Noninvasive Imaging in Myocarditis

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Increased recognition of the role of inflammation in acute and chronic dilated cardiomyopathy has revived an interest in noninvasive imaging for detection of myocarditis. Diagnostic strategies that are based on molecular imaging promise to further advance our understanding and improve diagnostic precision. This article reviews the strengths and limitations of common clinical tests used for the diagnosis of myocarditis, with a focus on the emerging role of cardiovascular magnetic resonance imaging. Novel imaging modalities that are currently in preclinical development are discussed with recommendations for future clinical research. (J Am Coll Cardiol 2006;48:2085–93) © 2006 by the American College of Cardiology Foundation

Myocarditis may be diagnosed by clinical, pathological, or a combination of diagnostic criteria. The lack of precision in diagnostic criteria and heterogeneity of presentations (1) has led to complex and confusing reports. Despite a lengthy list of potential causes, the most common etiology in North America and Europe remains a viral infection with associated myocardial inflammation (2). Advances in our understanding of persistent viral infection and the subtleties of immune activation in the past decade have led to revised pathological criteria, novel diagnostic tests, and new therapeutic strategies (2), at least for the most common forms of myocarditis. In light of these recent advances, we review the major features of viral and immune-mediated cardiomyopathy because they represent diagnostic targets for noninvasive imaging.

Myocardial inflammation per se is a nonspecific response to various triggers such as viral or bacterial infection, cardiotoxic agents, catecholamines, infarction, or mechanical injury. Whereas most of these etiologic factors may already be evident from the patient’s history, viral infection may come with nonspecific symptoms or without any symptoms at all. Viral myocarditis, however, is more frequent than is clinically obvious. Thus, we focus our review on viral myocarditis.

Several viruses have been associated with myocarditis based on the detection of viral genome in cardiac tissue of patients. These cardiotropic viruses include Coxsackie B virus, non-Coxsackie enteroviruses, certain strains of adenovirus, parvovirus B19, and Epstein-Barr virus (3). Immune activation follows acute viral infection with activation of T and B cells, antibody production, cytokine release, and complement activation (2). However, our knowledge of viral cardiomyopathy is limited in part because the mechanisms responsible for viral infection, details of viral life cycle, and character of the immune response are only well known for certain strains of CVB. Persistent inflammation and/or persistent viral infection may lead to dilated cardiomyopathy (DCM) (4,5). Apoptosis, which commonly accompanies acute and chronic viral myocarditis (5), may also provide an opportunity for novel imaging.

IS THERE A NEED FOR NONINVASIVE IMAGING IN MYOCARDITIS?

The need for accurate diagnostic imaging in myocarditis arises from the lack of specificity and sensitivity of routine cardiac tests. Myocarditis may present with a wide spectrum of symptoms, including chest pain, recent onset of heart failure from systolic or diastolic dysfunction, atrial or ventricular arrhythmias, cardiogenic shock, or even sudden death (1,2).

This diversity of clinical manifestations has made the true incidence of myocarditis difficult to determine. Myocarditis is not uncommon and has been found in 1% to 9% of routine autopsy cases, and in 5% to 12% of those performed for unexplained sudden cardiac death in young individuals (6,7). Further, it has been identified as a cause of DCM in 9% of cases in 1 large prospective series (8).

Endomyocardial biopsy (EMB) is still considered by many clinicians to be the gold standard for diagnosing myocarditis. The 1987 Dallas criteria require lymphocytic infiltration associated with myocyte injury in the absence of ischemia (9). These criteria are highly specific but have only a 10% to 22% sensitivity for myocarditis (10,11). The lack of precision of the Dallas criteria arise from sampling error caused by patchy involvement of the myocardium (2) and high interobserver variability in interpretation. To diagnose myocarditis with an 80% sensitivity, an estimated 17 right ventricular biopsy specimens (11) are needed. Autopsy and magnetic resonance imaging studies have shown that myocarditis more frequently affects the left ventricular (LV) free
wall than the septum (12–14). Thus, the risks and low sensitivity of EMB limit its current diagnostic use in acute DCM to a research tool or to exclude giant cell myocarditis. More and more experts have called for abandoning the use of the Dallas criteria (15). In chronic DCM, EMB remains the only way to confirm the presence of the viral genome and guide treatment for persistent viral infection. Other pathological diagnostic criteria for myocarditis, including the expression of class I and II human lymphocyte antigen on cardiac myocytes (16), may identify a subset of patients with chronic myocarditis who have a response to azathioprine and prednisone (17). The usefulness of these novel diagnostic tests will also be limited by sampling error and the risks of the EMB.

**ECHOCARDIOGRAPHY**

The most common echocardiographic features of acute myocarditis are quite nonspecific (18). Pinamonti et al. (18) reported echocardiographic patterns of dilated, hypertrophic, restrictive, and ischemic cardiomyopathy in 41 patients with histologically proven myocarditis. Segmental wall motion abnormalities (hypokinesia, akinesia, and dyskinesia) that can simulate acute myocardial infarction (AMI) are quite common (18,19). The LV is typically normal-sized or mildly dilated in patients with acute heart failure. Advances in the detection of subtle diastolic dysfunction, regional strain rates, and tissue characterization have increased the diagnostic role of echocardiography. In early stages, focal inflammation leads to local cell necrosis and tissue edema, often before global LV dilatation or dysfunction are evident. Increased sphericity and LV volume occur in acute, active myocarditis (20). Echocardiography is useful for detecting LV thrombus, transient LV aneurysm, right ventricular involvement, and pericardial effusion (18,19).

Transient increases in LV wall thickness have been reported (21). Hiramitsu et al. (21) investigated 25 patients with histologically proven myocarditis. The interventricular septum and LV wall thickness decreased from 14.3 ± 3.7 mm and 13.3 ± 2.4 mm in the acute phase to 9.7 ± 1.7 mm (p < 0.001) and 10.2 ± 1.7 mm (p < 0.0001) in the convalescent phase. In the acute phase, an increase in wall thickness as a measure of edema was present in 88.0% of cases compared with only 28% in the convalescent phase (p < 0.0001). In some cases, myocarditis can simulate symmetrical (21,22) or asymmetrical (23,24) hypertrophic cardiomyopathy. A relatively thicker posterior wall (ratio of end-diastolic posterior wall thickness to cavity dimensions >0.17 mm) has been associated with better prognosis and recovery in children presenting with dilated cardiomyopathy and myocarditis (25).

The acoustic properties of the myocardium can be defined using ultrasonic backscatter and infer the physical state of cardiac muscle. The myocardial density and elasticity are influenced by the extent of edema and cell infiltration. The cyclic variation of integrated backscatter can assess myocardial viability (26), cardiomyopathies (27), and cardiac allograft rejection (28). Lieback et al. (29) described texture analysis in 106 patients suspected of having myocarditis. The mean gray value (average brightness) was significantly higher in cases of histologic myocarditis compared with control subjects. The diagnostic accuracy, however, was not reported, and ultrasonic tissue characterization could not differentiate between idiopathic DCM and acute myocarditis. Nonetheless, several case reports suggest that an increase in brightness, heterogeneity, and contrast may be useful to confirm acute myocarditis (30,31).

Fulminant myocarditis (FM) has a more rapid onset of illness with severe hemodynamic compromise, but remarkably good long-term survival (1). Felker et al. (32) showed that FM can be distinguished from acute myocarditis by echocardiographic criteria. Patients with FM had near-normal LV diastolic dimensions (5.3 ± 0.9 cm) with increased septal thickness (1.2 ± 0.2 cm) at presentation, whereas those with acute myocarditis had increased diastolic dimensions but normal septal thickness. After 6 months, patients with FM had significant improvement in fractional shortening (30 ± 8%) compared with patients with acute myocarditis (19 ± 7%, p < 0.01).

Right ventricular function is an independent predictor of death or cardiac transplantation in acute myocarditis. Mendes et al. (33) assessed right ventricular systolic function (RVSF) by descent of the right ventricular base (34). Initial LV ejection fraction was significantly lower in myocarditis patients with depressed right ventricular function (27.5 ± 4.9% vs. 47.5 ± 6.3% for normal RVSF, p = 0.01). The likelihood of death or need for cardiac transplantation was also significantly greater in patients with abnormal RVSF (RV descent ≤1.7 cm) than in patients with normal RVSF (p < 0.03). Sixty percent of patients with abnormal RVSF died or required transplantation, compared with none of the patients with normal RVSF at 24 months. Multivariate analysis showed that right ventricular dysfunction as quantitated by right ventricular descent was the most powerful predictor of outcome.

Naqvi et al. (35) showed that contractile reserve as assessed by dobutamine echocardiography has prognostic
value in 22 patients with new-onset DCM. Baseline variables that were significantly predictive of follow-up LV ejection fraction were deceleration time (r = 0.69, p = 0.0006), wall motion score index (r = -0.63, p = 0.002), LV mass (r = 0.56, p = 0.008), and LV ejection fraction after dobutamine (r = 0.84, p = 0.0001). These data suggest that dobutamine echocardiography may be useful in the assessment of patients with recently diagnosed DCM, some of which may be caused by myocarditis.

Tissue Doppler (TD) has also been used to assess acute myocarditis. Urhausen et al. (36) reported a case of biopsy-proven myocarditis in which no abnormalities were shown using 2-dimensional echocardiography and color and pulsed-wave Doppler. However, a net loss of systolic regional wall velocity was evident by cardiac TD. In the same year, Adsett et al. (22) reported a case of biopsy-proven eosinophilic myocarditis. The TD parameters were measured and showed systolic and diastolic abnormalities. Color M-mode TD of the LV posterior wall showed a reduction of both mean myocardial velocities and myocardial velocity gradient in systole and diastole TD. The role of TD in acute myocarditis remains an area of active investigation.

GALLIUM-67 IMAGING

Gallium-67 is considered an excellent imaging agent for chronic inflammation and has been used for diagnosing several autoimmune chronic inflammatory conditions. Clinical and experimental studies have indicated the usefulness of gallium-67 citrate scintigraphy in detecting myocarditis (37). O’Connell et al. (38) compared gallium-67 with EMB in 68 DCM patients. Only 8% of the study population had histologic evidence of myocarditis; 87% of these patients were positive by gallium-67 scanning. Only a 1.8% incidence of myocarditis was detected histologically in the gallium-67 negative cohort. Subsequently, Matsura et al. (39) showed the usefulness of gallium-67 imaging, especially in identifying myocarditis in 46 consecutive children in the acute phase of Kawasaki disease. The use of gallium imaging has diminished over time mainly because of a lack of specificity.

INDIUM-111 ANTIMYOSIN ANTIBODY

Khaw et al. (40) developed a noninvasive imaging test to detect myocyte necrosis by using a monoclonal antibody directed against human cardiac myosin. Indium-111 radio-labeled antimyosin (AM) antibodies have been shown to detect myocardial necrosis in animal models (41) and human myocarditis (42). Yasuda et al. (43) first reported the use of indium-111 AM imaging in 28 patients clinically suspected of having myocarditis (Fig. 1). Antimyosin scans were positive in 61% of the study group, 9 of whom had evidence of myocarditis on EMB, and negative in 100% of patients without evidence of myocarditis by biopsy. Thus, the sensitivity of AM imaging was 100% and its specificity was 58%.

Carrio et al. (44) refined the technique by using the heart-to-lung (H/L) ratio, a semiquantitative approach for evaluating AM uptake in detecting myocyte damage. A significant difference in H/L ratio between normal subjects (1.46 ± 0.04) and myocarditis patients (2.0 ± 0.5) (p < 0.001) was shown. Narula et al. (45) confirmed the utility of the H/L ratio in the diagnosis of myocarditis.

Dec et al. (46) examined the sensitivity, specificity, and predictive value of indium-111 AM cardiac imaging in 82 patients presenting with clinically suspected myocarditis. Using planar and single-photon emission computed tomography cardiac imaging, the sensitivity of AM imaging was 83%, its specificity was 53%, and the negative predictive value was 92%. Narula et al. (45) also compared scintigraphic results with histological evaluation and found a high sensitivity for the detection of myocarditis (91% to 100%) and a high negative predictive value (93% to 100%). The specificity (31% to 44%) and positive predictive value (28% to 33%) were again found to be low. A positive AM scan predicted a significantly greater likelihood than myocardial biopsy of a subsequent improvement in ejection fraction in acute DCM patients.

Indium-111 AM imaging has also been used to diagnose and follow up the natural history of myocardial damage in adult patients with idiopathic, alcoholic, and inflammatory cardiomyopathies (47), and in children with cardiomyopathy (48). In a study of 10 patients with acute myocarditis, H/L ratios normalized (from 2.2 to <1.6) within 6 months in all patients (49). The intensity of AM uptake was the major determinant of survival in children, with a relative risk of 18 (95% confidence interval 1.54 to 242; p = 0.027) (48). One common finding across many studies is that a substantial percentage of patients with DCM are positive for AM scintigraphy although their EMB did not show histological evidence of myocarditis (50).

Thus, indium-111 AM antibody imaging seems to be a useful noninvasive screening method for diagnosing myocarditis with a high sensitivity (91% to 100%) and a high negative predictive value (93% to 100%) (45). It can be used to identify localized as well as diffuse myocardial damage. Limitations to this technique include its current limited availability in the U.S., radiation exposure, and 48-hour delays in obtaining imaging after injection to prevent blood pool effect.

CARDIAC MAGNETIC RESONANCE (CMR) IMAGING

Gagliardi et al. (51) published the first case series on the use of CMR for the noninvasive diagnosis of acute myocarditis in 11 infants and children. Compared with EMB (Dallas criteria), T2-weighted spin echo CMR sequences were found to have a 100% specificity and 100% sensitivity. This small study was followed by a second report by Gagliardi et al. (52) on 75 consecutive pediatric patients with acute symptomatic heart failure; EMB identified 51 patients with acute myocarditis and 24 with idiopathic DCM. Using
EMB as the diagnostic standard, T2-weighted CMR sequences achieved a sensitivity of 100% and a specificity of 90%. The same group reported preliminary data on the 53 children affected by myocarditis who had serial EMB and CMR studies every 6 months for a 2-year follow-up period. The sensitivity and specificity of CMR remained high during the subsequent evolution of the disease (52).

The use of ECG-triggered gadolinium-enhanced T1-weighted images to serially image the natural history of acute myocarditis was reported by Friedrich et al. (13). A total of 44 consecutive patients with suspected acute myocarditis based on clinical and laboratory features underwent serial contrast media–enhanced CMR to document the distribution of contrast uptake over a 3-month period. Acute myocarditis was associated with focal contrast enhancement on day 2 (Fig. 2), which evolved by day 7 into diffuse myocardial involvement that persisted until 2 to 4 weeks (Fig. 3). By day 84, the average myocardial contrast signal had returned to that of the controls.

Roditi et al. (53) assessed a combination of techniques, cine magnetic resonance angiography and T1 spin echo before and after gadolinium enhancement, in 12 patients with suspected acute myocarditis and 8 with chronic cardiomyopathy. Ten of 12 patients in the myocarditis group showed focal myocardial enhancement with associated regional wall motion abnormalities (hypokinesis, akinesis, or dyskinesis). The control group showed minimal focal enhancement. This study suggested that a combination of CMR findings may provide greater diagnostic accuracy for the diagnosis of acute myocarditis than regional wall motion or focal myocardial enhancement alone.

Laissy et al. (54) prospectively compared the value of different CMR modalities for the evaluation of cardiac and skeletal muscle enhancement in patients with acute myocarditis. A comprehensive imaging approach was used including axial T2-weighted sequences, precontrast and postcontrast ECG-gated T1-weighted sequences, cine-CMR, and serial dynamic turbo fast low-angle shot acquisitions. Twenty patients with myocarditis and 7 age- and gender-matched control subjects were studied. Subtraction gadolinium-enhanced T1-weighted CMR accurately identified myocardial involvement with 100% sensitivity and 100% specificity. Furthermore, a >45% myocardial enhancement score strongly supported the diagnosis of myocarditis. Turbo fast low-angle shot imaging displayed greater myocardial enhancement (p < 0.0001) and showed unexpected enhancement of skeletal muscle in the early and late stages of myocarditis (p < 0.0001).

Two studies suggest that CMR may differentiate ischemic from nonischemic cardiomyopathy (55,56). McCrohon et al. (55) performed gadolinium late enhancement (LE) CMR in 90 patients with heart failure and LV systolic dysfunction.
All patients (100%) with ischemic cardiomyopathy (n = 27) had either subendocardial or transmural enhancement. In contrast, the DCM group (n = 63) had 3 distinct myocardial patterns: no enhancement (59%), patchy or longitudinal striae of midwall enhancement consistent with fibrosis (28%), and myocardial enhancement indistinguishable from the patients with CAD (13%). These data suggest that gadolinium CMR accurately can exclude the presence of LV dysfunction related to CAD in most heart failure patients. Hunold et al. (56) subsequently identified different patterns of myocardial LE. In 402 patients with documented myocardial infarction, the subendocardial layer showed LE. In the nonischemic group (n = 19), the subendocardial layer was not involved in patients with myocarditis, DCM, or hypertrophic cardiomyopathy; LE in this group was localized to the epicardial or midmyocardial wall. Thus, the pattern and localization of LE in contrast-enhanced CMR can often help in distinguishing primary myocardial from ischemic disease.

In 2004, Mahrholdt et al. (57) used an inversion-recovery prepared gradient echo sequence, which is widely used for CMR of myocardial infarcts. Of 32 patients with suspected myocarditis, 88% showed patchy, epicardial, and lateral wall contrast enhancement (Fig. 4). The CMR-guided EMB from the regions of contrast enhancement showed active myocarditis in 19 of 21 patients. Active myocarditis was found in 1 of 11 patients in whom EMB was performed in regions without contrast enhancement. At 3 months, the area of LV contrast enhancement decreased from 9 ± 11% to 3 ± 4%. This decrease was associated with an improvement in the LV ejection fraction from 47 ± 19% to 60 ± 10%. This study confirmed the observation that acute myocarditis occurs frequently in the lateral epicardial region of the LV and indicated that CMR may help guide EMB sampling and increase the diagnostic yield of biopsy for detecting myocarditis.

In 2005, Abdel-Aty et al. (58) reported 25 patients with strong clinical evidence for acute myocarditis and compared...
different approaches using T2-weighted (noncontrast) and T1-weighted, contrast-enhanced techniques. Global T2 signal intensity and global early contrast enhancement were higher in patients than in control subjects (p < 0.001). The calculated sensitivity, specificity, and diagnostic accuracy for T2 at a cutoff value of 1.9 were 84%, 74%, and 79%, respectively. Interestingly, late gadolinium enhancement (LGE) had an excellent specificity (100%) but a low sensitivity (44%), resulting in an overall diagnostic accuracy of 71%. This may be because LGE may mainly reflect irreversible injury. Accordingly, the combined use of different CMR sequences may show a higher diagnostic accuracy than single-technique protocols. Indeed, the investigators found that the best diagnostic performance was obtained if any 2 of the 3 criteria (threshold ratio for early enhancement signal intensity, ratio in T2 images, and presence of LGE) were used for making a diagnosis.

Recently, Laissy et al. (59) used early- and delayed-perfusion CMR to differentiate acute myocarditis from AMI. Fifty-five patients with a clinical presentation suggestive but not typical of AMI were prospectively examined. Overall, 31 patients had AMI confirmed by coronary angiography. The 24 myocarditis patients had normal coronary angiography and resolution of clinical symptoms and wall motion abnormalities. A total of 96% of the myocarditis patients showed normal studies, whereas 100% of patients with AMI had segmental distribution of subendocardial defects (p < 0.001) by first-pass perfusion imaging. Distributions were also significantly different (p < 0.001) on delayed enhancement. In AMI patients, delayed enhancement showed a smaller number of segmental vascular distributions, whereas myocarditis patients usually had diffuse or nodular (83%) patchy distribution in a nonsegmental vascular distribution.

Wagner et al. (60) have provided the only study with long-term (30 ± 4 months) follow-up on the prognostic value of CMR. This study confirmed a decrease in myocardial enhancement over time in 16 acute myocarditis pa-

![Figure 3.](image1) Inversion-recovery prepared T1-weighted gradient echo images with typical late enhancement patterns in a patient with chronic myocarditis. (Left) Short-axis view with “midwall sign” (arrows), which likely represents fibrosis of the longitudinal myocardial fibers in the septum. (Right) Four-chamber view with patchy late enhancement areas with predominant subepicardial, mainly lateral distribution (arrows).

![Figure 4.](image2) Patient with edematous myocarditis, but lack of irreversible injury. (Left) T2-weighted image showing diffuse edema, mainly of the inferolateral segment. (Right) Late enhancement image with lack of high signal intensity areas. LAX = long axis; SAX = short axis.
patients. In the same study, the investigators reported that a persisting elevated early enhancement obtained 4 weeks after the onset of disease predicted reduced LV function and increased LV size and symptoms after a follow-up of 3 years.

In summary, CMR is likely to become the standard diagnostic test in suspected myocarditis and is widely regarded as the most powerful noninvasive tool for diagnosing myocarditis (61,62). Currently, there are no large-scale randomized data on a successful specific therapy for viral myocarditis. Several therapeutic approaches, however, are being studied, and substances will be available targeted toward viruses or immunologic substrates. If these become available, CMR may be a very efficient tool for selecting patients for endomyocardial biopsies and subsequent specific therapy.

**NOVEL DIAGNOSTIC AND PROGNOSTIC MODALITIES**

Most experimental data on myocarditis imaging have been generated from rodent models of transplant rejection. Insights from these studies are likely relevant to the study of myocarditis because the underlying pathology is similar and many of the mechanisms of inflammation are common to both disease processes. For example, intracellular adhesion molecule (ICAM)-1 and to a lesser extent vascular adhesion molecule–1 are expressed in acute myocarditis (63), and costimulatory molecules B7-1, B7-2, and CD-40 are expressed on cardiac myocytes in acute myocarditis and DCM (64). Weller et al. (65) detected acute transplant rejection in a rat model using myocardial contrast echocardiography (MCE) and ICAM-1-targeted microbubbles. Kondo et al. (66) also assessed the degree of rejection in a rodent model using myocardial contrast echocardiography (MCE) and ICAM-1-targeted microbubbles. Kondo et al. (66) also assessed the degree of rejection in a rodent model of transplantation using leukocyte-targeted MCE. Riou et al. (67) used leukocytes labeled with 99mTc-RP517 (a leukotriene B4 receptor antagonist) in a canine model of myocardial inflammation. Myocardial tracer uptake correlated well with tissue myeloperoxidase staining by histology.

Similar antigens may serve as cellular targets for molecular imaging in future studies of human myocarditis.

Similarly, a promising CMR method has used dextrancoated ultrasmall superparamagnetic iron oxide (USPIO) particles (68) to detect rodent transplant allograft rejection. The USPIO particles are taken up mainly by macrophages and shorten relaxation times. In this study, macrophages labeled with USPIO particles induced a significant decrease in allograft MR signal intensity that correlated with the pathological rejection grade.

Apoptosis (programmed cell death) is commonly observed in myocarditis and transplant rejection (69). With the onset of apoptosis, changes in the cell membrane phospholipid composition are marked by the sudden expression of phosphatidylserine, a phospholipid that ordinarily appears on the inner leaflet of the cell membrane, on the external leaflet of the membrane. Radiolabeled annexin-V, a protein with high affinity for phosphatidylserine, has been used to detect cells undergoing apoptosis in vivo. Tokita et al. (70) and Peker et al. (71) showed in rat models of myocarditis that 99mTc-annexin V uptake correlated closely with sites of apoptosis. Narula et al. (72) and Kown et al. (73) have also shown similar findings in cardiac transplantation patients during rejection episodes.

**CONCLUSIONS**

Accurate differentiation of acute inflammatory diseases of the myocardium (e.g., myocarditis, sarcoidosis) from idiopathic or genetic forms of DCM is clinically important because their long-term outcomes differ. Myocarditis is histologically characterized by varying degrees of myocardial necrosis, edema, apoptosis, and cellular infiltration. Noninvasive imaging techniques may hold the answer for selecting patients who may benefit from biopsy and for better defining the natural history of the disease via serial studies. Sensitivity and specificity play a crucial role in deciding on

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**Table 1.** Comparison of the Sensitivity, Specificity, and Predictive Values of Laboratory and Imaging Techniques Used in Myocarditis

<table>
<thead>
<tr>
<th>Technique</th>
<th>n</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive Predictive Value</th>
<th>Negative Predictive Value</th>
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AMA = indium-antimyosin antibody scintigraphy; CMR = cardiac magnetic resonance imaging; EMB-H = endomyocardial biopsy-histological study; EMB-IH = immunohistochemical study; GE T1 = gadolinium-enhanced T1-weighted; gRE = global (early) relative enhancement; IRGRE = inversion recovery gradient echo pulse sequence; LGE = late gadolinium enhancement.
diagnostic techniques. A combination of several techniques may be beneficial, especially in borderline cases (Table 1). Antimyosin antibody imaging is useful (when available) for detecting myocardial necrosis, an obligate component of myocarditis. Tissue Doppler echocardiographic imaging is exquisitely sensitive to myocardial contractile function and seems helpful in detecting alterations associated with myocardial inflammation and edema. CMR imaging is currently the most accurate diagnostic method for both guiding biopsy and following up disease activity over time. Annexin V imaging seems promising for detecting myocardial apoptosis and awaits future clinical trials. The ability to more precisely and noninvasively assess myocardial inflammation, necrosis, and apoptosis should spur the evaluation of new therapeutic strategies for the treatment of myocarditis and inflammatory cardiomyopathies.

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