J Cardiovasc Imaging. 2023 Oct;31(4):159-168
https://doi.org/10.4250/jcvi.2023.0028
pISSN 2586-7210·eISSN 2586-7296

Journal of Cardiovascular Imaging JCVI

Review Article

Check for updates

Cardiovascular Magnetic Resonance Versus Histopathologic Study for Diagnosis of Benign and Malignant Cardiac Tumours: A Systematic Review and Meta-Analysis

Sandra Nóbrega, MD[1], Catarina Martins da Costa, MD[1,2,3], Ana Filipa Amador, MD[1,2,3], Sofia Justo, MD[1], and Elisabete Martins, MD, PhD[1,2,3,4]

[1]Faculty of Medicine, University of Porto, Porto, Portugal
[2]Department of Cardiology, Centro Hospitalar Universitário São João, Porto, Portugal
[3]Member of the European Reference Network for Rare, Low-Prevalence, or Complex Diseases of the Heart (ERN GUARD-Heart), Amsterdam, The Netherlands
[4]Center for Health Technology and Services Research (CINTESIS@RISE), Faculty of Medicine, University of Porto, Portugal

OPEN ACCESS

Received: Feb 17, 2023
Revised: Jul 27, 2023
Accepted: Aug 6, 2023
Published online: Sep 11, 2023

Address for Correspondence:
Catarina Martins da Costa, MD
Department of Cardiology, Centro Hospitalar Universitário São João, Al. Prof. Hernâni Monteiro, 4200-319 Porto, Portugal.
Email: catarinamarcosta@gmail.com

ABSTRACT

BACKGROUND: The gold standard for diagnosis of cardiac tumours is histopathological examination. Cardiovascular magnetic resonance (CMR) is a valuable non-invasive, radiation-free tool for identifying and characterizing cardiac tumours. Our aim is to understand CMR diagnosis of cardiac tumours by distinguishing benign vs. malignant tumours compared to the gold standard.
METHODS: A systematic search was performed in the PubMed, Web of Science, and Scopus databases up to December 2022, and the results were reviewed by 2 independent investigators. Studies reporting CMR diagnosis were included in a meta-analysis, and pooled measures were obtained. The risk of bias was assessed using the Quality Assessment Tools from the National Institutes of Health.
RESULTS: A total of 2,321 results was obtained; 10 studies were eligible, including one identified by citation search. Eight studies were included in the meta-analysis, which presented a pooled sensitivity of 93% and specificity of 94%, a diagnostic odds ratio of 185, and an area under the curve of 0.98 for CMR diagnosis of benign vs. malignant tumours. Additionally, 4 studies evaluated whether CMR diagnosis of cardiac tumours matched specific histopathological subtypes, with 73.6% achieving the correct diagnosis.
CONCLUSIONS: To the best of our knowledge, this is the first published systematic review on CMR diagnosis of cardiac tumours. Compared to histopathological results, the ability to discriminate benign from malignant tumours was good but not outstanding. However, significant heterogeneity may have had an impact on our findings.

Keywords: Heart neoplasms; Cardiac imaging techniques; Magnetic resonance imaging; Pathology, surgical; Diagnosis

Journal of Cardiovascular Imaging JCVI

INTRODUCTION

Cardiac tumours represent a clinical diagnostic challenge, with the ability to distinguish subtypes being critical for proper management and therapeutic approach.[1-3] In general, cardiac tumours are divided into primary and secondary tumours.[2] Primary cardiac tumours arise from cardiac tissue and are classified as benign and malignant. Benign tumours include myxomas, lipomas, papillary fibroelastomas, rhabdomyomas, fibromas, and cardiac paragangliomas; malignant cardiac tumours include sarcomas, lymphomas, and mesotheliomas.[2] Secondary cardiac tumours are malignant, comprise mainly metastases of other tissue tumours, and are more common than primary cardiac tumours.[2]

The gold standard for the diagnosis and classification of cardiac tumours is biopsy or surgical resection of the tumour followed by histopathological examination.[1][2] Nonetheless, cardiovascular imaging is the first-line evaluation and may suggest a specific type of cardiac tumour.[4] Of the non-invasive imaging techniques, cardiovascular magnetic resonance (CMR) imaging stands out as a radiation-free tool due to the wide field of view, high tissue contrast, versatility in image planes, high spatial and temporal resolution, and the ability to discriminate tissue characteristics, such as water and fat content.[5][6] In this way, CMR study has the potential to contribute to the distinction between benign and malignant cardiac tumours and their subtypes, avoiding the technical difficulties and risks associated with an invasive procedure to obtain histopathologic specimens.[7] Disadvantages include long acquisition times, limited availability, and possible contraindications in claustrophobia and those with older-generation cardiac devices.[2]

The aim of this study is to understand the incremental value of CMR in the diagnosis and classification of cardiac tumours compared to the gold standard histopathological examination.

METHODS

This systematic review with meta-analysis was developed in accordance with the Preferred Reporting Items for a Systematic Review and Meta-Analysis of Diagnostic Test Accuracy Studies (PRISMA-DTA) Statement.[8] The PRISMA-DTA checklist can be found in **Supplementary Table 1**.

Search strategy and study selection

A systematic search was conducted in the PubMed, Web of Science, and Scopus databases, and additional articles were included by manually reviewing the reference lists of relevant articles. The query used in all databases included the following terms or their variations: “heart tumours,” “magnetic resonance imaging,” “reproducibility of results,” “differential diagnosis,” and “accuracy.” No limits were applied. The detailed search strategy for each database is described in **Supplementary Table 2**.

This search was conducted by 2 independent investigators, SN and CC, who analysed the results in 2 phases based on the inclusion and exclusion criteria described below. After removing duplicates, all titles and abstracts were examined. In a subsequent phase, the full articles were retrieved and analysed independently by the 2 investigators. When the full text was not available, the authors were asked for a full-text copy. Any discrepancies between the investigators in study selection were settled through consensus. The last search was performed in December 2022.

The eligibility criteria for study selection were predetermined. Inclusion criteria consisted of published studies that reported any quantitative data on the value of CMR in the diagnosis of cardiac tumours in humans, as well as information on how the final diagnosis was achieved. Exclusion criteria were as follows: non-human studies, case reports, systematic reviews, meta-analyses, studies reporting any information about cardiac masses other than cardiac tumours, and studies comparing CMR to another imaging method.

Data extraction

Following full-text analysis and selection of included studies based on the eligibility criteria, the investigators working independently and in duplicate collected the following information from each eligible study: year of publication; type of study; how final diagnosis was achieved; numbers of patients included in the study, with cardiac tumours, and with histological diagnosis; number of correct diagnoses as benign or malignant by CMR; and number of correct tumour subtype diagnoses by CMR. Patient demographic characteristics, such as age and sex, were also collected when available. These results were retrieved, examined, and summarized in a table by each investigator, and any disagreements were resolved through consensus.

Statistical analysis

When available, we collected the numbers of true positive (TP), true negative (TN), false positive (FP), and false negative (FN) results for each study and summarized them in a table. If the study did not provide this information, we used reported sensitivity, specificity, positive predictive value, negative

https://doi.org/10.4250/jcvi.2023.0028

Journal of Cardiovascular Imaging JCVI

predictive value, and total sample size to back-calculate integer numbers. For the meta-analysis, we used the bivariate random-effects model. The pooled estimates of sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR), and diagnostic odds ratio (DOR) with corresponding 95% confidence intervals (CIs) were analysed based on the bivariate model and are presented in a forest plot. A summary receiver operating characteristic curve was plotted to determine the area under the curve (AUC) as a global measure of test performance. Diagnostic accuracy was classified as low (AUC < 0.7), moderate (0.7 ≤ AUC < 0.9), or high (AUC ≥ 0.9).[9] We examined heterogeneity across studies by visually inspecting the forest plots of sensitivity, specificity, PLR, NLR, and DOR and further assessed heterogeneity using the I^2 test; I^2 > 50% was considered statistically significant heterogeneity.[10] Clinical utility was evaluated using a likelihood ratio scattergram. All statistical analyses were performed with Stata (version 17.0/SE; Stata Corporation, College Station, TX, USA), using the midas and metandi commands.[11][12] A p-value < 0.05 was considered statistically significant.

Quality assessment

Concerning the quality assessment of the studies included in this work, the risk of bias of each study was assessed independently by 2 investigators (SN and SJ) using the Quality Assessment Tools from the National Institutes of Health.[13]

RESULTS

Study selection

An initial search through the PubMed, Web of Science, and Scopus databases yielded 2,321 results: 510 from PubMed, 386 from Web of Science, and 1,425 from Scopus. Of those, 443 results were duplicates and were removed, and 1,059 were excluded for failing to meet the inclusion and exclusion criteria, with 959 corresponding to case reports. One additional study identified by citation list search was included. After screening by title and abstract, we retrieved the full text of 20 studies. This included one study for which the full text was unavailable, and our attempt to contact the authors to provide us a copy in English was unsuccessful. Nine articles were excluded: one result failed to avoid duplicate reporting bias, and 8 failed to report extractable data of CMR accuracy. The study selection process is represented in **Figure 1** as a PRISMA flow diagram.

Study characteristics

Ten studies were included in this review, and the characteristics of each are presented in **Table 1**. The CMR protocols used are described in **Table 2**.

Fussen et al.[14] studied 41 patients who had an echocardiogram or a thoracic computed tomography scan that revealed a cardiac mass. Twenty patients had histopathological data available,

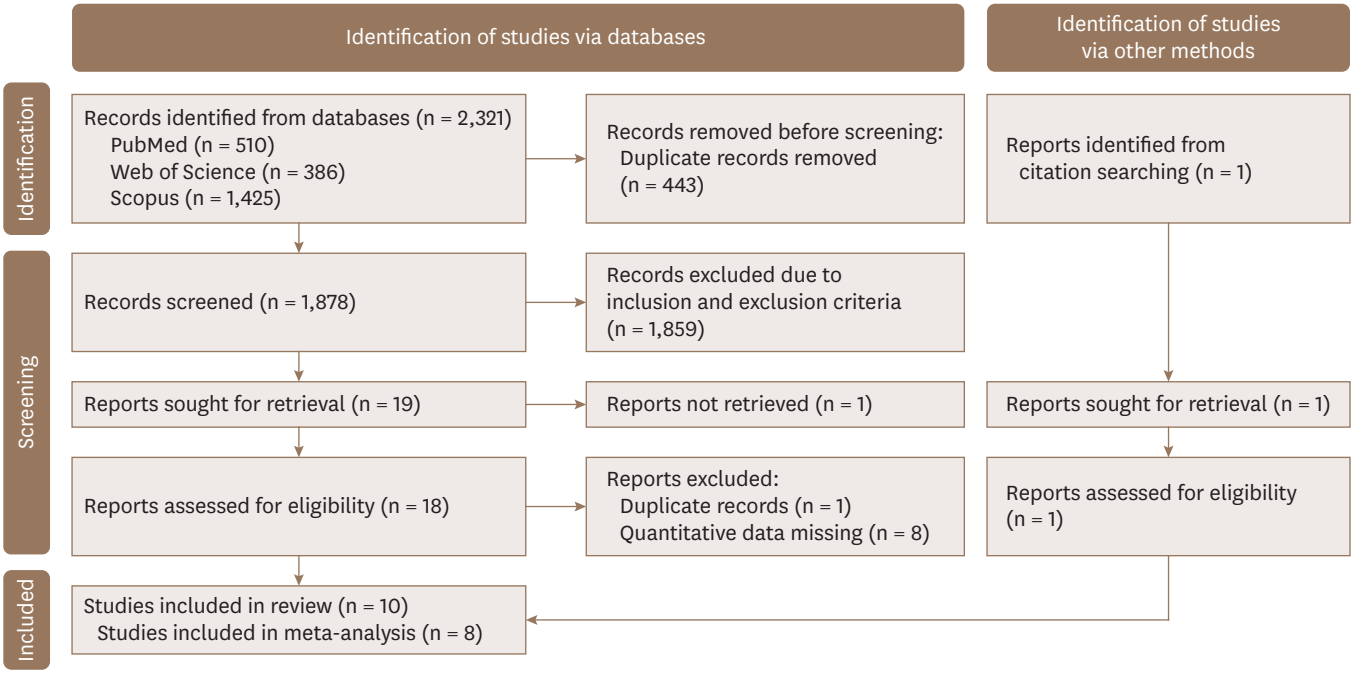


Figure 1. Preferred Reporting Items for a Systematic Review and Meta-Analysis flow diagram of study selection.

https://doi.org/10.4250/jcvi.2023.0028

Journal of Cardiovascular Imaging JCVI

Table 1. Cardiovascular magnetic resonance accuracy in the classification of cardiac tumours as benign or malignant and their subtypes

Study	Type of study	No. of patients (% males)	Age (years)	No. of patients with cardiac tumours	No. of patients with HP dx	Final dx	No. of correct dx of cardiac tumours/ No. of cardiac tumours	No. of correct dx of benign tumours/ No. of benign tumours	No. of correct dx of malignant tumours/ No. of malignant tumours	No. of correct tumour subtype dx/ No. of cardiac tumours	No. of correct tumour subtype dx/ No. of benign tumours	No. of correct tumour subtype diagnosis/ No. of malignant tumours
Fussen et al.[14] (2011)	Retrospective	41 (51.2)	61 ± 14	16	20	HP	15/16	9/9	6/7	12/16	9/9	3/7
Giusca et al.[15] (2017)	Multicentric retrospective	125*	†	45	45	HP	44/45	‡	‡	35/45	‡	‡
Hoffmann et al.[16] (2003)	Retrospective	55 (41.8)	47.7 ± 23.4	55	55	HP	R1: 42/55 R2: 41/55	R1: 23/33 R2: 24/33	R1: 19/22 R2: 17/22	‡	‡	‡
Kassi et al.[17] (2019)	Prospective	66 (54.5)	58 (45–66)	66	56	HP/clinical data	53/66	18/27	35/39	‡	‡	‡
Lemasle et al.[18] (2020)	Monocentric retrospective	119 (58.8)	58 ± 14	67	96	HP/imaging studies/AR	54/67	42/49	12/18	‡	‡	‡
Mousavi et al.[19] (2019)	Retrospective	145 (44.8)	58 ± 16	53	53	HP	R1: 47/53 R2: 50/53	R1: 25/25 R2: 25/25	R1: 22/28 R2: 25/28	18/25	18/25	‡
Patel et al.[23] (2016)	Retrospective	50 (50)	46 ± 17	35	50	HP	‡	‡	‡	24/35	11/14	13/21
Shenoy et al.[20] (2021)	Multicentric prospective	903 (45.6)	60 (47–69)	374	226	HP/clinical course	368/374	160/164	208/210	‡	‡	‡
Tumma et al.[21] (2016)	Retrospective	249 (43.0)	55.9 ± 17.9	51	‡	HP/imaging studies	50/51	31/32	19/19	‡	‡	‡
Zhu et al.[22] (2016)	Prospective monocentric	59 (44.1)	48.2 ± 21.1	39	23	HP	22/23	19/20	3/3	‡	‡	‡

Age data are shown as mean ± standard deviation or median (interquartile range).
AR: anticoagulation response, Dx: diagnosis, HP: histopathologic, R1: reader 1, R2: reader 2.
*Data by sex not available; †Age information not available; ‡Information not available.

9 of whom had benign tumours, 7 with malignant tumours, and 4 with a non-neoplastic mass. CMR correctly identified all 9 benign neoplasms and 6 of 7 (86.7%) malignant neoplasms. The other case of malignant tumour was misdiagnosed as a myxoma. Regarding diagnosis of tumour subtype, there were 9 patients with myxoma, and CMR achieved a correct diagnosis in all cases. However, CMR achieved a correct diagnosis of subtype in 3 of 7 patients with malignant tumours.

A study by Giusca et al.[15] included 125 patients who were referred for CMR for a suspected cardiac mass. Of those, 65 had cardiac tumours, with baseline characteristics available only for this group of patients (29 female patients with a mean age of 58 ± 16.5 years), 45 of whom had histopathological diagnosis. CMR achieved correct identification as benign or malignant in 44 of 45 (97.8%) cardiac tumours as well as a correct tumour subtype diagnosis in 35 of 45 (77.8%) patients.

In a study of 55 patients by Hoffmann et al.,[16] 2 readers blindly evaluated the CMR images and classified each as benign, likely benign, likely malignant, or malignant. All patients had confirmed cardiac tumours and histopathological correlation. Readers 1 and 2 correctly classified as benign or malignant 42 (76.4%) and 41 (74.5%) of the 55 cardiac tumours, respectively. Reader 1 correctly identified 23 of 33 (69.7%) benign tumours and 19 of 22 (86.4%) malignant tumours, labelling 5 benign tumours as malignant, 5 benign tumours as likely malignant, one malignant tumour as benign, and 2 malignant tumours as likely benign. Reader 2 correctly identified 24 of 33 (72.7%) benign tumours and 17 of 22 (77.3%) malignant tumours, misclassifying 3 benign tumours as malignant, 6 benign tumours as likely malignant, and 5 malignant tumours as likely benign. Collectively, the readers achieved means of 71.2% and 81.8% correct diagnoses for benign and malignant tumours, respectively.

Kassi et al.[17] examined 66 patients with suspected cardiac tumours, 56 of whom had a histopathological confirmation. There were 27 benign tumours and 39 malignant tumours among the patients. Using a CMR-based algorithm, 18 of 27 (66.7%) benign tumours were correctly classified, while 6 were classified as likely benign, and 3 were classified as malignant.

https://doi.org/10.4250/jcvi.2023.0028

Journal of Cardiovascular Imaging JCVI

Table 2. Cardiovascular magnetic resonance protocol used in each study

Study	Cine sequences	T1-TSE	T2-TSE	SPIR/ Fat sat	FPP	LGE
Fussen et al.[14] (2011)	+	+	+	+	op	+
Giusca et al.[15] (2017)	+	+	+	+	+	+
Hoffmann et al.[16] (2003)	+	+	+			+*
Lemasle et al.[18] (2020)	Not described					
Kassi et al.[17] (2019)	+	+	+		+	+
Mousavi et al.[19] (2019)	+	+	+	+	+	+*
Patel et al.[23] (2015)	+	+	+		+	+*
Shenoy et al.[20] (2021)	+	+	+	+	+	+
Tumma et al.[21] (2016)	+					+*
Zhu et al.[22] (2016)	+	+	+		+	+

FPP: first-pass perfusion, LGE: late gadolinium enhancement imaging, op: optional, SPIR: Spectral Presaturation with Inversion Recovery, T1-TSE: T1-weighted spin echo sequence, T2-TSE: axial T2-weighted spin echo sequence.
*Optional LGE with long inversion time inversion recovery for thrombus.

Thirty-five of 39 (89.7%) cases were correctly classified as malignant, while 4 were incorrectly classified as likely benign.

Lemasle et al.[18] studied 119 patients with cardiac masses: 96 had a histopathological diagnosis, and 112 had a final diagnosis based on histological results, anticoagulation response, and/or computed tomography and CMR findings. Sixty-seven patients underwent CMR and received a final diagnosis. In this study, CMR correctly classified 42 of the 49 (85.7%) benign masses, misclassified 2 as malignant, and returned an indeterminate classification in 5. On the other hand, 12 of 18 (66.7%) malignant masses were correctly identified, while 2 were diagnosed as benign, and 4 were indeterminate.

Mousavi et al.[19] included 125 patients with confirmed cardiac masses, 53 having a histopathological diagnosis of cardiac tumours. Two readers were instructed to propose a diagnosis based solely on the CMR of the 53 patients, blinded to any information or the interpretation of the other reviewer. Reader 1 correctly identified 88.7% (47 of 53) of the cases as benign or malignant, while reader 2 identified 94.3% (50 of 53), an average of 91.5% correct diagnosis between the 2 readers. Readers 1 and 2 correctly categorized 22 (78.6%) and 25 (89.3%) of 28 malignant tumours, respectively, for an average of 83.9% correct diagnosis. Both reviewers, on the other hand, correctly identified all 25 benign tumours (100%). The agreement rate between the readers was 100% and 95% for benign and malignant masses, respectively. One or both readers misdiagnosed 6 cases of malignant tumours as benign. In terms of tumour subtype classification, both readers correctly classified 18 of 25 (72%) benign tumours.

In 2022, Shenoy et al.[20] used CMR to evaluate 903 patients with suspected cardiac mass. Cardiac tumours were found in 374 patients, of whom 164 had benign and 210 had malignant tumours. Pathological information of the cardiac mass was available in 226 patients, representing 47% and 60% of those with a CMR diagnosis of benign and malignant tumours, respectively, while the remaining patients were diagnosed using all clinical data available, including imaging data, clinical course, and outcome. In 368 of 374 cases (98.4%), CMR correctly classified a mass as benign or malignant. Four benign tumours were incorrectly classified as malignant, and 2 malignant tumours were identified as benign.

Tumma et al.[21] included 249 patients with suspected masses on computed tomography scan or transthoracic or transesophageal echocardiogram, 51 of whom were confirmed to have a cardiac tumour. In their study, diagnosis was confirmed using not only biopsy but also surgery and/or positron emission tomography scans. CMR achieved an accurate diagnosis in 31 of 32 (96.9%) benign tumours and in 19 of 19 (100%) malignant tumours.

Zhu et al.[22] examined 59 patients with suspected cardiac masses. Thirty-nine patients were diagnosed with cardiac tumours, 29 of which were benign and 10 malignant. Histopathological diagnosis was available for 23 cases of cardiac tumours; among the patients with pathological validation, a diagnostic accuracy of 96% in distinguishing benign and malignant tumours was reported. CMR correctly identified 19 of 20 (95%) benign tumours and 3 of 3 (100%) malignant tumours, with one case of myxoma misclassified as malignant.

Patel et al.[23] included 50 patients with histopathological diagnosis of cardiac masses and tried to classify the correct tumour subtype for each patient, not resorting to the simple classification of benign or malignant, differing from the other studies included in this review. CMR provided the correct subtype diagnosis in 68% of the cases (34 of 50): 10 of 15 (66.7%) nonneoplastic masses, 11 of 14 (78.6%) benign tumours, and 13 of 21 (61.9%) malignant tumours.

Quantitative synthesis

Of the 10 articles included in this review, a quantitative synthesis of benign vs. malignant diagnosis of cardiac tumours was available in 9 (not included, Giusca et al.[15]). Global accuracy of CMR ranged between 76.4% and 98.4%; among all 750 patients, 698 were correctly diagnosed (93%), 26 were wrongly diagnosed (3.5%), and 26 were classified as likely benign/malignant or indeterminate (3.5%).

Concerning tumour subtypes, 4 studies included a quantitative synthesis.[14][15][19][23] Of a total of 121 patients with

https://doi.org/10.4250/jcvi.2023.0028

Journal of Cardiovascular Imaging JCVI

histopathological examination, 89 (73.6%) had their tumour subtype correctly diagnosed. Of 48 patients with benign tumours, 38 (79.2%) had their tumour subtype correctly diagnosed, and of 28 patients with malignant tumours, 16 (57.1%) had their tumour subtype correctly diagnosed.

There were 52 misdiagnoses within 9 studies; 26 cases were classified as likely benign/malignant or indeterminate, and 26 were misdiagnosed as benign or malignant (15 benign tumours were classified as malignant and 9 malignant tumours were classified as benign). Misdiagnosis of malignant tumours may have serious implications for patients as it delays treatment and increases the risk of a worse prognosis.[2] On the other hand, CMR is a non-invasive and relatively accessible tool that can allow earlier detection of a malignant tumour.

Additionally, 3 studies comprised 39 incorrectly diagnosed cardiac tumours and used the classifications "likely benign/malignant" or "indeterminate".[16-18] Of those, 13 were misdiagnosed (33.3%)—10 benign tumours and 3 malignant tumours, and 26 were identified as likely benign/malignant or indeterminate (66.6%)—16 benign tumours and 10 malignant tumours.

Meta-analysis

Regarding diagnosis of benign vs. malignant tumours, 2-by-2 tables containing TP, FN, FP, and TN values were available in 8 studies[14][16-22] and were included in the meta-analysis. **Table 3** displays the data entered into the Stata software. These studies reported a total of 705 cardiac tumours, 359 benign and 346 malignant.

Our meta-analysis yielded an overall sensitivity of 93% (95% confidence interval [CI], 82% to 97%; I^2, 87.89%) and specificity of 94% (95% CI, 84–98%; I^2, 82.59%); the corresponding forest plot is shown in **Figure 2**. The pooled PLR and NLR were 14.6 (95% CI, 5.3–40.1; I^2, 75.75%) and 0.08 (95% CI, 0.03–0.21; I^2, 89.34%), respectively, and the pooled DOR was 185 (95% CI, 32–1,085; I^2, 100%). The forest plots of these measures as shown in **Figure 2**. ROC analysis (**Figure 3**) demonstrated an AUC of 0.98 (95% CI, 0.96–0.99). The likelihood ratio scattergram (**Figure 4**) revealed a summary point estimate of likelihood ratios obtained as functions of mean sensitivity and specificity in the left upper quadrant.

Our results demonstrated substantial heterogeneity among studies (I^2 > 50%) when calculating the pooled measures (**Figure 2**).

Quality assessment

Quality assessment of the studies included in this work was performed using the Quality Assessment Tools from the National Institutes of Health, as in **Figure 5**. Questions 7, 8, and 10 were not applicable to quality assessment and were not considered when rating the studies. Quality was rated as poor (0–3 of 11 questions), fair (4–7 of 11 questions), or good (8–11 of 11 questions). Two articles were rated as "good" quality, while the remaining articles were rated as "fair."

DISCUSSION

To the best of our knowledge, this is the first published systematic review reporting on CMR diagnosis of cardiac tumours compared to the gold standard. We analysed 8 studies and found that CMR has a high match, among both CMR and histopathological results, in the diagnosis of benign vs. malignant cardiac tumours, with a pooled sensitivity of 93% (95% CI, 82–97%) and a pooled specificity of 94% (95% CI, 84–98%). A pooled PLR and NLR of 14.6 (95% CI, 5.3–40.1) and 0.08 (95% CI, 0.03–0.21), respectively, combined with the likelihood ratio scattergram that revealed a summary point estimate of likelihood ratios in the left upper quadrant, suggested that CMR is useful for both confirmation and exclusion of both benign and malignant tumours in patients with cardiac tumours. The DOR is a single summary statistic that evaluates how well the test distinguishes between patients with and without the disease: the higher the value, the better the discriminatory test performance.[24] A pooled DOR of 185 (95%

Table 3. Cardiovascular magnetic resonance results compared to final diagnosis

Study	Total	TP	FN	FP	TN	Sensitivity	Specificity	PPV	NPV
Fussen et al.[14] (2011)	16	9	0	1	6	100%	86%	90%	%
Hoffmann et al.[16] (2003)	55	23	10	3	19	53%	86%	88%	65%
Kassi et al.[17] (2019)	66	18	9	4	35	94%	89%	82%	97%
Lemasle et al.[18] (2020)	67	42	7	6	12	86%	66%	89%	63%
Mousavi et al.[19] (2019)	53	25	0	3	25	100%	89%	89%	100%
Shenoy et al.[20] (2021)	374	160	4	2	208	97%	99%	99%	98%
Tumma et al.[21] (2016)	41	31	1	0	19	97%	100%	100%	95%
Zhu et al.[22] (2016)	23	19	1	0	3	95%	100%	100%	75%

FN: false negative, FP: false positive, NPV: negative predictive value, PPV: positive predictive value, TN: true negative, TP: true positive.

https://doi.org/10.4250/jcvi.2023.0028

Journal of Cardiovascular Imaging JCVI

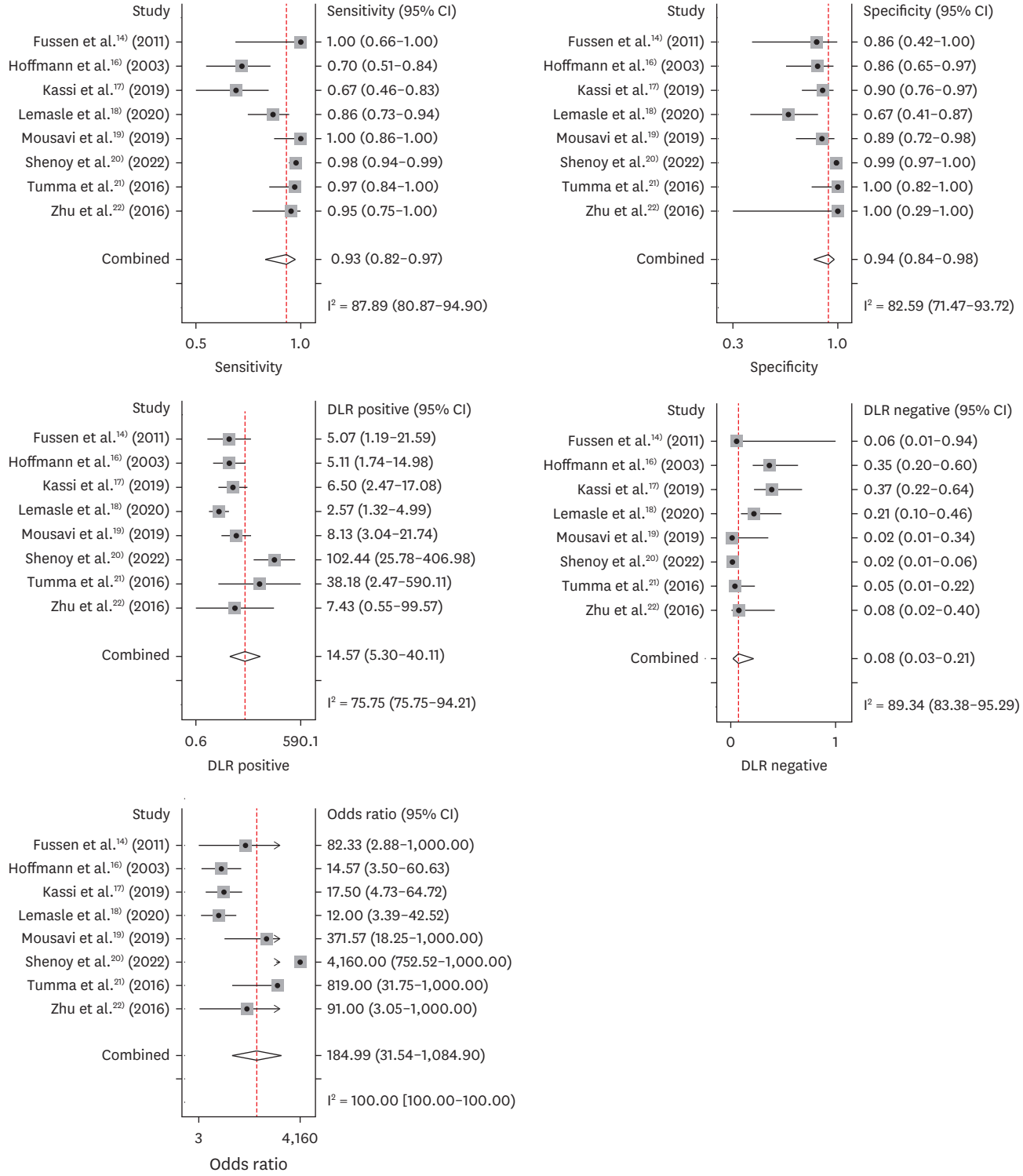


Figure 2. Forest plots of sensitivity and specificity, positive and negative likelihood ratios, and diagnostic odds ratio.
CI: confidence interval, DLR: diagnostic likelihood ratio.

CI, 32–1,085) suggests that CMR distinguishes well benign and malignant cardiac tumours. The high diagnostic accuracy of CMR is also supported by an AUC of 0.98 (95% CI, 0.96–0.99).

Only 4 studies compared CMR and histopathology for tumour subtype diagnosis, with 73.6% correct diagnosis: 79.2% for benign and 57.2% for malignant tumours. These findings reflect

https://doi.org/10.4250/jcvi.2023.0028

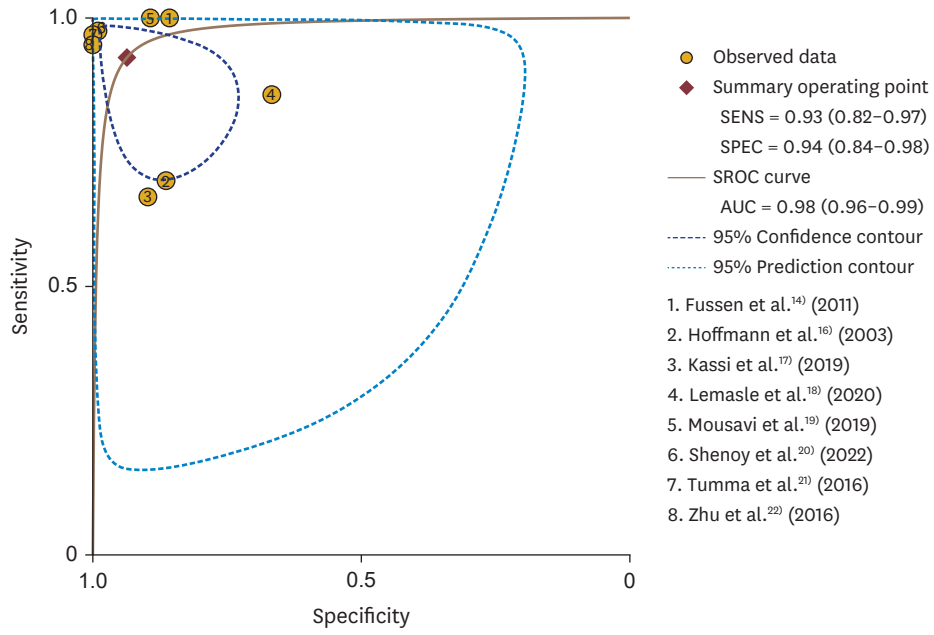


Figure 3. SROC curve for the differentiation of malignant and benign tumours by cardiovascular magnetic resonance.
AUC: area under the curve, SENS: sensitivity, SPEC: specificity, SROC: summary receiver operating characteristic curve.

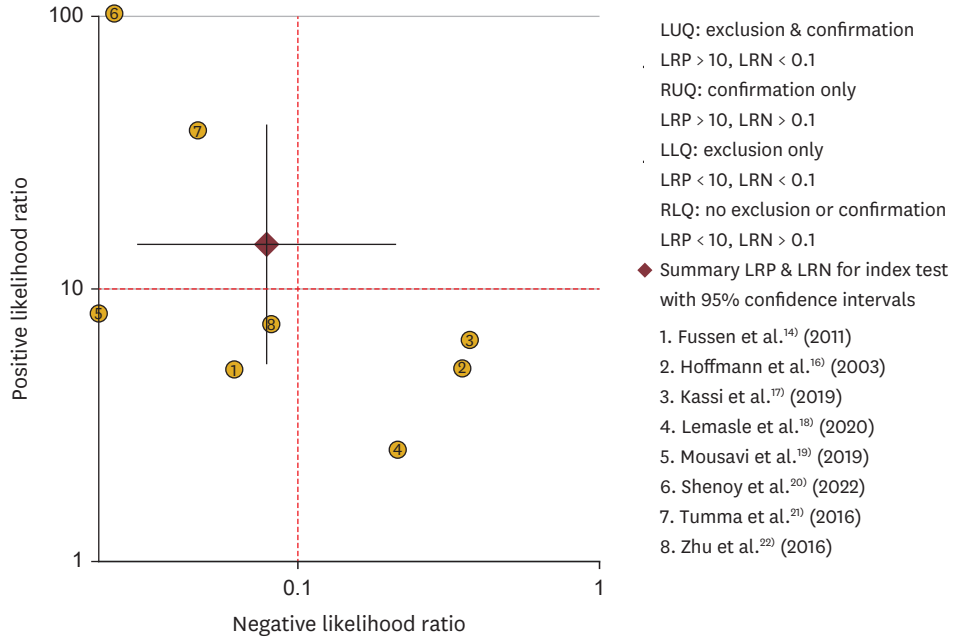


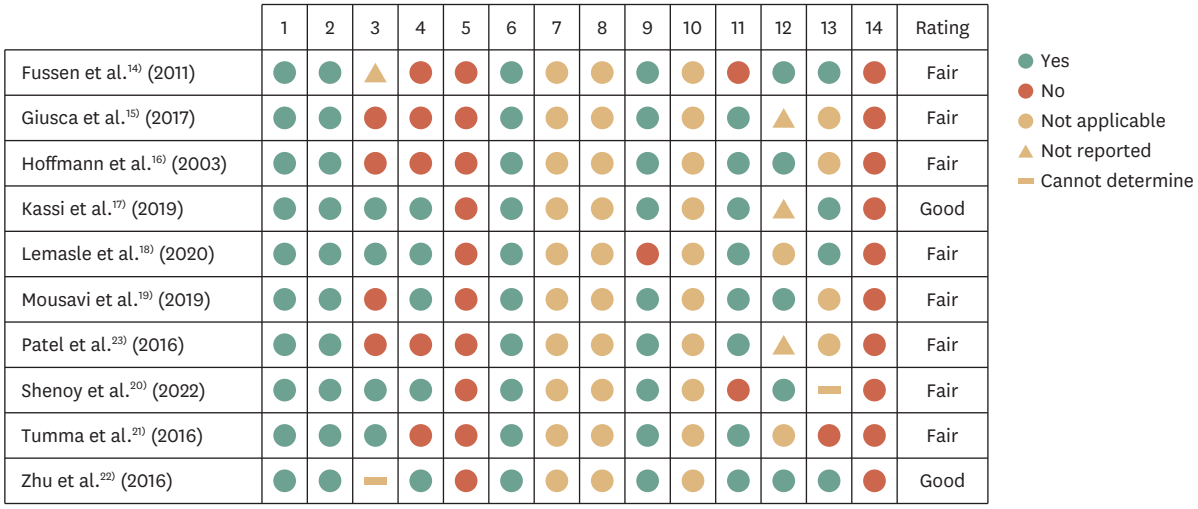
Figure 4. Likelihood ratio scattergrams of cardiovascular magnetic resonance for diagnosis of cardiac tumours.
LLQ: left lower quadrant, LRN: likelihood ratio negative, LRP: likelihood ratio positive, LUQ: left upper quadrant, RLQ: right lower quadrant, RUQ: right upper quadrant.

that, despite its excellent soft tissue contrast and high spatial resolution, CMR is limited in diagnosing specific tumours, especially malignant tumours. This has obvious implications for patient management and treatment. A standardized CMR protocol, probably using artificial intelligence tools to standardise cardiac tumour diagnosis and reduce misdiagnosis, should be developed.

Our study revealed substantial heterogeneity ($I^2 > 50\%$) in the pooled measures, and this should be taken into consideration when interpreting our results. The differences may be explained by the small number of studies included, the small number

https://doi.org/10.4250/jcvi.2023.0028

Journal of Cardiovascular Imaging JCVI



1: Was the research question or objective in this paper clearly stated?; 2: Was the study population clearly specified and defined?; 3: Was the participation rate of eligible persons at least 50%?; 4: Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?; 5: Was a sample size justification, power description, or variance and effect estimates provided?; 6: For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?; 7: Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?; 8: For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?; 9: Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?; 10: Was the exposure(s) assessed more than once over time?; 11: Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?; 12: Were the outcome assessors blinded to the exposure status of participants?; 13: Was loss to follow-up after baseline 20% or less?; 14: Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?.

Figure 5. Results of the quality assessment performed using the Quality Assessment Tools from the National Institutes of Health.

of patients per study, and a lack of information on histology results per se, with studies reporting a final diagnosis obtained through a combination of histological, clinical, imaging, and/or outcome information. Moreover, benign vs. malign diagnosis is not described in most studies, and the non-uniformity may contribute to heterogeneity. The fair quality of most articles included may also preclude the validity of our results and introduce bias. Subgroup analyses were not pre-specified and were not performed due to the small number of studies.[8] Other limitations were identified: 1) only 2 studies were of "good" quality, while the others were rated as "fair"; and 2) in studies involving 2 readers evaluating the CMR images, we analysed the information from the reader who provided the most accurate diagnosis, which may overestimate our results.

Despite the limitations previously mentioned, this study provides an appropriate review of the available evidence on this topic. Given the paucity of current literature on the subject, more research into the diagnostic incremental role of CMR is recommended. More studies with a larger number of patients, as well as studies with final diagnoses based solely on histopathology, are needed to verify our results.

In conclusion, our study suggests that CMR has high agreement with histopathological results in the differentiation of benign and malignant tumours; its capacity to distinguish cardiac tumour subtypes was not outstanding. However, substantial heterogeneity and the several limitations identified may affect our findings. Additional research is required to reinforce the clinical validity of cardiac tumour diagnosis by CMR since any eventual replacement of histopathological diagnosis demands a proven high accuracy.

ORCID iDs
Sandra Nóbrega
https://orcid.org/0009-0000-3887-4174
Catarina Martins da Costa
https://orcid.org/0000-0003-3313-7735
Ana Filipa Amador
https://orcid.org/0000-0003-2410-7075
Sofia Justo
https://orcid.org/0009-0008-9995-0175
Elisabete Martins
https://orcid.org/0000-0002-6944-2953

Conflict of Interest
The authors have no financial conflicts of interest.

Author Contributions
Conceptualization: Costa CM; Data curation: Costa CM; Formal analysis: Nóbrega S; Methodology: Amador AF; Validation: Justo S; Writing - original draft: Nóbrega S, Costa CM; Writing - review & editing: Martins E.

Journal of Cardiovascular Imaging JCVI

SUPPLEMENTARY MATERIALS

Supplementary Table 1

PRISMA-DTA checklist

Click here to view

Supplementary Table 2

Details of search strategy in each database

Click here to view

REFERENCES

1. Bussani R, Castrichini M, Restivo L, et al. Cardiac tumors: diagnosis, prognosis, and treatment. *Curr Cardiol Rep* 2020;22:169.
PUBMED | CROSSREF
2. Tyebally S, Chen D, Bhattacharyya S, et al. Cardiac tumors: *JACC CardioOncology* state-of-the-art review. *JACC CardioOncol* 2020;2:293-311.
PUBMED | CROSSREF
3. Maleszewski JJ, Anavekar NS, Moynihan TJ, Klarich KW. Pathology, imaging, and treatment of cardiac tumours. *Nat Rev Cardiol* 2017;14:536-49.
PUBMED | CROSSREF
4. Aggeli C, Dimitroglou Y, Raftopoulos L, et al. Cardiac masses: the role of cardiovascular imaging in the differential diagnosis. *Diagnostics (Basel)* 2020;10:1088.
PUBMED | CROSSREF
5. Motwani M, Kidambi A, Herzog BA, Uddin A, Greenwood JP, Plein S. MR imaging of cardiac tumors and masses: a review of methods and clinical applications. *Radiology* 2013;268:26-43.
PUBMED | CROSSREF
6. Braggion-Santos MF, Koenigkam-Santos M, Teixeira SR, Volpe GJ, Trad HS, Schmidt A. Magnetic resonance imaging evaluation of cardiac masses. *Arq Bras Cardiol* 2013;101:263-72.
PUBMED | CROSSREF
7. Poterucha TJ, Kochav J, O'Connor DS, Rosner GF. Cardiac tumors: clinical presentation, diagnosis, and management. *Curr Treat Options Oncol* 2019;20:66.
PUBMED | CROSSREF
8. McInnes MDF, Moher D, Thombs BD, et al. Preferred reporting items for a systematic review and meta-analysis of diagnostic test accuracy studies: the PRISMA-DTA statement. *JAMA* 2018;319:388-96.
PUBMED | CROSSREF
9. Okeh UM, Okoro CN. Evaluating measures of indicators of diagnostic test performance: fundamental meanings and formulars. *J Biomet Biostat* 2012;3:132.
CROSSREF
10. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ* 2003;327:557-60.
PUBMED | CROSSREF
11. Dwamena B. Meta-analytical Integration of Diagnostic Accuracy Studies in Stata. Boston, MA: Stata Users Group, 2007.
12. Harbord R. METANDI: Stata Module to Perform Meta-Analysis of Diagnostic Accuracy. Chestnut Hill, MA: Boston College Department of Economics, 2008.
13. National Heart, Lung, and Blood Institute. Quality assessment tool for observational cohort and cross-sectional studies [Internet]. Bethesda, MD: National Heart, Lung, and Blood Institute; 2021 [cited 2022 Dec 31]; Available at: https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools.
14. Fussen S, De Boeck BW, Zellweger MJ, et al. Cardiovascular magnetic resonance imaging for diagnosis and clinical management of suspected cardiac masses and tumours. *Eur Heart J* 2011;32:1551-60.
PUBMED | CROSSREF
15. Giusca S, Mereles D, Ochs A, et al. Incremental value of cardiac magnetic resonance for the evaluation of cardiac tumors in adults: experience of a high volume tertiary cardiology centre. *Int J Cardiovasc Imaging* 2017;33:879-88.
PUBMED | CROSSREF
16. Hoffmann U, Globits S, Schima W, et al. Usefulness of magnetic resonance imaging of cardiac and paracardiac masses. *Am J Cardiol* 2003;92:890-5.
PUBMED | CROSSREF
17. Kassi M, Polsani V, Schutt RC, et al. Differentiating benign from malignant cardiac tumors with cardiac magnetic resonance imaging. *J Thorac Cardiovasc Surg* 2019;157:1912-1922.e2.
PUBMED | CROSSREF
18. Lemasle M, Lavie Badie Y, Cariou E, et al. Contribution and performance of multimodal imaging in the diagnosis and management of cardiac masses. *Int J Cardiovasc Imaging* 2020;36:971-81.
PUBMED | CROSSREF
19. Mousavi N, Cheezum MK, Aghayev A, et al. Assessment of cardiac masses by cardiac magnetic resonance imaging: histological correlation and clinical outcomes. *J Am Heart Assoc* 2019;8:e007829.
PUBMED | CROSSREF
20. Shenoy C, Grizzard JD, Shah DJ, et al. Cardiovascular magnetic resonance imaging in suspected cardiac tumour: a multicentre outcomes study. *Eur Heart J* 2021;43:71-80.
PUBMED | CROSSREF
21. Tumma R, Dong W, Wang J, Litt H, Han Y. Evaluation of cardiac masses by CMR-strengths and pitfalls: a tertiary center experience. *Int J Cardiovasc Imaging* 2016;32:913-20.
PUBMED | CROSSREF
22. Zhu D, Yin S, Cheng W, et al. Cardiac MRI-based multi-modality imaging in clinical decision-making: preliminary assessment of a management algorithm for patients with suspected cardiac mass. *Int J Cardiol* 2016;203:474-81.
PUBMED | CROSSREF
23. Patel R, Lim RP, Saric M, et al. Diagnostic performance of cardiac magnetic resonance imaging and echocardiography in evaluation of cardiac and paracardiac masses. *Am J Cardiol* 2016;117:135-40.
PUBMED | CROSSREF
24. Glas AS, Lijmer JG, Prins MH, Bonsel GJ, Bossuyt PM. The diagnostic odds ratio: a single indicator of test performance. *J Clin Epidemiol* 2003;56:1129-35.
PUBMED | CROSSREF