CMR and Advanced Cardiac Imaging at Vannini Hospital: The Heart Imaging Team

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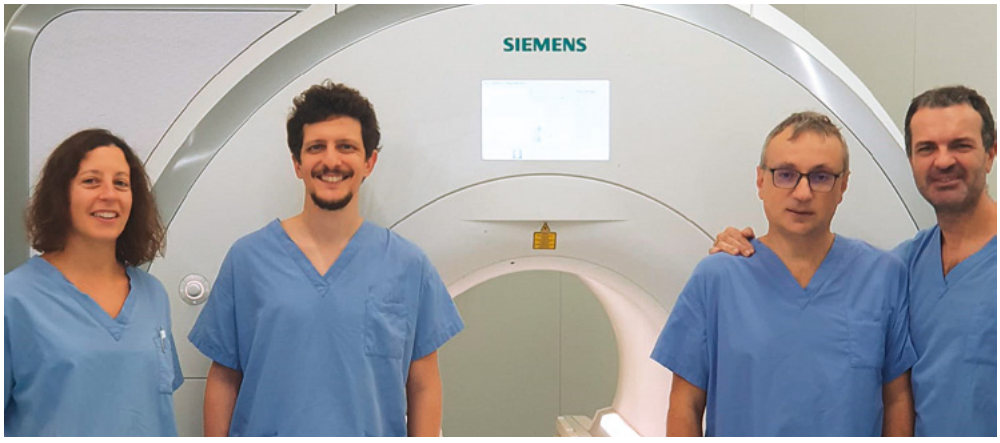
Introduction

Cardiovascular imaging with computed tomography (CT) and cardiovascular magnetic resonance (CMR) have seen a notable increase in indications and requests in recent years. This shows clearly when comparing clinical indications available in 2004 [1] with an update published by the Society for Cardovascular Magnetic Resonance (SCMR) [2], and by looking at the more recent European Society of Cardiology guidelines for acute coronary syndromes [3] and cardiomyopathies [4] in which cardiac CT and CMR both have a relevant role within the diagnostic work-up and prognostic stratification. Amidst the increasing importance of these techniques in the clinical arena, the need has emerged to expand training in advanced cardiac imaging and to boost the sharing of competencies between the different actors at play, including both radiologists and cardiologists [5, 6]. Continuing medical education, training, and certification of competencies remain of utmost importance, with the aim of delivering appropriate guidelines-directed diagnostic procedures to the highest share of eligible patients. Here, we summarize the approach to advanced cardiac imaging as practiced at our center, Madre Giuseppina Vannini Hospital in Rome, Italy, a first-level community hospital. Managing a relatively high volume of unselected patients, close collaboration between cardiologists and radiologists, and continuous optimization of resources are mandatory to effectively continuing our activities.

The Heart Imaging Team

At our hospital, cardiologist-radiologist collaboration started about twenty years ago with the implementation of cardiac CT and CMR services. During this time, we developed and put into practice the concept of a pragmatic multidisciplinary approach quite conventionally in the form of a "heart team" made up of cardiologists and cardiac surgeons [7]. Our Heart Imaging Team (HIT) works in concert to provide the most appropriate use of advanced cardiac imaging, including discussion of indications, running of the service, and interpretation of reported results in the clinical context of the patient. The high quality of the CMR service is testified by the level 3 EACVI certification held by team members and the ESC accreditation of our CMR laboratory [8]. Our team consists of four physicians: two cardiologists



1 The Heart Imaging Team of Vannini Hospital (from left to right): Federica Ciolina, Luca Arcari, Giovanni Camastra, Massimiliano Danti.

and two radiologists, all working under the supervision of their respective unit directors in cardiology and radiology. The decision to perform CT or CMR procedures is made both by internal (HIT) or external referring physicians. However, the HIT provides support through a dedicated cardio-radiologic outpatient service where the requests for an advanced cardiac imaging examination from external referring physicians are critically reviewed. In this way, we ensure to maximize the appropriateness of indications. Even though each member of the HIT is an independent and expert user who can autonomously perform and report advanced cardiac imaging examinations, we strive to guarantee the presence of at least two HIT members, one cardiologist and one radiologist, when scans are performed. By doing so, we aim to exploit specific expertise, for example regarding the appropriate evaluation of extracardiac findings [9] (Fig. 1) and the tailoring of the scan to the special clinical characteristics of the patient [10]. Indeed, we pay great attention to the clinical background of our patients, where the result of the imaging examination is often just one piece of a more complex puzzle. The review of any relevant clinical documentation such as electrocardiograms, echocardiograms, and coronary angiograms is performed before execution/reporting of the examination. Finally, we are keen to share feedback with referring physicians and to discuss the clinical implications of the imaging findings. Overall, it is our opinion that this kind of multidisciplinary approach could contribute to improving the patients' care.

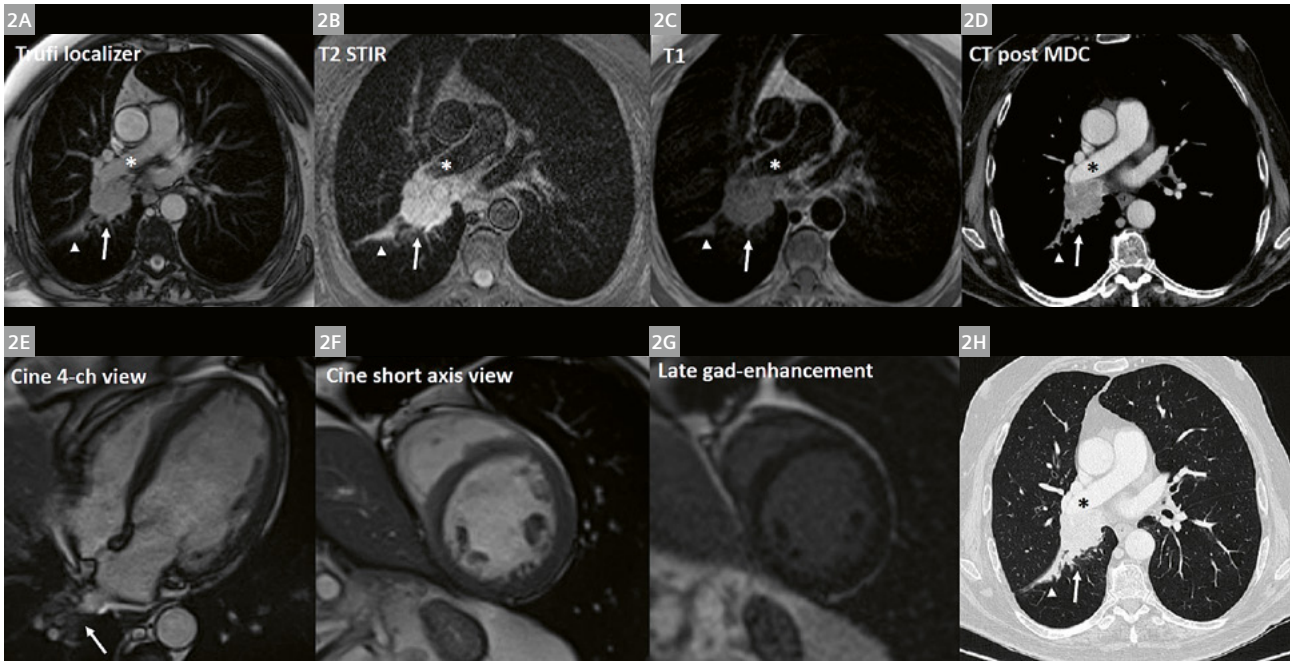
Optimizing resources

Optimizing the available resources is essential in our daily clinical practice. Indeed, our community hospital serves a densely populated, multicultural, and diverse neighborhood in the city of Rome, providing access to patients through a dedicated emergency department and offering, among others, surgical and orthopedic health services. Our CMR service shares the infrastructure with these other providers. In this context, the ability to perform a quick examination is essential. Our standard CMR protocol can be carried out in approximately 30 minutes (Table 1) and provides the relevant information needed for the diagnosis of the main pathologies encountered in clinical practice. This approach is in line with the more recent SCMR recommendations [11]. Moreover, correct patient preparation and briefing before the scan can help improve the quality of the images and reduce the duration of the examination; breathing instructions should be clearly understood and reproduced by the patient, the feeling of contrast injection should be anticipated. The protocol reported in Table 1 can be further personalized for specific patient needs. For example, flow imaging can be added if valvular heart disease is present, or contrast agent administration can be avoided if tissue mapping is sufficient to reach a diagnosis (Fig. 2) as may be the case with cardiac amyloidosis [12]. Reducing the scan time can improve patient adherence to the breathing instructions, result in better diagnostic imaging quality and better access to care in the context of limited

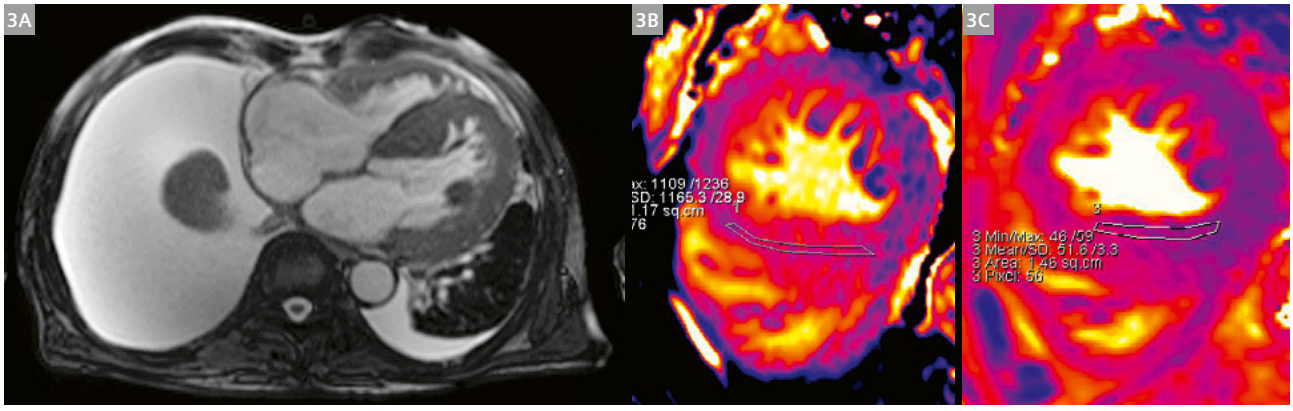
	Cine-bSSFP	TIRM	T1 MAPPING	T2 MAPPING	PERFUSION	Cine-bSSFP	T1 SCOUT	T1 LGE	T1 MAPPING POST
Acquisition time (s)	6 per slice	12 per slice	11 per slice	8 per slice	60	6 per slice	28 per slice	12 per slice (high-res)	11 per slice
Slice thickness (mm)	8	8	8	8	8	8	8	8	8
Gap	25%	50%	150%	150%	90%	25%	20%	20%	150%
Matrix	256 × 143	256 × 143	256 × 143	160 × 75	160 × 75	256 × 143	192 × 78	256 × 160	256 × 143
TE (ms)	1.21	52	1.8	1.8	1.18	1.21	1.12	3.19	1.8
TR (ms)	51.3	593	306.2	213	177.70	51.3	23	635	306.2
Flip angle	70°	180°	35°	70°	12°	70°	50°	25°	35°
Planes	4-chamber 2-chamber 3-chamber	4-chamber Basal-SAX Mid-SAX Apical-SAX	4-chamber Basal-SAX Mid-SAX Apical-SAX	4-chamber Basal-SAX Mid-SAX Apical-SAX	4-chamber Basal-SAX Mid-SAX Apical-SAX	SAX	Mid-SAX	SAX (overview) 4-chamber (high-res) 2-chamber (high-res) 3-chamber (high-res)	4-chamber Basal-SAX Mid-SAX Apical-SAX

Table 1: Our standard CMR protocol.

resources. A special situation is that of patients with suspected myocardial ischemia undergoing CMR stress perfusion imaging. In these cases, the clinical question can be evaluated with an abbreviated protocol lasting approximately 20 minutes (Table 2) [13]. In these patients, except for those where scar imaging is needed to identify ischemic necrotic myocardium, tissue characterization is less important; nevertheless, we strive to perform T1 and T2 mapping in all patients given the known prognostic relevance of this evaluation in patients with coronary artery disease [14]. In our opinion, rest perfusion can be avoided in most of the cases. Indeed, literature suggests that, in the presence of an expert operator, it does not improve the diagnostic accuracy of stress imaging by itself (plus LGE) [15] (Fig. 3). When stress perfusion CMR is performed, at least two members of the HIT are present at the scanner. One stands at the control station to guide perfusion imaging acquisition and contrast media administration, the other is in the



2 Images from a 64-year-old male with left bundle branch block and non-ischemic dilated cardiomyopathy. **(2A)** Trufi localizer showed a right pulmonary hilar mass (arrow) close to the right pulmonary artery (asterisk) with linear consolidation in the lung parenchyma (arrowhead). T2 STIR **(2B)**, and T1-weighted images **(2C)** confirm the solid mass. **(2E)** Cine 4-chamber view shows left ventricle dilatation and tissue close to right inferior pulmonary vein (arrows). **(2F)** Short-axis view confirmed the mild left ventricle dilatation without signs of fibrosis on late gadolinium enhancement image **(2G)**. **(2D)** Portal phase mediastinal view and **(2H)** lung window confirmed the presence of a right hilar mass (arrows) infiltrating right pulmonary artery (asterisk) and determining partial atelectasia of the right inferior lobe (arrowhead).

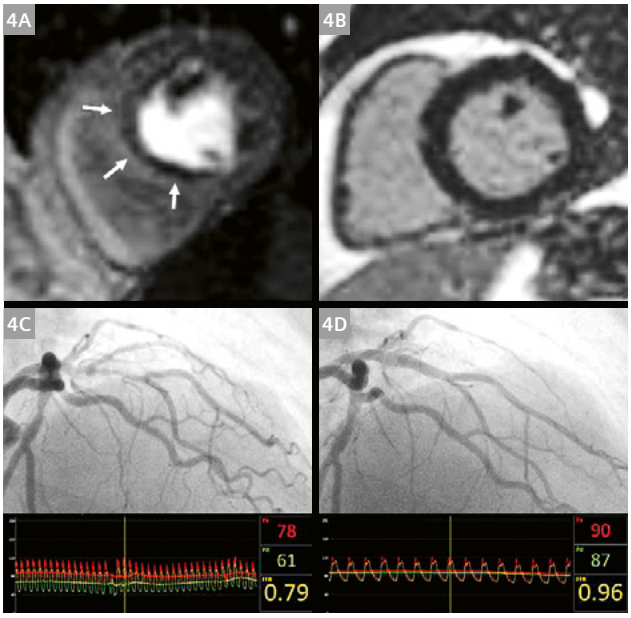


3 A 92-year-old patient hospitalized for heart failure underwent CMR due to suspected amyloidosis. TrueFISP images show left ventricular hypertrophy and large pleural effusion **(3A)**. The non-contrast CMR with tissue mapping revealed relevant increase of native T1 affecting the hypertrophied interventricular septum **(3B)** and mild increase of T2 values **(3C)** indicating concomitant mild myocardial edema. CMR findings are consistent with cardiac amyloidosis. In-center normality range for native T1 is 970 ± 20 msec and for T2 is 46 ± 2 msec.

scanner room to administer the stress agent, monitor patient reactions and vital signs, and treat any side effects should they develop. Adenosine as a pharmacological stress agent can cause several non-severe side-effects, such as flushing, chest pain, palpitations, and breathlessness, for which patients should be briefed before the examination to improve adherence to breathing instructions. The patient is required to sign a specific informed consent form for stress-perfusion imaging.

Implementing a clinical and research workflow

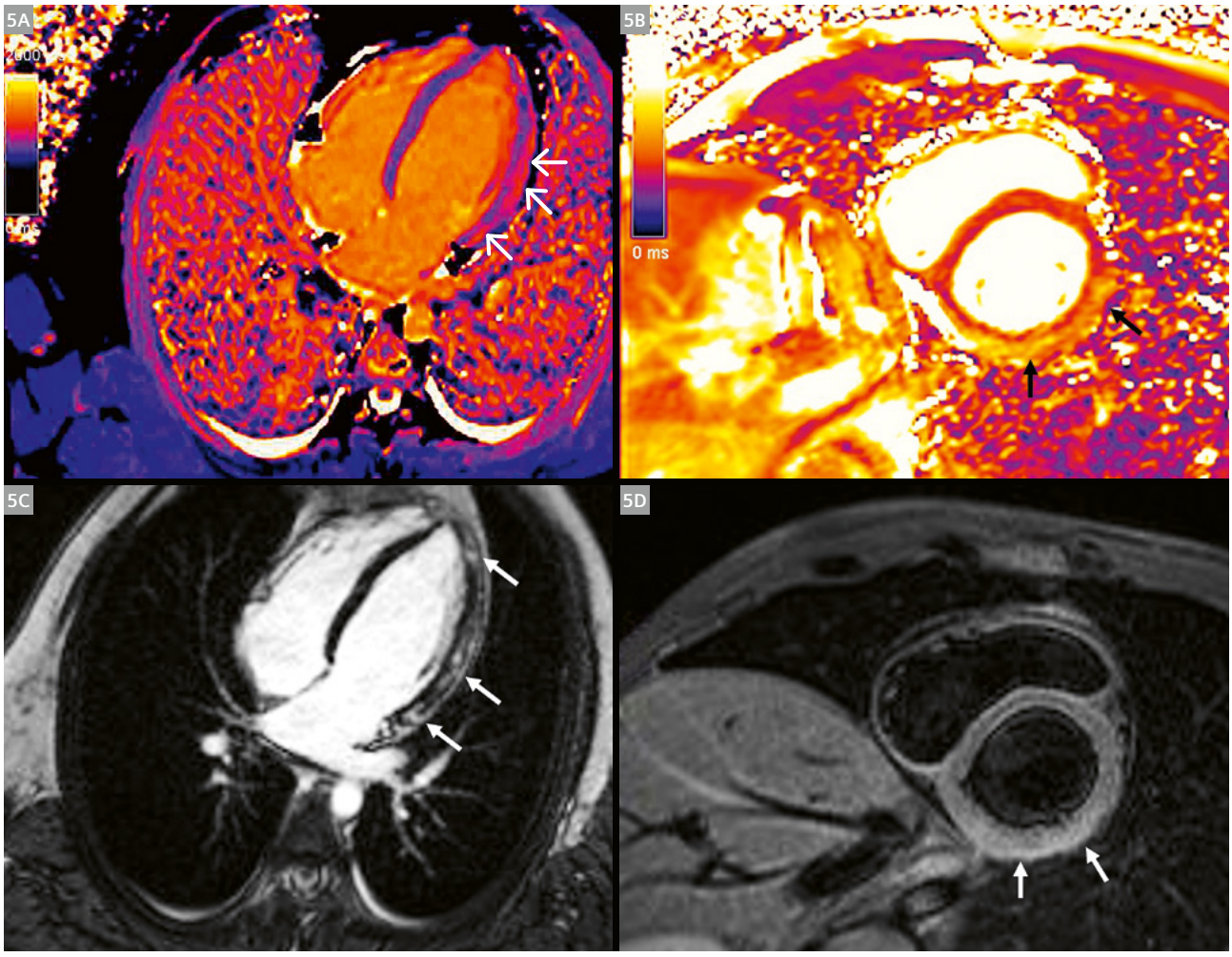
The presence of a HIT and the close collaboration with the hospital clinics where the two HIT cardiologists also serve as consultants for the ward, echo lab, and emergency departments, leads to the smooth integration of the radiological data with the patient's subsequent management, including treatment changes and planning of further medical procedures. One typical example of the impact that a CMR examination can have is that of patients with myocardial infarction with non-obstructive coronary artery disease (MINOCA) [16], for which the etiology is unclear after first-level examinations. In this context, CMR can provide relevant information to drive the diagnosis and subsequent treatment [17]. The presence of a scar, whether ischemic or non-ischemic, can inform the clinician about further treatments and specific follow-ups to be performed (Fig. 4).



4 First-pass perfusion imaging in a patient with effort angina shows a subendocardial defect affecting the subendocardium of interventricular septum at mid-left ventricular level **(4A)**. LGE imaging shows absence of replacement fibrosis **(4B)**. The patient underwent coronary angiography with fractional flow reserve revealing a significant stenosis (FFR 0.79) of the left anterior descending artery **(4C)**, which was effectively treated with angioplasty and stent implantation (FFR 0.96) **(4D)**.

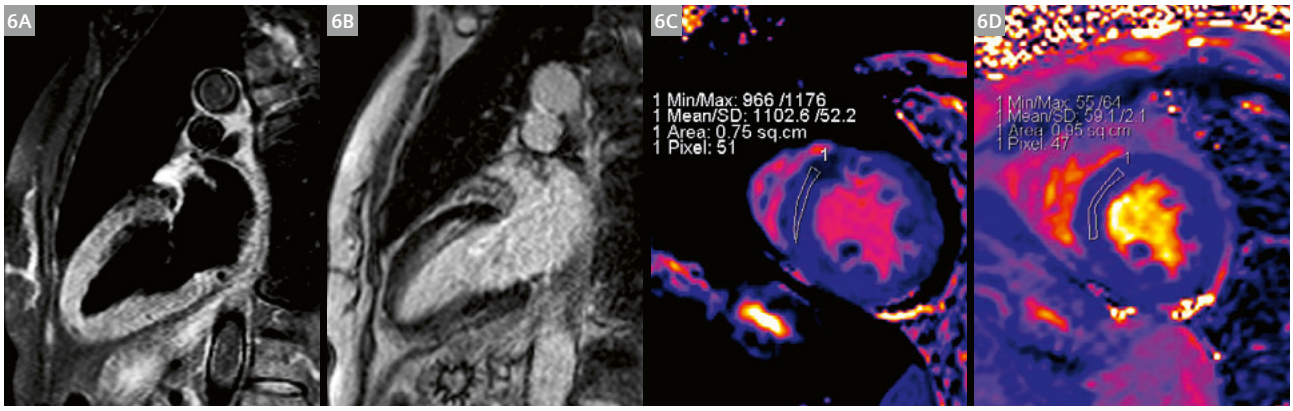
	Cine-bSSFP	PERFUSION (test)	PERFUSION (stress)	Cine-bSSFP	T1 SCOUT	T1 LGE	PERFUSION (rest – optional)
Acquisition time (s)	6 per slice	10	60	6 per slice	28 per slice	12 per slice (high-res)	60
Slice thickness (mm)	8	8	8	8	8	8	8
Gap	25%	90%	90%	25%	20%	20%	150%
Matrix	256 × 143	160 × 75	160 × 75	256 × 143	192 × 78	256 × 160	256 × 143
TE (ms)	1.21	1.18	1.18	1.21	1.12	3.19	1.8
TR (ms)	51.3	177.70	177.70	51.3	23	635	306.2
Flip angle	70°	12°	12°	70°	50°	25°	35°
Planes	4-chamber 2-chamber 3-chamber	Basal-SAX Mid-SAX Apical-SAX	Basal-SAX Mid-SAX Apical-SAX	SAX	Mid-SAX	SAX (overview) 4-chamber (high-res) 2-chamber (high-res) 3-chamber (high-res)	Basal-SAX Mid-SAX Apical-SAX

Table 2: Abbreviated protocol.



5 Images from a patient in his thirties, presented to the emergency department after complaining of chest pain and fever. ECG consistent with inferior STEMI. Urgent coronary angiography revealed patent coronary arteries; troponin T rose to 1130 pg/mL (normal value below 14 pg/mL). CMR examination was performed a few days later. Native T1 (4-chamber long-axis view in **5A**) and T2 (basal short-axis view in **5B**) revealed increased signal intensity in the lateral to inferior left ventricular wall (arrows). Bottom panels represent LGE imaging **(5C)** and T2 STIR imaging **(5D)** in the same view as the upper panel; areas of increased signal intensity are indicated by the arrows. The presence of non-ischemic LGE (patchy sub-epicardial and intra-myocardial) plus myocardial edema is consistent with a diagnosis of acute myocarditis.

This comprehensive approach to advanced cardiac imaging used in our institution, from the indications to the execution, reporting, and clinical impact of these procedures, makes it possible to collect relevant data for research purposes. This activity is also supported by the availability of relatively recent quantitative tools for tissue characterization, such as T1 and T2 mapping. Prospective and standardized collection of this data is performed on consecutive patients, especially that pertaining to some specific subgroups of diseases, such as myocarditis [18] (Fig. 5) and takotsubo syndrome [19] (Fig. 6). Notably, the analysis of mapping data is made in accordance with indications from expert consensus [20] and by using standardized and reproducible methods [21] (Fig. 2). Finally, we often undervalue the amount of information acquired during a CMR scan. Indeed, even with standard T1 and T2 mapping acquisition, a large volume of extracardiac data pertaining to the lungs, spleen, and liver is collected and can be further analyzed [22, 23]. To this extent, the implementation of artificial intelligence-based technology could boost analysis of images and potentially very large datasets [24] and further improve the role of tissue characterization in magnetic resonance imaging as a pivotal diagnostic examination in a wide range of cardiac and non-cardiac pathologies.



6 CMR of a patient with suspected takotsubo syndrome, confirming the clinical suspicion. T2-STIR sequence of 2-chamber view shows increased signal at mid-apical level consistent with myocardial edemia (arrows in **6A**). LGE imaging in the same plane excludes the presence of replacement fibrosis **(6B)**. Quantitative analysis with native T1 **(6C)** and T2 **(6D)** mapping is performed at mid-septal level from short-axis view, as indicated by expert consensus. The parametric evaluation of myocardial edema offers more accurate diagnostic and, potentially, prognostic information in this setting [19].

Summary

A high-quality CMR service can be effectively deployed in the context of a first-level setting of care, in accordance with current clinical practice guidelines. To enhance the clinical relevance of imaging findings, a multimodality (imaging) and multispecialty (physicians) approach is essential. This requires appropriate training, infrastructure availability, and close collaboration between the professionals involved.

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