Current state of knowledge on aetiology, diagnosis, management, and therapy of myocarditis: a position statement of the European Society of Cardiology Working Group on Myocardial and Pericardial Diseases

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In this position statement of the ESC Working Group on Myocardial and Pericardial Diseases an expert consensus group reviews the current knowledge on clinical presentation, diagnosis and treatment of myocarditis, and proposes new diagnostic criteria for clinically suspected myocarditis and its distinct biopsy-proven pathogenetic forms. The aims are to bridge the gap between clinical and tissue-based diagnosis, to improve management and provide a common reference point for future registries and multicentre randomised controlled trials of aetiology-driven treatment in inflammatory heart muscle disease.

**Keywords**
- Myocarditis
- Cardiomyopathy
- Diagnosis
- Therapy

**Introduction**

Myocarditis is a challenging diagnosis due to the heterogeneity of clinical presentations.1-3 The actual incidence of myocarditis is also difficult to determine as endomyocardial biopsy (EMB), the diagnostic gold standard,1-3 is used infrequently.2,3 Studies addressing the issue of sudden cardiac death in young people report a highly variable autopsy prevalence of myocarditis, ranging from 2 to 42% of cases.4,5 Similarly, biopsy-proven myocarditis is reported in 9–16% of adult patients with unexplained non-ischaeimic dilated cardiomyopathy (DCM)6,7 and in 46% of children with an identified cause of DCM.8 In patients presenting with mild symptoms and minimal ventricular dysfunction, myocarditis often resolves spontaneously without specific treatment.9 However, in up to 30% of cases, biopsy-proven myocarditis can progress to...
Viral myocarditis

Histological evidence for myocarditis associated with positive viral polymerase chain reaction (PCR) (Table 1).

Autoimmune myocarditis

Histological myocarditis with negative viral PCR, with or without serum cardiac autoantibodies (aabs) (Table 2).

Viral and immune myocarditis

Histological myocarditis with positive viral PCR and positive cardiac aabs (Table 2).

Aetiology of myocarditis

Although the aetiology of myocarditis often remains undetermined, a large variety of infectious agents, systemic diseases, drugs, and toxins can cause the disease (Table 1). \(^1\)–\(^3\),\(^16\)–\(^21\) Some causes of myocarditis are now largely historical or occur in very specific scenarios such as sepsis or in immunocompromised patients. Molecular techniques, mainly (reverse transcriptase)(RT)-PCR amplification,\(^7\),\(^18\),\(^19\),\(^22\),\(^24\)–\(^24\) suggest that viral infections are the most important cause of myocarditis in North America and Europe with genomes of enterovirus, adenovirus, influenza viruses, human herpes virus-6 (HHV-6), Epstein-Barr-virus, cytomegalovirus, hepatitis C virus, and parvovirus B19 reported in the myocardium of patients with myocarditis and DCM. Lymphocytic and giant cell myocarditis are presumed idiopathic or autoimmune if no viruses are identified in EMB and other known causes are excluded (Figure 1).\(^7\) Similarly, the diagnosis of idiopathic granulomatous myocarditis (cardiac sarcoidosis) requires negative stains for microorganisms.\(^2\) Autoimmune myocarditis may occur with exclusive cardiac involvement or in the context of autoimmune disorders with extra-cardiac manifestations,\(^9\),\(^11\),\(^17\) most frequently in sarcoidosis (Figure 1), hypereosinophilic syndrome, scleroderma, and systemic lupus erythematosus.

Pathogenesis

In human myocarditis, there is evidence for viral and autoimmune mechanisms, acting in individuals with or without a genetic predisposition (familial or sporadic cases, respectively).\(^14\),\(^15\),\(^18\),\(^35\)–\(^103\) Murine studies of viral myocarditis\(^2\),\(^3\),\(^104\)–\(^107\) are based mostly on Coxsackie-virus B3-infected animals, which exhibit strain-specific susceptibility. Enteroviruses that preferentially enter cardiomyocytes via specific receptors cause severe cytopathic effects due to virus replication in the first 2 weeks post-infection. As a consequence, a humoral and cellular immune response, mainly consisting of macrophages and CD4+ and CD8+ T-lymphocytes, is initiated in resistant
animals (C57BL/6 mice, Sv129 mice) and leads to the elimination of the infectious agent within 2 weeks following infection. In susceptible mouse strains (e.g. A/J, ABY/SnJ, ASW/SnJ, ACA/SnJ, SWR/J, Balb/c), viral RNA and inflammation persist in the heart for several weeks. 104 – 105 There is evidence that in these susceptible mice mouse strains (e.g. A/J, ABY/SnJ, ASW/SnJ, ACA/SnJ, SWR/J, Balb/c), viral RNA and inflammation persist in the heart for several weeks. 104 – 105 There is evidence that in these susceptible mice

### Table 1 Causes of myocarditis/inflammatory cardiomyopathy

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infectious</td>
<td>Staphylococcus, Streptococcus, Pneumococcus, Meningococcus, Gonococcus, Salmonella, Corynebacterium diphtheriae, Haemophilus influenzae, Mycobacterium (tuberculosis), Mycoplasma pneumoniae, Brucella</td>
</tr>
<tr>
<td>Spirochaetal</td>
<td>Borrelia (Lyme disease), Leptospira (Weil disease)</td>
</tr>
<tr>
<td>Fungal</td>
<td>Aspergillus, Actinomyces, Blastomyces, Candida, Coccidiodes, Cryptococcus, Histoplasma, Mucormycoses, Nocardia, Spirorixth</td>
</tr>
<tr>
<td>Protozoal</td>
<td>Trypanosoma cruzi, Toxoplasma gondii, Entamoeba, Leishmania</td>
</tr>
<tr>
<td>Parasitic</td>
<td>Trichinella spiralis, Echinococcus granulosus, Taenia solium</td>
</tr>
<tr>
<td>Ricettsial</td>
<td>Coxieilla burnetii (Q fever), R. rickettsi (Rocky Mountain spotted fever), R. tsutsugamushi</td>
</tr>
<tr>
<td>Viral</td>
<td>RNA viruses: Coxsackieviruses A and B, echoviruses, influenza A and B viruses, respiratory syncytial virus, mumps virus, measles virus, rubella virus, hepatitis C virus, dengue virus, yellow fever virus, Chikungunya virus, Junin virus, Lassa fever virus, rabies virus, human immunodeficiency virus-1 DNA viruses: adenoviruses, parvovirus B19, cytomegalovirus, human herpes virus-6, Epstein-Barr virus, varicella-zoster virus, herpes simplex virus, variola virus, vaccinia virus</td>
</tr>
</tbody>
</table>

### Table 2 Immune-mediated myocarditis

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allergens</td>
<td>Tetanus toxoid, vaccines, serum sickness</td>
</tr>
<tr>
<td></td>
<td>Drugs: penicillin, cefacof, colchicine, furosemide, isoniazid, lidocaine, tetracycline, sulfonamides, penhoitoin, phenylbutazone, methyldopa, thiazie diuretics, amitriptyline</td>
</tr>
<tr>
<td>Alloantigens</td>
<td>Heart transplant rejection</td>
</tr>
<tr>
<td>Autoantigens</td>
<td>Infection-negative lymphocytic, infection-negative giant cell</td>
</tr>
<tr>
<td></td>
<td>Associated with autoimmune or immune-oriented disorders: systemic lupus erythematosus, rheumatoid arthritis, Churg-Strauss syndrome, Kawasaki’s disease, inflammatory bowel disease, scleroderma, polymyositis, myasthenia gravis, insulin-dependent diabetes mellitus, thyrotoxicosis, sarcoidosis, Wegner’s granulomatosis, rheumatic heart disease (rheumatic fever)</td>
</tr>
</tbody>
</table>

### Table 3 Toxic myocarditis

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drugs</td>
<td>Amphetamines, anthraclyines, cocaine, cyclophosphamide, ethanol, fluorouracil, lithium, catecholamines, hemetine, interleukin-2, trastuzumab, clozopine</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Copper, iron, lead (rare, more commonly cause intramyocyte accumulation)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Scorpion sting, snake, and spider bites, bee and wasp stings, carbon monoxide, inhalants, phosphorus, arsenic, sodium azide</td>
</tr>
<tr>
<td>Hormones</td>
<td>Phaeochromocytoma, vitamins: beri--beri</td>
</tr>
<tr>
<td>Physical agents</td>
<td>Radiation, electric shock</td>
</tr>
</tbody>
</table>

### Clinical presentation

Myocarditis presents in many different ways, ranging from mild symptoms of chest pain and palpitations associated with transient ECG changes to life-threatening cardiogenic shock and ventricular arrhythmia (Table 3). The disease may affect individuals of all ages, although it is most frequent in the young. This diversity of clinical scenarios implies that the diagnosis of myocarditis requires a high level of suspicion early in the course of the disease and the use of appropriate investigations to identify its cause. In all cases of suspected myocarditis, it is mandatory to exclude coronary artery disease and other cardiovascular, e.g. hypertension, or extra-cardiac non-inflammatory diseases that could explain the clinical presentation. Rarely patients with other cardiovascular disorders such as coronary artery disease, cardiomyopathy, and hypertensive heart disease present with a clinical deterioration caused by myocarditis that is mistakenly attributed to the natural history of the preexisting disease. If this is strongly suspected by the clinician, further investigation including EMB may be appropriate. Myocarditis can be an incidental finding in autopsy studies of individuals who died of non-cardiac death or in myocardial samples obtained for clinical reasons unrelated to the clinical suspicion of myocarditis, for example following valve surgery or in explanted hearts taken from patients that have received inotropic drugs. In these circumstances, the significance of myocardial inflammation must be interpreted cautiously in the light of the clinical scenario.
Diagnosis of myocarditis

Non-invasive imaging techniques such as cardiac magnetic resonance (CMR) imaging can be useful in making the diagnosis of myocarditis and for monitoring disease progression, but we strongly endorse the concept that EMB should be the gold standard for the diagnosis of definite myocarditis.\(^{1-3}\) However, this implies that all patients with suspected myocarditis should undergo an EMB which is not routine practice; moreover, current guidelines recommend EMB only in a limited number of clinical scenarios that do not include some common

<table>
<thead>
<tr>
<th>Cardiac autoantibody (Ab)</th>
<th>% aabs positive</th>
<th>%antibody positive</th>
<th>Functional effect/clinical relevance</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle-specific ASA,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(AF, AFA, AMLA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myoc</td>
<td>28–59(^{a})</td>
<td>9–41(^{a})</td>
<td>NT 0–25</td>
<td>Myocytolysis 72,77,57,64</td>
</tr>
<tr>
<td>DCM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac-specific</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AHA</td>
<td>41–56(^{a,a})</td>
<td>26–30(^{a,a})</td>
<td>1–4 3</td>
<td>Cardiac- and disease-specific early predictors; predict DCM development in relatives 9(^{a},50),35(^{a},36),118(^{a},52)</td>
</tr>
<tr>
<td>Anti-Beta1-AR</td>
<td>33</td>
<td>40–51(^{a})</td>
<td>13–55 0–13</td>
<td>Negative predictors, pro-apoptotic and other in vitro effects(^{a}) 48,55,61–63,66(^{a},72,74–76), 78,84,109,88,90,92,93,98</td>
</tr>
<tr>
<td>Anti-Beta2-AR</td>
<td>NT</td>
<td>30–38(^{a})</td>
<td>33 15</td>
<td>Association with idiopathic arrhythmia 53(^{a},62,69)</td>
</tr>
<tr>
<td>Anti-muscarinic acetylcholine</td>
<td>NT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>receptor-2</td>
<td>NT</td>
<td>30–75(^{a})</td>
<td>37 18</td>
<td>Negative inotropic effects in rat and human myocytes in vitro 56,66(^{a},85–87,91)</td>
</tr>
<tr>
<td>Cardiopressant</td>
<td>NT</td>
<td>64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fy-gamma-receptor 2a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anti-Ky channel-interacting</td>
<td>NT</td>
<td>14(^{a})</td>
<td>8 4</td>
<td>Increased cell death in myocytes in vitro 68,95,96</td>
</tr>
<tr>
<td>protein 2, KChP2.6—ELISA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anti-Alpha-MHC (cardiac-specific)</td>
<td>17–37(^{a,a})</td>
<td>20–46(^{a,a})</td>
<td>4–16 0–2.5</td>
<td>Negative predictors, pro-apoptotic 109,51(^{a},60), 118(^{a},140)</td>
</tr>
<tr>
<td>Anti-MHC (cardiac-specific)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anti-Tropomyosin</td>
<td>NT</td>
<td>17–35</td>
<td>25 0–15</td>
<td>51(^{a})</td>
</tr>
<tr>
<td>Anti-non-myofibrillar</td>
<td>NT</td>
<td>55(^{a})</td>
<td>21 NT</td>
<td>67</td>
</tr>
<tr>
<td>Anti-MHC</td>
<td>NT</td>
<td>46(^{a,a})</td>
<td>17 0</td>
<td>51(^{a})</td>
</tr>
<tr>
<td>Anti-actin</td>
<td>NT</td>
<td>67(^{a})</td>
<td>42 NT</td>
<td>67</td>
</tr>
<tr>
<td>Anti-Troponin I,T</td>
<td>NT</td>
<td>71(^{a})</td>
<td>21 NT</td>
<td>67</td>
</tr>
<tr>
<td>Anti-laminin</td>
<td>NT</td>
<td>1.7–20(^{a})</td>
<td>0–18 0–4</td>
<td>Negative predictors 66,68,80</td>
</tr>
<tr>
<td>Anti-HSP60,70</td>
<td>NT</td>
<td>73</td>
<td>25–35 6</td>
<td>97</td>
</tr>
<tr>
<td>Anti-s.Na/K-ATPase</td>
<td>NT</td>
<td>91(^{a,a})</td>
<td>57(^{a,a}) 0 0</td>
<td>Inotropic 81–83(^{a})</td>
</tr>
<tr>
<td>Anti-ANT</td>
<td>NT</td>
<td>13(^{a})</td>
<td>31(^{a}) 10 0</td>
<td>65</td>
</tr>
<tr>
<td>Anti-BCKD-E2</td>
<td>NT</td>
<td>100(^{a})</td>
<td>60(^{a}) 4 0</td>
<td>46</td>
</tr>
</tbody>
</table>

| Table 2 Serum cardiac autoantibodies in autoimmune myocarditis/dilated cardiomyopathy: frequency in myocarditis/dilated cardiomyopathy, other cardiac disease (OCD) and normals |

\(^{a}\)Cardiac and disease-specific for myocarditis/DCM.

\(^{b}\)Increase L-type Ca\(^{2+}\) current; short-term positive inotropic effects; increase in cytoplasmic cAMP, and cAMP/FRET-activity.

\(^{a}\)77% (in Chagas-DCM).

\(^{a}\)In atrial fibrillation patients.

\(^{a}\)In selected ELISA-positive heart failure patients.
**Figure 1** Upper panel: histopathology and immunopathology of acute lymphocytic myocarditis (first row, ×100), chronic lymphocytic myocarditis (second row, ×200), sarcoidosis (third row, ×100), and giant cell myocarditis (fourth row, ×200). Left column = haematoxylin-eosin (HE); middle column = staining with anti-CD3 antibody (pan T lymphocyte marker); right column = staining with anti-CD68 antibody (macrophage marker). Lower panel: short-axis (upper line) and long-axis (lower line) CMR images of a young patient with acute myocarditis. In the first two columns, cine-SSFP images are shown in diastole and systole and suggest absence of any wall motion abnormality. In the next column, T2-weighted edema images demonstrate the presence of patchy focal edema in the subepicardium of the inferolateral wall (red arrows). In the last column, T1-weighted LGE images demonstrate presence of subepicardially distributed LGE (red arrows) which is typical for acute myocarditis.
presentations of myocarditis, in particular, pseudo-infarction. In order to improve recognition of myocarditis in clinical practice and to aid selection of patients that require further diagnostic evaluation and treatment, we propose new criteria for clinically suspected myocarditis for which biopsy analysis is recommended (Table 4). These criteria are based upon consensus of experts and require validation in future multicentre registries and randomized trials in patients who have undergone EMB. Medical centres that cannot safely perform EMB or do not have access to state-of-the-art CMR should refer patients with clinically suspected myocarditis to a tertiary referral unit experienced in EMB and CMR, particularly when patients present with haemodynamic instability or life-threatening arrhythmia.

**Firstline tests in patients with a clinical presentation consistent with myocarditis**

**Electrocardiogram (ECG)**

Electrocardiogram (ECG) is usually abnormal in myocarditis though ECG signs are neither specific nor sensitive (Table 4). Some ECG changes are more suggestive of myocarditis than others. For example, ST-T segment elevation in myocarditis is typically concave (rather than convex in myocardial ischaemia) and diffuse without reciprocal changes. A-V block in the presence of mild left ventricular dilatation can be due to various causes (including laminopathy), but it may also be suggestive of Lyme disease, cardiac sarcoidosis, or giant cell myocarditis. In recent studies, QRS prolongation was an independent negative predictor for survival (which could be also due solely to asynchrony in left bundle branch block), while Q-waves and repolarization abnormalities were unrelated to outcome or immunohistological features of inflammation on EMB.

**Recommendation**

1. Standard 12-lead electrocardiogram should be performed in all patients with clinically suspected myocarditis.

**Echocardiography**

Echocardiography helps to rule out non-inflammatory cardiac disease such as valve disease and to monitor changes in cardiac chamber size, wall thickness, ventricular function, and pericardial effusions. Global ventricular dysfunction, regional wall motion abnormalities, and diastolic dysfunction with preserved ejection fraction may occur in myocarditis. Histologically proven myocarditis may resemble dilated, hypertrophic, and restrictive cardiomyopathy and can mimic ischaemic heart disease. Fulminant myocarditis often presents with a non-dilated, thickened, and hypococontractile left ventricle as the intense inflammatory response results in interstitial oedema and loss of ventricular contractility. The role of newer imaging techniques such as tissue Doppler or strain-rate imaging in the diagnosis of myocarditis remains to be determined.

**Recommendations**

2. All patients with clinically suspected myocarditis should undergo a standard trans-thoracic echocardiogram at presentation.

3. Trans-thoracic echocardiogram should be repeated during hospitalization if there is any worsening of haemodynamics.
Nuclear imaging
Data on radionuclide evaluation, including antimyosin antibody imaging, are scarce but suggest that its sensitivity for detecting myocardial inflammation is variable and its specificity low.125-128 Due to their limited availability and risk from radiation exposure, nuclear techniques are not routinely recommended for the diagnosis of myocarditis, with the possible exception of sarcoidosis.

Thallium 201 and technetium 99m scintigraphy have been used to detect cardiac sarcoidosis but lack specificity. Gallium-67 scintigraphy and more recently positron emission tomography using 18 fluorodeoxyglucose are probably more sensitive and may be useful in the acute phase of sarcoidosis and to monitor disease progression.129-132 The detection of extracardiac disease can suggest a diagnosis of cardiac sarcoidosis.

Recommendations
4. Nuclear imaging is not routinely recommended in the diagnosis of myocarditis, with the possible exception of suspected cardiac sarcoidosis.

Cardiovascular magnetic resonance (CMR) imaging
Cardiovascular magnetic resonance imaging provides non-invasive tissue characterization of the myocardium and can support the diagnosis of myocarditis (Figure 1).133-139 The timing of CMR in suspected myocarditis will depend upon local availability and expertise, but it is reasonable to first perform CMR in clinically stable patients, prior to EMB. It should not be performed in life-threatening presentations where EMB is urgently indicated.130,139 Cardiovascular magnetic resonance imaging techniques have been evaluated in animal models of myocarditis as well as in patients.19,20,125,133-139 Based on pre-clinical and clinical studies, an ‘International Consensus Group on CMR Diagnosis of Myocarditis’ published detailed recommendations on the indication, implementation, and analysis of appropriate CMR techniques for non-invasive diagnosis of myocarditis (Lake Louise criteria).20 The combined use of three different CMR techniques is suggested (Table 5).134,136-139 One study has demonstrated good correlation between CMR and EMB in troponin-positive patients without coronary artery disease132; however, correlation is worse in patients with a longer history of symptoms and histologically confirmed
chronic myocarditis and in addition CMR cannot exclude viral forms of myocarditis.137

Table 4 Diagnostic criteria for clinically suspected myocarditis

<table>
<thead>
<tr>
<th>Clinical presentations*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute chest pain, pericarditic, or pseudo-ischaemic</td>
</tr>
<tr>
<td>New-onset (days up to 3 months) or worsening of: dyspnoea at rest or exercise, and/or fatigue, with or without left and/or right heart failure signs</td>
</tr>
<tr>
<td>Subacute/chronic (&gt; 3 months) or worsening of: dyspnoea at rest or exercise, and/or fatigue, with or without left and/or right heart failure signs</td>
</tr>
<tr>
<td>Palpitation, and/or unexplained arrhythmia symptoms and/or syncope, and/or aborted sudden cardiac death</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diagnostic criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. ECG/Holter/stress test features</td>
</tr>
<tr>
<td>Newly abnormal 12 lead ECG and/or Holter and/or stress testing, any of the following: I to III degree atrioventricular block, or bundle branch block, ST/T wave change (ST elevation or non-ST elevation, T wave inversion), sinus arrest, ventricular tachycardia or fibrillation and asystole, atrial fibrillation, reduced R wave height, intraventricular conduction delay (widened QRS complex), abnormal Q waves, low voltage, frequent premature beats, supraventricular tachycardia</td>
</tr>
<tr>
<td>II. Myocardioctylolysis markers</td>
</tr>
<tr>
<td>Elevated TnT/TnI</td>
</tr>
<tr>
<td>III. Functional and structural abnormalities on cardiac imaging (echo/angio/CMR)</td>
</tr>
<tr>
<td>New, otherwise unexplained LV and/or RV structure and function abnormality (including incidental finding in apparently asymptomatic subjects): regional wall motion or global systolic or diastolic function abnormality, with or without ventricular dilatation, with or without increased wall thickness, with or without pericardial effusion, with or without endocardial thrombi</td>
</tr>
<tr>
<td>IV. Tissue characterization by CMR</td>
</tr>
<tr>
<td>Oedema and/or LGE of classical myocarditic pattern (see text)</td>
</tr>
</tbody>
</table>

Clinically suspected myocarditis if ≥ 1 clinical presentation and ≥ 1 diagnostic criteria from different categories, in the absence of: (1) angiographically detectable coronary artery disease (coronary stenosis ≥ 50%); (2) known pre-existing cardiovascular disease or extra-cardiac causes that could explain the syndrome (e.g. valve disease, congenital heart disease, hyperthyroidism, etc.) (see text). Suspicion is higher with higher number of fulfilled criteria.

*If the patient is asymptomatic ≥ 2 diagnostic criteria should be met.

Viral antibodies
Positive viral serology does not imply myocardial infection but rather indicates the interaction of the peripheral immune system with an infectious agent. Polyclonal stimulation of antibodies (IgM and IgG) may furthermore lead to incorrect diagnosis. Thus, viral serology is of limited utility in the diagnosis of viral myocarditis147 because the prevalence of circulating IgG antibodies to cardiotropic viruses in the general population is high in the absence of viral heart disease.2,16,23,25,31,105 In addition, infection with non-cardiotropic enteroviruses may cause an antibody response which is indistinguishable from the response to cardiotropic viruses2,16,23,25,31,105 and, in a recent study, there was no correlation between virus serology and EMB findings.147 Circumstances in which serological testing may be helpful include suspected hepatitis C, rickettsial phase 1 and phase 2, Lyme disease in endemic areas, and human immunodeficiency in high-risk patients.

Table 5).9,35,36,46–98,109,118 Lack of viral genome on EMB with detectable serum aabs suggests immune-mediated DCM or myocarditis.9,15,16,100 Antibodies of IgG class, which are shown to be cardiac and disease-specific for myocarditis/DCM, can be used as autoimmune biomarkers for identifying at risk relatives and those patients in whom, in the absence of active infection of the myocardium, immunosuppression and/or immunomodulation may be beneficial9,15,16,33,35,100,118 Detection of cardiodepressant antibodies in DCM also predicts haemodynamic benefits from

Biomarkers
Inflammatory markers
Erythrocyte sedimentation rate and reactive C protein levels are often raised in myocarditis, but they do not confirm the diagnosis and are often increased in acute pericarditis.52

Troponin and BNP levels
While cardiac troponins are more sensitive of myocyte injury in patients with clinically suspected myocarditis than creatine kinase levels,140,141 they are non-specific and when normal do not exclude myocarditis.142 This also applies to cardiac hormones such as brain natriuretic peptides,143 circulating cytokines,144 markers related to extracellular matrix degradation,145 and new biomarkers such as pentraxin 3, galectin 3, and growth differentiation factor 15.146
in progress to overcome this difficulty.37 Collaborative work among European research antibody laboratories is validated against the results obtained in research laboratories; commercially available cardiac autoantibody tests have been shown to be inconsistent with the diagnosis (Table 3). These are based on a clinical presentation consistent with myocarditis or DCM 90,95 (Table 2). At present, no commercially available cardiac autoantibody tests have been validated against the results obtained in research laboratories; collaborative work among European research antibody laboratories is in progress to overcome this difficulty.37

### Table 5  Diagnostic cardiac magnetic resonance criteria for myocarditis

In the setting of clinically suspected myocarditis (Tables 3–4), CMR findings are consistent with myocardial inflammation, if at least two of the following criteria are present:

<table>
<thead>
<tr>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Regional or global myocardial signal intensity increase in T2-weighted oedema images6</td>
</tr>
<tr>
<td>(2) Increased global myocardial early gadolinium enhancement ratio between myocardium and skeletal muscle in gadolinium-enhanced T1-weighted images6</td>
</tr>
<tr>
<td>(3) There is at least one focal lesion with non-ischaemic regional distribution in inversion recovery-prepared gadolinium-enhanced T1-weighted images (late gadolinium enhancement)6</td>
</tr>
</tbody>
</table>

A CMR study is consistent with myocyte injury and/or scar caused by myocardial inflammation if Criterion 3 is present. A repeat CMR study between 1 and 2 weeks after the initial CMR study is recommended if:

- None of the criteria are present, but the onset of symptoms has been very recent and there is strong clinical evidence for myocardial inflammation
- One of the criteria is present

The presence of LV dysfunction or pericardial effusion provides additional, supportive evidence for myocarditis.

### Proposed criteria for clinically suspected myocarditis

In this position statement, we propose new criteria for the diagnosis of clinically suspected myocarditis. These are based on a clinical presentation consistent with the diagnosis (Table 3) and the presence of one or more abnormalities on non-invasive testing (Table 4).

### Recommendations

7. Troponins, erythrocyte sedimentation rate, reactive C protein levels should be assessed in all patients.
8. Routine viral serology testing is not recommended.
9. Serum samples should be assessed, if possible, for cardiac autoantibodies, if one (or more) of the published tests is available (Table 2), according to specific centre expertise. Disease-specific autoantibodies should preferably be tested.

### Ancillary features which support the clinical suspicion of myocarditis

- Fever ≥38.0°C at presentation or within the preceding 30 days with or without evidence of a respiratory (chills, headache, muscle aches, general malaise) or gastrointestinal (decreased appetite, nausea, vomiting, diarrhoea) infection;
- peri-partum period121;
- previous clinically suspected or definite myocarditis (according to the criteria set in Table 4);
- personal and/or family history of allergic asthma, other types of allergy, extra-cardiac autoimmune disease, toxic agents;
- family history of DCM, myocarditis (according to the present criteria).

### Second level investigations in clinically suspected myocarditis

In patients fulfilling the diagnostic criteria for clinically suspected myocarditis, we recommend selective coronary angiography and EMB (Figure 3). This recommendation also applies to patients with an acute coronary syndrome-like presentation (with or without ST segment elevation), increased cardiac troponins, preserved ventricular systolic function with or without features suggestive of myocarditis on CMR (Figure 1).20 At present, there are limited data on the prognostic implications of CMR findings in this context, and this common scenario was not included in a recently published AHA/ACC/HFSA scientific statement on EMB.120 Therefore, in the absence of robust prospective data (in suspected myocarditis with pseudo-infarct presentation and immunoabsorption,85 Some autoantibodies have been described to be negative predictors in myocarditis or DCM10,97 (Table 2). At present, no commercially available cardiac autoantibody tests have been validated against the results obtained in research laboratories; collaborative work among European research antibody laboratories is in progress to overcome this difficulty.37

### Table 2

<table>
<thead>
<tr>
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</tr>
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<tbody>
<tr>
<td>Global signal intensity (SI) increase has to be quantified by an SI ratio of myocardium over skeletal muscle of ≥2.0. If the edema is more subendocardial or transmural in combination with a colocalized ischemic (including the subendocardial layer) pattern of late gadolinium enhancement, acute myocardial infarction is more likely and should be reported.</td>
</tr>
<tr>
<td>A global SI enhancement ratio of myocardium over skeletal muscle of ≥4.0 or an absolute myocardial enhancement of ≥45% is consistent with myocarditis.</td>
</tr>
<tr>
<td>Images should be obtained at least 5 min after gadolinium injection; foci typically exclude the subendocardial layer, are often multifocal, and involve the subepicardium. If the late gadolinium enhancement pattern clearly indicates myocardial infarction and is colocalized with a transmural regional edema, acute myocardial infarction is more likely and should be reported.</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Clinical presentations of myocarditis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myocarditis should be suspected in the presence of:</td>
</tr>
<tr>
<td>1 or more of the clinical presentations in Table 4, with or without ancillary features (see below), and</td>
</tr>
<tr>
<td>1 or more of the diagnostic criteria from different categories (I to IV) in Table 4 or when the patient is asymptomatic, 2 or more diagnostic criteria from different categories (I to IV).</td>
</tr>
</tbody>
</table>

### Table 4

<table>
<thead>
<tr>
<th>Diagnostic criteria for myocarditis</th>
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- One of the criteria is present

The presence of LV dysfunction or pericardial effusion provides additional, supportive evidence for myocarditis.

Ancillary features which support the clinical suspicion of myocarditis include:

- Fever ≥38.0°C at presentation or within the preceding 30 days with or without evidence of a respiratory (chills, headache, muscle aches, general malaise) or gastrointestinal (decreased appetite, nausea, vomiting, diarrhoea) infection;
- peri-partum period121;
- personal and/or family history of allergic asthma, other types of allergy, extra-cardiac autoimmune disease, toxic agents;
- family history of DCM, myocarditis (according to the present criteria).
normal coronary arteries), the definitive diagnosis of myocarditis should still be based on EMB (Figure 3).

### Endomyocardial biopsy

Endomyocardial biopsy confirms the diagnosis of myocarditis and identifies the underlying aetiology and the type of inflammation (e.g., giant cell, eosinophilic myocarditis, sarcoidosis) which imply different treatments and prognosis (Figure 1). Importantly, EMB is also the basis for safe (infection negative) immunosuppression and antiviral treatment. If EMB is performed by experienced teams, its complication rate is low (0–0.8%).

The recent scientific statement on EMB gave highest levels of recommendations in the life-threatening clinical presentations. Recommendations in the life-threatening clinical presentations have been reported as the main predictor of death or progression of heart failure.

#### Clinical management

Outcome and prognosis of myocarditis depends on aetiology, clinical presentation, and disease stage. Acute myocarditis resolves in about 50% of cases in the first 2–4 weeks, but about 25% will develop persistent cardiac dysfunction and 12–25% may acutely deteriorate and either die or progress to end-stage DCM with a need for heart transplantation. Biventricular dysfunction at presentation has been reported as the main predictor of death or...
transplantation. Fulminant myocarditis is said to differ from (sub)acute lymphocytic myocarditis in its mode of onset, degree of haemodynamic compromise, and better outcome, but data are relatively scarce in adult patients. Fulminant myocarditis of unknown aetiology is more frequent in children and prevalent in neonates with a dismal prognosis. Most studies suggest that survival rates in giant-cell myocarditis are markedly worse.

Molecular detection techniques for viral genome in EMB specimens have provided conflicting prognostic information. Viral persistence in the myocardium has been associated with ventricular dysfunction and viral genome clearance with improvement of ventricular function and a better 10-year prognosis. In contrast, in a recent report, immunohistological evidence of inflammation but not the presence of viral genome alone was an independent predictor of survival. This discrepancy may relate to the variability in the viral epidemiology of different populations and to low numbers of events.

The frequency of specific viruses among patients who recover spontaneously is largely unknown. This may also confer some bias to the published studies on prognosis. The molecular mechanisms responsible for the reactivation of latent viral infection, the influence of immune activation triggering viral replication in chronic myocarditis, and immune-independent viral pathogenesis in non-inflamed hearts are remaining gaps in the understanding of viral pathogenicity.

(a) Conventional medical treatment

As large multicentre randomized controlled trials examining distinct pathogenic subsets are not available, recommendations are based on the consensus of the expert Task Force. The core principles of treatment in myocarditis are optimal care of arrhythmia and of heart failure and, where supported by evidence, aetiology-targeted therapy.

1. Haemodynamically unstable patients

Patients with haemodynamically unstable heart failure should be managed promptly according to current ESC guidelines for heart failure in intensive care units with respiratory and mechanical cardio-pulmonary support facilities. In acute/fulminant cases with cardiogenic shock and severe ventricular dysfunction, ventricular assist devices or extracorporeal membrane oxygenation (ECMO) may be needed to provide a bridge to transplant or to recovery. Because of its simplicity and effectiveness, ECMO therapy can rescue this group of patients.

2. Haemodynamically stable patients

When myocarditis is suspected in asymptomatic or mildly symptomatic patients according to the criteria shown in Table 4, admission to hospital and clinical monitoring are recommended until a definite diagnosis is established, since the situation can evolve rapidly and a cardiopulmonary emergency (e.g. severe heart block or life-threatening arrhythmia) is possible and unpredictable, even if systolic function is initially preserved. Exercise testing is contraindicated in the acute stage as it can precipitate arrhythmia.

Patients with haemodynamically stable heart failure should be treated with diuretics, angiotensin-converting enzyme inhibitor, or angiotensin receptor blockade and beta-adrenergic blockade. In patients who have persistent heart failure symptoms despite optimal management, additional treatment with aldosterone antagonists should be considered. The procedure for weaning of heart failure therapy following recovery of ventricular function is not defined.

Non-steroidal anti-inflammatory drugs, in particular acetylsalicylic acid, are a cornerstone of treatment for acute pericarditis, but have been associated with increased mortality in experimental models of myocarditis. Clinical data for their administration in myocarditis are inconclusive, and controlled trials are needed.

3. Arrhythmia

There are no specific recommendations for the management of arrhythmia in myocarditis, and so management should be in line with current ESC guidelines. Sinus bradycardia, prolonged QRS duration, increased left ventricular hypokinesis on echocardiography, persistent or fluctuating cardiac troponin levels may precede a life-threatening arrhythmia. Temporary pacing may be needed for complete atrio-ventricular block. Indication for cardioverter defibrillator implantation (ICD) is controversial, because myocarditis may heal completely. Bridging by a lifescape in patients with myocarditis and severe ventricular arrhythmia (ventricular tachycardia or fibrillation) could solve the transient problem.

4. Avoidance of exercise

Physical activity should be restricted during the acute phase of myocarditis until the disease has completely resolved. Athletes should be temporarily excluded from competitive and amateur-leisure time sport activity regardless of age, gender, severity of symptoms, or therapeutic regimen. After resolution of the clinical presentation (at least 6 months after the onset of the disease), clinical
reassessment is indicated before the athlete resumes competitive sport. \textsuperscript{164,165} Pre-participation screening should be performed every 6 months during the follow-up. \textsuperscript{164,165} Although the duration of restricted physical activity in non-athletes is undefined, based upon expert opinion of this Task Force, it seems reasonable to give similar recommendations.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{Recommendation} & \\
\hline
20. Physical activity should be restricted during the acute phase of myocarditis and for at least 6 months in athletes and non-athletes. This recommendation is based upon expert opinion of this Task Force. & \\
\hline
\end{tabular}
\caption{Recommendations for physical activity restriction.}
\end{table}

\section*{(b) Immunomodulatory therapy}

\textbf{Anti-viral therapies}

There is still no approved antiviral-therapy for the treatment of enteroviral infections. Vaccines may be an option in the future. \textsuperscript{166} Treatment with acyclovir, gancyclovir, and valacyclovir may be considered in patients with herpes virus infection, \textsuperscript{167} although their efficacy is unproven in myocarditis. Preliminary data on interferon-beta treatment suggest that it eliminates enteroviral and adenoviral genomes in patients with left ventricular dysfunction. \textsuperscript{168} is associated with improvement in NYHA functional class, \textsuperscript{169} and, specifically in enteroviral infection, with a better 10-year prognosis. \textsuperscript{172} In general, we recommend involvement of infectious disease specialists when deciding on the use of specific antiviral therapies.

\textbf{High dose intravenous immunoglobulin}

High dose intravenous immunoglobulin (IVIG) modulates the immune and inflammatory response by a variety of mechanisms and is used in a number of systemic autoimmune diseases. \textsuperscript{170} Its use has been associated with improved left ventricular ejection fraction in chronic symptomatic heart failure of various causes. \textsuperscript{171} but IVIG was ineffective in the IMAC controlled trial of recent-onset DCM in which only 15\% of patients had biopsy-proven myocarditis of non-specified cause. \textsuperscript{172} Nevertheless, IVIG has no major side-effects and may be used in myocarditis refractory to conventional heart failure therapy, both viral and autoimmune forms, particularly if autoantibody-mediated. \textsuperscript{173} In the absence of multi-centre randomized studies in biopsy-proven myocarditis/DCM of viral or autoimmune origin, we do not give recommendations for the use of IVIG.

\textbf{Immunoadsorption (IA)}

Various aabs have been detected in myocarditis and DCM patients and for some a pathogenic role has been proposed (Table 2). Thus, therapeutic strategies used in other auto-immune disorders, \textsuperscript{173–175} such as neutralization or immunoadsorption (IA) of disease-causing aabs, might offer treatment options for autoimmune myocarditis/DCM. Small randomized studies with DCM patients have shown that IA induces improvement of LV function and decreases myocardial inflammation\textsuperscript{176,182}; a larger randomized controlled clinical trial is currently underway in Europe. Until these results are available, we do not give recommendations for the use of immunoadsorption.

\section*{(c) Immunosuppressive therapy}

\textbf{Anti-viral therapies}

Most data on safety and efficacy of immunosuppressive regimes in myocarditis have been obtained using steroids alone, azathioprine and steroids, or cyclosporine A, azathioprine and steroids. Information on other drugs is not available. Data from the few randomized clinical trials of immunosuppression in myocarditis and DCM are shown in Table 6. Response to therapy is reported mainly in chronic virus-negative forms, in giant cell myocarditis, and in active myocarditis defined as autoimmune (e.g. virus-negative and autoantibody positive). Conversely, immunosuppression had a neutral effect in the Myocarditis Treatment Trial, where patients had myocarditis of unknown aetiology. \textsuperscript{6} It is necessary to identify possible drugs causing hypersensitivity reactions, particularly in patients with hypereosinophilia,\textsuperscript{10}; the inducing drug (Table 1) should not be reintroduced after recovery.\textsuperscript{10}

Recently, a single-centre controlled trial suggested a beneficial effect of combined steroid and azathioprine therapy in virus-negative myocarditis.\textsuperscript{101} These data need to be confirmed in multicentre studies.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{Recommendations} & \\
\hline
21. Immunosuppression should be started only after ruling out active infection on EMB by PCR. & \\
22. Based on experience with non-cardiac autoimmune disease, the task group recommends consideration of immunosuppression in proven autoimmune (e.g. infection-negative) forms of myocarditis, with no contraindications to immunosuppression, including giant cell myocarditis, cardiac sarcoidosis, and myocarditis associated with known extra-cardiac autoimmune disease.\textsuperscript{10,99} & \\
23. Steroid therapy is indicated in cardiac sarcoidosis in the presence of ventricular dysfunction and/or arrhythmia and in some forms of infection-negative eosinophilic or toxic myocarditis with heart failure and/or arrhythmia. & \\
24. Immunosuppression may be considered, on an individual basis, in infection-negative lymphocytic myocarditis refractory to standard therapy in patients with no contraindications to immunosuppression. & \\
25. Follow-up EMB may be required to guide the intensity and the length of immunosuppression. & \\
\hline
\end{tabular}
\caption{Recommendations for immunosuppressive therapy.}
\end{table}

\section*{(d) Follow-up}

Myocarditis patients can have partial or full clinical recovery; some may relapse many years after the first episode. Relapses should be managed similarly to the index episode. In patients who do not resolve, disease may continue subclinically and lead to DCM.

The myocarditis patient with pseudo-infect presentation, normal coronary arteries, and preserved ventricular function should be discharged when cardiac enzymes have come into the normal range, and offered long-term non-invasive cardiological follow-up. In the event of prolonged (weeks or even months) documented increase of cardiac enzymes, and/or progressive reduction in left and/or right ventricular function, the patient should be readmitted to hospital to perform EMB.
Persistently elevated troponin T values could be due to heterophile antibodies interfering with the assay. Performing a troponin I could clarify whether persistent enzyme elevations are due to an ana- phile antibodies interfering with the assay. Performing a troponin I could clarify whether persistent enzyme elevations are due to an ana-

<table>
<thead>
<tr>
<th>Trial</th>
<th>Year</th>
<th>Type</th>
<th>Pts (n)</th>
<th>Diagnosis</th>
<th>Primary endpoint</th>
<th>Results</th>
<th>Author/Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prednisone trial for DCM</td>
<td>1989</td>
<td>Randomized controlled trial (RCT): prednisone (PDN)</td>
<td>102</td>
<td>‘Reactive’ DCM (n = 60)</td>
<td>Either higher LV ejection fraction (LVEF) at 3 months or lower LV end-diastolic dimension and better exercise tolerance</td>
<td>Favourable</td>
<td>Parrillo ’76</td>
</tr>
<tr>
<td>MTT</td>
<td>1995</td>
<td>RCT: PDN and cyclosporine or azathioprine</td>
<td>111</td>
<td>Acute biopsy-proven myocarditis (unknown aetiology)</td>
<td>LVEF at 6 months</td>
<td>Neutral</td>
<td>Mason ’6</td>
</tr>
<tr>
<td>Giant cell myocarditis treatment trial</td>
<td>2008</td>
<td>Prospective: PDN and cyclosporine</td>
<td>11</td>
<td>Giant cell myocarditis (autoimmune)</td>
<td>Survival at 1 year</td>
<td>Favourable</td>
<td>Cooper ’99</td>
</tr>
<tr>
<td></td>
<td>2003</td>
<td>Prospective: PDN and azathioprine</td>
<td>41</td>
<td>Active myocarditis and chronic heart failure (aetiology known in retrospect)</td>
<td>LVEF at 1 year</td>
<td>Favourable in virus-negative aabs-positive autoimmune forms</td>
<td>Frustaci ’100</td>
</tr>
<tr>
<td></td>
<td>2001</td>
<td>RCT: PDN and azathioprine</td>
<td>84</td>
<td>Inflammatory DCM (unknown aetiology, increased HLA expression on EMB)</td>
<td>LVEF at 3 months, sustained at 2 years</td>
<td>Favourable</td>
<td>Wojnicz ’103</td>
</tr>
<tr>
<td>TIMIC</td>
<td>2009</td>
<td>RCT: PDN and azathioprine</td>
<td>85</td>
<td>Inflammatory virus-negative DCM</td>
<td>LVEF at 6 months</td>
<td>Favourable</td>
<td>Frustaci ’101</td>
</tr>
</tbody>
</table>

Table 6: Controlled immunosuppression trials in myocarditis and dilated cardiomyopathy

Summary

This position statement reviews current knowledge, and proposes new diagnostic criteria for clinically suspected myocarditis and its distinct biopsy-proven pathogenic forms. The aims are to bridge the gap between clinical and tissue-based diagnosis, to improve management and provide a common reference point for future registries and multicentre randomized controlled trials of aetiology-driven treatment in inflammatory heart muscle disease.

Supplementary material

Supplementary material is available at European Heart Journal online.

Conflict of interest: none declared.

References


