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# Major incidental findings on routine cardiovascular magnetic resonance imaging prior to first-time catheter ablation of atrial fibrillation

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ABSTRACT

*Introduction:* Preprocedural cardiovascular magnetic resonance (CMR) or computed tomography (CT) imaging of the left atrium/pulmonary veins is usually employed to guide catheter ablation of atrial fibrillation (AFCA). Incidental findings (IFs) are common on cardiac imaging prior to AFCA. However, previous studies have mainly focused on extracardiac IFs detected on CT scan. We aimed to assess the prevalence of relevant cardiac and extracardiac IFs on routine preprocedural CMR in a large patient cohort scheduled for first-time AFCA and report its impact on clinical decision-making and management.

*Methods and results:* We included 2000 consecutive patients (62 ± 10 years; 59% male) who underwent CMR prior to first-time AFCA between April 2015 and March 2019. Among these patients 172 (8.6%) had a total of 184 major IFs. Detection of major IFs resulted in cancellation of the scheduled AFCA procedure in 88 patients (4.4%). Forty-two patients (2.1%) have never been ablated, 46 (2.3%) underwent postponed AFCA after a median time of 83 (32–213) days. The remaining 84 patients (4.2%) underwent an individualized approach to AFCA. The most common major IFs were accessory or anomalous PVs in 76 (3.8%), extracardiac abnormalities suspicious of malignancy in 29 (1.5%), and positive stress perfusion imaging in 19 (7.2% of 261 tested) patients. In 19 patients (1.0%) preprocedural CMR provided the diagnosis of a previously unknown structural cardiac disease.

*Conclusions:* Unexpected relevant findings on routine preprocedural CMR affected clinical decision-making and management in 8.6% of patients scheduled for first-time AFCA. However, whether preprocedural CMR imaging may improve overall clinical outcome needs to be addressed in future research.

## 1. Introduction

The cornerstone of catheter ablation of atrial fibrillation (AFCA) is pulmonary vein (PV) isolation (PVI) achieved by radiofrequency catheter or cryo-balloon ablation. A detailed understanding of the PV anatomy is crucial for an effective and safe AFCA procedure. Preprocedural three-dimensional cardiovascular magnetic resonance (CMR) or computed tomography (CT) imaging of the left atrium (LA) and PVs are usually employed for detailed anatomical depiction and three-dimensional mesh model generation to guide catheter mapping and ablation [1,2]. Incidental findings (IFs) are common on cardiac imaging prior to AFCA. However, there are only few studies that have mainly focused on radiological extracardiac IFs detected on preprocedural cardiac CT scan [3–6]. In contrast to CT imaging, CMR allows not only for radiation-free evaluation of the cardiac anatomy but also for detailed tissue characterization and functional assessment to detect underlying cardiac and adjacent extracardiac pathologies.

Therefore, we aimed to assess the prevalence of relevant cardiac and extracardiac IFs on routine preprocedural CMR in a large consecutive patient cohort scheduled for first-time AFCA and report its impact on clinical decision-making and management.

## 2. Methods

### 2.1. Patient selection

The present single-center study included all consecutive patients who underwent routine preprocedural CMR imaging prior to first-time

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catheter ablation of paroxysmal or persistent AF at our institution between April 2015 and March 2019. Patients with long-standing persistent AF or native LA macro-reentrant tachycardia have been grouped with persistent AF. Main exclusion criteria were i) contraindication to AFCA; ii) referral for repeat AFCA; iii) prior cardiac CT/CMR imaging; iv) contraindication to CMR imaging. The study was conducted in accordance with the local institutional review board, and written informed consent was obtained from all patients prior to the CMR examination and AFCA procedure.

### 2.2. CMR imaging protocol

All CMR examinations were carried out on a 1.5 Tesla MR scanner (Philips Ingenia, Best, The Netherlands) equipped with a 28-element array coil with full in-coil signal digitalization and optical transmission. CMR protocols strictly adhered to standard procedures [7] with CMR diagnostic modules tailored to the clinical indication: preprocedural CMR consisted of survey images (balanced turbo field echo sequence) with full thoracic coverage, cardiac cine and late-gadolinium enhancement (LGE) imaging, and three-dimensional CMR angiography of the LA/PVs. Patients complaining about chest pain and no recent coronary angiography (<1 year) underwent additional adenosine stress perfusion imaging as previously described [8].

Cine imaging consisted of steady-state free precession (SSFP) sequences (30–40 cardiac phases per cardiac cycle, reconstructed spatial resolution 1.3 × 1.3 × 8.0 $mm^3$) covering all standard cardiac geometries (i.e. multiple short axis views and a 4-, 3-, and 2-chamber view). Cardiac chamber parameters were determined by level III certified CMR readers (IP and CJ) [9]. In patients with additional stress testing, perfusion imaging was performed after at least 3 min of continuous intravenous adenosine infusion (140 µg/kg/min; total infusion duration, max. 6 min); three short-axis views (apical, mid and basal geometry; in-plane spatial resolution, 2.2 × 2.2 $mm^2$; slice thickness, 10 mm) were acquired per cardiac cycle during first-pass of an intravenous bolus of gadolinium-DOTA (Dotarem®, Guerbet, France; dosage, 0.1 mmol/kg; infusion rate, 4.0 ml/s). For detection of myocardial ischemia, adenosine stress CMR perfusion and LGE scans were evaluated visually according to the 16-segment model. CMR stress testing was considered positive if a regional hypoenhancement on adenosine stress CMR perfusion scans was detected in ≥ 2 left ventricular segments in the absence of LGE [10]. Three-dimensional contrast-enhanced CMR angiography of the LA/PVs (isotropic spatial resolution, 1.0 × 1.0 × 1.0 $mm^3$) was acquired using real-time bolus tracking during bolus injection of 0.1 mmol/kg gadolinium-DOTA (injection rate, 4.0 ml/s). Volume-rendering reconstruction and multiplanar reformatting of the angiographic dataset was additionally employed for the detection of anatomical variants of the LA/PVs. Finally, 10–15 min after contrast agent application, LGE imaging was carried out in all cardiac standard geometries using an inversion-prepared three-dimensional spoiled gradient echo sequence (in-plane spatial resolution, 1.6x1.6 $mm^2$; slice thickness, 5.0 mm) with an individually adapted inversion delay (230–320 ms) to null myocardial tissue signal.

### 2.3. Definition of major IFs and AFCA procedure

An IF was defined as major when any newly detected cardiac or extracardiac finding either resulted in cancellation of the scheduled AFCA procedure due to the necessity for subsequent diagnostic workup and/or therapeutic measures, or intentional deviation from the standard ablation protocol leading to an individualized ablation strategy [11]. Known cardiac or extracardiac abnormalities were not considered as major IFs.

All AFCA procedures were performed under deep sedation either by single-shot cryo-balloon ablation or electroanatomical mapping-guided point-by-point radiofrequency catheter ablation according to our institutional protocol [12]. The aim of the AFCA procedures was to achieve isolation of all PVs and restore stable sinus rhythm [13]. Additional ablation lesions were created at the discretion of the operator in ≥ 1 of the following scenarios: i) presence of atrial low-voltage (<0.5 mV) areas; ii) detection of non-PV-triggers; iii) spontaneous or inducible atrial or supraventricular arrhythmias; or iv) electrical cardioversion-resistent AF after complete isolation of all PVs [12]. In patients with accessory or anomalous PVs the ablation strategy was individually tailored with the attempt to isolate all aberrant PVs draining into the left or right atrium in addition to PVI. In patients with superior-type partial anomalous pulmonary venous connection (PAPVC; right superior pulmonary vein into proximal superior vena cava [SVC]) undergoing radiofrequency AFCA, electrical isolation of the SVC was performed in addition to PVI.

**Table 1**
Baseline characteristics.

| | All patients (N = 2000) | IF positive (n = 172) | IF negative (n = 1828) | *P*-value |
|---|---|---|---|---|
| Age, years | 62 ± 10 | 63 ± 11 | 62 ± 10 | 0.500 |
| Male sex, n (%) | 1189 (59) | 92 (60) | 1097 (54) | 0.096 |
| BMI ($kg/m^2$) | 29 ± 5 | 30 ± 6 | 29 ± 5 | 0.186 |
| Hypertension, n (%) | 1601 (80) | 148 (86) | 1453(80) | 0.040 |
| Diabetes, n (%) | 333 (17) | 35 (20) | 298 (16) | 0.173 |
| CAD, n (%) | 258 (13) | 28 (16) | 230 (13) | 0.167 |
| Prior MI, n (%) | 84 (4) | 6 (4) | 78 (4) | 0.626 |
| GFR < 60 ml/min, n (%) | 298 (15) | 28 (17) | 270 (15) | 0.598 |
| AF-related characteristics | | | | |
| Paroxysmal AF, n (%) | 950 (48) | 70 (41) | 880 (48) | 0.060 |
| Persistent AF, n (%) | 1050 (52) | 102 (59) | 948 (52) | 0.060 |
| $CHA_2DS_2$-VASc, score | 2.3 ± 1.4 | 2.5 ± 1.4 | 2.3 ± 1.4 | 0.075 |
| Prior stroke or TIA, n (%) | 136 (7) | 12 (7) | 124 (7) | 0.925 |
| Baseline CMR characteristics | | | | |
| LVEF, % | 54 ± 10 | 53 ± 11 | 54 ± 10 | 0.032 |
| LVEDD, mm | 52.1 ± 6.1 | 52.3 ± 6.5 | 52.1 ± 6.0 | 0.731 |
| LVEDV, ml | 148.8 ± 44.1 | 150.6 ± 49.0 | 148.7 ± 43.6 | 0.590 |
| LVESV, ml | 69.3 ± 31.6 | 73.0 ± 38.0 | 69.0 ± 31.0 | 0.118 |
| IVS, mm | 10.6 ± 1.9 | 11,1 ± 2.4 | 10,5 ± 1.8 | <0.001 |
| LA volume, $cm^2$ | 27.8 ± 7.1 | 29.1 ± 8.0 | 27.7 ± 7.0 | 0.017 |
| Antiarrhythmic drugs | | | | |
| ß-blocker, n (%) | 1686 (84) | 146 (85) | 1540 (84) | 0.826 |
| Digitalis, n (%) | 161 (8) | 16 (9) | 145 (8) | 0.528 |
| Class I AAD, n (%) | 308 (15) | 20 (12) | 288 (16) | 0.152 |
| Amiodarone, n (%) | 191 (10) | 23 (13) | 168 (9) | 0.074 |

Plus-minus values are means ± standard deviation. BMI, body-mass index; CAD, coronary artery disease; MI, myocardial infarction; GFR, glomerular filtration rate; AF, atrial fibrillation; TIA, transient ischemic attack; LVEF, left ventricular ejection fraction; LVEDD, LV end diastolic diameter; LVEDV, LV end diastolic volume; LVESV, LV end systolic volume; IVS, interventricular septum; LA volume, left atrium volume; AAD, antiarrhythmic drug.

### 2.4. Statistical analysis

Data are expressed as number and percentage for categorial variables and median (interquartile range) or mean ± standard deviation for continuous variables. The chi-square and Fisher's exact tests were used to compare categorical variables. Continuous variables between groups were analyzed by the Student *t*-test or Mann-Whitney test, as appropriate. A probability value < 0.05 was considered statistically significant. Statistical analysis was performed using SPSS 26.0 software package (SPSS Inc., Chicago, IL).

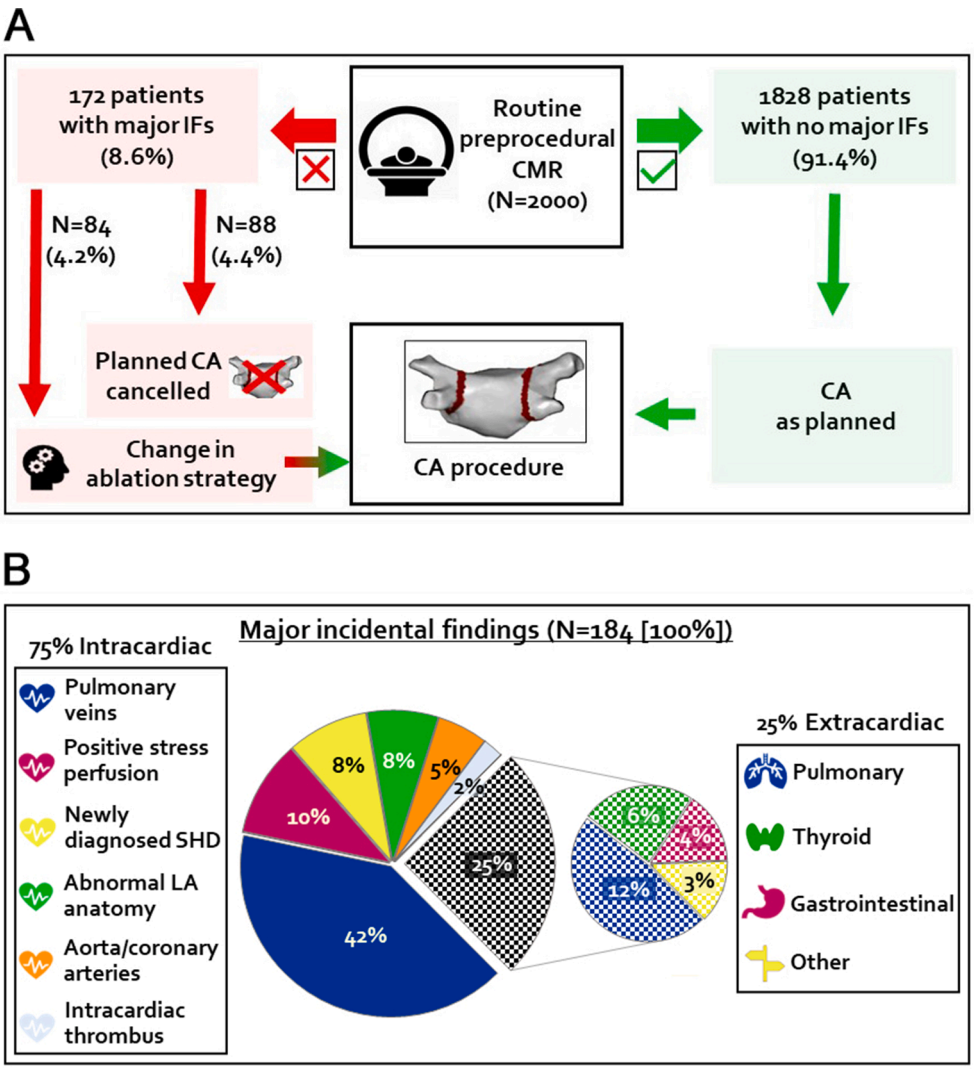


**Fig. 1. Major IFs detected on preprocedural CMR prior to first-time AF ablation. A)** Clinical decision pathway according to the presence or absence of major IFs. **B)** Distribution of the 184 major IFs detected in 172 patients. IF, incidental finding; CMR, cardiovascular magnetic resonance; AF, atrial fibrillation; CA, catheter ablation; SHD, structural heart disease; LA, left atrium.

## 3. Results

### 3.1. Patient population

A total of 2000 consecutive patients with a mean age of 62 ± 10 years (59% male) were included. Nine hundred fifty patients (48%) presented with paroxysmal AF, 1050 patients (52%) with persistent AF [13]. The mean left ventricular ejection fraction was 54 ± 10%. The mean $CHA_2DS_2$-VASc-Score was 2.3 ± 1.4; 7% of the study patients experienced a prior cerebral ischemic event. Detailed patient characteristics of the whole study population and subgroups according to the presence or absence of major IFs are listed in Table 1. All patients underwent standard preprocedural CMR imaging including contrast-enhanced three-dimensional CMR angiography of the LA/PVs. Additional adenosine stress perfusion imaging was performed in 261 patients (13%).

### 3.2. Major IFs and patient management

Among the entire study cohort 172 patients (8.6%) had a total of 184 major IFs. One major IF was detected in 161 patients (93.6%), 2 major IFs in 10 patients (5.8%), and 3 major IFs in 1 patient (0.6%). Preprocedural detection of a major IF resulted in cancellation of the scheduled AFCA procedure in 88 patients (4.4% of the whole study population). After completion of detailed diagnostic work-up, 42 of these patients (47%) have thereupon never been ablated (which constitutes 2.1% of the entire cohort), whereas 46 patients (53%) underwent postponed AFCA after a median time from CMR imaging of 83 (32–213) days. Overall 4.2% of the patients had procedure-relevant aberrant LA/PV anatomical findings and underwent an individualized approach to AFCA (Fig. 1A). The 184 detected cardiac (75%) and extracardiac (25%) major IFs are summarized in Fig. 1B. Figs. 2 and 3 depict different examples of previously unknown cardiac and extracardiac major IFs.

The most common major IFs were aberrant (accessory or anomalous) PVs in 76 patients (3.8%) (Fig. 2), pulmonary and extrapulmonary abnormalities suspicious of malignancy in 29 patients (1.5%) (Fig. 3E + F), and positive stress perfusion imaging in 19 patients (1.0% overall; 7.2% of 261 tested patients). In 19 patients (1.0%) preprocedural CMR provided the diagnosis of a previously unknown intracardiac thrombus or structural heart disease including sarcoidosis in 5 (2 with isolated cardiac form; Fig. 3C) and hypertrophic cardiomyopathy in 4 subjects.

### 3.3. Aberrant LA/PV anatomical findings

Eighty-nine aberrant LA/PV anatomical findings were detected in 87 patients. The most frequent PV findings were accessory PVs (roof-top, n

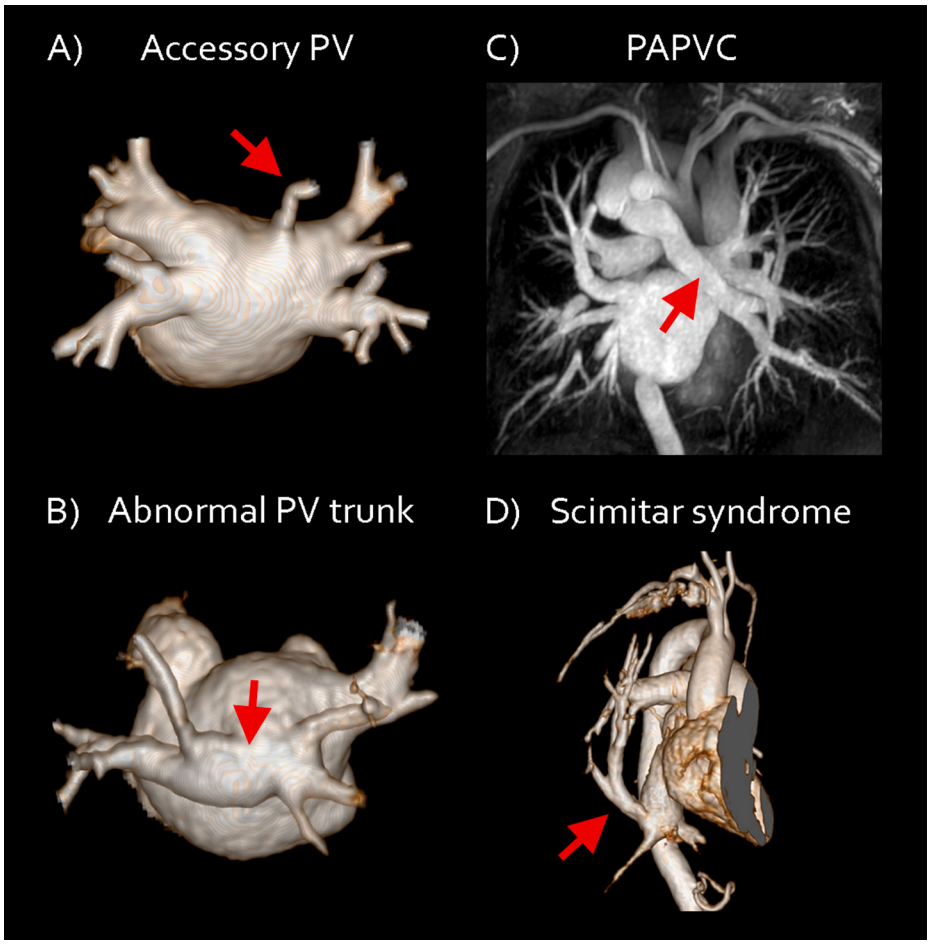


**Fig. 2. Representative examples of major incidental PV findings detected on routine preprocedural CMR.** Key pathological findings are indicated (arrows). **A**, accessory roof-top pulmonary vein (PV). **B**, inferior common ostium in a patient with previously undetected hypoplastic left upper lobe of the lung; note the absence of a left superior pulmonary vein. **C**, superior-type partial anomalous pulmonary venous connection (PAPVC) with drainage of the right PVs into a massively dilated vena anonyma and significant left to right shunt (Qp/Qs = 2.55; left-to-right shunt fraction = 61%). **D**, inferior-type PAPVC (Scimitar syndrome) with drainage of the right PVs into the inferior vena cava and significant left to right shunt (Qp/Qs = 1.78; left-to-right shunt fraction = 44%).

= 59; posterior, n = 11) (Fig. 2A) followed by PAPVC (n = 5) (Fig. 2C + D) and abnormal common inferior PV trunk (n = 1) (Fig. 2B). Significant LA diverticulum (n = 9) and cor triatriatum (n = 4) constituted atrial IFs (Fig. 3A + B). The majority of these patients (97%) underwent an individualized approach to AFCA including 2 patients with superior-type PAPVC, who underwent electrical isolation of the SVC in addition to PVI. The remaining 3 patients with PAPVC (including 1 Scimitar syndrome; Fig. 2D) underwent cardiothoracic surgery. The frequent findings of a common ostium [n = 382 (19.1%)] and right middle PV(s) [n = 301 (15.1%)] were not considered as major IFs since they did basically not affect the strategy of circumferential antral PVI. Nevertheless, prior awareness of these PV anatomical variants may also impact selection of the appropriate mapping and ablation technology (single-shot cryo-balloon vs. electroanatomical mapping-guided point-by-point radiofrequency ablation) and creation of an additional carina line of the right-sided PVs.

## 4. Discussion

To the best of our knowledge, our study is the first and largest to describe the impact of routine preprocedural CMR-detected major IFs on clinical decision-making and management in a large cohort of patients scheduled for first-time AFCA. The prevalence of major IFs was 8.6%, which resulted in subsequent cancellation of the scheduled AFCA procedure in 4.4% of the whole study population.

Incidental findings are common on cardiac imaging prior to AFCA but have so far mostly been reported for preprocedural cardiac CT scans in small study groups (≤250 patients) with focus on extracardiac findings [3–6]. The reported prevalence of IFs was considerably high ranging between 23 and 69%, which can likely be attributed to substantial differences in definition of IFs and reporting of any minor findings among the studies. In contrast, we have strictly focused on clinically relevant IFs leading to subsequent changes in patient management, as recently suggested [11]. Moreover, the dedicated use of preprocedural CMR in our study allowed not only for radiation-free evaluation of the LA/PV anatomy, but also for detailed tissue characterization and functional assessment. Hence, the unique potential to assess myocardial injury by delayed enhancement as well as to perform stress perfusion imaging and cardiac shunt quantification constitute primary advantages of combined single-session CMR over CT scanning for detection of cardiac IFs [8]. Regarding extracardiac IFs, the 1.5% rate of unexpected findings suspicious of malignancy in our study population compares well to that reported in previous studies on preprocedural CT imaging [3,4,6].

Of particular interest for the interventional electrophysiologist is the awareness of aberrant LA/PV anatomical findings, which led to an individualized ablation approach in > 4% of our patients. Although multislice CT angiography of the LA/PVs may have provided similar anatomic information, CMR enabled additional cardiac functional assessment and shunt quantification in cases with PAPVC and/or septal defects.

## 5. Conclusion

In summary, unexpected relevant findings on routine preprocedural CMR affected clinical decision-making and therapeutic management in 1 out of 12 patients scheduled for first-time AFCA at our institution. However, whether preprocedural CMR imaging significantly improves safety and outcome of AFCA compared to CT or no imaging needs to be investigated in a randomized controlled trial.

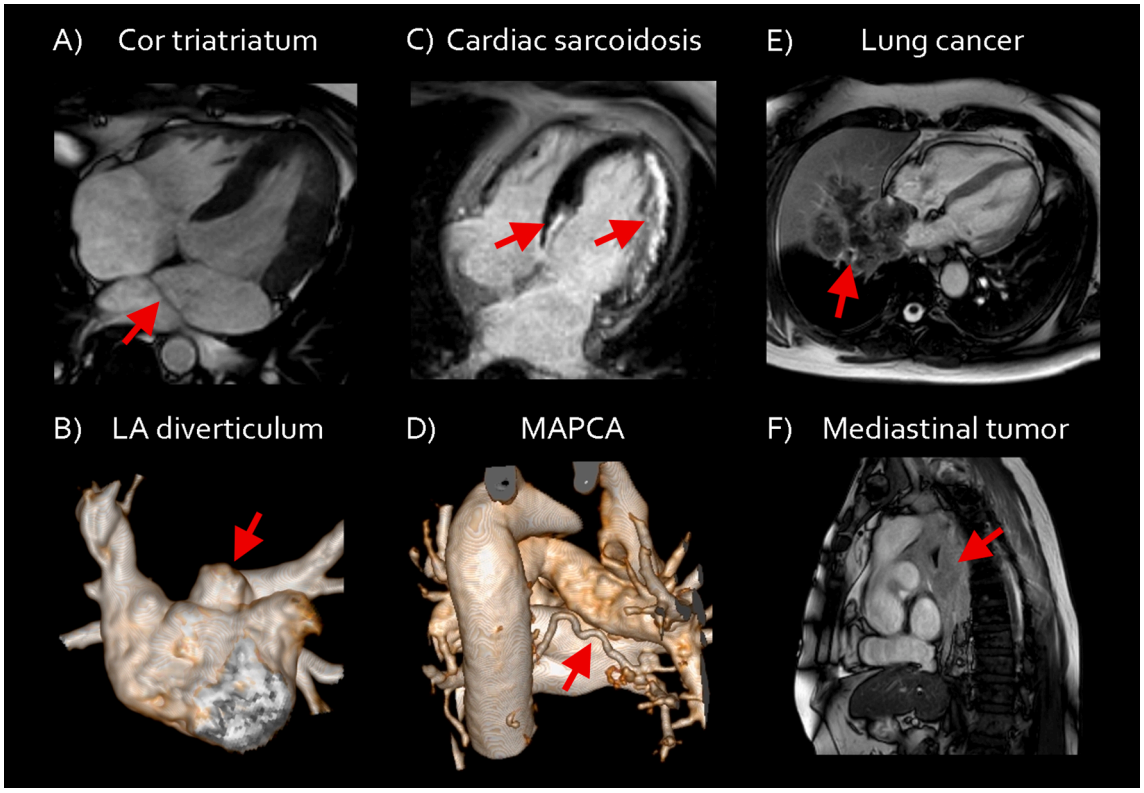


**Fig. 3. Representative examples of major incidental cardiac (A-D) and extracardiac (E-F) findings detected on routine preprocedural CMR.** Key pathological findings are indicated (arrows). **A**, cor triatriatum sinister. **B**, left atrial (LA) diverticulum located between the roof and left superior pulmonary vein. **C**, isolated cardiac sarcoidosis (arrows point to areas of delayed enhancement). **D**, major aortopulmonary collateral artery (MAPCA) taking course from the descending thoracic aorta to the right lower lobar artery. **E**, lung cancer (central bronchial carcinoma). **F**, mediastinal tumor with large and infiltrative lesions.

## 6. Disclosures

S. Richter has received speaker honoraria and proctor fees from Abbott, Biotronik, and Medtronic to his institution without personal financial benefits. G. Hindricks has received research grants from Abbott and Boston Scientific to his institution without personal financial benefits. The remaining authors have declared no conflicts of interest.

**Data availability**

The data underlying this article may be shared on reasonable request to the corresponding author.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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