

Differentiation of Cardiomyopathies by use of CMR

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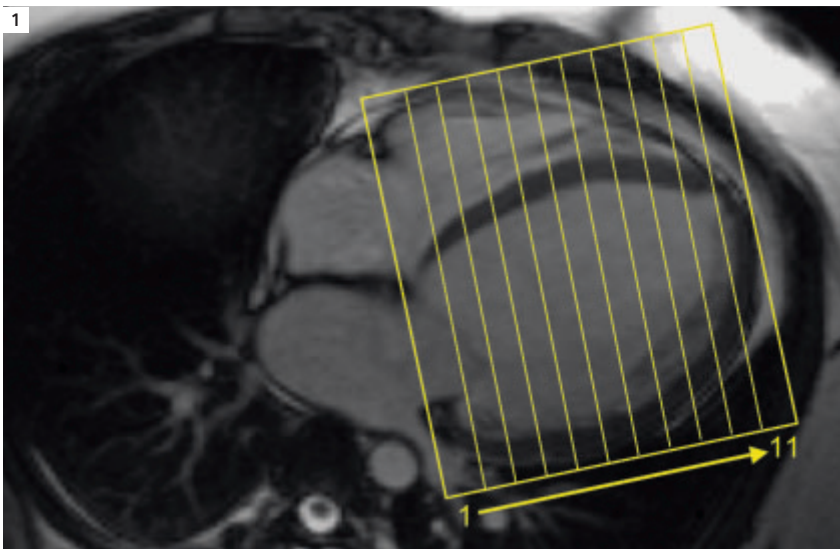
CMR can yield information on cardiac anatomy, function, tissue characterization, perfusion, and valvular flow in one single study.

Introduction

Primary cardiomyopathies (CMP) are diagnosed by exclusion of other cardiac diseases. Secondary or specific cardiomyopathies are defined as distinct myocardial diseases with specific origin as ischemic, hypertensive, inflammatory. The identification of the etiology for a non-ischemic cardiomyopathy is often difficult and suboptimal with conventional imaging and invasive testing. A "standard" investigative route is focused around a detailed history, ECG, transthoracic echocardiography, holter monitoring, exercise treadmill testing, and invasive angiography. These tests often produce a clear diagnosis, such as coronary artery disease, valvular heart disease, dilated cardiomy-

opathy, or hypertrophic cardiomyopathy. Nevertheless, establishing a diagnosis of cardiomyopathy can still be difficult and may be not possible to do with certainty. In recent years, advances in cardiovascular magnetic resonance (CMR) have brought this technology into routine clinical use. In a single 45–60 minute study, CMR can yield information on cardiac anatomy, function, tissue characterization, perfusion, and valvular flow. This technology not only helps to determine the etiology and presence for a cardiomyopathic process, but also provides a robust imaging tool to follow patients over time and provide prognostic information.

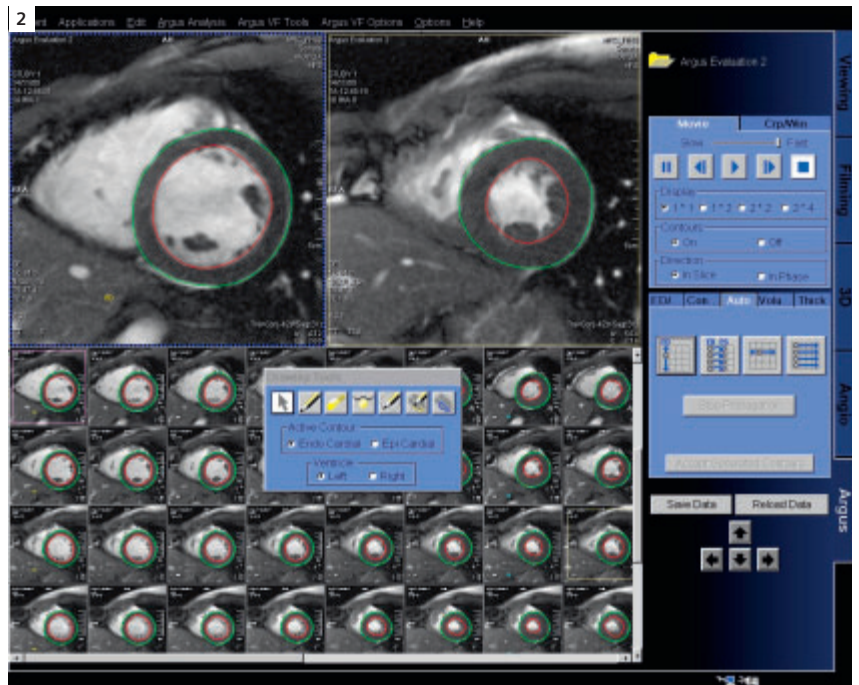
A number of CMR techniques are useful in the assessment of cardiomyopathy. Initially a detailed assessment of cardiac anatomy is performed using at least transaxial (and also usually coronal and sagittal) HASTE (Half-Fourier Acquisition Single-Shot Turbo Spin-Echo) imaging, which can be completed in approximately 3 minutes. This serves to identify at an early stage important shunts, anomalous pulmonary venous drainage, or congenital anomalies which may explain increased chamber dimensions suggestive of a cardiomyopathy. Alternatively, a multislice single-shot TrueFISP morphology sequence can be performed. TrueFISP cine imaging of long and short axis function is performed to assess overall myocardial function, followed by a stack of 8–12 short axis TrueFISP cines of the LV and RV from base to apex, which is regarded as the "gold standard" test for quantitative assessment of biventricular volumes and function (Fig. 1). Assessment of volumes and mass can be performed by manual planimetry of the epi- and endocardial border in diastole and the endocardial border in systole (Fig. 2). Alternatively, the analysis can be performed using semi-



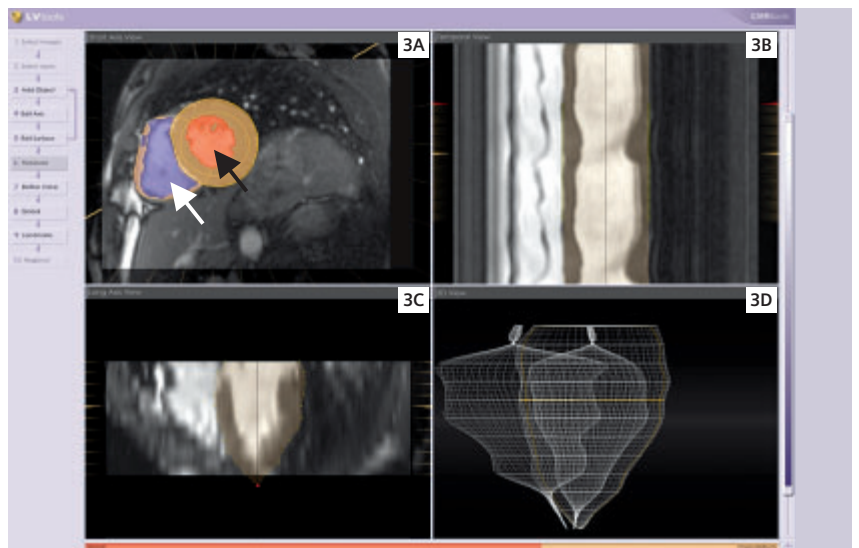
1 Method of acquisition of short axis stack of cine-images from base to apex. The first slice (1) is typically taken parallel to the annulus of the mitral and tricuspid valve. Serial slices 10 mm apart are acquired from base to apex (slice 11) usually with a slice thickness of 7 mm and 3 mm gaps, at our institution. Breath-hold is typically no longer than 8–10 seconds.

automated software (Fig. 3). A completely automatic VF analysis tool has recently been introduced by Siemens Medical Solutions (Inline VF). For patients with subtle reductions in function by echocardiography, CMR can establish ventricular dysfunction with greater confidence because of the availability of normal values which are corrected for age, sex and body surface area. CMR also provides a more suitable method for follow up of serial measurements given the superior interstudy reproducibility over other imaging modalities which are more routinely used, especially 2D echocardiography.

A number of other more specialized imaging sequences are also performed in a patient with suspected cardiomyopathy. T1 and T2-weighted turbo-spin echo (TSE) sequences are useful to assess the pericardium where the clinical question resolves around constrictive vs. restrictive cardiomyopathy. Short T1 Inversion Recovery (STIR) imaging with a triple inversion protocol, nulls signal from fat, is T2-weighted and is used to identify areas of increased myocardial water content, indicative of myocardial oedema and inflammation which are seen in conditions such as acute myocarditis and acute myocardial infarction. Myocardial T2*-weighted imaging is used to quantify myocardial iron. Imaging performed immediately (1–3 minutes) following intravenous gadolinium is a sensitive tool to detect intracardiac thrombi by providing the best delineation between the enhanced blood-pool and myocardium on one side and the dark thrombus on the other side. Further, late gadolinium enhancement (LGE) imaging using sequences such as inversion recovery TurboFLASH (IR GRE) or phase-sensitive inversion recovery (PSIR) sequences is then performed approximately 5–20 minutes after gadolinium administration (the delay between contrast administration and image acquisition depends on the concentration of gadolinium given, typically 0.1–0.2 mmol/kg body weight). The presence of LGE is indicative of abnormal myocardial interstitium such as myocardial fibrosis and infarction. In non-ischemic cardiomyopathy, there are several typical patterns of LGE which are very helpful in determining etiology and providing prognostic information. Please refer to the article of I. Klem (pg. 14) for details about typical LGE pattern caused by ischemic heart disease.



2 Contouring of epicardial and endocardial borders in diastole and systole to measure LV mass, volumes, and function. The volumes are calculated by summing the volume of the blood in each slice. The mass is determined from the volumes of myocardium in diastole multiplied by the myocardial density (1.05 g/cm^3).



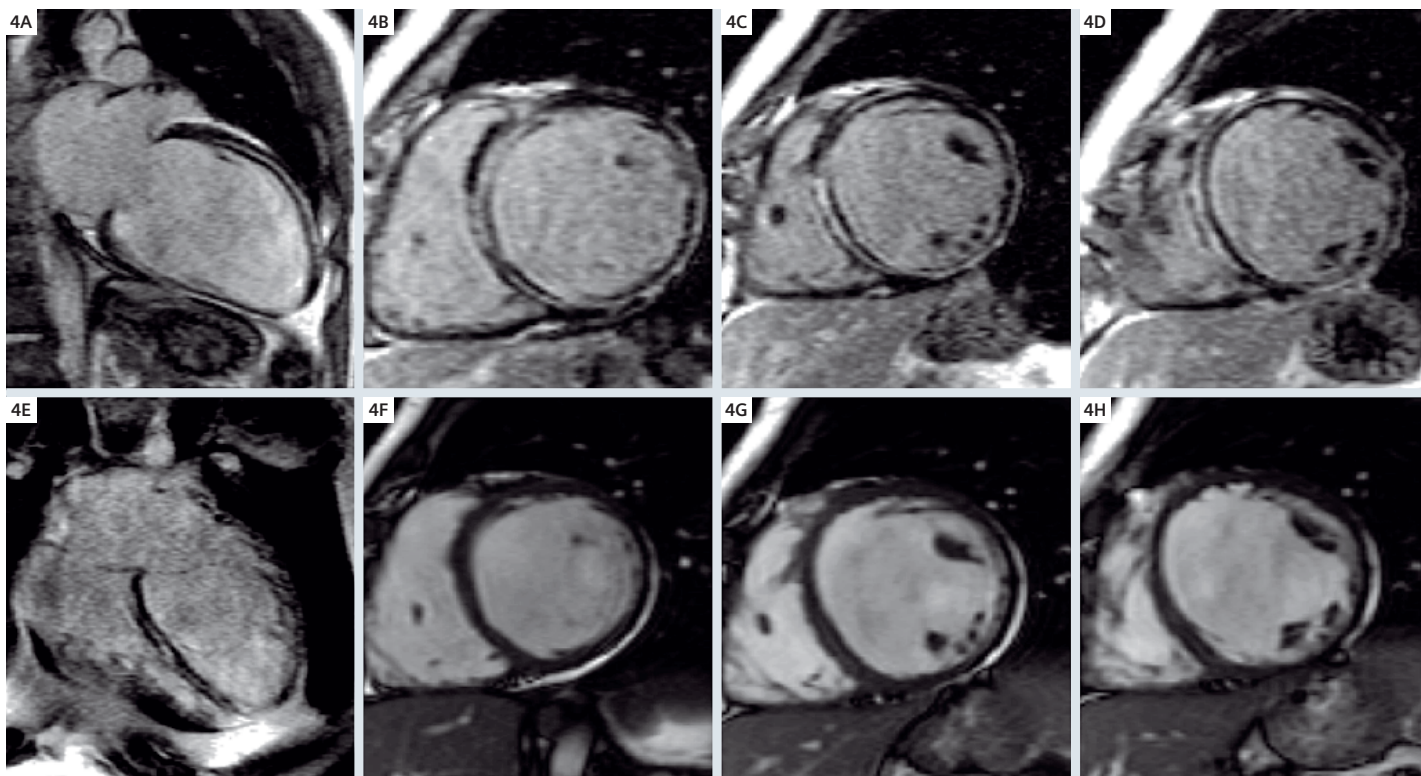
3 Semiautomated analysis of left and right ventricular mass, volume, and function. There are several software packages that can perform this assisted analysis and the one shown here is CMRtools® (Cardiovascular Imaging Solutions, London, UK; www.cmrtools.com). A 3-dimensional model of the epicardial and endocardial contours is generated, incorporating user-defined guide-points and shown in panel D. This model calculates the contours for all slices and is fully adjustable. The model is checked against a composite long axis image (panel C) and the time activity image (panel B) to ensure it is consistent through planes and time. Finally, thresholding of blood to account for papillary muscles is performed with an intensity based tool (LV blood orange with black arrow; RV blood blue with white arrow). The atrial contribution to volumes is excluded in diastole and systole by defining the mitral and tricuspid valve annuli from the long-axis cines.

Dilated Cardiomyopathy

CMR is superior to nuclear scintigraphic techniques to distinguish non-ischemic from ischemic etiologies of cardiomyopathy.

We use the term dilated cardiomyopathy to refer to patients with systolic dysfunction, a dilated heart and a cause from muscle dysfunction which has not resulted from the various manifestations of coronary artery disease. For many patients who present with systolic dysfunction and dilated heart, the ruling out of coronary artery disease as the etiology is of importance since this has a major impact on prognosis and treatment strategies [1-3]. There are studies using LGE as a novel non-invasive test to determine if LV dysfunction has an ischaemic etiology. In the absence of LGE in those with a dilated heart, an ischaemic etiology is extremely unlikely (97% negative predictive value), and in the presence of an ischaemic etiology, the amount of LGE correlates with the degree of severity of underlying CAD [4-7]. By contrast, patients with normal coronaries by angiography and LV dysfunction may still have an ischemic etiology for LV dysfunction (thrombosis on a non-stenotic plaque, or embolism in up to 13% of individuals),

and may have been inappropriately diagnosed as having a dilated cardiomyopathy [5]. The results of the LGE technique as a non-invasive method of differentiating ischaemic and dilated cardiomyopathy are superior to other techniques because the myocardial substrate can be interrogated with such high resolution. Additionally, CMR is superior to nuclear scintigraphic techniques to distinguish non-ischemic from ischemic etiologies. CMR is not limited by attenuation artefacts, which lead to false positive results for presence of myocardial infarction. Comparative studies between SPECT and CMR perfusion imaging have also demonstrated that CMR can better identify small myocardial infarctions than nuclear techniques [9]. Perfusion can also be assessed by both techniques to identify ischaemia, but CMR has superior spatial resolution and provides sensitivity and specificity values ranging between 83% and 95% and 53% and 95% respectively [10]. While the absence of LGE does not completely rule out an ischemic etiology in the rare setting of global myocardial hibernation in the absence of infarction, first-pass myocardial perfu-



4 Late gadolinium enhancement in dilated cardiomyopathy. There is mid-wall enhancement which is most marked in the septum. Vertical (A) and horizontal (E) long axis and three short axis (B, C, D) planes. Corresponding frames from the SSFP short axis cine are shown (F, G, H).

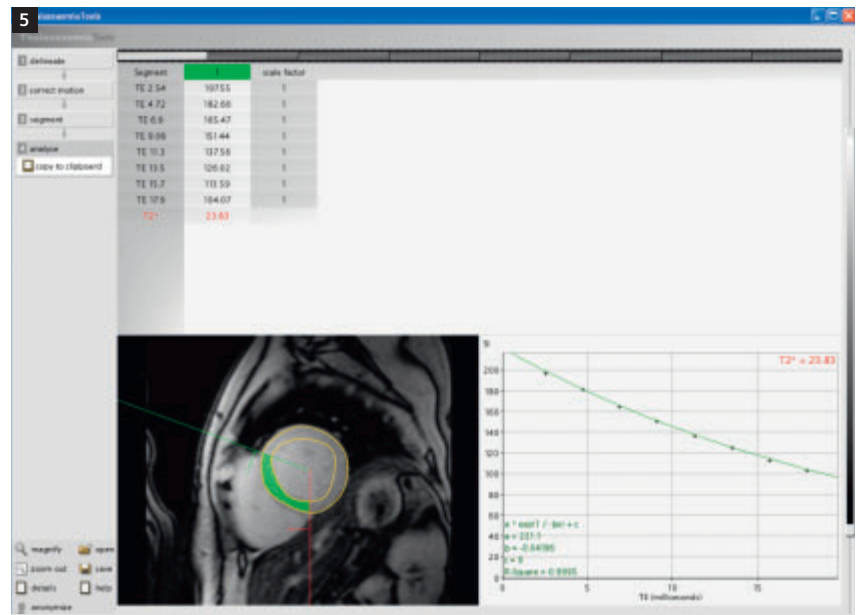
sion imaging or proximal coronary artery MR angiography can be performed.

Myocardial fibrosis, in a non-infarct pattern, is seen in up to 30% of patients with DCM, typically in a mid-wall septal distribution (“mid-wall striae”, Fig. 4). The presence of fibrosis has important prognostic implications, with the presence of mid-wall fibrosis in DCM being associated with an increased risk of sudden cardiac death and ventricular tachycardia (VT), independent of other more traditional markers of increased risk [11]. These findings might also suggest the use of CMR for better identification of patients with need for an ICD implantation.

As highlighted above, CMR is the reference standard method of assessment of myocardial volumes and function. The interstudy and interindividual variability is less than 5%, thus making this technique accurate for picking up subtle reductions in ventricular function. This low variability also allows for accurate serial measurements over time to monitor for changes in function and monitor response to medical therapies. Furthermore, given the excellent interstudy reproducibility, smaller sample sizes are needed to detect true clinical differences between patient populations in research studies [12]. One example of this would be in a drug trial designed to detect a 10 g difference in LV mass with anti-hypertensive treatment, a sample size of 505 would be needed with 2D echo versus only 14 with CMR, for a power of 80% and P-value of 0.05 [13].

Thalassemia

Heart failure due to iron overload is the principle cause of death in patients with thalassemia, accounting for up to 71% of all deaths, with 50% of these patients dying before the age of 35, despite iron-chelating therapy [14-16]. This form of cardiomyopathy is reversible but intensive iron chelation is necessary to remove myocardial iron [17]. Unfortunately once heart failure symptoms occur in iron overload cardiomyopathy, the prognosis is poor. In the past, total body iron stores and approximation of myocardial iron loading were assessed by serum ferritin levels and liver biopsy, and indeed these parameters were also used to monitor success or failure of chelation therapy. It is now recognized that there can be marked discordance between liver and heart iron loading making early detection of myocardial iron chal-

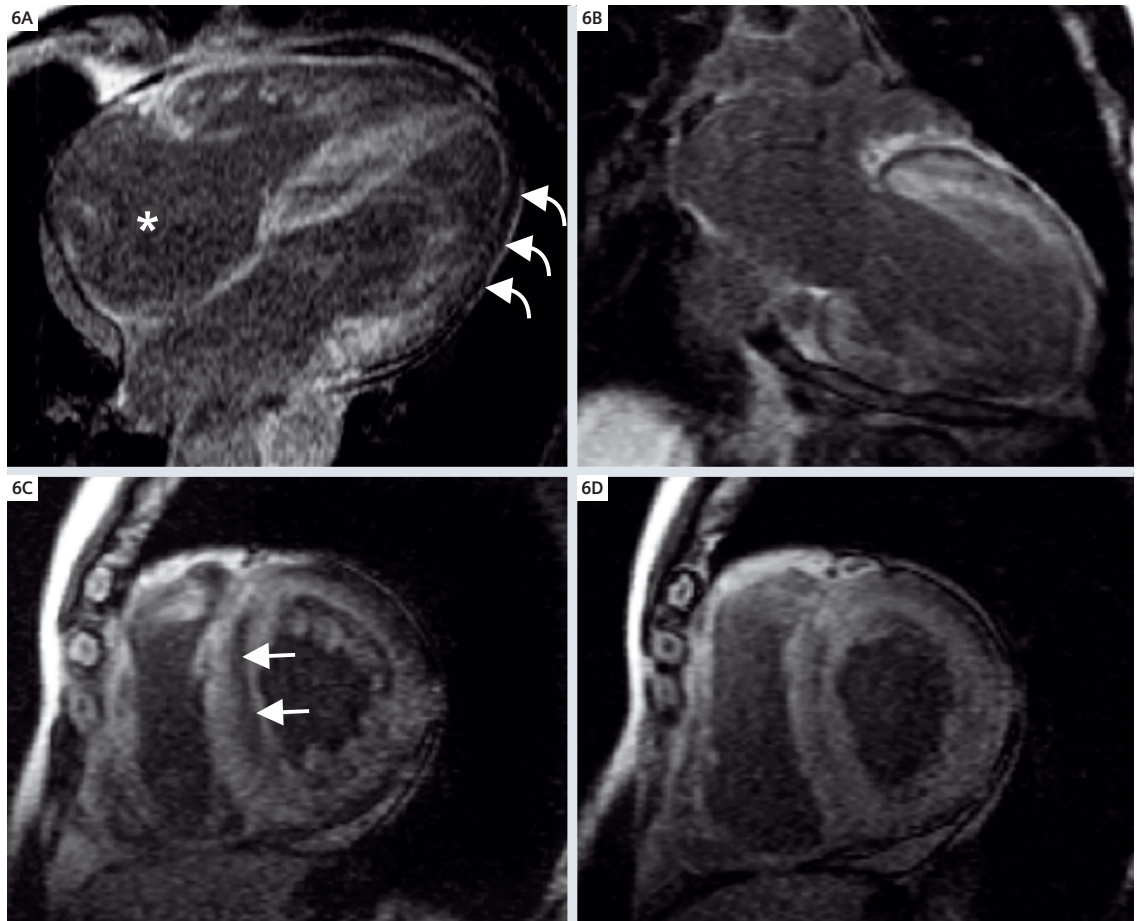


5 Myocardial T2* analysis using Thalassaemia-Tools® (plug-in of CMRtools®). The gradient echo images are loaded and the interventricular septum is defined. This area is least affected by variable susceptibility artefact commonly seen adjacent to the anterior and inferior walls (cardiac veins with deoxygenated blood) and the lateral wall (lungs). The software generates the signal against echo-time points and best fits the decay curve to estimate the T2* (in this case normal at 23.8 ms). When the myocardial T2* is very short (<10 ms), the latter points are comprised of noise rather than signal and the software can be instructed to discount such points to ensure the curve fits the “signal rich” initial decay points. This method is known as truncation. Other mathematical solutions for the data fitting exist including modeling of a constant for the baseline offset, and bi-exponential decay modeling. The truncation technique has been used for the major randomized controlled trials and its performance is well understood. The other techniques yield slightly different T2* values and therefore consistent analysis technique is important.

lenging using conventional techniques [18]. Since 2000 a new CMR technique has been able to address this problem. T2* is a relaxation parameter assessed by CMR arising principally from local magnetic field inhomogeneities that are increased with particulate storage iron deposition. This parameter is reproducible and correlates with liver and myocardial iron stores. It can be easily imaged and quantified in the heart using gradient echo techniques (Fig. 5). There is no better method of quantification of myocardial iron content than with this new CMR technique.

Using T2* it has been shown that there is no clinically useful correlation between myocardial iron and liver iron or ferritin levels confirming that reliance on these conventional parameters as a marker of cardiac iron loading is unreliable [18, 19]. The

CMR Thalassemia protocols are available with the Cardiac Suite (standard package) on all 1.5T MAGNETOM Tim systems.



6 Late gadolinium enhancement in cardiac amyloidosis. Horizontal (A) and vertical (B) long axis and two short axis (C, D) planes. Typical findings are shown including low intensity blood pool marked by * (LGE usually has high signal in the blood pool), and general enhancement favoring the subendocardium – the short curly white arrows show epicardial sparing. Mid-wall “sparing” is seen in the septum (zebra pattern – short white arrows).

The incidence of development of heart failure in those with a $T2^* < 6$ ms is very high, whereas it is uncommon in patients with a $T2^* > 10$ ms.

degree of myocardial iron is directly correlated with the severity of LV dysfunction. In a cross-sectional study, 89% of thalassemia patients with new onset cardiac failure had a $T2^*$ less than 10 ms. Therefore the threshold of <10 ms for myocardial $T2^*$ is now taken as indicating severe iron loading. Mild to moderate iron loading is indicated by a myocardial $T2^*$ of 10–20 ms, and >20 ms is normal (the median for the normal population is approximately 40 ms). In a prospective follow-up study, the incidence of development of heart failure in those with a $T2^* < 6$ ms is very high, whereas it is uncommon in patients with a $T2^* > 10$ ms. Arrhythmias however occur with a wider distribution of myocardial $T2^*$. $T2^*$ has been also used to monitor success of chelation therapy. Improvement in both cardiac function and myocardial $T2^*$

over a one-year period was found using 24-hour continuous intravenous deferoxamine for 12 months in heart failure [20]. A cross-sectional study showed that the oral chelator deferiprone was associated with superior ejection fraction and myocardial $T2^*$ than the standard treatment of injected subcutaneous deferoxamine [21]. Recently 2 prospective randomized controlled trials have confirmed that deferiprone has superior efficacy in removing cardiac iron. The first study indicated superiority of deferiprone as monotherapy over deferoxamine in reducing cardiac iron overload and improving ejection fraction [22]. In a second trial, the authors found that combination chelation therapy (deferiprone plus deferoxamine) improved both myocardial $T2^*$ and ejection fraction in comparison with deferoxamine monotherapy [23].

Since the introduction of the T2* technique to the management of thalassemia patients, with particular emphasis on intensification or alteration of chelation therapies, UK mortality rates in this condition have reduced by 80% [24]. This pattern has also been documented in Italy [15], and Cyprus [25]. This is a substantial health improvement for beta-thalassemia patients which has world-wide importance.

Myocardial inflammation: Viral Myocarditis, Sarcoidosis, SLE

Viral myocarditis is a common cause of dilated cardiomyopathy. In Europe, Parvovirus, Herpes virus and Coxsackie virus are most often found to be the culprit. Myocardial inflammation on the basis of systemic disease often determines the overall prognosis of the patient. However, based on autopsy studies, myocardial involvement is often clinically underdiagnosed, e.g. in sarcoidosis about 50% of cases are positive at autopsy [28]. Moreover, myocarditis can be of different origin including bacterial, viral, toxic or involvement in systemic diseases [29]. Focal and diffuse tissue changes on a histological level vary depending on the agents and the time course of the disease. Cellular infiltration with and without myocyte necrosis has been described [30, 31]. The broad clinical spectrum from subclinical disease to severe heart failure and a course of the disease from complete convalescence to dilated cardiomyopathy depends on the extent of the myocardial damage and its immediate detection. Therefore an early non-invasive differentiation is warranted.

Contrast-enhanced CMR (ceCMR) has been used to detect myocardial inflammation for several years [32]. A good correlation between ceCMR and endomyocardial biopsy including a relation to severity of disease was published recently [33,34]. Nevertheless, in our experience, some patients with inflammatory myocardial reaction may be overlooked by only applying LGE imaging. Exploiting the unique tissue characterization capabilities of CMR, a multi-sequential approach was introduced, which was shown to increase the diagnostic accuracy of magnetic resonance imaging to detect myocarditis [35]. This includes

- T2-weighted fast spin echo for oedema detection,
- T1-weighted spin echo imaging before and early after contrast to delineate increased interstitial space and

- LGE imaging to visualize necrotic areas.

The combined approach differentiates between reversible and irreversible damage and allows to a certain extent to assess the acuity of inflammation.

Applying a similar approach, we were able to detect myocardial involvement in sarcoidosis even when left-ventricular function was still preserved [36]. Different CMR techniques have proven useful during follow-up including steroid therapy in sarcoidosis [37, 38]. The extent of LGE may indicate the risk of the patients, but larger prospective trials are needed to address this issue. Interestingly, there is also first evidence that in systemic lupus erythematosus quantification of T2 is helpful in characterizing myocardial involvement [39]. Currently we recommend the combination of T1 and T2-weighted sequences. The proposed approach is published and is meanwhile optimized for different types of scanners. Nevertheless, we expect further technical improvement including more robust techniques.

T2-weighted imaging

For T2 we use a short TI fast spin-echo sequence with triple inversion (STIR). More recent approaches (works in progress) include T2-weighted gradient echo attempting to overcome some of the drawbacks of the spin-echo approach: Insufficient blood suppression in areas of slow flow and posterolateral signal loss due to mistriggering, but they have not been proven in that setting yet.

Used parameters are as follows: TR = 2RR, TE 65 ms, TI 140 ms, slice thickness 15 mm, gap 5 mm, FoV 340–380 mm, matrix 256 x 256. Global instead of regional myocardial signal is measured. Skeletal muscle is used as a reference structure to minimize heart rate effects.

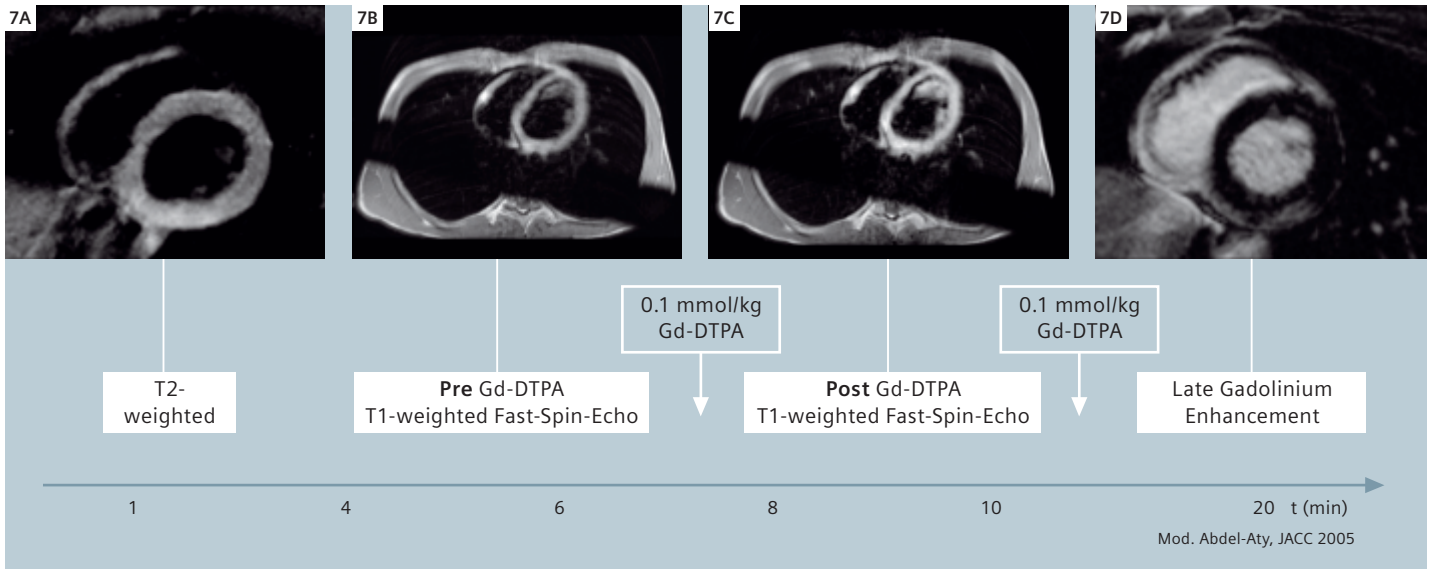
Contrast-enhanced T1-weighted imaging

For contrast enhanced T1-weighted imaging we recommend differentiating an early from a late phase. The early phase encloses the first 4 minutes after contrast administration, encompasses the steady-state during the whole period (non-breath-hold sequence). Hyperemia, increased distribution volume in the intercellular space and capillary leakage result in increased contrast enhancement in this phase. Here, we recommend a continuous non-breathhold interleaved multislice T1-weighted fast spin-echo sequence.

Since the introduction of the CMR T2* technique, mortality rates in thalassemia patients could be reduced by 80% in the UK.

There is a good correlation between ceCMR and endomyocardial biopsy including a relation to severity of myocardial inflammation.

TSE T1 & T2, 2D IR/PSIR sequences are provided in the Cardiac Suite (standard) on all MAGNETOM Tim systems.



7 Myocarditis CMR Protocol. Multi-sequential approach for assessment of myocardial inflammation. After assessment of left-ventricular function, T2- and T1-weighted sequences are acquired. See text for more details.

Quantitative analysis of the T1-weighted sequences for the assessment of the „relative enhancement“ takes ~5-10 minutes.

It is prone to flow artifacts, so saturation bands across the atria and the aorta might be helpful. Typical parameters: TR 475–480 ms, TE 30 ms, matrix 256 x 256; slice thickness 6 mm, number of acquisitions 4–6. We compare signal intensity before and after contrast and calculate a ratio of myocardial over skeletal muscle enhancement (a number we have called “relative enhancement”) to control for heart rate effects. In addition to optimization for different scanners, normal values for the quantification of signal enhancement were established. The complete quantitative analysis of all sequences takes ~5–10 minutes.

LGE imaging

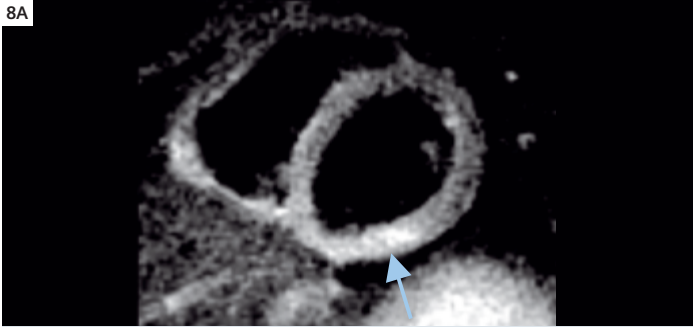
The third part of the protocol includes the assessment of late Gd enhancement images. The interpretation for clinical use is usually done qualitatively. In contrary to the “ischemic pattern”, LGE in patients with myocarditis is usually not located at myocardial segments consistent with coronary territories and can be located subepicardially or intramyocardially. According to recent studies there is even suspicion of a predominant localization of certain viruses in particular myocardial segments. LGE may appear grayish (instead of white) in myocarditis and have a patchy or solid appearance. LGE may reduce in size over the course of myocarditis – however, it is still unknown,

whether shrinkage of disseminated fibrotic areas, reduction of interstitial space (e.g. after oedema), or both cause this phenomenon (Figs. 7-9). CMR has been accepted, meanwhile, as clinically helpful in the diagnosis of myocarditis even if certain technical questions remain under discussion. Accordingly the recent conjoint report of the American College of Cardiology and the SCMR has classified its use as “appropriate” or “Class A Indication” in inflammatory cardiomyopathy [31].

Hypertrophic Cardiomyopathy (HCM)

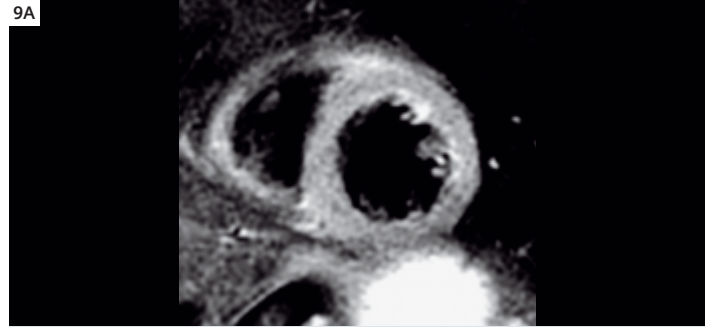
As a screening tool, echocardiography is used but it was recently shown that localized apical and anterolateral hypertrophies are under-diagnosed when applying echo [40]. This is of potential impact for risk stratification and screening of relatives. In CMR, the detection and quantification of hypertrophy can be easily done by application of cine-images (state of the art: steady-state free precession sequences, e.g. TrueFISP). The combination with parallel imaging (iPAT) allows a fast and robust coverage of the heart. The routinely used protocol includes standard long-axis and full coverage short-axis slices (Fig. 10). The localization of obstruction can be visualized by a signal loss due to the turbulent flow, the dimension of the left ventricular outflow tract can be measured applying cine-images of the LVOT [41]. This approach is not only helpful for the differentiation

ACC & SCMR classified the use of CMR in inflammatory CMP as a „Class A Indication“.



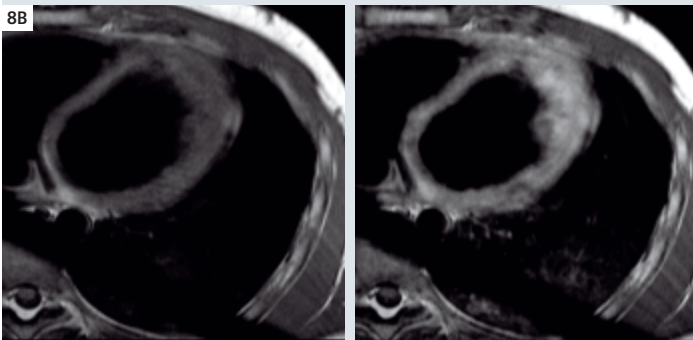
8 Myocarditis. 24-year-old male patient, admitted to our emergency unit with severe chest pain, history of respiratory infection, no known risk factors for coronary artery disease. ECG: left bundle branch block. Laboratory: Increased cardiac markers.

A) Oedema imaging: T2-weighted (T2w) images, increased global signal (ratio = 2.5), inferiorly a focal oedema can be visualized (arrow). Recovery during follow-up.

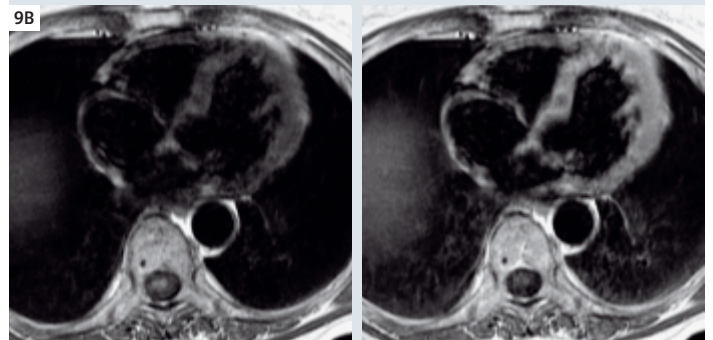


9 Myocarditis. 64-year-old female patient, admitted to the emergency room with severe chest pain, history of diarrhea. ECG: ST-Elevation in leads I, II, aVL, V5-6; T-wave inversion in lead II. Laboratory findings: CK two-fold elevated, Troponin highly elevated, leucocytes 16 Gpt/l, CRP 28 mg/dl (normal <5 mg/dl). Transthoracic echo: wall motion abnormalities in anteroseptal and anterolateral segments, LV ejection fraction 28%. Coronary angiography: exclusion of significant coronary artery disease (CAD). CMR-findings:

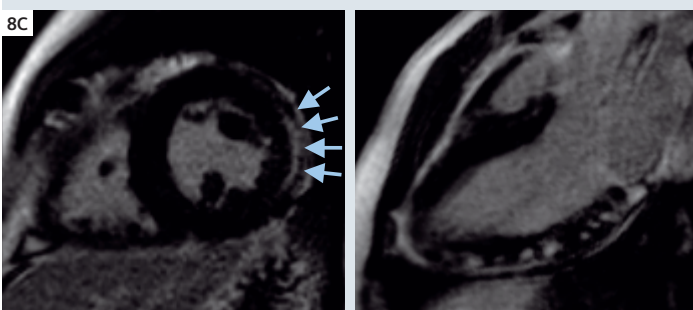
A) Oedema imaging: T2-weighted images, increased global signal (ratio = 2.3) – normalization during follow up.



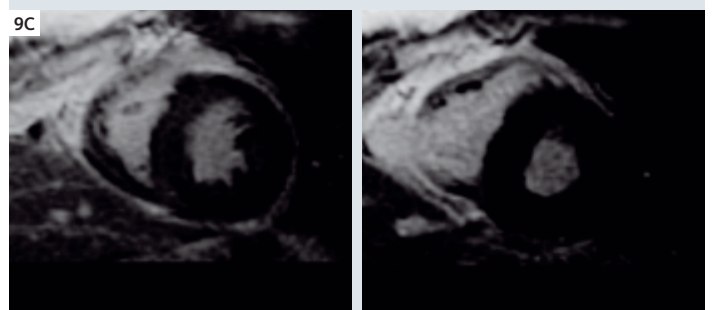
B) Early enhancement: T1w FSE before and after contrast application. Quantification of signal increase showed an increased value (ratio = 4.9) Normalization could be verified during follow-up.



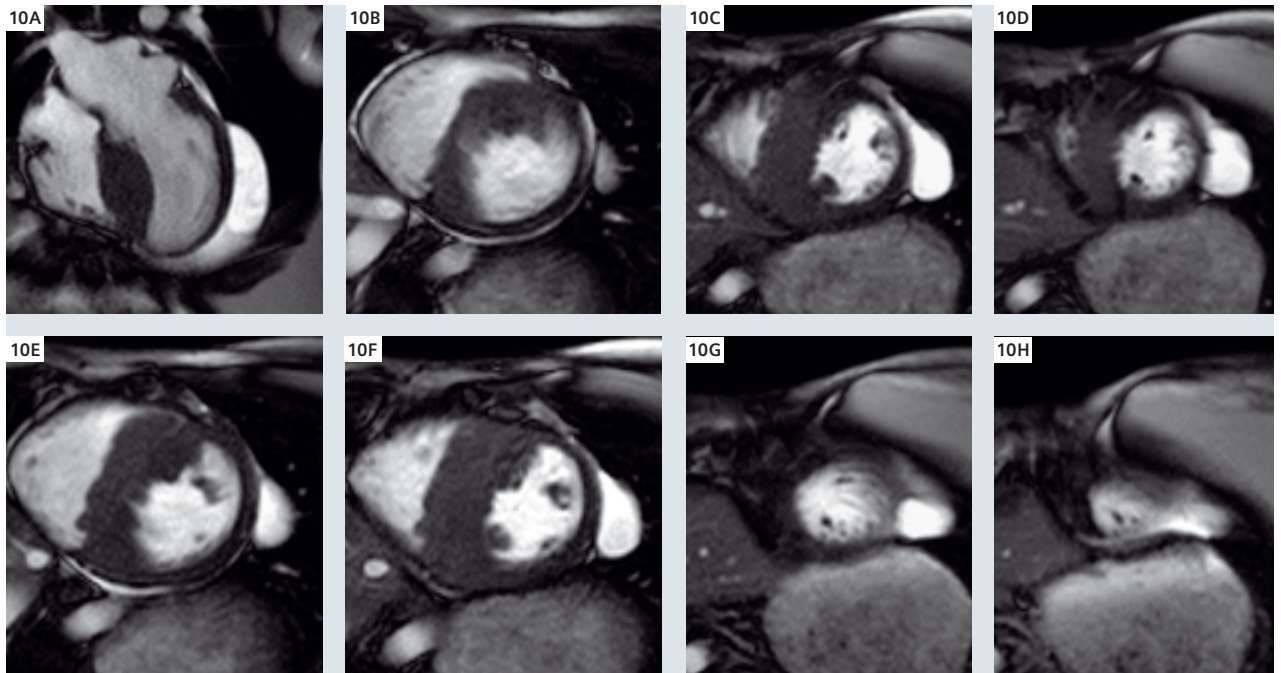
B) Early enhancement: Showing T1w FSE before and after contrast application. Quantification of signal-increase showed a significant increase (ratio = 5.6) – normalization during follow up.



C) Late gadolinium enhancement (LGE): Typical subepicardial enhancement in the lateral wall as seen in the mid-cavity short axis orientation (left, arrows) and patchy enhancement in the inferolateral wall from base to apex as seen in the LVOT orientation (bright spots, right), indicative of fibrotic areas – persistent during follow-up. Note the saturation bands on both images, placed to prevent artefacts due to flow in atria or aorta. Diagnosis: active myocarditis.



C) Late gadolinium enhancement (LGE): no evidence for LGE
Diagnosis: active myocarditis.



10 Hypertrophic Obstructive Cardiomyopathy. TrueFISP cine-images. Long-axis (4-chamber view) showing septal hypertrophy (A). Complete coverage of the left ventricle in short-axis orientation (B–H).

There is initial evidence for a correlation of LGE to higher risk regarding development of heart failure and sudden cardiac death in HOCM.

CMR is a reliable method for diagnosing cardiac amyloid by the presence of a typical LGE pattern, which is not seen in other LVH pathologies.

between obstructive and non-obstructive forms, but also allows us to understand the relationship between the evolution of obstruction and post-interventional tissue changes, e.g. following septal embolisation [42] (Fig. 11). The verification of new therapeutic approaches like septal ablation can be improved using ce CMR which is also useful during follow-up [43, 44].

We believe that the application of LGE is promising for further risk stratification in HOCM. There is initial evidence for a correlation to higher risk regarding development of heart failure and sudden cardiac death [45] (Fig. 12). LGE in HOCM usually appears as intramyocardial spots in the ventricular septum at the junction of RV and LV, and may extend as patchy areas throughout the hypertrophic myocardium. CMR is unique in simultaneously correlating the morphological abnormalities in HCM to their underlying tissue injury, thus providing a comprehensive characterization of the disease phenotype and elucidating the cause of LVH. Those data are not available by use of other non-invasive modalities free of ionizing radiation.

Amyloidosis

Cardiac involvement is frequent in AL amyloidosis, and is a key determinant of treatment options and

prognosis. Unfortunately, cardiac involvement remains the principle cause of death in approximately half of patients with AL amyloidosis. In general, the diagnosis of cardiac amyloidosis is made by echocardiography, demonstrating left ventricular hypertrophy and variable degrees of diastolic dysfunction in the setting of a histological diagnosis of amyloidosis (usually from outside the heart). In the presence of concurrent risk factors for LVH, however, the diagnosis can be difficult to make. By contrast, CMR is a reliable method for diagnosing cardiac amyloid by the presence of a typical LGE pattern, which is not seen in other LVH pathologies, with widespread enhancement preferentially affecting the subendocardium (Fig. 6). The wash-in and wash-out kinetics of gadolinium are markedly abnormal. LGE imaging therefore typically shows a dark blood pool. Since the mid-wall is relatively spared in the ventricular septum, there may be a characteristic zebra pattern with subendocardial enhancement of the LV and RV endocardium (for optimal LGE imaging in patients with suspicion of cardiac amyloidosis, see article of Voros et al., p. 86). Other features which are characteristic of cardiac amyloidosis include a thickened inter-atrial septum and RA free wall hypertrophy. Significant-

ly, the LGE in amyloidosis is not representative of fibrosis but instead of interstitial expansion by amyloid fibrils (protein). Most recently the gadolinium kinetics has been shown to predict prognosis. This CMR technique allows for more robust diagnosis of cardiac amyloid without the need for cardiac biopsy, and may also prove useful for monitoring serial changes over time with new treatments.

Arrhythmogenic Right Ventricular Dysplasia/Cardiomyopathy

ARVD/ARVC is a genetically determined disease with the risk of malignant arrhythmias and sudden cardiac death (SCD) even in young patients. Current guidelines require a composite of clinical, functional and morphologic criteria to diagnose ARVC.

For years, CMR has been presented in the textbooks as particularly suitable for diagnosing ARVC especially through detection of right ventricular (RV) fatty infiltration. In daily practise, however, it is a lot more cumbersome.

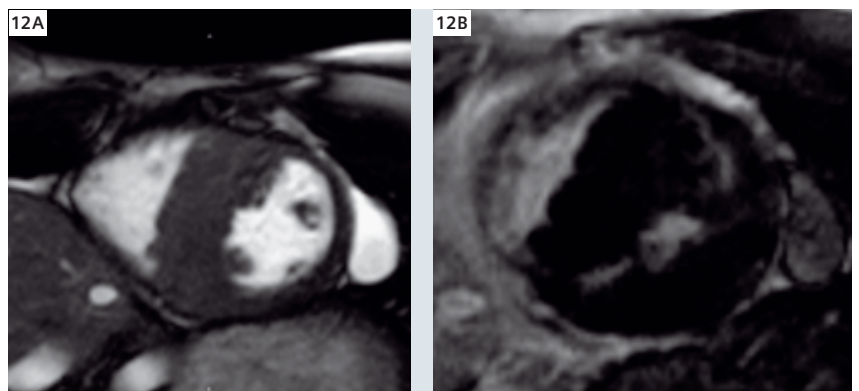
It is indeed easier to visualize and quantify the right ventricle by applying CMR than by use of echocardiography. We prefer the axial and sagittal orientation to a classical short axis approach for better delineation of the tricuspid valve plane and the outflow tract area. Due to the thinner RV walls, reproducibility of volume and functional measurements is still lower than for the left ventricle. Slice thickness should be reduced to 5 or 6 mm as a maximum; contiguous slice acquisition is warranted [46].

The literature has suggested the use of fast spin-echo T1-weighted images with and without fat saturation technique to detect fatty infiltration in the RV wall. In the "real world", sensitivity, specificity and reproducibility of this approach have been disappointing [47]. Indeed, pathologists have described fibro-fatty infiltration instead of pure fatty infiltration. This matches the first reports describing delayed enhancement in the RV wall [48] which nevertheless await verification from other groups. Newer sequence developments allow fat suppression in LGE images which offers the opportunity to investigate the fibro-fatty infiltration and may bring us closer to the proposed criteria of ARVC.

In agreement with other groups we found the detection of global and regional wall motion ab-



11 Hypertrophic Obstructive Cardiomyopathy. 57-year-old patient, scan was done seven days after interventional septal ablation. **Left:** Bright signal in the septal wall showing the oedema (STIR sequence). The oedema was resolved after 6 weeks. **Right:** After contrast application bright signal in the septal wall showing scar tissue (late gadolinium enhancement imaging). Lesion persists.



12 Fibrosis in hypertrophic cardiomyopathy. **Left:** Short-axis image showing septal hypertrophy. **Right:** Same short-axis view with LGE imaging: Bright signal shows fibrosis. The primary location of the enhancement at the insertion points of RV is a typical finding in HCM.

normalities the most helpful criterion in daily practise. Micro-aneurysms and bulging are highly suggestive of ARVC. However, one has to be familiar with the typical regional RV contraction patterns (e.g. around the moderator band or RVOT) to avoid false positive reports (Fig. 13).

Conclusion

CMR allows not only to differentiate ischemic from non-ischemic cardiomyopathic origins but also allows to establish the etiology within the non-ischemic category such as myocarditis, amyloidosis, thalassaemia or ARVD. CMR enables this by providing multiple different sequences that allow for visualization (and sometimes also quantification)

T1-weighted TSE and delayed enhancement sequences can be used to detect fibro-fatty infiltrations in ARVD.

There is an incremental value of CMR in the risk assessment of certain cardiomyopathies (e.g. HOCM, DCM).

All 2D sequences needed for cardiomyopathy evaluation are provided in the Cardiac Suite as standard on all MAGNETOM Tim systems.

of tissue alterations such as iron deposition, oedema, fibrosis etc. with high diagnostic accuracy. Since recent studies showed an incremental value of CMR in the risk assessment of certain cardiomyopathies (e.g. for sudden cardiac death and VT in HOCM and DCM), CMR has been increasingly used to ensure the best treatment for the right patient at the right time.

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