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PICTORIAL ESSAY

Magnetic Resonance Imaging Findings of Cardiac Metastases: A Pictorial Essay

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INTRODUCTION

Tumours metastatic to the heart may involve the pericardium, epicardium, myocardium and/or endocardium.[1,2] These metastases are approximately 30 times more common than primary cardiac tumours.[3] Cardiac metastases occur with an incidence of 1.5% to 20% according to postmortem statistics.[4] Echocardiographic data have suggested an increase in the incidence of cardiac metastases over the past 30 years due to increased life expectancy in patients with a known malignancy who have benefitted from progress in cancer treatment.[5]

Over 90% of cardiac metastases remain clinically silent, explaining the lack of antemortem diagnosis.[2] Tumours that most commonly involve the heart include lung cancer, breast cancer, melanoma, and lymphoma, reflecting the relatively high prevalence of these malignancies in the population.[6] In all, 36% to 39% of cardiac metastases originate from primary lung cancer, followed by 10% to 12% from breast cancer and 10% to 21% from haematological malignancies.[1,4] Tumours such as melanoma have a much higher propensity (nearly 50%) to involve the heart.[1,7] Following melanoma, the tumours that tend to metastasise to the heart include ovarian, gastric, renal, and pancreatic carcinomas.[1,4]

Cardiac metastases may manifest a variety of appearances. A mass stemming from the lung or mediastinum can directly invade the heart. Additionally, tumour cells that reach the heart via the pulmonary veins (haematogenous spread) can manifest as a central mass.[8] Metastases may present as pericardial effusion and nodularity, as well as myocardial nodules.

Echocardiography is the most frequently used initial modality for the diagnosis of any cardiac mass, though there are some limitations regarding its diagnostic capabilities. First, it is difficult to differentiate a cardiac thrombus from an endocardial mass with

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echocardiography unless it is performed with contrast imaging.[9] Moreover, metastases to the heart with extracardiac extension cannot be evaluated solely by using echocardiography. Cardiac magnetic resonance imaging (MRI) provides a more comprehensive anatomical evaluation by demonstrating the entire thoracic cavity and serves as an excellent diagnostic tool in patients with suspected cardiac metastases. The use of contrast medium adds extra value to cardiac MRI images since it may allow the distinction between a mass that shows contrast enhancement versus a non-enhancing thrombus. Cardiac MRI offers excellent soft tissue contrast resolution, allowing the clinician to distinguish between metastatic lesions and myocardial tissue. The differentiation between benign and malignant tumour, thrombus and blood may be provided by MRI with relative ease.

This pictorial essay presents our experience and highlight the diverse appearances of cardiac involvement by metastases.

CARDIOVASCULAR MAGNETIC RESONANCE PROTOCOL

A total of 1119 consecutive cardiac MRI studies that were carried out at our institution from January 2015 to March 2022 were reviewed and 22 cases of metastases involving the heart were detected. These 22 patients were aged 14 to 98 years, and their demographics as well as features and locations of the lesions were recorded.

Cardiac MRI studies were performed using a 1.5T scanner (Aera; Siemens, Erlangen, Germany) with phased array coil systems. The protocol was the standardised protocol as previously described by the Society for Cardiovascular Magnetic Resonance,[10] which includes steady-state free precession cine imaging, bright-blood and dark-blood single-shot imaging, T1-weighted and T2-weighted fast spin-echo imaging, and early and late perfusion imaging during and after the administration of contrast medium.[10-12]

IMAGING FINDINGS

All cardiac MRI images were evaluated by a radiologist specialising in cardiac imaging with experience of >20 years. Table 1 shows the origins of the primary tumours, while Tables 2 and 3 show the sites of cardiac involvement. Half of the patients were male, suggesting an absence of gender predilection. The mean age of the patients was 58.5 years, with a standard deviation of 21.1 years.

Table 1. Distribution of cardiac metastases according to the origin of the primary tumour (n = 22).*

Lung cancer	3 (14%)
Renal cell carcinoma	3 (14%)
Thymoma	2 (9%)
Gastric carcinoma	2 (9%)
Hepatocellular carcinoma	2 (9%)
Leiomyosarcoma	2 (9%)
Lymphoma	1 (5%)
Leukaemia	1 (5%)
Nasopharyngeal carcinoma	1 (5%)
Melanoma	1 (5%)
Mediastinal teratoma	1 (5%)
Thyroid carcinoma	1 (5%)
Neuroblastoma	1 (5%)
Primary hepatic sarcoma	1 (5%)

* Data are shown as No. (%).

Table 2. Distribution of cardiac metastases according to the involvement of the cardiac chambers (n = 22).* †

Left ventricle	5 (23%)
Right ventricle	3 (14%)
Right atrium	7 (32%)
Left atrium	2 (9%)

* Data are shown as No. (%).
† In the remaining five patients, no defined cardiac chamber involvement was identified; due to the epicardial fat or pericardium being involved by the mass, it was not possible to assign a specific chamber to the lesion.

Table 3. Distribution of cardiac metastases according to the involvement of the cardiac tissue layers (n = 22).* †

Epicardial fat	1 (5%)
Pericardium	10 (46%)
Myocardium	13 (59%)
Endocardium	6 (27%)

* Data are shown as No. (%).
† More than one involvement possible.

Lymphatic Spread

Figure 1 depicts metastatic involvement of pericardial fat surrounding the right coronary artery from a mediastinal lymphoma. Lymphatic drainage of the pericardial space is by lymphatic channels located in the pericardium that converge at the root of the aorta, where these channels are most often obstructed, giving rise to pericardial effusion.[8] Figure 2 shows an example of pericardial metastasis from renal cell carcinoma. Metastatic involvement of the pericardium gives rise to pericarditis initially, followed by haemorrhagic effusion.[13] The development of symptoms during the progression of pericardial effusion depends on the rate of accumulation of fluid. Although the accumulation of large amounts of fluid over time may not cause symptoms, rapid accumulation of small amounts of fluid

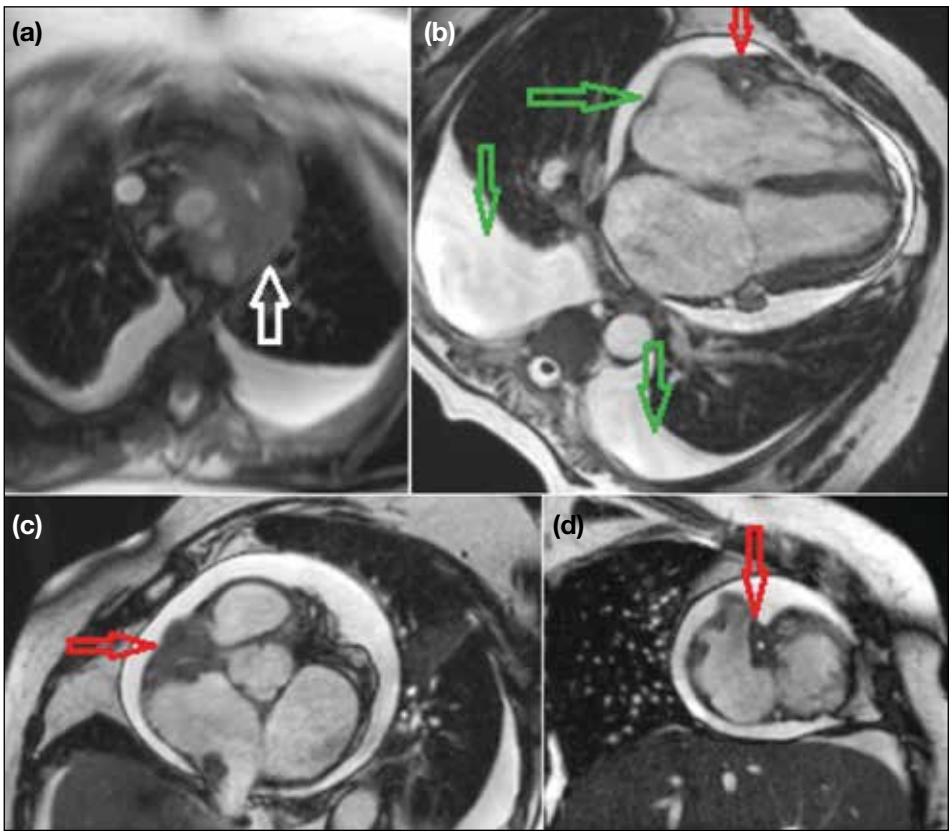

Figure 1. Cardiac magnetic resonance imaging of a 74-year-old female patient with a diagnosis of mediastinal lymphoma (white arrow in [a]). (b-d) Images showing lymphoma infiltration around right coronary artery and its branches (red arrows). Pericardial and bilateral pleural effusions were also noted (green arrows in [b]).

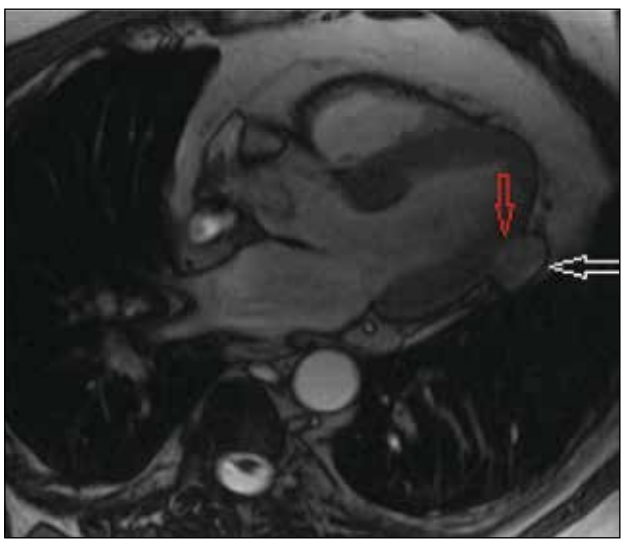

Figure 2. Three-chamber cardiac magnetic resonance image of a 77-year-old male patient with known renal cell carcinoma showed the presence of a pericardial mass (white arrow) at the level of mid-lateral segment of the left ventricle. The tumour showed slight myocardial invasion at the outermost portion of the left ventricular muscle (red arrow).

may cause serious symptoms.[13] In addition to pericardial effusion, deposits of malignant cells on the pericardium may also result in constrictive pericarditis, leading to the deterioration of heart function.[2]

Haematogenous Spread

Figures 3 and 4 demonstrate the myocardial metastasis of a uterine leiomyosarcoma and an iliopsoas muscle sarcoma, respectively. Figures 5 and 6 depict the metastasis of gastric carcinoma to different chambers of the heart. Figure 7 shows the myocardial involvement of leukaemia that diffusely involved the left ventricular myocardium. Figure 8 depicts a nasopharyngeal carcinoma metastasis that caused left myocardial involvement.

Local Extension

Locally aggressive tumours can directly extend into the pericardium and cause frank invasion.[2] This typically occurs in patients with massive lung carcinomas; however, oesophageal carcinomas and mediastinal

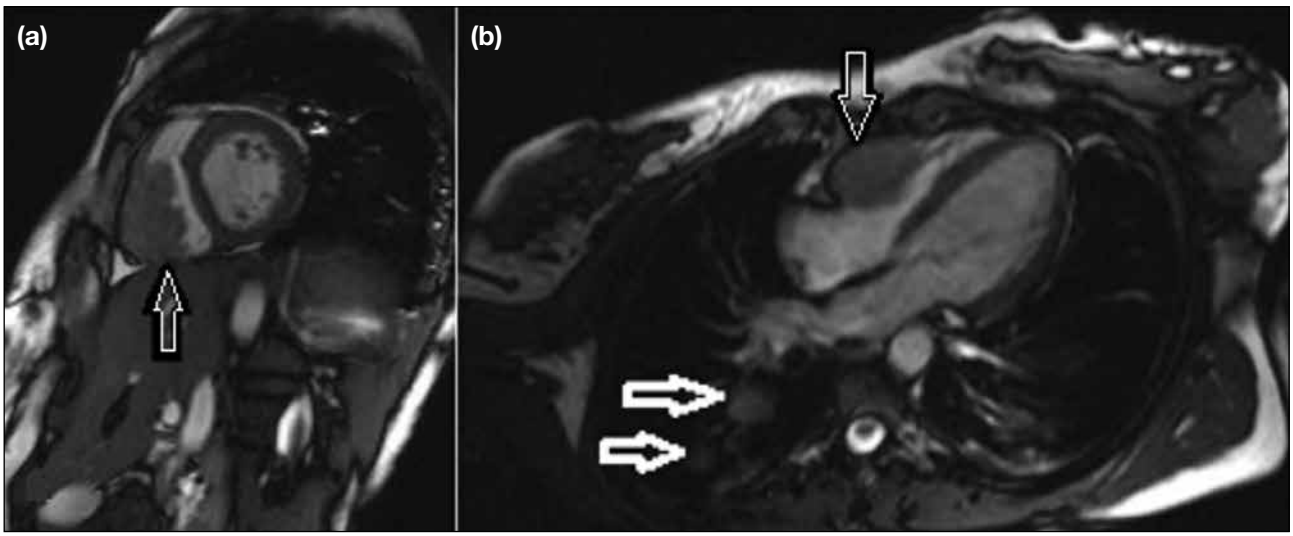

Figure 3. Two-chamber cardiac magnetic resonance image of a 52-year-old female patient diagnosed with uterine leiomyosarcoma (a). The mass is contiguous and indistinguishable from the right ventricular wall (black arrow). (b) A four-chamber image demonstrates the metastatic lesion (black arrow) in the right ventricle. The patient presented with several metastases, and two of them are clearly seen in the posterior right lung (white arrows).

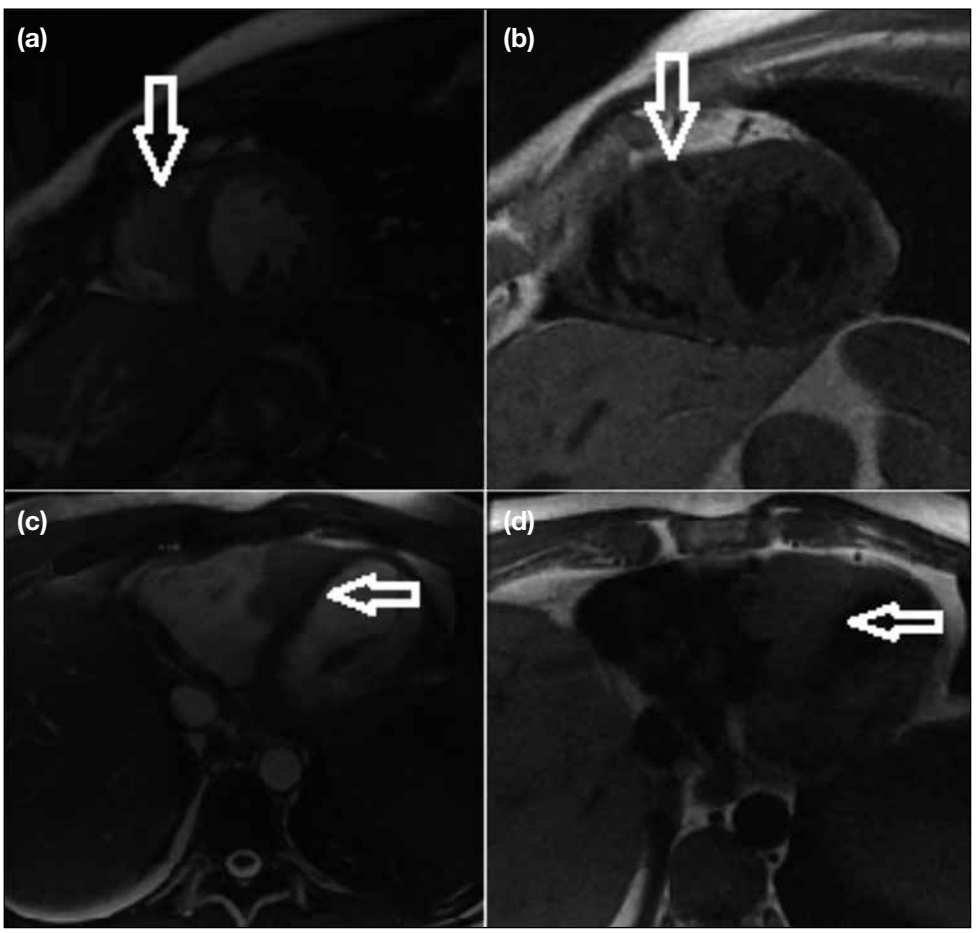

Figure 4. Cardiac magnetic resonance imaging of a 28-year-old male patient with a history of non-Hodgkin lymphoma. The patient was treated with both chemotherapy and radiotherapy in childhood and was later diagnosed with high-grade iliopsoas leiomyosarcoma. The images showed the same lesion at different sequences and projections, which is a mass arising from the interventricular septum with a broad base extending into the right ventricular chamber (arrows), consistent with a metastasis from the leiomyosarcoma. (a) Short-axis cine steady-state free precession gradient echo sequence. (b) Short-axis T1-weighted double inversion black-blood turbo spin echo sequence. (c) Axial steady-state free precession gradient echo sequence. (d) Axial T1-weighted double inversion black-blood turbo spin echo sequence.

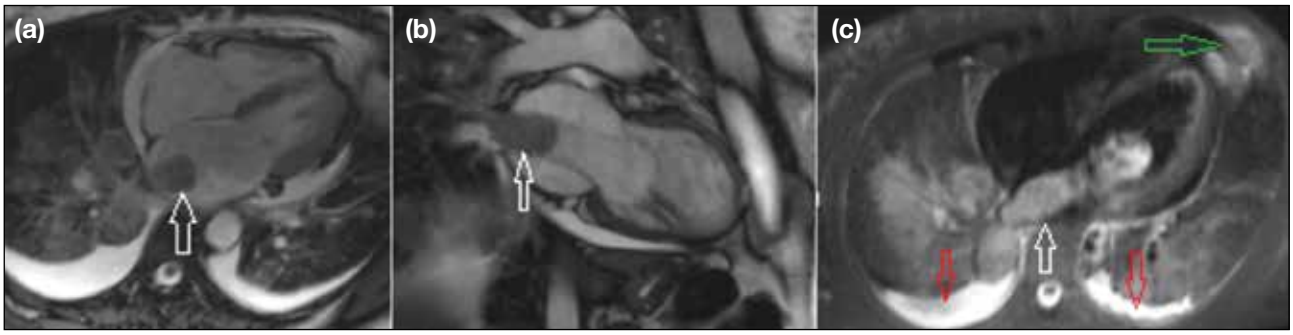

Figure 5. Cardiac magnetic resonance imaging of a 49-year-old female patient with a diagnosis of gastric carcinoma with multiple bone metastases. The images showed the same lesion at different sequences, which is a mass attached to the left atrial wall and extending into the atrial cavity that was considered to be gastric cell carcinoma metastasis (white arrows). Bilateral pleural effusions and left costal metastases (green and red arrows) are shown in (c). (a) Four-chamber cine steady-state free precession gradient echo sequence. (b) Two-chamber cine steady-state free precession gradient echo sequence. (c) Axial T2-weighted triple inversion turbo spin echo sequence.

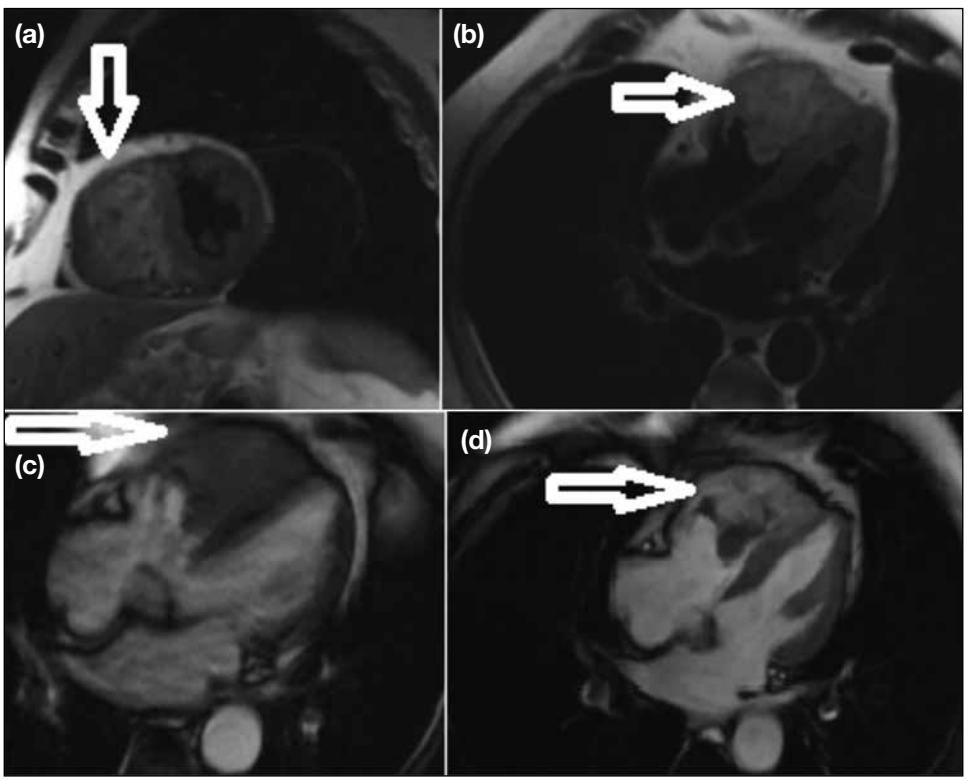

Figure 6. Cardiac magnetic resonance imaging of a 66-year-old male patient with known gastric cancer who was referred to the hospital with symptoms of right heart failure revealed the presence of a right ventricular mass from a gastric cancer metastasis. Two-chamber (a), dark blood four-chamber (b), pre-contrast four-chamber (c), and post-contrast four-chamber (d) images showing the mass located at the right ventricular apex extending into the right ventricular space (arrows), not only filling most of the right ventricle but also infiltrating the interventricular septum at the apical and mid anteroinferoseptal levels.

lymphomas may also directly invade the heart due to anatomical proximity.[9] Figures 9 and 10 show a central primary lung carcinoma invading the pericardium and myocardium. A large neuroblastoma in the thoracic cavity invading the heart is shown in Figure 11. Similarly, a mediastinal teratoma involving the pericardium is shown in Figure 12. Large masses occurring in organs close to the heart may involve the heart via anatomical proximity as shown in Figure 13.

Some tumours, including renal cell carcinoma and hepatocellular carcinoma, may extend into the inferior vena cava (IVC), allowing for growth into the right atrium via transvenous extension.[2] Figure 14 shows a hepatocellular carcinoma causing cardiac metastasis via the IVC. The superior vena cava may also serve as a transportation route for cancer cells to the heart, as seen with thoracic and mediastinal tumours.[13] Figures 15 and 16 demonstrate a case of invasive thymoma and a thyroid

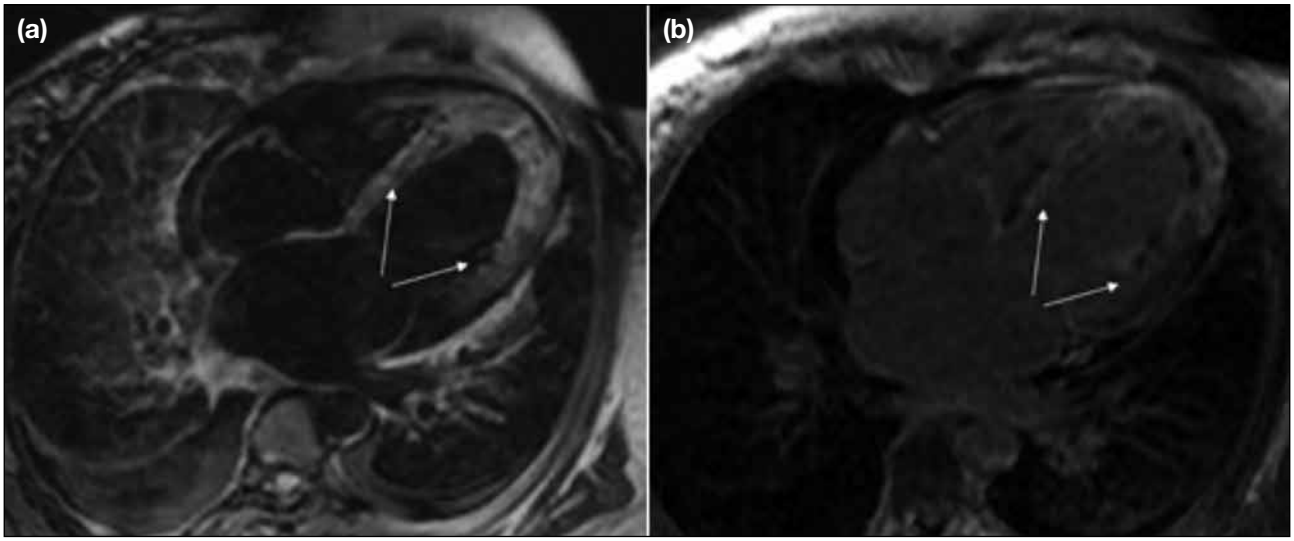

Figure 7. Four-chamber magnetic resonance images at two sequences revealing the left ventricular myocardial infiltration (arrows) in a patient with leukaemia. (a) Four-chamber T2-weighted triple inversion turbo spin echo sequence. (b) Four-chamber phase-sensitive inversion recovery sequence with late gadolinium enhancement.

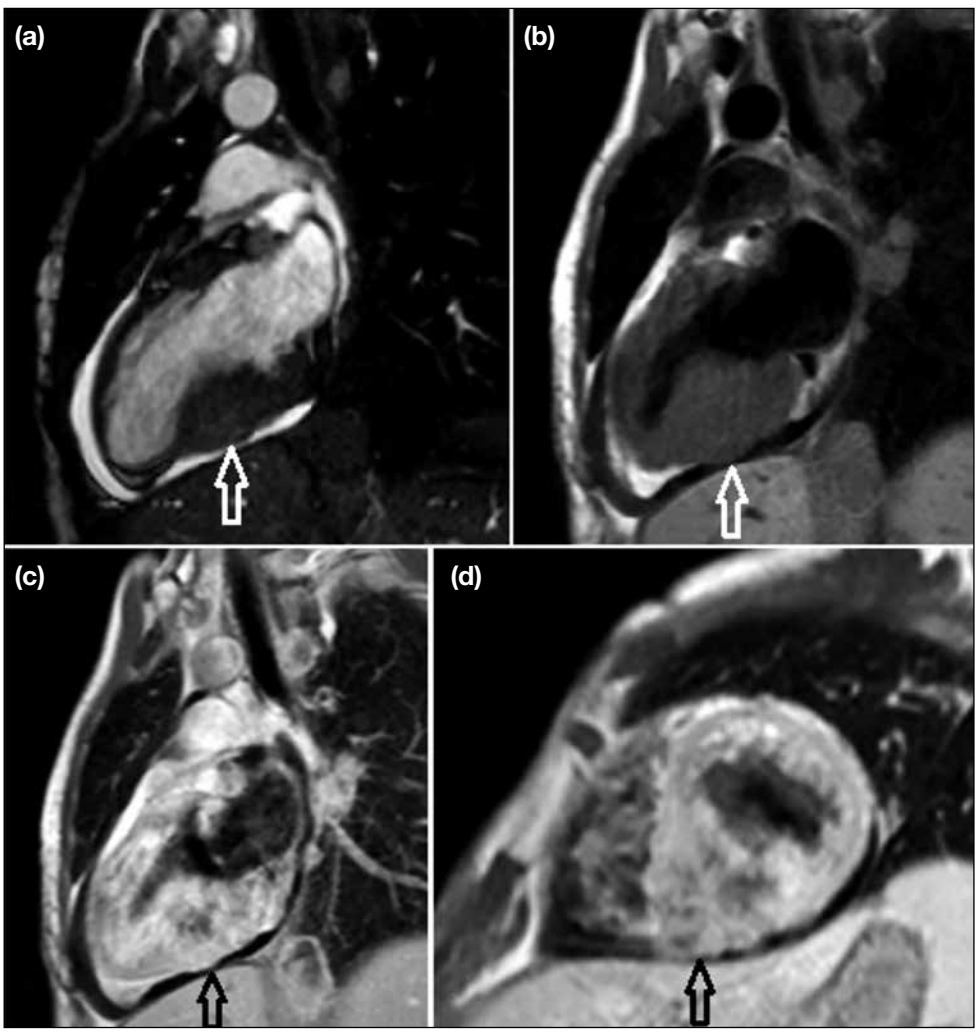

Figure 8. Cardiac magnetic resonance imaging at different sequences of a 24-year-old male patient with a diagnosis of nasopharyngeal carcinoma. Two-chamber planes showed an irregular expansion of the inferior wall of the left ventricle (arrows in a-c). (d) The short axis image demonstrates asymmetrical involvement of the left ventricle by the metastatic mass (arrow). The patient also had bilateral adrenal and lung metastases (not shown). (a) Two-chamber cine steady-state free precession gradient echo sequence. (b) Two-chamber T1-weighted double inversion black-blood turbo spin echo sequence. (c) Two-chamber phase-sensitive inversion recovery sequence with late gadolinium enhancement. (d) Short-axis phase-sensitive inversion recovery sequence with late gadolinium enhancement.

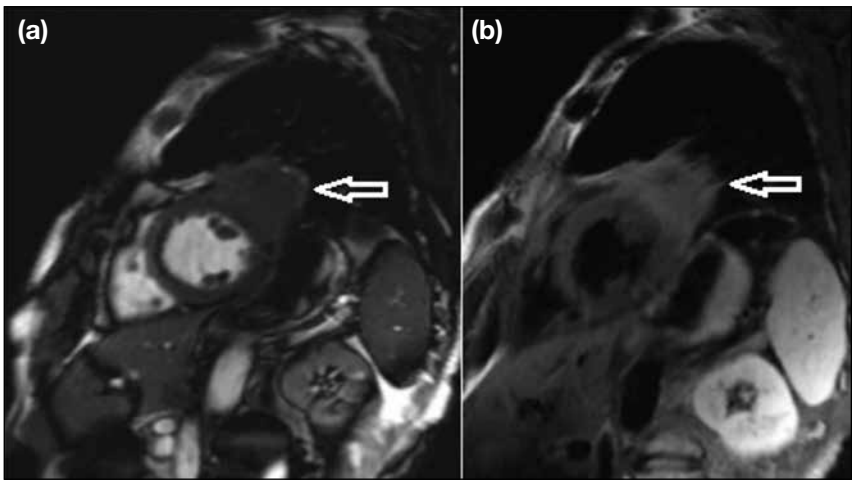

Figure 9. Cardiac magnetic resonance images showing the same lesion at two sequences, which is a central lung mass (arrows) with a broad base and direct invasion to the heart causing loss of the normal myocardial signal at the outermost part of the left ventricle. The patient had no cardiac symptoms. (a) Short-axis cine steady-state free precession gradient echo sequence. (b) Short-axis phase-sensitive inversion recovery sequence with late gadolinium enhancement.

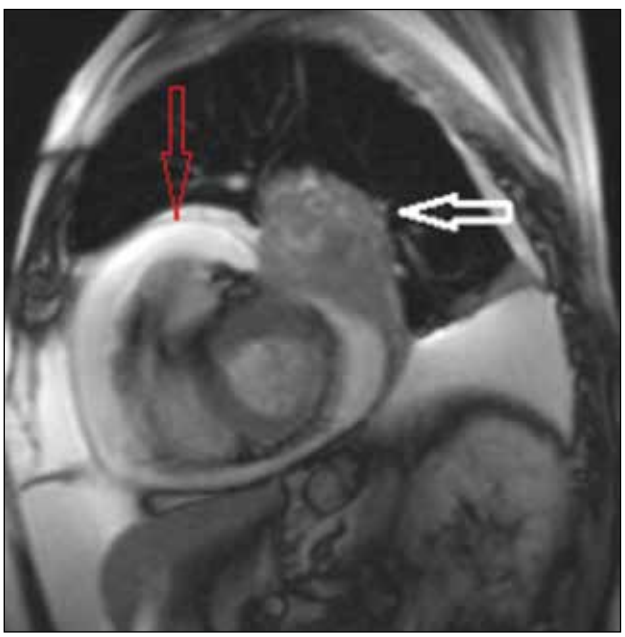

Figure 10. Cardiac magnetic resonance image of a 67-year-old male patient who presented with a cough that had lasted for >6 months. Computed tomography of the thorax showed a central lung mass (not shown) invading the heart. The image depicted the lesion (white arrow) and its extension through the pericardium and myocardium. A pericardial effusion, most probably due to the tumoural involvement, was also noted (red arrow).

carcinoma, respectively, in which the malignant tissue arising from the thymus and thyroid gland reached the right atrium through the superior vena cava. Figure 17 shows left atrial metastatic involvement of a melanoma case through the left pulmonary vein enabling the tumour cells to reach the left atrium from the left lung mass.

DISCUSSION

Metastatic dissemination to the heart from noncardiac tumours may occur via the lymphatics, or via haematogenous routes that include both arterial and transvenous dissemination.[9] While lymphatic spread or direct invasion targets the pericardium first, myocardial or endocardial involvement is more common in haematogenous metastases for anatomical reasons.[1,2]

Metastatic cardiac tumours have a poor prognosis, camouflaging themselves until a serious complication develops. The symptoms are broad and range from mild chest pain to cardiac rupture leading to sudden death. Pericardial and myocardial metastases may especially mimic acute coronary syndrome, and the onset of a new cardiac symptom in any cancer patient should be

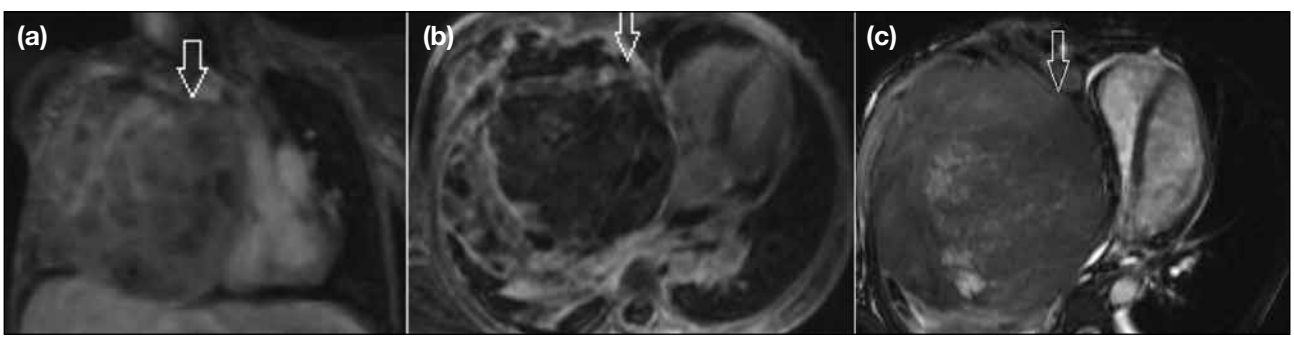

Figure 11. Cardiac magnetic resonance images of a 15-year-old female patient diagnosed with intrathoracic (a) and intraabdominal (b) neuroblastoma (arrows). The tumour has invaded the right atrium (c) [arrow].

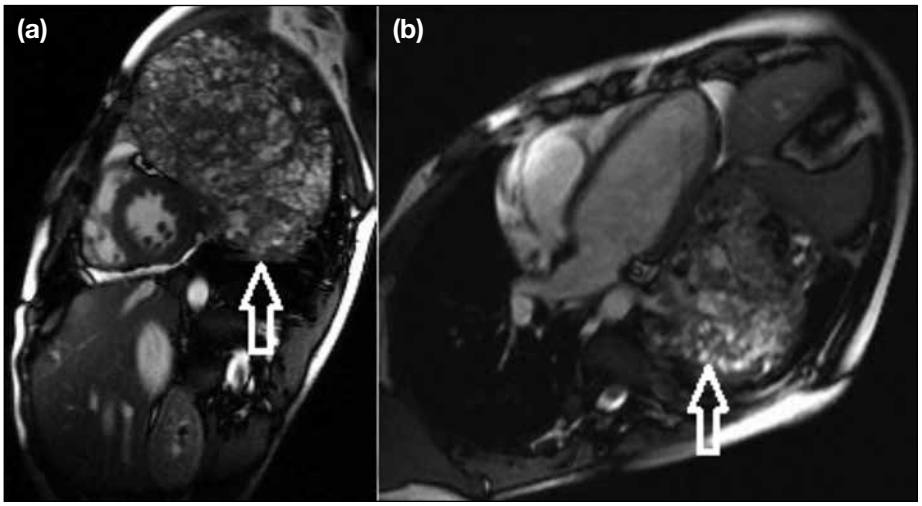

Figure 12. (a, b) Cardiac magnetic resonance images at two sequences of a 14-year-old male patient with a large mediastinal teratoma occupying most of the left hemithorax (arrows). The mass invaded the pericardium of the left ventricle at the level of the midlateral and midanterior myocardial segments with possible invasion of the myocardium. (a) Short-axis cine steady-state free precession gradient echo sequence. (b) Two-chamber cine steady-state free precession gradient echo sequence.

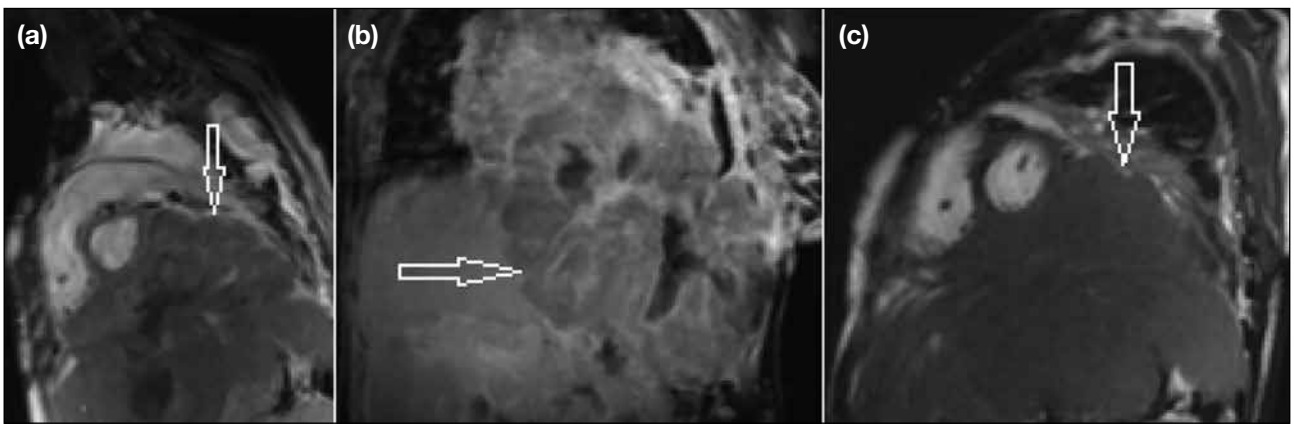

Figure 13. Cardiac magnetic resonance images in sagittal (a), coronal (b), and short axis (c) views of a 57-year-old female patient who was diagnosed with primary hepatic sarcoma arising from the left lobe of the liver. (a), (b), and (c) demonstrate the presence of a large mass invading the heart with atrial, vascular, and ventricular involvement, respectively (arrows).

approached with the suspicion of cardiac metastases. Imaging findings of cardiac metastases are diverse.[14] There was one melanoma patient with left atrial metastasis in our cohort. It was demonstrated in a recent study of 23 patients with melanoma metastatic to the heart that although all chambers may be involved, right ventricular involvement was most common.[15] If hepatocellular carcinoma metastasises to the heart, the route is usually extension into the IVC, allowing for growth into the right atrium via transvenous access as with our cases.[16,17] The two cases of uterine leiomyosarcoma in our patient group showed metastasis to the ventricles. However, the atria can also be involved.[18] Cardiac metastases from renal cell carcinoma are not frequently encountered and they may have varying imaging appearances.[19-21] A new cardiac symptom in a patient with a known renal cell carcinoma should alert the clinician to a possible cardiac metastasis. Although there were no examples in our patient cohort, malignant neuroendocrine tumours and benign uterine leiomyomas may also metastasise to the heart.[22-24]

CONCLUSION

Cardiac metastases are far more common than previously thought and should be taken into consideration in oncology patients presenting with a new cardiac symptom. The clinical scenario of cardiac metastases includes a variety of signs and symptoms depending on the anatomical site of the involvement. Although echocardiography is the preferred initial diagnostic

modality owing to its relatively easy accessibility and availability, cardiac MRI may also provide a comprehensive visualisation of both cardiac and extracardiac involvement.

Figure 14. Cardiac magnetic resonance image from a patient with hepatocellular carcinoma arising from the dome of the liver (arrow). The tumour invaded the hepatic vein leading to the haematogenous dissemination of the cells via the inferior vena cava, eventually resulting in a mass that filled the right atrium.

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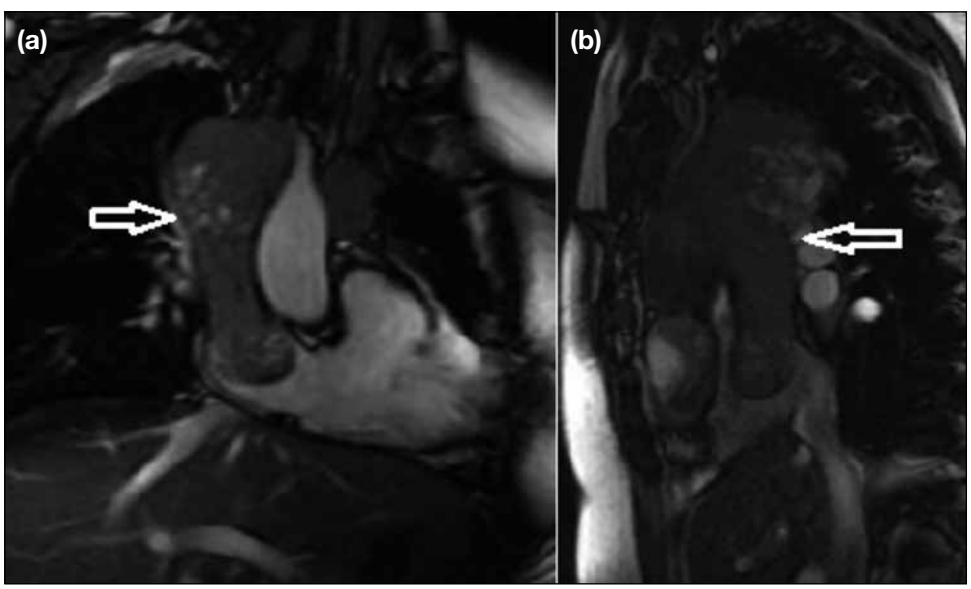

Figure 15. Cardiac magnetic resonance images of a 74-year-old male patient diagnosed with invasive thymoma. Coronal (a) and sagittal (b) images showing the tumour (arrows) reaching the right atrium via the superior vena cava.

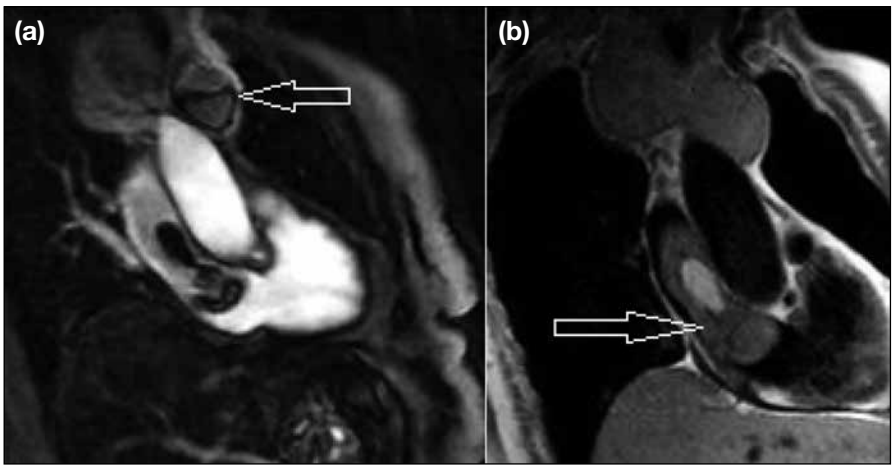

Figure 16. Cardiac magnetic resonance imaging of a 98-year-old female patient with superior vena cava syndrome revealed a retrosternal superior mediastinal mass that was continuous with the thyroid gland. (a) The mass entered the left brachiocephalic vein, expanding its lumen (arrow). (a, b) The tumour cells travelled through the vasculature all the way to the left brachiocephalic vein and superior vena cava, reaching the right atrium (arrow in [b]). The presence of an irregular area at the distal end of the mass that showed no contrast enhancement was consistent with an extension of the tumoural mass accompanying a distally located thrombus. The retrosternal mass was biopsied under ultrasound guidance and the patient was diagnosed with thyroid carcinoma.

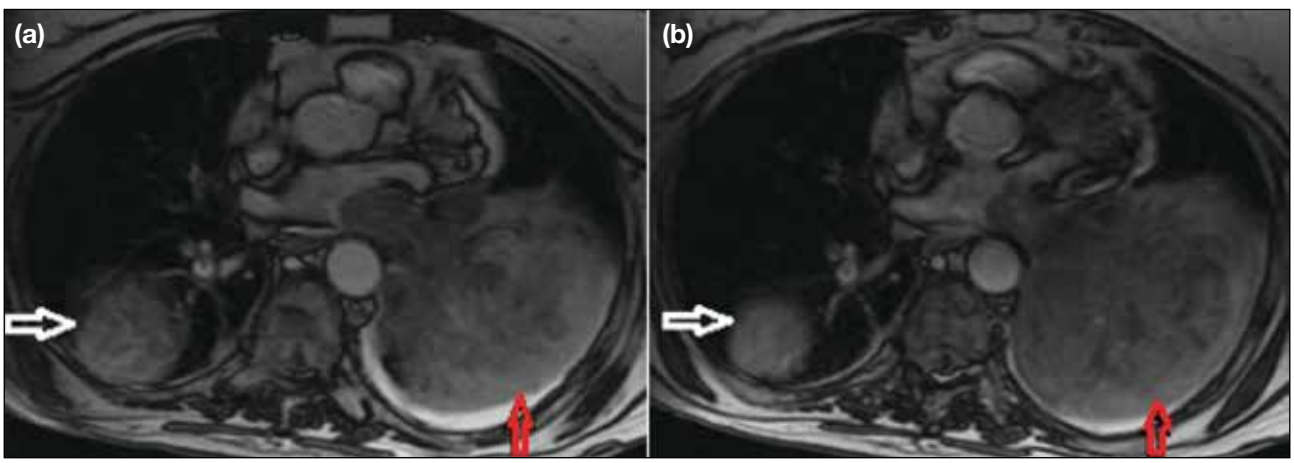

Figure 17. Cardiac magnetic resonance images of a 63-year-old female patient with a 2-year history of metastatic melanoma, which are sequential slices that clearly and continuously demonstrate the invasion of the mass. Metastatic masses in the right (white arrows) and left lung (red arrows) were seen. The mass in the left lung caused invasion of the left pulmonary vein leading to involvement of the left atrium.

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