁸F-FDG-PET ¹⁸F-fluorodesoxyglucose positron emission tomography

Fig. 5 Before- and after- test decision-making according to mass localization. * $P < 0.05$; ** $P < 0.01$; *** $P \leq 0.001$ after versus before. *Cardiac CT* cardiac computed tomography, *CMR* cardiac magnetic resonance, *TTE* transthoracic echocardiography, *TEE* transesophageal echocardiography, *$^{18}\text{F-FDG PET-CT}$* 18 -fluorodeoxyglucose positron emission tomography



19 (31%) cases using TEE, 16 (25%) cases using cardiac CT, 9 (13%) cases using CMR, or for 7 (19%) cases using $^{18}\text{F-FDG PET-CT}$.

Impact of cardiac imaging result on outcomes

Twenty-eight (24%) patients died during the follow-up: 24 (20%), 3 (3%) and 1 (1%) with malignant, benign and indeterminate etiology, respectively. Patients with masses linked to benign etiology based on definitive diagnosis, had a better survival rate than patients with malignant masses. Survival according to final diagnosis and cardiac imaging results is presented in Fig. 6. For each modality, survival of patients with benign or indeterminate etiology was better than for patients with malignant etiology. Among patients diagnosed with benign or undetermined etiology, no death was related to cardiac disease.

Discussion

Our study shows that all non-invasive cardiac imaging modalities (i.e. TEE, cardiac CT, CMR and $^{18}\text{F-FDG PET-CT}$) are effective in providing a course of action in the management of cardiac masses. TEE provides a therapeutic decision in almost three quarters of left atrial tumors, whereas cardiac CT and CMR are contributive, whatever the location. $^{18}\text{F-FDG PET-CT}$ results in decision-making for all patients after its completion. Anticoagulation indication is not influenced by $^{18}\text{F-FDG PET-CT}$, suggesting that

other modalities are sufficient for cardiac thrombus diagnosis. $^{18}\text{F-FDG PET-CT}$ is the most efficient test to differentiate between benign and malignant etiologies [4]. Finally, a benign or undetermined diagnosis given by each modality is associated with good prognosis, close to those related to pathological findings.

Our study shows the predominant role of TEE in atrial tumor management, in particular of the left atrium. These results can be explained by the high prevalence of myxomas in this cavity, which usually have a typical presentation, without alternative diagnosis, and do not require further investigations before surgery [5, 6]. The TEE contribution for right atrial masses appears less obvious, probably because of wider etiologies [6]. TEE appears to be the first-line examination for atrial masses, whereas its contribution for ventricular masses seems more limited [7, 8].

Cardiac CT and CMR appear to be contributive examinations whatever the location and the management perspective. Despite a lower spatial and temporal resolution, soft tissue contrast and extra-cardiac exploration allowed by both cardiac CT and CMR lead to a better performance than echocardiography to characterize a cardiac mass [9, 10]. Although CMR has been widely validated for exploring cardiac masses [11–13], there is no study comparing cardiac CT with other imaging modalities for cardiac mass exploration. However, American recommendations for cardiac imaging recommend TTE, TEE, cardiac CT and CMR evaluation without distinction [14].

Finally, $^{18}\text{F-FDG PET-CT}$ is most of the time the last examination before transcatheter biopsy or surgery for

Table 4 Benign, malignant or indeterminate etiology for each modality and comparison than final diagnosis

	Final diagnosis	
	Benign	Malignant
A		
TEE (n = 61)		
Correct hypothesis	32 (68%) ^a	9 (64%) ^b
False hypothesis	0 ^c	1 (7%) ^d
Indeterminate	15 (32%) ^e	4 (29%) ^f
Total	47 (100%)	14 (100%)
B		
CT (n = 65)		
Correct hypothesis	31 (76%) ^a	16 (67%) ^b
False hypothesis	1 (2%) ^c	1 (4%) ^d
Indeterminate	9 (22%) ^e	7 (29%) ^f
Total	41 (100%)	24 (100%)
C		
CMR (n = 67)		
Correct hypothesis	42 (86%) ^a	12 (67%) ^b
False hypothesis	2 (4%) ^c	2 (11%) ^d
Indeterminate	5 (10%) ^e	4 (22%) ^f
Total	49 (100%)	18 (100%)
D		
¹⁸ F-FDG PET-CT (n = 38)		
Correct hypothesis	17 (77%) ^a	14 (88%) ^b
False hypothesis	0 ^c	0 ^d
Indeterminate	5 (23%) ^e	2 (13%) ^f
Total	22 (100%)	16 (100%)

Fourfold table showing the number of masses correctly or falsely classified as malignant or benign on TOE (A), CT (B), CMR (C) and ¹⁸F-FDG-PET (D) respectively. Given in parenthesis is the percentage of a true benign, b true malignant, c false malignant and d false benign ratings on each modality with respect to the overall number of benign and malignant masses as determined by the reference standard. Percentage of missed benign (e) and missed malignant (f) masses on each modality in relation to the total number of benign and malignant masses

CT cardiac computed tomography, CMR cardiac magnetic resonance, TEE transesophageal echocardiography, ¹⁸F-FDG PET-CT ¹⁸F-fluorodesoxyglucose positron emission tomography coupled with computed tomography

histological purpose. However, our methodology making ¹⁸F-FDG PET-CT the last line, explains that all decisions were made after its completion and can lead to overestimating its contribution. Performances of ¹⁸F-FDG PET-CT overcome the single information by combining radiotracer uptake on the mass, and giving information on local–regional extension and other whole body lesions. To optimize its accuracy, this examination must be carried out under good conditions with preparation (low-carbohydrate and high-fat diet), which can complicate the procedure [15].

Survival analyses show that non-invasive cardiac imaging can detect patients with a good prognosis based on a result indicating a benign or undetermined etiology. Similar findings have already been reported for CMR on a population of 53 patients [16]. Other confounders like complications associated with the management of malignant tumors could impact the overall survival, independently of the mass etiology. However, prognostic performance and comparison of each non-invasive modality had never been explored previously.

Up to now, there is no guideline for the use of non-invasive cardiac imaging in the cardiac masses exploration algorithm. A recent study proposed a decision algorithm focusing on CMR without integrating cardiac CT [11]. Based on our results, we propose a new diagnostic algorithm for the exploration of cardiac masses (Fig. 7) with a choice of the first-line imaging modality based on mass localization.

The main strength of this study is its originality, as it is the first to compare different imaging modalities available today to explore heart masses. In addition, the population studied is significant for a rare disease. However, the sample is quite small for an epidemiologic study: for example, the sex-ratio of the population, with a preponderance of men in the population (59%), does not seem intuitive since we would expect parity. This slight difference can probably be attributed to a random sampling and should lead to a careful interpretation of the results.

Limitations

Our study has limitations associated with a single-site and retrospective study. We can suppose that site experience could impact the validity of our results: prescription and protocol of imaging tests, interpretation and therapeutic approach. The Interpretation of imaging examinations was not performed blindly. Due to the retrospective design and the impact of the result on the decision-making at the time of the test, it was not possible to perform a standardized or blind review of the tests. As a result, the interpretation of tests is subject to some variability inherent in each modality. The strength of this retrospective work is to show, in a real-life cohort, the contribution of each modality despite this interpretation-induced variability.

There is also a recruitment bias with patients selected only from a tertiary center of cardiology and cardiac surgery. This bias may explain the low proportion of secondary tumors compared to the rate found in epidemiological studies [1, 17]. However, it strengthens the study by selecting more complex diagnostic situations.

Table 5 Performance of each imaging modality to diagnose a benign or malignant mass

	N	Se, %	Sp, %	NPV, %	PPV, %	AUC	SD	P-value	95% CI
Benign									
TEE	47	68	93	46	97	0.805	0.06	<0.001	0.69–0.92
CMR	49	86	89	70	95	0.873	0.05	<0.001	0.77–0.98
Cardiac CT	41	76	96	70	97	0.857	0.05	<0.001	0.77–0.95
¹⁸ F-FDG PET-CT	22	77	100	76	100	0.886	0.06	<0.001	0.78–1.00
Malignant									
TEE	14	64	100	90	100	0.821	0.08	<0.001	0.66–0.98
CMR	18	67	96	89	86	0.813	0.07	<0.001	0.68–0.95
Cardiac CT	24	67	98	83	94	0.821	0.06	<0.001	0.70–0.94
¹⁸ F-FDG PET-CT	16	88	100	92	100	0.938	0.05	<0.001	0.84–1.00

AUC area under the curve, Cardiac CT cardiac computed tomography, CI confidence interval, CMR cardiac magnetic resonance, NPV negative predictive value, PPV positive predictive value, Se sensitivity, SD standard deviation, Sp specificity, TEE transthoracic echocardiography, ¹⁸F-FDG PET-CT ¹⁸F-fluorodeoxyglucose positron emission tomography coupled with computed tomography

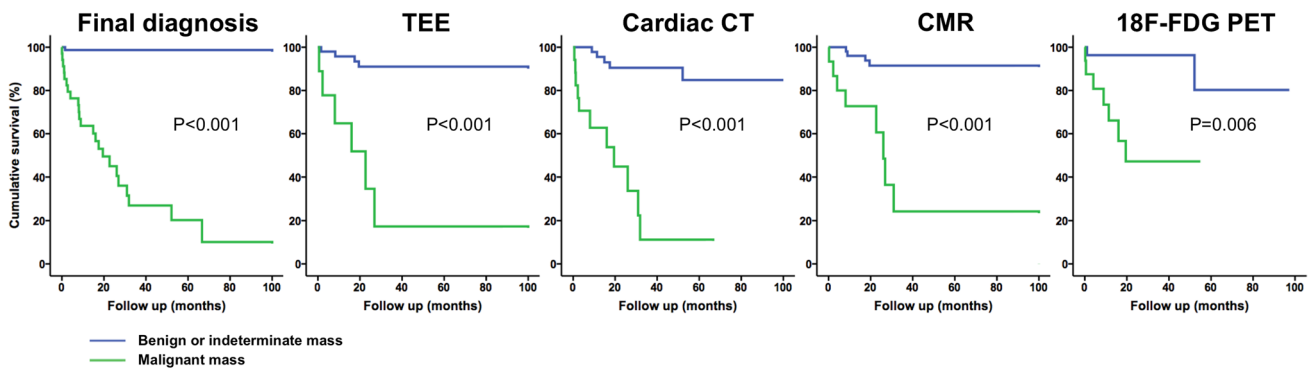


Fig. 6 Survival according to final diagnosis and cardiac imaging results. Cardiac CT cardiac computed tomography, CMR cardiac magnetic resonance, TTE transthoracic echocardiography, TEE

transthoracic echocardiography, ¹⁸F-FDG PET-CT ¹⁸F-fluorodeoxyglucose positron emission tomography

Prioritization of examinations by the clinician represents an evident bias on our study, modifying the contribution of the different imaging modalities. In addition, availability of each technique and lack of consensus probably led to the over-prescription of imaging tests.

Finally, temporal changes related to the long inclusion period, may have had an impact on performed tests and therefore on study results.

the usefulness of each technique is not equal, depending on the location of the mass within the heart. In the first line, TEE is interesting for atrial masses, cardiac CT and CMR for ventricular or suspected malignant masses, and ¹⁸F-FDG PET-CT is the most effective test to distinguish between benign and malignant etiologies. A final classification as benign or indeterminate etiology means a good prognosis.

Conclusion

All non-invasive cardiac imaging techniques are useful for cardiac mass exploration and management, as they make it possible to increase the decision-making rate and to differentiate benign and malignant etiologies. However,

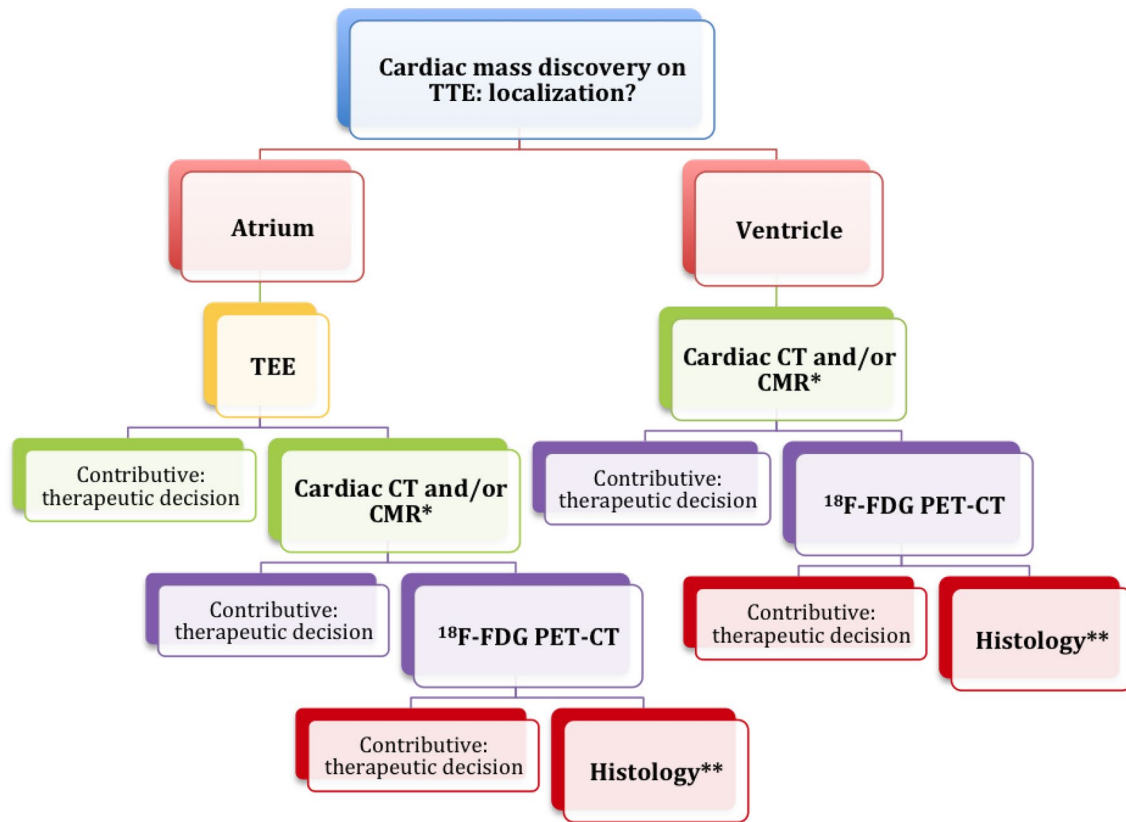


Fig. 7 Proposal of a new diagnostic algorithm. *Cardiac CT* cardiac computed tomography, *CMR* cardiac magnetic resonance, *TTE* transthoracic echocardiography, *TEE* transesophageal echocardiography, *¹⁸F-FDG PET-CT* ¹⁸-fluorodeoxyglucose positron emission tomogra-

phy. *Depending on local availability and possible contraindications of the patient, CMR should be preferred in case of left ventricular mass. **Histological evidence by biopsy or surgery

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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