EHRA/HRS/APHRS Expert Consensus on Ventricular Arrhythmias

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Introduction

This international consensus statement of the European Heart Rhythm Association (EHRA), Heart Rhythm Society (HRS), and Asia Pacific Heart Rhythm Society is intended to provide clinical guidance for the management of patients with ventricular arrhythmias (VAs). It summarizes the consensus of the international writing group members and is based on a systematic review of the medical literature regarding VAs.

The spectrum of VAs ranges from those that are benign and asymptomatic to those that produce severe symptoms including sudden cardiac death (SCD). In addition, many patients exhibit multiple forms of VAs over time. Thus, clinicians who encounter patients with VAs face important questions regarding which diagnostic tests are needed and which treatments, if any, should be offered. The Writing Committee recognizes that the manner in which patients present with VAs varies greatly. The electrocardiographic recording of a VA may be the first and only manifestation of a cardiac abnormality; alternatively, patients with a prior diagnosis of cardiac disease may later develop these arrhythmias. Thus, the specific arrhythmia and the underlying structural heart disease (SHD), if any, may have important prognostic and treatment implications.

This document addresses the indications for diagnostic testing, the present state of prognostic risk stratification, and the treatment strategies that have been demonstrated to improve the clinical outcome of patients with VAs. In addition, this document includes recommendations for referral of patients to centres with specialized expertise in the management of arrhythmias. Wherever appropriate, the reader is referred to other publications regarding the indications for implantable cardioverter-defibrillator (ICD) implantation,[1,2] catheter ablation,[3] inherited arrhythmia syndromes,[4,5] congenital heart disease (CHD),[6] the use of amiodarone,[7] and the management of patient with ICD shocks,[8] syncope,[9] or those nearing end of life.[10] The consensus recommendations in this document use the standard Class I, IIa, IIb, and III classification[11] and the corresponding language: 'is recommended' for Class I consensus recommendation; 'can be useful' for a Class IIa consensus recommendation; 'may be considered' to signify a Class IIb consensus recommendation; 'should not' or 'is not recommended' for a Class III consensus recommendation (failure to provide any additional benefit and/or may be harmful). The level of evidence supporting these recommendations is defined as 'A', 'B', or 'C' depending on the number of populations studied, whether data are derived from randomized clinical trials, non-randomized studies, or, in the absence of large studies, the consensus opinions of experts from case studies or standards of care. Most medical interventions to prevent sudden death and to treat VAs were developed in an era when patient cohorts were small and the accepted standards to demonstrate effectiveness were lower than today. Many interventions to terminate or suppress VAs have since been used in many patients, and over time different treatment 'patterns' have developed in different regions of the world. The writing group has tried to accommodate reasonable variations in treatment in our recommendations, and have relied upon expert consensus for many of the recommendations put forward in this document. This is reflected by the relatively low

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level of evidence that supports the majority of our recommendations. Each of the recommendations was voted upon by the Writing Committee and only those where there was at least 80% agreement have been included.

The consensus group has approached VAs by whether they are sustained or non-sustained. The first part of this document deals with non-sustained arrhythmias, discussed in two parts [premature ventricular complexes (PVCs) and non-sustained ventricular tachycardia (NSVT)].

The consensus group believes that patients with non-sustained VAs need a standardized diagnostic workup. This is summarized here, and explained in the two sections.

For treatment of patients with non-sustained VAs, we propose the following consensus recommendations.

Expert consensus recommendations on general diagnostic work-up

(1) All patients with documented non-sustained or sustained VAs should have a resting 12-lead electrocardiogram (ECG) and a transthoracic echocardiogram to detect underlying heart disease including inherited and acquired cardiomyopathies. Especially in patients in whom the arrhythmia morphology suggests such a specific aetiology, valvular and right heart morphology and function should be assessed. IIa LOE B

(2) Repeat 12-lead ECGs should be considered whenever an inherited arrhythmia syndrome with varying electrocardiographic manifestations or a transient condition (e.g. coronary spasm) is suspected. IIa LOE C

(3) In selected patients, and especially in those with sustained arrhythmias, a second imaging modality (e.g. a magnetic resonance study, stress testing with perfusion scanning, or echocardiography) should be considered to detect subtle SHD. IIa LOE B

(4) A test for myocardial ischaemia should be considered in all patients with VAs in whom the clinical presentation and/or the type of arrhythmia suggests the presence of coronary artery disease. IIa LOE C

(5) The risk of cardiac events is often dictated by an underlying heart disease rather than the arrhythmia. Therefore, optimal treatment of underlying cardiovascular diseases and risk factors is recommended. I LOE A

(6) Prolonged ECG monitoring by Holter ECG, prolonged ECG event monitoring, or implantable loop recorders should be considered when documentation of further, potentially longer arrhythmias would change management. IIa LOE C

(7) In patients with incompletely characterized arrhythmias with wide QRS complexes, both supraventricular and VAs should be considered in developing a care plan. IIa LOE C

Expert consensus recommendations on non-sustained

(1) Infrequent ventricular ectopic beats, couplets, and triplets without other signs of an underlying SHD or an inherited arrhythmia syndrome should be considered as a normal variant in asymptomatic patients. IIa LOE C

(2) An invasive electrophysiological study (EPS) should be considered in patients with significant SHD and non-sustained VAs especially if accompanied by unexplained symptoms such as syncope, near-syncope, or sustained palpitations IIa LOE C

(3) No treatment other than reassurance is needed for patients with neither SHD nor an inherited arrhythmogenic disorder who have asymptomatic or mildly symptomatic PVCs. I LOE C

(4) It is recommended to treat survivors of a myocardial infarction (MI) and other patient with reduced left ventricular (LV) function and non-sustained VAs with a beta-blocker unless these agents are contraindicated. I LOE A

(5) A therapeutic trial of beta-blockers may be considered in symptomatic patients with non-sustained VAs. IIb LOE C

(6) In suitable patients without SHD, a non-dihydropyridine calcium channel antagonist may be considered as an alternative to beta-blocker treatment. IIb C

(7) In patients who suffer from symptomatic non-sustained VAs on an adequately dosed beta-blocker or a non-dihydropyridine calcium channel antagonist, treatment with an antiarrhythmic drug (AAD; amiodarone, flecainide, mexiletine, propafenone, sotalol) may be considered to improve symptoms associated with arrhythmia episodes. IIb LOE C

   (a) Flecainide and propafenone are not recommended to suppress PVCs in patients with reduced LV function (unless caused by ventricular ectopy itself), myocardial ischaemia, or myocardial scar. III LOE A

   (b) Sotalol should be used with caution in patients with chronic kidney disease and should be avoided in patients with a prolonged QT interval at baseline or with excessive prolongation of QT interval (.0.50 s) upon therapy initiation. I LOE B

   (c) Amiodarone appears to have less overall pro-arrhythmic risk than other AADs in patients with heart failure and may be preferred to other membrane-active AADs unless a functioning defibrillator has been implanted. IIb LOE C

(8) Catheter ablation may be beneficial by improving symptoms or LV dysfunction in patients suffering from frequent non-sustained VAs (e.g. .PVC 10 000 per 24 h) in patients with significant symptoms or LV dysfunction without another detectable cause. IIa LOE B

(9) Amiodarone, sotalol, and/or other beta-blockers are useful pharmacological adjuncts to implantation of a defibrillator (e.g. to reduce shocks) and to suppress symptomatic NSVT in patients who are unsuitable for ICD therapy, in addition to optimal medical therapy for patients with heart failure. IIb LOE B

Premature ventricular complexes

Premature ventricular complexes (PVCs) are common both in patients with and without SHD and may be asymptomatic even for patients with high frequency of these beats. Other patients may be highly symptomatic with relatively few ectopic beats.[12] Although a recent meta-analysis[13] of patients without clinically apparent SHD demonstrated an increased incidence of adverse events in patients with frequent PVCs, only one of the included studies used echocardiography to establish structural disease. The independent prognostic importance of PVCs in the presence of structural disease is not clear. Early studies demonstrated an association with increased cardiovascular mortality after MI[14,15] and with increased total mortality in patients with LV hypertrophy (LVH).[16] However, these studies were observational and performed in an era prior to modern management.[17] In a study of patients with congestive heart failure [ejection fraction (EF), 35%], PVC frequency did not predict the risk of sudden death and did not provide prognostic information beyond other clinical variables.[18]

Premature ventricular complex-induced cardiomyopathy

Several studies have demonstrated an association between frequent PVCs and a potentially reversible cardiomyopathy, which in selected patients resolves after catheter ablation.[19–24] The number of PVCs/24 h that is associated with impaired LV function has generally been reported at burdens above 15 – 25% of the total cardiac beats, though this may be as low as 10%[21–30] (Table 1). However, since PVCs may be the result of an underlying cardiomyopathy, it may be difficult to prospectively determine which of these sequences is operative in a given patient.[31] Importantly, the vast majority of patients with frequent PVCs will not go on to develop cardiomyopathy but currently available data do not allow for accurate risk prediction. A recent longitudinal study followed 239 patients with frequent PVCs (.1000 per day) and no SHD [echo and magnetic resonance imaging (MRI)] for 5.6 years with no adverse cardiac events and no decline in overall LV ejection fraction (LVEF).[32]

Diagnostic evaluation

Electrocardiogram and ambulatory monitoring

The presence of at least some PVCs during 24 h ambulatory monitoring is extremely common and may be considered normal. Because the finding of PVCs during 24 h ambulatory monitoring is very likely, any conclusion that they are related to symptoms requires careful correlation. In two studies in which SHD was rigorously excluded, only 2 and 4% had .50 or .100 PVCs/24 h, respectively.[33,34] The vast majority of patients without SHD who have PVCs have a benign prognosis. An exception may be a very small subset of patients with PVCs that have a short coupling interval (,300 ms) between the premature and the preceding beats, a finding which suggests the short QT syndrome and increases the risk of malignant VAs.[35] It should be emphasized that this is a very small minority of patients with PVCs. As with other VAs, the first step in the evaluation of a patient with PVCs is to determine the presence or absence of SHD (Figures 1 and 2). For patients with arrhythmic or other cardiac symptoms, a resting 12-lead ECG is very helpful to evaluate the presence of myocardial scar (Q-waves or fractionated QRS complexes), the QT interval, ventricular hypertrophy, and other evidence of SHD. An echocardiogram provides assessment of right ventricular (RV) and LV structure and function, valvular abnormalities, and pulmonary artery systolic pressure and is recommended for patients with symptomatic PVCs, a high frequency of PVCs (.10% burden), or when the presence of SHD is suspected.

Exercise testing

For selected patients, especially when there is a suggestion of symptoms associated with exercise, exercise stress testing should be considered to determine whether PVCs are potentiated or suppressed by exercise, to assess whether longer duration VAs are provoked. A negative exercise test can decrease the probability that catecholaminergic polymorphic ventricular tachycardia (CPVT) is the underlying cause. Premature ventricular complexes that worsen with exercise should prompt further investigation as these patients are more likely to require treatment.

Imaging investigations

Although the majority of patients with PVCs can be accurately assessed with a 12-lead ECG and echocardiography, contrastenhanced MRI may provide additional

Table 1 PVC burden associated with LV dysfunction

	n	%LVd	%VEs LVd	%VEs normal LV	P	Predictive PVC burden
Ban et al.[21]	127 (28 LVd)	22%	31 + 11%	22 + 10%	0.001	26%
Deyell et al.[25]	90 (24 LVd)	27%	32 + 12%	27 + 12%	0.077	–
Munoz et al.[26]	70 (LVd 17)	24%	29 + 15%	17 + 14%	0.004	10% RV; 20% LV
Olgun et al.[27]	51 (21 LVd)	41%	30 + 11%	14 + 15%	0.0001	–
Hasdemir et al.[28]	249 (17 LVd)	7%	29 + 9%	8 + 7%	0.001	16%
Baman et al.[29]	174 (57 LVd)	33%	33 + 13%	13 + 12%	0.0001	24%
Kanei et al.[30]	108 (21 LVd)	19%	13 + 11%[a]	7 + 9%[a]	0.004	–

Lowest PVC count associated with LV dysfunction was 10% (Baman).

LV = left ventricle; LVD = left ventricular dysfunction; PVC = premature ventricular complexes; VE = ventricular ectopic.

[a]Assuming 100 000 beats/24 h.

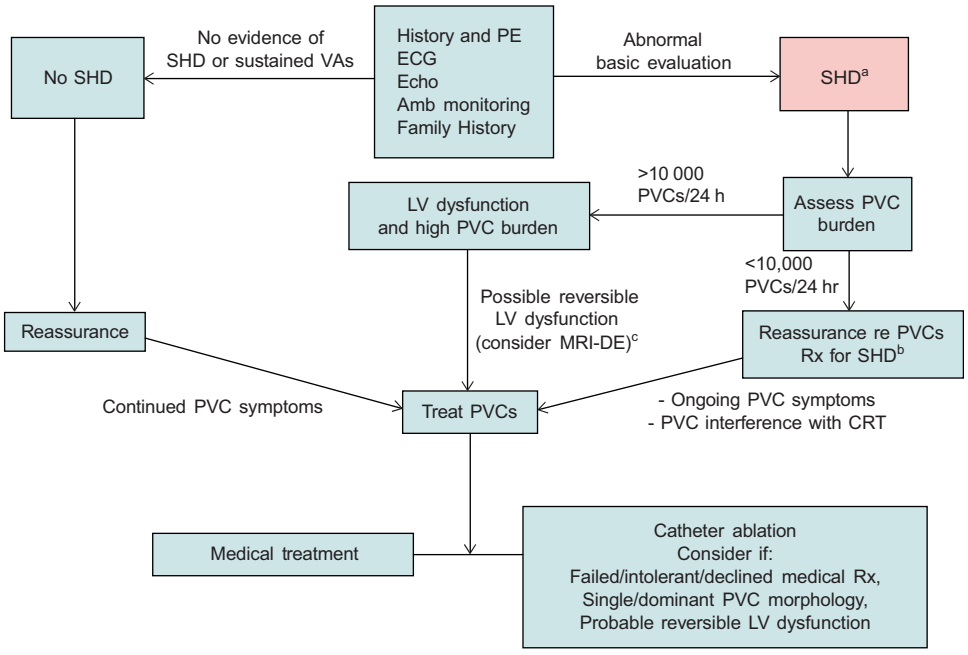

Figure 1 Management of PVCs. a. See table for definitions of structural heart disease; b. Medical therapy + ICD; c. Absence of high scar burden suggests reversibility. CRT = cardiac resynchronisation therapy; ICD = implantable cardioverter-defibrillator; LV = left ventricular; MRI-DE = magnetic resonance imaging with delayed enhancement; PE = physical examination; PVC = premature ventricular complexes; Rx = therapy; SHD = structural heart disease; VAs = ventricular arrhythmias.

diagnostic and prognostic data when the presence or absence of SHD remains in doubt.[36] While there are no large-scale studies investigating which patients should undergo MRI, the management of several forms of SHD associated with PVCs may be guided by MRI, including dilated cardiomyopathy, hypertrophic cardiomyopathy (HCM), sarcoidosis, amyloidosis, and arrhythmogenic right ventricular cardiomyopathy (ARVC).[37–39] In these conditions, the presence of ventricular wall motion abnormalities or myocardial scar detected by delayed gadolinium enhancement may provide useful prognostic information. In selected patients for whom the diagnosis of ARVC is suspected, the signal-averaged

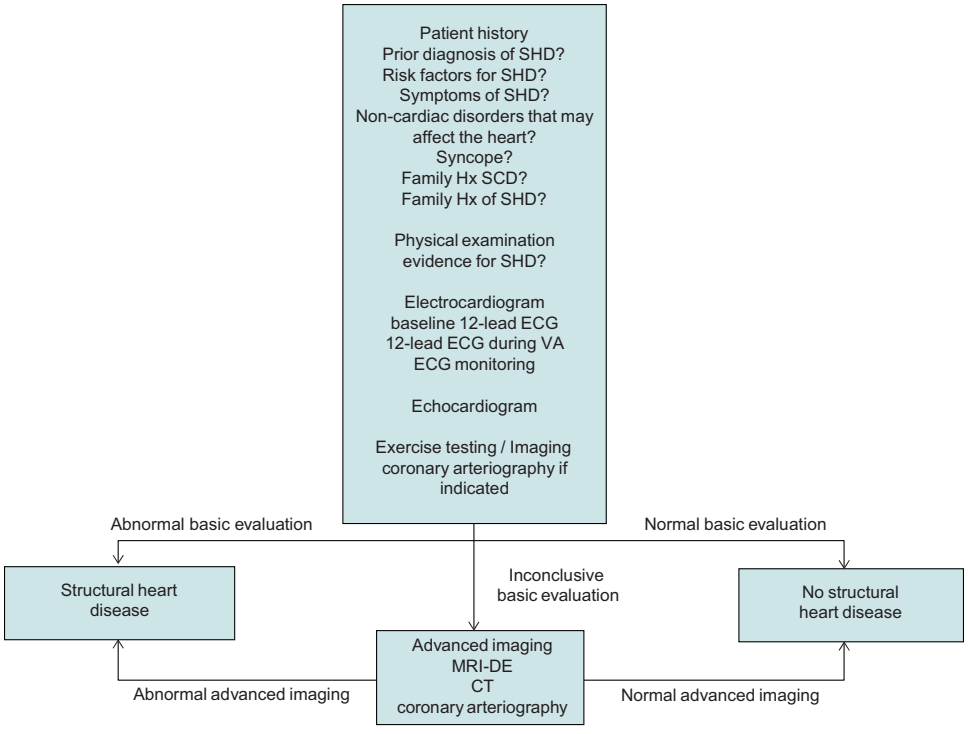

Figure 2 Evaluation for the presence or absence of structural heart disease. CT = computed tomography; MRI-DE = magnetic resonance imaging with delayed enhancement; VA = ventricular arrhythmia.

ECG (SAECG) may provide useful information and forms a minor diagnostic criterion for this disorder.

Treatment

Indications for treatment in patients without structural heart disease

In the absence of SHD, the most common indication for treating PVCs remains the presence of symptoms that are not improved by explanation of their benign nature and reassurance from the physician. In addition, some patients may require treatment for frequent asymptomatic PVCs if longitudinal imaging surveillance reveals an interval decline in LV systolic function or an increase in chamber volume. For patients with .10 000 PVCs/24 h, follow-up with repeat echocardiography and Holter monitoring should be considered. In patients with fewer PVCs, further investigation is only necessary should symptoms increase. It should also be recognized that PVC burden often fluctuates over time.

Indications for treatment in patients with structural heart disease

In patients with SHD, symptoms form the primary grounds for considering whether treatment is indicated. Elimination of high burden PVCs (.10%) in patients with impaired LV function can be associated with significant improvement of LV function,[19,20] even when significant scarring is present.[22,23] Catheter ablation may also be helpful when frequent PVCs interfere with cardiac resynchronization therapy.[40]

Management of premature ventricular complexes (options)

Medical therapy

For patients without SHD and mild symptoms, the first step in treatment of patients with PVCs is education of the benign nature of this arrhythmia and reassurance. No large-scale randomized trials of drug treatment for PVCs in the absence of heart disease have been performed. For patients whose symptoms are not effectively managed in this manner, a trial of beta-blockers or non-dihydropyridine calcium antagonists may be considered though the efficacy of these agents is quite limited with only 10 – 15% of patients achieving .90% PVC suppression,[41] similar to placebo.[42] It should also be recognized that the data supporting the use of calcium blockers are less than for beta-blockers and that these agents may themselves produce significant symptoms. While membrane-active AADs are more effective to suppress PVCs, the risk – benefit ratio has not been carefully evaluated in patients without SHD. Nevertheless, these agents are highly effective and may significantly improve symptoms in markedly symptomatic patients. Because these agents may increase the risk of mortality in patients with significant SHD, perhaps with the exception of amiodarone, caution is advised before using them for PVC suppression.[41,43]

Catheter ablation

Randomized trials of PVC suppression with catheter ablation have not been performed. However, multiple studies indicate high efficacy of ablation with PVC elimination in 74 – 100% of patients.[44–57] However, these studies have typically included highly symptomatic patients typically with a very high burden of PVCs. Thus, catheter ablation should only be considered for patients who are markedly symptomatic with very frequent PVCs. In addition, procedural success may be dependent on site of origin with lower efficacy reported for coronary venous and epicardial foci than for other sites.[49,58] Although complete PVC elimination is the goal of ablation, it should be noted that partial success may still be associated with significant improvement in LV systolic function. The efficacy of catheter ablation may be reduced for patients with multiple morphologies of PVCs or those for whom the clinical PVC morphology cannot be induced at the time of the procedure. The published complication rates of catheter ablation for PVC suppression are generally low ("1%). Catheter ablation of PVCs is recommended for highly selected patients who remain very symptomatic despite conservative treatment or for those with very high PVC burdens associated with a decline in LV systolic function.

Non-sustained ventricular tachycardia

Although several different definitions have been used,[59] NSVT is defined as runs of beats arising from the ventricles with duration between 3 beats and 30 s and with cycle length of ,600 ms (.100 b.p.m.).[60] Similar to PVCs, NSVT is a relatively common finding in patients with either structurally normal or abnormal hearts.[59,61,62] Non-sustained ventricular tachycardia is found in nearly 6% of patients evaluated for palpitations.[63] Diagnostic and therapeutic considerations for NSVT are included in several [3,60,64] recent guideline and consensus documents. In general, therapy for the underlying cardiac disease is indicated rather than for the arrhythmia itself. However, the finding of NSVT should always trigger further evaluation of the patient and a practical approach can be usefully divided into a general approach (Table 2), patients with an apparently normal heart (Table 3) and those with SHD (Table 4).

Non-sustained ventricular tachycardia in the structurally normal heart

Exercise-related NSVT is relatively common and appears to be associated with a worse prognosis when it occurs during recovery.[65,66] Polymorphic NSVT requires extensive evaluation in both symptomatic and asymptomatic patients with careful assessment for the presence of coronary ischaemia. An important inherited arrhythmia which may present as exercise-induced NSVT is CPVT.[72,73] This condition is typically manifested by polymorphic or bidirectional VT which are triggered by sympathetic stimulation and exercise (commonly

Table 2 Evaluation of patients with nonsustained ventricular tachycardia

Standard evaluation
History
Prior cardiovascular disease?
Hypertension, known cardiac disease?
Syncope or near-syncope?
Sustained palpitations?
Relation of symptoms to exercise?
Family history
SCD, inherited arrhythmia syndromes, coronary artery disease, cardiomyopathy?
Medications
QT prolonging drugs, sodium channel blockers, drug interactions?
Physical examination
Evidence of cardiac disease?
Twelve-lead ECG
Q-waves, ischaemic changes, prolonged or fractionated QRS, QT prolongation or shortening, ST elevation V1 – V3, early repolarization, epsilon waves, or anterior T-wave inversion
Echocardiography
Ventricular chamber dimensions and thickness, wall motion, systolic and diastolic function, valvular function, congenital anomalies, pulmonary arterial systolic pressure
Laboratory
Serum electrolytes, renal function
Further evaluation
Exercise testing
Suspicion of coronary artery disease, exercise-related symptoms, borderline QT interval
Coronary arteriography
Suspicion of coronary artery disease or coronary artery anomaly
Cardiac MRI
Suspicion of ARVC, HCM, cardiac sarcoidosis, congenital anomalies
Genetic testing
Suspicion of inherited arrhythmia syndrome, family history of inherited arrhythmia syndrome
Electrophysiological testing
Sustained palpitations without diagnosis, suspicion of AV block, coronary artery disease with NSVT, and moderate LV dysfunction

ARVC = arrhythmogenic right ventricular cardiomyopathy; AV = atrioventricular; HCM = hypertrophic cardiomyopathy; LV = left ventricular; MRI = magnetic resonance imaging; NSVT = non-sustained ventricular tachycardia; SCD =sudden cardiac death.

occurring at an exercise level of 120 – 130 b.p.m.) and is associated with an increased risk of sudden death. The underlying mechanism of CPVT is calcium overload leading to delayed afterdepolarizations as a result of mutations in the genes coding for ryanodine receptor or calsequestrin proteins. Non-sustained ventricular tachycardia is a relatively common finding among athletes.[67,68] Other causes of NSVT in the absence of SHD include QT interval prolongation caused by mutations in proteins regulating repolarizing currents drugs (LQTS) or electrolyte abnormalities. Athletes with NSVT should be evaluated for the presence of HCM, a diagnosis which may overlap with some degree of LVH as an adaptation to exercise. Because of this challenging distinction, expert consultation should be obtained if this diagnosis is suspected. Although only limited data are available regarding the significance of NSVT in athletes without a structural cardiac disease, discontinuation of training is not generally recommended.

Non-sustained ventricular tachycardia in structural heart disease

Non-sustained ventricular tachycardia is common in ischaemic heart disease and can be recorded in 30 – 80% of patients during long-term ECG monitoring where it is usually asymptomatic.[60] No studies have demonstrated a mortality benefit of suppressing NSVT with either AADs or catheter ablation and treatment is usually not indicated in asymptomatic patients. A range of studies have demonstrated that NSVT occurring during the first few days after an acute coronary event has no adverse long-term prognostic significance. However, when NSVT occurs 48 h or more after MI, there is an increased mortality and morbidity even when asymptomatic.[74] For a patient with non-ischaemic dilated cardiomyopathy, the prognostic significance of NSVT is uncertain and no studies have provided precise guidance for treatment in this group of patients.[75]

The occurrence of NSVT in patients with an implanted ICD is associated with an increased frequency of shocks and all-cause mortality.[76] For these patients, programming the ICD to a long VT detection time and a high ventricular fibrillation (VF) detection rate may be especially important.[77,78]

Diagnostic evaluation

For patients with an apparently normal heart, the 12-lead ECG should be scrutinized for evidence of typical outflow tract VT,[53,54,56,62] (Figure 3) polymorphic VT (PMVT), including torsades de pointes (TdP), or an inherited arrhythmia syndrome, such as the long QT, short QT, Brugada, or early repolarization syndromes (ERS)[4] (Figure 4). Outflow tract VAs typically have an inferior axis with either RV or LV origin. When the precordial transition is ,V3 and the ratio of the R- and S-waves in lead V2 during PVCs or VT divided by this ratio during sinus rhythm exceeds 0.6, a LV outflow tract origin is strongly suggested. In addition to the ECG, an echocardiogram to assess the presence or absence of SHD should also be considered for all patients with NSVT. For cases where SHD is suspected but cannot be definitively diagnosed with echocardiography, cardiac MRI may be especially useful to confirm the presence or absence of myocardial scar or wall motion abnormalities. Classification of NSVT should be attempted using a scheme similar to Tables 3 and 4. Evaluation in CHD is described in a separate section.

Treatment

Non-sustained ventricular tachycardia in the absence of structural heart disease

Most short-lasting monomorphic NSVTs originate from the RV or LV outflow tracts (Table 3, Figure 3). These arrhythmias only require treatment if they are symptomatic, incessant, or produce LV dysfunction. Sudden death

Table 3 Non-sustained ventricular tachycardia with apparent normal heart

NSVT clinical presentation	ECG	Risk of sudden cardiac death	Diagnostic evaluation	Alternative diagnostic considerations	Treatment	Treatment to be considered	Key references
Typical RVOT	LBBB, inf axis, axis transition V3 – V4	Very rare	Standard	Differentiate from ARVC	Beta-blocker, verapamil, IC drugs with symptoms	Catheter ablation	Latif et al.[62]
Typical LVOT	Inferior axis, transition, V3	Very rare	Standard	RVOT VT	Beta-blocker, verapamil, IC drugs with symptoms	Catheter ablation	Latif et al.[62]
Idiopathic reentrant LV tachycardia	RBBB, LS axis	Very rare	Standard EP testing	Ischaemic heart disease, CM	Verapamil if symptomatic	Catheter ablation	Latif et al.[62]
Other focal VT	Multiple morphologies, monomorphic	Uncommon	Exercise testing or catecholamine stimulation	Ischaemic heart disease, CM	Beta-blocker for the arrhythmia	Catheter ablation	Latif et al.[62]
Exercise	Multiple	Increased risk when NSVT in recovery	Ischaemic heart disease, cardiomyopathy	CPVT	Underlying disease	Beta-blockers, flecainide	Jouven et al.[65], Frolkis et al.[66]
Athlete	Multiple	If it disappears with increased exercise low risk	Evaluate for latent HCM or ischaemic heart disease	HCM	No treatment training can continue	None	Biffi et al.[67,68]
Hypertension valvular disease	Multiple morphology	As without arrhythmia	Consider ischaemic heart disease	Ischaemic heart disease, CM	Treat HTN	Beta-blocker	
Polymorphic VT	Polymorphic	High	Evaluated for CAD, CPVT, inherited arrhythmia syndromes	Purkinje fibre triggering focus	Underlying disease	Revascularization, ICD, beta-blocker, catheter ablation	Zipes et al.[60]
TdP VT	Long QT, TdP	High	Medications, congenital LQTS	Medications, K^+, Mg^{++}, Ca^{++}	Stop medications, correct electrolytes	ICD, beta-blocker	Sauer and Newton-Cheh[69]

ARVC = arrhythmogenic right ventricular cardiomyopathy; CAD = coronary artery disease; CM = cardiomyopathy; HTN = hypertension; CPVT = catecholaminergic polymorphic ventricular tachycardia; HCM = hypertrophic cardiomyopathy; ICD = implantable cardioverter-defibrillator; LS = left-superior; LV = left ventricular; LVOT = left ventricular outflow tract; NSVT = non-sustained ventricular tachycardia; RBBB = right bundle branch block; RVOT = right ventricular outflow tract; TdP = torsade de pointes; VT = ventricular tachycardia.

Table 4 Non-sustained ventricular tachycardia in structural heart disease

Clinical setting	Risk of sudden cardiac death	Arrhythmia specialist evaluation	Diagnostic evaluation	Diagnostics to be considered	Treatment	Treatment to be considered	Key references
ACS within 48 h	No increased risk	No	Coronary artery disease	Monitoring	Beta-blockers		Hohnloser et al.[70]
ACS after 48 h	Risk increased	Yes	Consider EPS if moderate LV dysfunction	Continued evaluation for repetitive arrhythmias	Beta-blockers	ICD	Zipes et al.[60]
Previous MI, EF 31 – 40	Increased risk	Yes	EPS		ICD withinducible VT/VF	ICD, see relevant guidelines	Zipes et al.[60]
Previous MI, EF ≤ 30	Increased risk	Yes	Non-driven by arrhythmia		ICD	Antiarrhythmic medical therapy or ablation with symptoms	Zipes et al.[60]
Chronic heart failure, EF ≤ 30							
Syncope with chronic CAD, EF –40	Increased risk	Yes	EP testing, ischaemia testing	Monitoring	ICD with inducible VT/VF	Additional antiarrhythmic therapy or ablation	Zipes et al.[60]
Non-ischaemic dilated CM	Uncertain	Yes	Uncertain	EP testing	Uncertain	ICD, see relevant guidelines	Zipes et al.[60]
HCM	Increased risk	Yes	Echo, MRI	MRI-DE	Beta-blocker, ICD		Zipes et al.[60]
LQTS	Increased risk	Yes	Genetic screening		Beta-blocker	ICD	Zipes et al.[60]
Short QT syndrome	Increased risk	Yes	Provocative testing				
Brugada syndrome	Increased risk	Yes	Provocative testing	Genetic screening	With syncope or cardiac arrest: ICD	Quinidine	Aliot et al.[3]
ER syndrome	Increased risk	Yes					

CAD = coronary artery disease; CM = cardiomyopathy; EF = ejection fraction; EP = electrophysiology; EPS = electrophysiological study; ER = early repolarisation; HCM = hypertrophic cardiomyopathy; ICD = implantable cardioverter defibrillator; LV = left ventricular; MI = myocardial infarction; VF = ventricular fibrillation; VT = ventricular tachycardia.

is very rare in patients with outflow tract VT. The treatment of these arrhythmias is either medical with a beta-blocker, a non-hydropyridine calcium blocker, class IC drugs, or with catheter ablation.[60] Non-sustained ventricular tachycardia with a focal mechanism may also occur from the papillary muscles and respond to beta-blockers or catheter ablation.[58,79,80] In addition, reentrant LV VT utilizing false tendons can be treated with verapamil, though with a relatively high recurrence risk on oral therapy.[71,81,82] Catheter ablation is effective for idiopathic reentrant LV VT and should be considered even when this sustained arrhythmia is terminated by intravenous verapamil. Catheter ablation can be recommended for patients with idiopathic NSVT that is highly symptomatic and drug refractory, especially if it is exercise-induced.

Non-sustained ventricular tachycardia in patients with structural heart disease

The recording of polymorphic NSVT should prompt a thorough evaluation for the presence of coronary ischaemia as the primary therapy for this arrhythmia should be directed to improving coronary perfusion. If non-sustained PMVT can be classified as a CPVT, the risk of life-threatening arrhythmia is high and beta-blockade therapy with potential placement of an ICD is recommended.[4,83] In cases of TdP VT, any medication or electrolyte disturbance that prolongs repolarization should be addressed.

Although an ICD should be considered for all patients with a significantly reduced LVEF (,0.35),[84–86] there may be a role for programmed electrical stimulation in selected patients with NSVT and ischaemic heart disease who have less severe LV dysfunction (LVEF , 0.40).[87,88] Implantable cardioverter-defibrillator implantation is recommended in this group of patients if VF or sustained VT is inducible with programmed electrical stimulation.[60] Similarly, if NSVT is observed in a patient with a prior MI, a history of syncope, and LVEF . 40%, EPS is generally recommended to guide treatment, usually with ICD implantation, should sustained VT be inducible. Non-sustained ventricular tachycardia in an asymptomatic patient with a LVEF . 40% does not usually require specific antiarrhythmic therapy, and the goal is optimized treatment of the underlying heart disease. In the setting of HCM, ICD therapy is an appropriate consideration if NSVT is present with or without other major risk factors.[60] In general, AAD therapy may be considered for patients with SHD who experience symptomatic, recurrent NSVT not resolved by revascularization, optimization of medical therapy, or treatment of reversible factors.

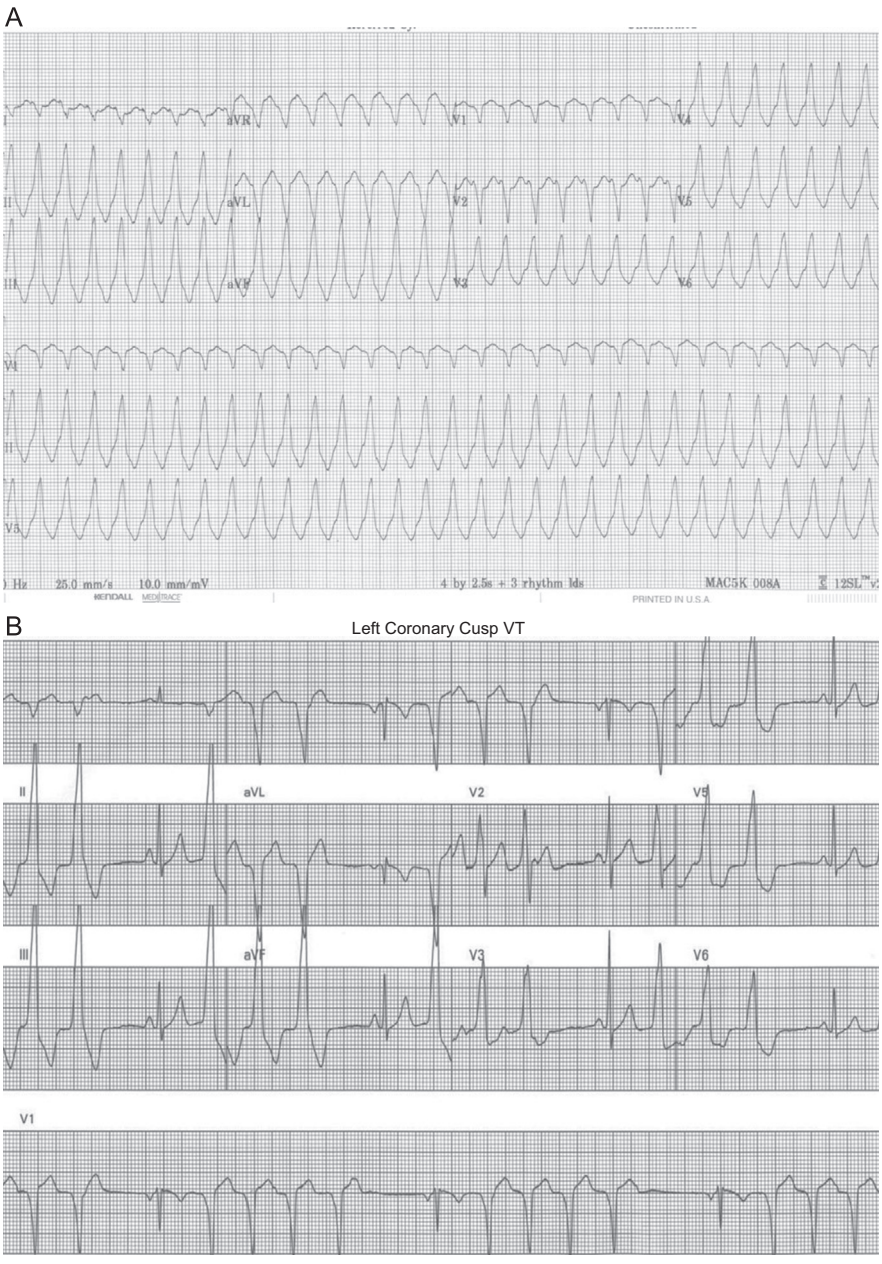

Figure 3 (**A**) Right ventricular (RV) outflow tract VT. (**B**) Left coronary cusp VT.

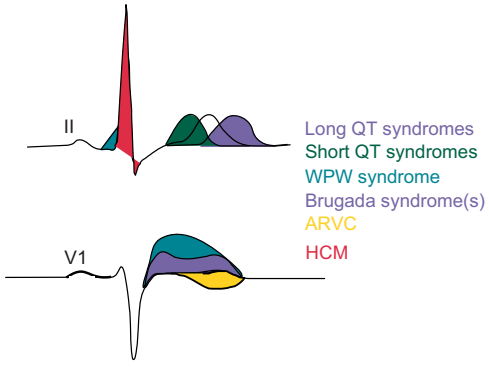

Figure 4 Electrocardiograms (ECGs) in long OT syndrome, short OT syndrome, Brugada syndrome, arrhythmogenic right ventricular cardiomyopathy, hypertrophic cardiomyopathy WPW syndrome.

Sustained monomorphic ventricular tachycardia

Expert consensus recommendations on SMVT

(1) A 12-lead ECG should be recorded during sustained VTs whenever possible and practical. I LOE B
(2) For patients with newly diagnosed sustained monomorphic VT (SMVT) and no evidence of SHD on resting ECG or echocardiography
  (a) cardiac MRI may provide additional information IIb, LOE B
  (b) signal-averaged ECG may provide additional information IIb. LOE C
  (c) exercise testing may provide additional information IIb. LOE B
(3) For patients with a wide QRS complex tachycardia in whom the diagnosis is uncertain, an invasive EPS should be considered to identify the tachycardia mechanism. IIa LOE C
(4) For patients with SHD and SMVT, an ICD is recommended in the absence of contraindications. I LOE A
(5) For patients with SHD and recurrent SMVT, specific treatment of Vas with AADs (amiodarone, mexiletine, or sotalol), catheter ablation, and/or antitachycardia pacing (ATP) from an ICD should be considered in addition to an ICD. Treatment of the underlying SHD or ischaemia will in most cases not be sufficient to prevent monomorphic VT (MMVT) recurrences. IIa LOE B
(6) For patients with an ICD as primary prophylaxis, programming to a long VT detection interval and a high VF detection rate should be considered. IIa LOE A.

Monomorphic VT is defined as sustained when lasting longer than 30 s or requires earlier intervention due to haemodynamic instability.[89] Most commonly, sustained MMVT occurs in the setting of diseased myocardium, but may also be idiopathic, occurring in patients with no detectable myocardial disease.

Importance and prognosis

No structural disease—idiopathic ventricular tachycardia

In the absence of SHD, SMVT is generally associated with an excellent prognosis.[60,90–92] The presence of syncope or PMVT is unusual in the absence of SHD or an inherited arrhythmia syndrome. Rarely, idiopathic VT can have a malignant clinical course, usually with a very rapid rate or a short initiating coupling interval.[93]

Sustained monomorphic ventricular tachycardia in patients with structural heart disease

The large majority of patients with SMVT who present for therapy have significant SHD. The most frequent aetiology is ischaemic heart disease, comprising 54 – 59% of patients for whom an ICD is implanted[94] or who are referred for catheter ablation.[92] Sustained VT is associated with increased mortality risk in the setting of reduced ventricular systolic function.[95–98] The mortality risk attributable to VT in patients with preserved ventricular function is less well defined. Implantable cardioverter-defibrillator shocks are also associated with inherent risk and multiple studies have demonstrated that defibrillator shocks, both appropriate and inappropriate, are associated with increased mortality and reduced quality of life.[78,99–103] The association of ICD shocks and total mortality appears mainly to be a function of worsening cardiac disease rather than a specific consequence of shocks. Programming of ICDs with long VT detection times prior to the delivery of antitachycardia therapies and rapid VF detection rates reduces shocks and improves mortality in patients receiving an ICD for primary prophylaxis.[77] The value of programming a long VT detection time in patients with a history of sustained MMVT or VF is less certain. Although it has not been determined whether suppression of VT by either pharmacological means or catheter ablation improves survival in patients with sustained MMVT, treatment to avoid recurrent symptoms is appropriate and these therapies may improve survival in patients presenting with recurrent VT storm.[104,105]

Diagnostic evaluation

Electrocardiogram

The key distinction to make in the investigation of SMVT is to discern the presence or absence of SHD, see Table 2. A 12-lead ECG helps to confirm the diagnosis of VT,[106–110] provide important insight into the underlying mechanism (Tables 3 and 4), identify the presence of SHD,[111] and suggest the site of origin. This is especially important when catheter ablation is planned.[112,113] A resting ECG should be performed in all patients with sustained VT. The presence of Q-waves or fragmentation of the QRS complex suggests underlying structural disease (Figure 5).[114,115]

Cardiac imaging

The presence of myocardial scar is more likely to be associated with poorly tolerated VT, haemodynamic collapse, degeneration to VF, and sudden death. In most cases, echocardiography can adequately demonstrate myocardial structure and function. If echocardiography is normal, more detailed imaging using cardiac MRI can exclude less clearly evident myocardial scar, arrhythmogenic RV cardiomyopathy, non-ischaemic cardiomyopathy with preserved EF, HCM, or cardiac sarcoidosis.[116] It may also be helpful to reevaluate ventricular function when a patient with previously known SHD presents with SMVT.

Signal-averaged electrocardiogram

An SAECG, recorded during the baseline rhythm may permit the identification of slow myocardial conduction by recording low-amplitude potentials but does not help in scar localization.

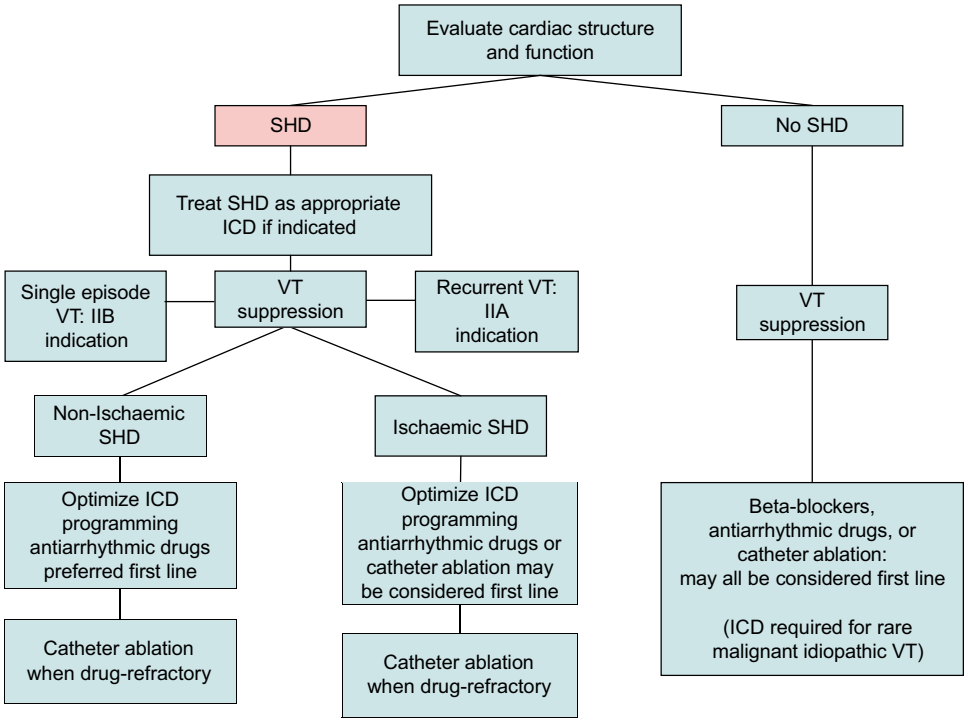

Figure 5 Sustained monomorphic ventricular tachycardia evaluation and management. ICD = implantable cardioverter-defibrillator; SHD = structural heart disease; VT = ventricular tachycardia.

A negative test has been associated with better prognosis[117] but with only modest positive predictive value.[118] The SAECG may be most useful in identifying ARVC where a positive test forms a minor criterion in the diagnostic component for this disorder.[39,119]

Invasive electrophysiological study

Patients presenting with syncope or sustained palpitations who have evidence of myocardial scar as well as those with a wide-complex tachycardia for whom the diagnosis of VT is not certain may benefit from a provocative EPS. Although the standalone negative and positive predictive values of this testing are limited,[88,120] inducible SMVT is highly associated with recurrent VT and may provide clues to the cause of syncope or other symptoms suggestive of a VA. Electroanatomical mapping of the RV has been used to identify otherwise unapparent RV scar.[121,122]

Testing for ischaemia

Transient myocardial ischaemia is an uncommon sole cause of recurrent sustained VT that is monomorphic. Most patients with coronary artery disease who develop sustained MMVT have a fixed region of myocardial scar that is a sequela of prior MI, often occurring many years earlier.[95–97] Patients with a new presentation of sustained MMVT should have a thorough evaluation to define the presence or absence of underlying heart disease, which includes echocardiography, exercise testing, and stress/perfusion imaging. For most patients where the coronary artery disease is suspected as the underlying diagnosis, coronary angiography should be considered.[123–126] However, treatment of ischaemia alone is unlikely to prevent recurrences of MMVT. Cardiac MRI and positron emission tomograph - computed tomography may provide evidence for myocardial scar that is not evident with other imaging modalities and may be especially useful to differential occult SHD from idiopathic VT.[127]

Treatment

Acute therapy for sustained ventricular tachycardia

Ventricular fibrillation should be immediately defibrillated using a non-synchronized mode. The use of intravenous amiodarone has been associated with a higher survival probability than when lidocaine is administered to patients resuscitated from VF.[128] The acute treatment of sustained VT is largely based on the patient's symptoms and haemodynamic tolerance of the arrhythmia. For patients with sustained MMVT who are unconscious or who have experienced haemodynamic collapse, direct current cardioversion synchronized to the QRS on the surface ECG should be immediately performed. Patients who are conscious but have marked hypotension or profound symptoms from VT should be given prompt intravenous sedation and then cardioverted. A trial of intravenous lidocaine (1 mg/ kg) may be given as preparation is made for sedation, though the efficacy for termination of sustained VT is only "15%.[129] For patients with sustained VT who are haemodynamically stable or have only mild symptoms, a 12-lead ECG should be recorded and carefully analysed before therapy is initiated. For patients without SHD and a QRS morphology suggesting an idiopathic outflow tract VT, a trial of a short-acting intravenous beta-blocker may be useful to terminate VT. However, for patients with SHD with sustained VT, the most efficacious pharmacological agent is intravenous amiodarone.[129] This agent may be associated with hypotension if administered rapidly, usually

via a central venous catheter. These patients must be continuously observed and intravenous sedation and cardioversion should be readily available and applied if symptoms worsen or haemodynamic deterioration occurs. Patients with TdP VT should be cardioverted if the arrhythmia is sustained. For those with recurrent non-sustained TdP VT, atrial pacing at a rate of at least 90 b.p.m. is highly effective to prevent recurrences. Intravenous isoproterenol can be useful to sup-press recurrent TdP or VF in patients with the Brugada syndrome (BrS).

Pharmacological therapy for idiopathic ventricular tachycardia

The indication for treatment of idiopathic VT derives largely from the symptom burden. Beta-blockade and non-hydropyridine calcium channel blockade are low-risk therapies which have modest effectiveness.[130,131] Antiarrhythmic drug therapy using sotalol, flecainide, mexiletine, propafenone, or amiodarone is more effective, but carries the potential for pro-arrhythmic risk, and a greater side-effect profile.[132] Catheter ablation for idiopathic ventricular tachycardia For focal VT with an ECG pattern highly suggestive of right ventricular outflow tract (RVOT) VT,[113] catheter ablation is highly successful and carries low procedural risk. The most frequent limitation is the lack of VT inducibility during the procedure. The success rate of ablation of outflow tract VTs arising from non-RVOT sites may be somewhat lower and may involve greater procedural complexity but should be considered. Fascicular VT and focal VTs from non-outflow tract sites such as the LV or RV papillary muscles may also be amenable to catheter ablation, with the principal limitation being inducibility of the arrhythmia and achieving adequate mapping and catheter contact to abolish the VT.[3,44–58,71,79,132–134] In addition, it should be appreciated that papillary muscle VT has a significant risk of recurrence after initially apparent successful catheter ablation.

Pharmacological therapy for ventricular tachycardia with structural heart disease

The presence of SHD increases the risk of pro-arrhythmia from membrane-active AADs, such that they are generally used only with the added protection afforded by an ICD.[43] There is no evidence that antiarrhythmic therapy alone improves survival in patients with sustained MMVT.[135–137] Sotalol has been demonstrated to reduce the frequency of sustained MMVT recurrences[138,139] in patients with SHD. In the OPTIC trial, sotalol reduced all-cause ICD shocks at 1 year from 38.5 to 24.3% [hazard ratio (HR) 0.61, P ¼ 0.055].[138] A smaller study suggested that sotalol was inferior to metoprolol.[140] In these trials, sotalol was associated with a safety profile which was similar to that of beta-blockers alone. In the presence of a normal or near-normal QT interval at baseline, and normal or near-normal renal function, sotalol is a reasonable first pharmacological therapy to suppress recurrences of sustained MMVT. In comparison with beta-blocker therapy alone, amiodarone has been demonstrated to markedly reduce recurrent appropriate ICD therapy during 1-year follow-up when used for secondary prophylaxis (HR 0.30, P , 0.001).[138] However, longer term use of amiodarone for secondary prophylaxis is associated with high rates of VT recurrence and serious adverse effects and may increase mortality compared with placebo.[141,142] Other AADs that have been used to reduce recurrences of sustained MMVT include dofetilide[143] and the combination of mexilitene and amiodarone.[144] Dofetilide is not Food and Drug Administration approved for use in VAs and is not available in many parts of the world. Limited experience is also present with combinations of sotalol and either quinidine or procainamide,[145] or amiodarone plus mexiletine plus either quinidine or procainamide.[146]

Implantable cardioverter-defibrillator implantation and programming

An ICD is indicated for most patients with SHD and sustained VT.[64] Implantable cardioverter-defibrillator implantation has been demonstrated to improve survival in patients with VT and reduced systolic function.[95–97] Implantable cardioverter-defibrillator implantation is indicated for patients with sustained MMVT and myocardial scar, even when systolic function is normal or near-normal[1] based upon extrapolation from randomized trials including patients with low EF. Although evidence of mortality benefit is scant in the absence of severe systolic dysfunction, ICD implantation may simplify management and follow-up of these patients.

Catheter ablation

Catheter ablation for VT is an important non-pharmacological alternative or adjunct to AAD therapy.[3] Catheter ablation has been demonstrated to reduce appropriate ICD shocks for patients with ischaemic cardiomyopathy when utilized after a first presentation with VA.[147] In patients with prior MI, reduced EF, and haemodynamically stable VT, catheter ablation significantly reduces recurrences of VT, with the greatest benefit in patients with EF . 30%.[148] Cooled tip catheter ablation was superior to AAD therapy for reducing recurrences of sustained MMVT in patients with ischaemic heart disease who had failed amiodarone.[149] Although catheter ablation reduces recurrences of sustained MMVT in patients with ischaemic cardiomyopathy, a reduction in mortality has yet to be demonstrated.[150] Catheter ablation has also been successfully used in patients with non-ischaemic cardiomyopathy where the ablation target is often on the epicardial surface of the ventricles and the procedure may be more complex.[151–156] The long-term effectiveness of catheter ablation for non-ischaemic cardiomyopathies has been less well studied than for ischaemic cardiomyopathies.

While either catheter ablation or AAD therapy may be used as a first-line therapy for VT in the setting of prior MI, catheter ablation is the preferred therapy for patients presenting with incessant sustained MMVT. While encouraging, the long-term success of catheter ablation for sustained MMVT in patients with non-ischaemic cardiomyopathy is less well defined than in patients with ischaemic heart disease.[157] Thus, AAD therapy is often used as first-line therapy with catheter ablation reserved for those with recurrent VT while receiving medications. Procedural complications with catheter ablation of sustained

MMVT in the presence of SHD have generally been reported in ,5% of patients and may include atrioventricular (AV) conduction block, cardiac perforation, stroke/transient ischaemic attack, heart failure, or death, usually in ,3% of patients.[158]

Sustained polymorphic ventricular tachycardia/ ventricular fibrillation

Expert consensus recommendations on sustained polymorphic VT/VF

1. Patients with polymorphic VT or VF should be thoroughly evaluated for the presence of SHD, inherited arrhythmia syndromes, early repolarization, coronary artery spasm, and pro-arrhythmic effects of medications using:
   a. Twelve-lead ECG during the arrhythmia (when feasible) and during normal rhythm. I LOE C
   b. Echocardiography. I LOE B
   c. Coronary arteriography. I LOE B
2. Specific antiarrhythmic therapies, e.g. quinidine in patients with idiopathic VF, sodium channel blocker therapy in patients with long QT syndrome (LQTS) III, intensive autonomic inhibition in patients with catecholaminergic VTs, or quinidine in BrS, should be considered in close cooperation with a specialist in these diseases to reduce the risk of recurrence as an adjunct to—and rarely as an alternative to—defibrillator therapy in survivors of polymorphic VAs. Detailed guidance can be found in the APHRS/EHRA/HRS document on inherited arrhythmia syndromes. IIa LOE B
3. For patients with VT/VF storm, reversible factors such as electrolyte abnormalities, pro-arrhythmic drugs, ischaemia, and decompensated chronic heart failure should be corrected. I LOE C
4. Pharmacological suppression of VT/VF storm with beta-adrenergic blockers, amiodarone, and/or lidocaine should be considered in all patients. IIa LOE C
5. For patients with VT/VF storm in whom pharmacological suppression has not been effective and who are unstable, neuraxial modulation, mechanical ventilation, catheter ablation, and/or anaesthesia may be considered. IIb LOE C
6. Catheter ablation of VTs or a triggering focus of VF should be considered in patients with VT/VF storm when adequate experience is available. IIa LOE C
7. For patients with VT/VF storm and significant SHD, implantation of a LV assist device (LVAD) or heart transplant evaluation should be considered and discussed early after the initial event. IIa LOE C

Polymorphic ventricular tachycardia is defined as a ventricular rhythm faster than 100 b.p.m., with clearly defined QRS complexes that change continuously from beat to beat indicating a changing ventricular activation sequence. The QT interval can either be normal or prolonged during intervening sinus rhythm in patients with PMVT. When PMVT occurs in the setting of a prolonged QT interval and has a distinctive pattern where the QRS complexes appear to be twisting around the isoelectric baseline, the arrhythmia is referred to as TdP.[159] In cases of TdP, a long – short ventricular cycle length typically characterizes the initiating sequence, and the QT interval is almost always prolonged during sinus rhythm.[160] Torsades de pointes VT is strongly associated with drugs or electrolyte abnormalities that delay repolarization. Thus, the occurrence of this arrhythmia should always prompt a search for precipitating factors that should be corrected.

Polymorphic VT has more than one morphologically distinct QRS complex occurring during the same episode of VT, but the QRS is not continuously changing. Ventricular fibrillation differs from PMVT in that VF is a chaotic tachycardia without consistently identifiable QRS complexes. It is important to distinguish PMVT, TdP, and VF because the mechanisms and the ultimate therapies for each may differ.

Importance and prognosis

Following cardiopulmonary resuscitation and protection of cerebral function in a patient with VF or sustained PMVT, the initial diagnostic step is to exclude an acute coronary syndrome (ACS) or MI.[161–165] An ischaemic cause of these arrhythmias is very common and emergent coronary angiography and revascularization may significantly improve prognosis.[166] In the absence of evidence for myocardial ischaemia, the structure and function of the ventricles should be assessed with echocardiography. A scheme for a diagnostic workup is shown in Figure 6. Patients who have impaired LV systolic function after MI (LVEF, 0.35) are at higher risk of sudden death in the first 3 months and may benefit from a wearable defibrillator. The LV function should be reassessed 40 days after MI to determine whether there is an indication for an ICD. Patients who are treated with coronary revascularization after MI are also at risk, especially if the LVEF is ,0.35. These patients may also benefit from a wearable defibrillator with reassessment of LV function and the indication for an ICD at 90 days post-revascularization.

Patients without structural heart disease

Polymorphic VT or VF in the absence of SHD suggests the presence of an inherited arrhythmia syndrome such as CPVT, the long QT, short QT, Brugada, or ERS (see Table 5).[4] A resting 12-lead ECG should be recorded as close as possible to the VA episode as the chances of making the correct diagnosis is highest at this time. Recording of all 12 ECG leads over a longer period may be very useful to identify the morphology and location of PVCs that

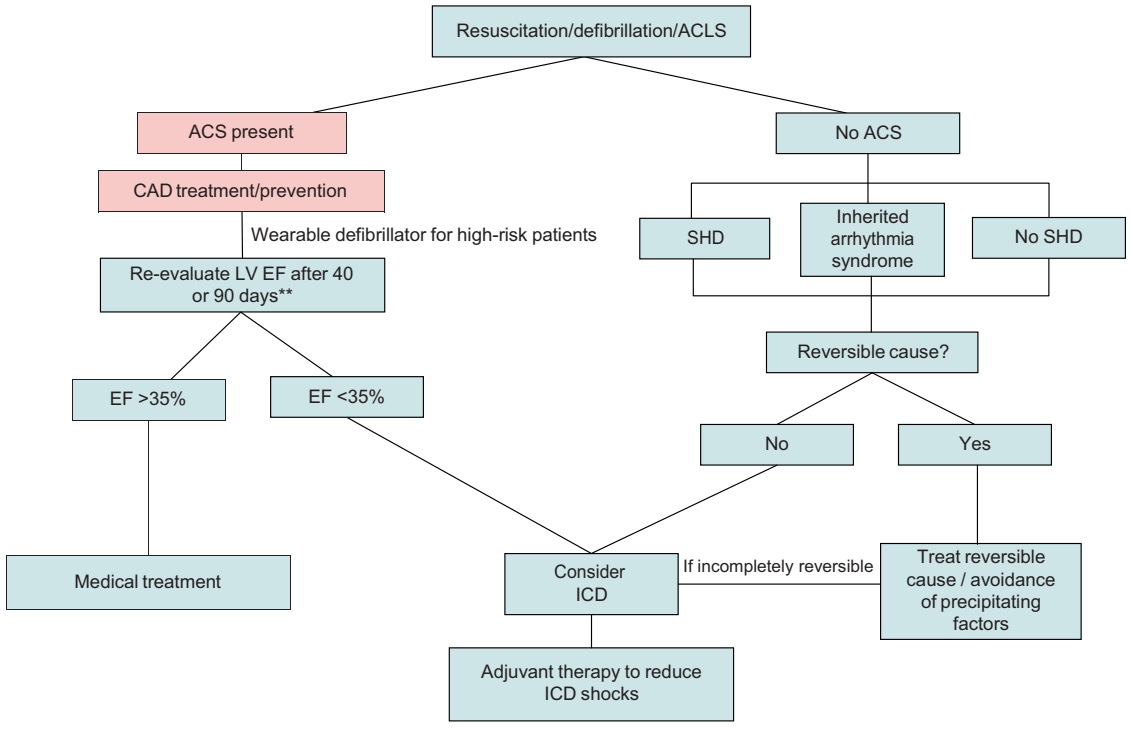

Figure 6 Sustained polymorphic ventricular tachycardia / ventricular fibrillation. **LV function should be reassessed at 40 days after MI or 90 days after revascularization. ACLS = advance cardiovascular life support; ACS = acute coronary syndrome; CAD = coronary artery disease; ICD = implantable cardioverter defibrillator; LVEF = left ventricular ejection fraction; SHD = structural heart disease.

trigger PMVT or VF. Use of the Valsalva manoeuvre or high precordial leads may improve the sensitivity of the 12-lead ECG for detecting such triggers.[167,168] In addition, the QRS and QT changes occurring after extrasystoles[169] as well as during standing[170] may help to identify J-wave abnormalities or abnormalities of the QT interval. Ambulatory monitoring may help identifying QTc prolongation during sleep. The role of genetic testing has been recently reviewed[4] and plays an important part in the evaluation of patients in whom an inherited arrhythmia syndrome is suspected

Table 5 Conditions that can cause PVT/VF in the absence of SHD and potential therapies

Clues	Tests to Consider	Diagnoses	Therapies
Long QT/T-wave alternans	ECG/Monitor	Congenital LQTS	Beta-blockers/stellatectomy
TdP pattern	Epinephrine challenge		Avoid QT prolonging drugs
History of seizures	Genetic testing		Mexilitine/flecainide (LTQ3)
Specific trigger (loud noise)			Pacemaker/ICD
Long QT/T-wave alternans	ECG/Monitor	Acquired LQTS	Mg^{++}/K^{+}
TdP pattern			Stop offending drug
Renal failure			Temporary pacing
New medication or drug abuse			
AV block	ECG/Monitor	Bradycardia	Pacemaker
Incomplete RBBB with STE in leads V1 – V2	ECG	BrS	Isoproterenol/quinidine
Fever	Drug challenge		Anipyretic
	Genetic testing		Ablation
			ICD
Monomorhic PVC trigger	ECG/Monitor	Focal PVC origin	Ablation/ICD
J-point elevation	ECG	Early repolarization	ICD
Ventricular pre-excitation	ECG	WPW	Ablation
Short QT interval	ECG	Short QTS	ICD
Bidirectional VT pattern exercise-induced	Digoxin level	CPVT	Stop digoxin
	Exercise test	Andersen-Tawil syndrome	Beta-blockers/CCBs/flecainide
	Genetic testing	Digoxin toxicity	ICD
STE and chest pain	Proactive testing	Coronary spasm	Vasodilators/coronary stent ICD
Short-coupled PVC trigger	ECG/Monitor	Idiopathic	ICD

BrS = Brugada syndrome; CCBs = calcium channel blockers; CPVT = catecholaminergic polymorphic ventricular tachycardia; ICD = implantable cardioverter-defibrillator; LQTS = long QT syndrome; PVC = premature ventricular complex; RBBB = right bundle branch block; short QTS = short QT syndrome; STE = ST elevation; TdP = torsade de pointes; VT = ventricular tachycardia; WPW = Wolff-Parkinson-White (syndrome).

Table 6 Conditions that can cause PVT/VF in patients with SHD and potential therapies

Clues	Tests to consider	Diagnoses	Therapies
ECG evidence of ischaemia, injury, or infarction	Stress test	Coronary artery disease	Coronary revascularization
Angina/heart failure Prior coronary revascularization	Coronary angiography Echo/MRI	Post-myocardial infarction	Beta-blockers Sotalol/amiodarone Intra-aortic balloon pump ICD
Heart failure	Echo/MRI	Dilated non-ischaemic cardiomyopathy	Avoid cardiotoxins
Alcoholism	Coronary angiography		Beta-blockers Sotalol/amiodarone/ICD
Systolic murmur Syncope Family history of sudden death left ventricular hypertrophy	Echo/MRI Genetic testing	Hypertrophic cardiomyopathy	Beta-blockers Sotalol/amiodarone/ICD
Family history of sudden death Epsilon wave	Echo/MRI Genetic testing	Arrhythmogenic cardiomyopathy	Beta-blockers Sotalol/amiodarone/ICD
Pulmonary symptoms Dermatitis	Echo/MRI Chest CT Tissue biopsy	Sarcoidosis	Immunosuppresion Beta-blockers Sotalol/amiodarone/ICD
Recent flu-like illness	Serology Cardiac biopsy Echo/MRI	Myocartitis	Beta-blockers Sotalol/amiodarone/ICD
Mid-systolic click Systolic murmur Marfanoid body habitus	Echo/MRI	Mitral valve prolapse	Beta-blockers Sotalol/amiodarone/ICD

CT = computed tomography; ICD = implantable cardioverter-defibrillator; MRI = magnetic resonance imaging.

and for the family members of patients with these syndromes.

Exercise testing. In the setting of a normal resting 12-lead ECG, the occurrence of polymorphic PVCs and bidirectional VT during exercise suggests the diagnosis of CPVT.[171–175] Exercise testing may be helpful to evaluate the efficacy of beta-blocker in patients with CPVT. Exercise testing is also useful in the diagnosis of LQTS when the QT is of borderline duration at rest.[176–178] The absence of QTc shortening at higher heart rate favours the diagnosis of long QT.[176–178] The recovery phase of exercise testing may unmask BrS or LQTS patients with a normal ECG at baseline.[179,180]

Pharmacological testing. Different tests have been proposed to evaluate polymorphic VT/VF in the absence of SHD.[181] The role of these provocative tests for unmasking inherited arrhythmia syndromes has been recently extensively reviewed.[4] Intravenous sodium channel blocker challenge[167] may unmask the BrS. Epinephrine challenge may help unmasking the LQTS, especially LQTS Types 1 and 2.[182–184] Isoproterenol challenge has been proposed to identify the early stages of ARVC, though this is rarely used in modern practice.[185] It can also be an option for familial screening of CPVT when stress testing is negative. Adenosine may be used to unmask pre-excitation in patients with the Wolff-Parkinson-White (WPW) syndrome where the diagnosis is unclear during baseline electrocardiographic recordings.[186]

Patients with structural heart disease

The resting ECG evidence of ischaemia, injury, or infarction - see Table 6.

Acute coronary syndromes and old Q-wave MI are the principal causes of PMVT/VF associated with a normal QTc interval.[165] In addition, transient myocardial ischaemia may induce PMVT or VF, especially during conditions of stress or exercise. The presence of ST depression, elevation, or Q-waves in a patient with PMVT or VF should lead to prompt coronary angiography. In the absence of acute ECG evidence of ischaemia or injury, an invasive or noninvasive evaluation of coronary artery perfusion is indicated. It should be noted that LV and RV function may be depressed immediately after cardiac arrest and may markedly improve over a period of days to weeks. A prolonged or fragmented QRS (fQRS) is a predictor of SCD, appropriate ICD shocks, and all-cause mortality in patients with ischaemic cardiomyopathy.[187,188] The presence of fQRS in patients with left bundle branch block (LBBB) is of particular prognostic significance.

The resting ECG may strongly suggest the diagnosis of a dilated cardiomyopathy when the QRS is prolonged or ARVC when epsilon waves or localized QRS duration $\geq$110 ms are recorded in surface leads V1, V2, or V3, with inverted T-waves in V2 and V3.[4] The presence of PVCs with a LBBB morphology and QRS axis of 2908 to +1108 also suggests ARVC. In HCM patients, LVH may be associated with pathological Q-waves, giant ($\geq$10 mm) T-negative wave, or ST depression.

Treatment

Implantable cardioverter-defibrillator therapy

The ICD is the primary therapy for patients with sustained PMVT or VF when there is no completely reversible cause.[4,189]

Antiarrhythmic drug therapy

While beta-adrenergic blockers may help to stabilize patients during acute ischaemia, the primary therapy for ischaemia-induced PMVT or VF is coronary revascularization. Beta-blockers are recommended for patients with LQTS and CPVT.[4,190–192] In small case series, quinidine has been shown to be effective for preventing polymorphic VT/ VF recurrence in idiopathic VF, BrS, short QT syndrome, and ERS.[193–196] Although calcium channel blockers (verapamil) in combination with beta-blockers have been proposed for treatment of CPVT,[197,198] their efficacy seems quite limited. Flecainide may be considered in association with beta-blockers in case of recurring polymorphic VT/VF in the setting of CPVT[199] and LQT3.[200]

Catheter ablation

Catheter ablation may be considered for patients with recurrent PMVT or VF when there is a consistent PVC morphology (or a limited number of morphologies) that trigger these arrhythmias.[201–208] When a patient has polymorphic VT/VF induced by the same PVC morphology, the target of catheter ablation is usually a rapidly firing focus situated in the Purkinje network of either the RV or LV.[204] These Purkinje fibres may induce PMVT or VF in patients without SHD or in patients with prior MI.[204,206] Purkinje network triggers of polymorphic VT or VF are characterized by episodes of frequent arrhythmias usually with the same initiating QRS morphology that is relatively narrow. Patients presenting with this syndrome should be monitored, ideally with continuous 12-lead electrocardiography, to identify the triggering PVC morphology. If possible, catheter ablation should be performed during a period of increased arrhythmia frequency to maximize the chances of recording electrograms from the triggering focus. In cases of recurrent polymorphic VT/VF in patients with the BrS, an epicardial substrate involving the RVOT may be amenable to catheter ablation.[209,210] Even when catheter ablation of foci triggering PMVT or VF has been successful, an ICD remains indicated.[204]

The resuscitated cardiac arrest survivor

Patients who are resuscitated from cardiac arrest must be rapidly evaluated for the presence of SHD, an inherited arrhythmia syndrome, a triggering VA focus, or a non-cardiac cause (see Figure 6). Immediately following resuscitation, the clinical focus must be to minimize cerebral damage, often with the use of therapeutic hypothermia.[161–164] Evidence of MI or ischaemia usually requires prompt coronary angiography and revascularization.[166] In addition, the function of both ventricles should be evaluated with echocardiography. These considerations have been discussed in detail in the preceding sections.

Ventricular tachycardia/ventricular fibrillation storm

Ventricular tachycardia/ventricular fibrillation storm represents a true medical emergency that requires a multidisciplinary approach to care (Table 7).[70,211–231] Ventricular tachycardia/ventricular fibrillation storm is generally defined as the occurrence of three or more episodes of VT or VF within 24 h, requiring either ATP or cardioversion/defibrillation. Upon hospitalization, the patient's risk should be stratified according to haemodynamic tolerance of the clinical VT and co-morbidities.[211] High-risk patients should be admitted to an intensive care unit and evaluated for sedation, intubation, and mechanical haemodynamic support.

Acute treatment is aimed to reduce VA episodes and maximize the chances of survival. For patients with an ICD, the detection criteria and therapies should be reprogrammed to minimize inappropriate shocks,[77] prevent shocks for potentially self-terminating VTs, and favour ATP therapies when feasible. Even though triggers of VT/VF storm are only rarely found,[70] patients should be screened for such reversible causes as electrolyte imbalances, ischaemia, acute valvular disease, and pro-arrhythmic drugs.

Antiarrhythmic drugs should be used for the acute phase to stabilize the patient.[214,223] Beta-blockers have improved short-term outcome.[212] Short-acting drugs, such as esmolol, might be considered in severely compromised patients, when an acute hypotensive effect is potentially likely.[228] Even in patients already on oral beta- blocker therapy, intravenous administration of beta-blockers may help to reduce further ES episodes.[213] Beta-blockers can be combined with amiodarone to improve rhythm stability.[212] Because intravenous lidocaine is relatively ineffective for termination of haemodynamically stable VTs and its prophylactic use has been associated with higher mortality,[214] this agent is a third choice drug for short-term treatment. In patients with severely impaired LV systolic function, the use of AADs should be weighed against the risks of worsening congestive heart failure and pro-arrhythmia.

Table 7 Management of VT/VF storm

Intensive care unit admission
Device reprogramming
Correct underlying problems (ischaemia, electrolyte disturbances, pro-arrhythmic drugs)
Beta-blockade
Antiarrhythmic therapy
Sedation, intubation/deep sedation
Mechanical haemodynamic support (intra-aortic balloon pump)
Neuraxial modulation (thoracic epidural anesthesia, cardiac sympathetic denervation)
Catheter ablation (any time it is feasible)

Catheter ablation should be considered early after hospitalization (within 48 h) in patients with recurrent shocks despite acute treatment after the correction of metabolic, respiratory, and circulatory imbalances and a trial of AADs. Catheter ablation has been demonstrated to restore stable sinus rhythm maintenance during 7 days of in-hospital monitoring.[104] Complete elimination of VT inducibility during programmed electrical stimulation after ablation is associated with reduced VT recurrence during long-term follow-up; prevention of clinical VT inducibility has also been associated with a significant reduction of cardiac mortality.[104] Beneficial effects of catheter ablation on VT recurrences and survival are evident both in low- and high-risk patients.[211] For patients who cannot be stabilized pharmacologically, neuraxial modulation, such as left cardiac sympathetic denervation (CSD) and spinal cord stimulation, may significantly reduce arrhythmias burden.[212,215,216] This may allow stabilization before catheter ablation or LVAD implantation. Since VT/VF storm may be an indicator of poor prognosis,[217–221] especially in patients with advanced SHD, early consultation with heart failure specialists should be considered to evaluate the advisability of mechanical cardiac support or cardiac transplantation.

Ventricular arrhythmias in patients with a left ventricular assist device

Left ventricular assist devices can be used as a bridge to cardiac transplantation or as a permanent, destination therapy for congestive heart failure. Despite their effectiveness, VAs occur in 25 – 59% of patients after LVAD implantation and are associated with a markedly increased risk of ICD shocks and overall mortality.[230–241] Pre-operative VAs are the strongest predictor of VT or VF after LVAD implantation (HR 13.7).[233] For patients with pre-operative VAs, the risk of post-operative VT or VF is "50% within the first 18 months after LVAD implantation.[232,233,242] Although LVADs provide haemodynamic support during VAs, patients may experience palpitations, dyspnoea, and right heart failure. Post-operative VT and VF in LVAD recipients tend to be refractory to AAD therapy and may require catheter ablation.[230,237,243–247] Since many forms of VT in patients with non-ischaemic dilated cardiomyopathy have critical zones of reentrant circuits in the subepicardial myocardium, the postoperative pericardial scarring produced by LVAD implantation renders post-operative epicardial access for ablation very difficult. Thus, patients with non-ischaemic dilated cardiomyopathies who have pre-operative VT may benefit from concomitant surgical ablation of VT at the time of LVAD implantation.[248,249]

Ventricular arrhythmias in congenital heart disease

Expert consensus recommendations on VAs in CHD

(1) Electrophysiological testing is indicated in adults with unexplained syncope and 'high-risk' CHD substrates associated with primary VAs or poorly tolerated atrial tachyarrhythmias, such as tetralogy of Fallot, transposition of the great arteries with atrial switch surgery, or significant systemic or single ventricular dysfunction. I LOE C.

(2) In patients with CHD who have an implanted defibrillator and recurrent MMVT, VT storm, or multiple appropriate shocks, additional therapy including ATP, treatment with antiarrhythmic agents, and/or catheter ablation is indicated as adjunctive therapy to reduce the arrhythmia episodes. These therapies should be decided and initiated in an adequately trained centre. I LOE C

(3) In patients with CHD and sustained VAs who require surgical haemodynamic interventions, pre-operative electrophysiological testing and intra-operative ablation should be considered when adequate expertise is available. IIa LOE C

(4) Patients with good ventricular function, who are asymptomatic, have normal or near-normal ventricular haemodynamics and low-risk subtypes of CHD may reasonably be followed without advanced therapy and invasive evaluation despite the presence of moderately frequent and/or complex ventricular ectopy. IIb LOE C

(5) Catheter ablation may be appropriate for patients with CHD who have newly recognized or progressive ventricular dysfunction and a high burden of monomorphic ventricular ectopy. IIb LOE C

Ventricular arrhythmias are common in patients with CHD, often encountered as asymptomatic findings of PVCs and NSVT [250–254] on routine monitoring studies, and sometimes requiring treatment.[255] Ventricular arrhythmias may occur in any congenital defect, but the most common is tetralogy of Fallot and its variants, a malformation that has a long history of surgical repair, is prevalent, and often arrhythmogenic (Table 8, Figure 7). A recent consensus document addresses recognition and management details in greater detail.[256,257]

The connection between PVCs or NSVT, SMVT, and risk of SCD is not well established in CHD patients, although occurrence of sustained VT is generally considered to imply an elevated risk of SCD. Sustained VT is a rare clinical arrhythmia in CHD, with relatively few cases reported in large series in recent decades. Sudden cardiac arrest causes approximately one-fifth of the mortality in adults with CHD,[258,259] with greater risk noted in certain types (e.g. tetralogy of Fallot, Ebstein's disease, left-sided obstructive disease).[260] However, the annual mortality rates are low compared with adult populations (0.1 – 0.3% per patient-year).[261–264]

Patients with CHD deemed at elevated risk for SCD are considered for ICD implantation, although this may be

Table 8 Arrhythmia considerations in selected congential heart disease

	Ventriculotomy	RV pressure/volume overload	SVT	VT	Bradycardia	Systemic ventricle
Tetralogy of Fallot	+	++	+++	++	+	LV
Atrial switch for d-TGA	+/2	++	+++	+	++	RV
Ebstein's disease	+/2	++	+++	+	+	LV
Arterial switch for d-TGA	+/2	2	+	+	2	LV
Single ventricle	2	++	+++	+	++	Either
Simple repairs	2	2	2	2	2	LV

d-TGA, transposition of the great vessels.
SVT includes atrial reentry in addition to accessory pathway mediated and atrioventricular nodal reentrant tachycardia.
Bradycardia includes relative frequency of heart block and significant sinus node dysfunction that may require pacing/limit drug therapy.
LV = left ventricle; RV = right ventricle; SVT = supraventricular tachycardia; VT = ventricular tachycardia.

difficult in small patients or those with malformations that limit lead placement. Indications for ICD implantation in CHD are largely based on expert consensus. Risk assessment strategies,[265–270] descriptions of implantation techniques,[271] and current guidelines for ICD implantation in CHD[1,6,272,273] are available from other sources and not discussed here. A recent consensus document addresses recognition and management details in greater detail.[256,257]

Indications for programmed ventricular stimulation in patients with congenital heart disease

Inducible VAs (VF, MMVT, or PMVT) predict increased risk of both arrhythmia event and overall mortality in CHD patients carefully selected for programmed ventricular stimulation.[265,266,274] Selection to enhance risk may include arrhythmia symptoms[275] (sustained palpitations/syncope) and/or combinations of less robust predictors, such as older age, QRS duration .180 ms, complex ventricular ectopy, RV or LV dysfunction, and depressed exercise tolerance.[276,277] In older patients with CHD[274] and in patients with tetralogy of Fallot,[265] positive ventricular stimulation is associated with increased risk of ICD use, sudden death, and poor haemodynamic outcome, resulting in a positive predictive value of 20 – 60%.[266,278] In contrast, EP testing in unselected and younger patient groups with CHD appears to have less predictive value.[267,268,279] Supraventricular arrhythmia, particularly atrial tachycardia, is common in patients with CHD[255] and may contribute a substantial portion of inappropriate ICD therapies,[280] suggesting that assessment for atrial tachycardia should be included when EPSs are performed in these patients.

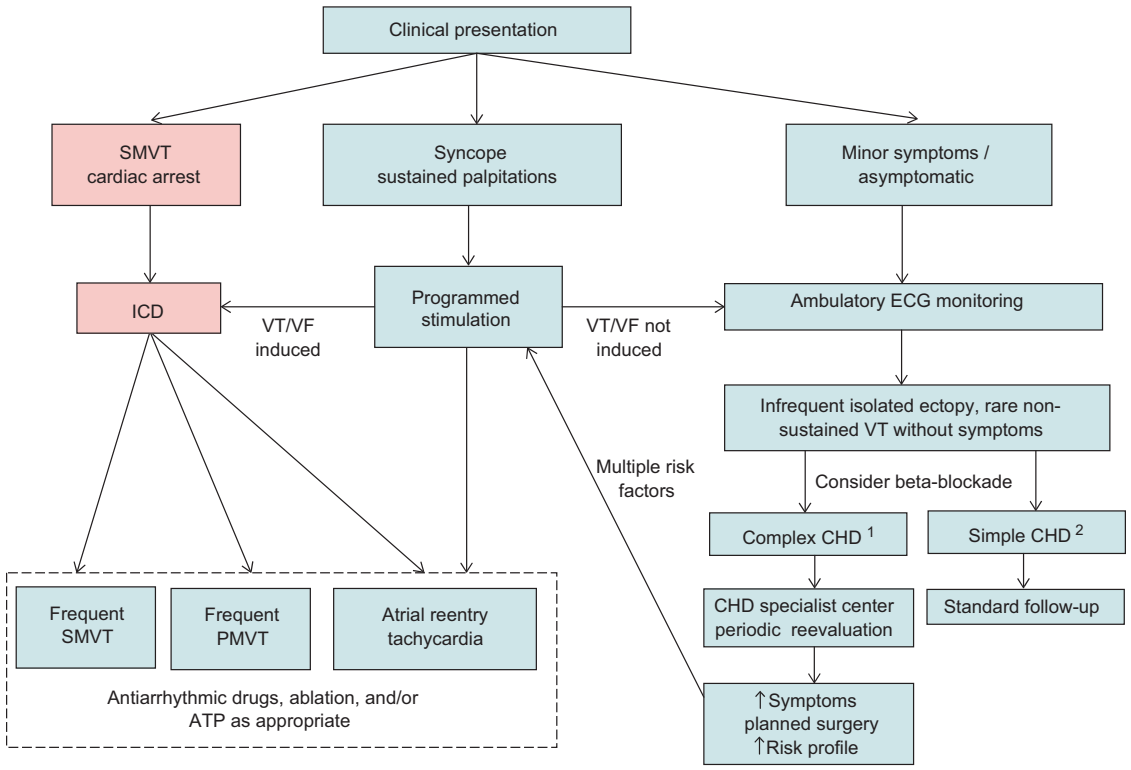

Figure 7 Management of VAs in CHD. ATP = antitachycardia pacing; CHD = congenital heart disease; d-TGA = transposition of the great vessels; ICD = implantable cardioverter-defibrillator; LVOTO = LV outflow tract obstruction; PMVT = polymorphic ventricular tachycardia; SMVT = sustained monomorphic ventricular tachycardia.

Table 9 Clinical factors to consider when evaluating CHD patient for electrophysiological study

	Findings	Response
Highest risk features	Sustained MMVT Cardiac arrest	ICD therapy EPS prior if potential for SVT trigger
High risk	Syncope Sustained palpitations	Haemodynamic evaluation and EPS
Intermediate risk	Older age at initial repair (.1 year) Older age (.25 – 30 years) Prior palliative procedures Ventriculotomy RV haemodynamic burden • RVp .50% systemic • Moderate + pulmonary insufficiency • RV end-diastolic volumes .150 mL/m^2 (Ref[279]) • Increased heart size on CXR • RV function, 45% • QRSd .180 ms LV dysfunction (,55% for tetralogy) NSVT on monitoring • ? significance of rare NSVT on CRMD monitoring Less clear symptoms VO2 max , "20 cc/kg/min T-wave alternans	In the presence of multiple risk beta-blocker or EPS
Low risk	Simple 'repairs' without residual Expected or less isolated ectopy on monitoring No symptoms Good exercise capacity Good biventricular function	
Complicating Features	Need for CRMD management Anticipated haemodynamic interventions • Pulmonary valve replacement • Tricuspid valvuloplasty • CRT	Consider staged interventions including follow-up studies after remodeling

CHD = congenital heart disease; CRT = cardiac resynchronisation therapy; CXR = chest X-rays; EPS = electrophysiological study; ICD = implantable cardioverter-defibillator; LV = left ventricular; MMVT = monomorphic ventricular tachycardia; NSVT = non-sustained ventricular tachycardia; RVp = right ventricular pressure; SVT = supraventricular tachycardia.

Multiple criteria should thus be used to determine which patients with VAs should undergo EPS, including symptoms, haemodynamic status,[281,282] and surgical history (flowchart/Table 9).[269,278,283] Deferring EPS in favour of clinical surveillance is warranted for patients with favourable risk profiles (good ventricular function, lesser grades of ectopy, minimal arrhythmia symptoms).

Management of ventricular tachycardia and premature ventricular complexes in patients with congenital heart disease

Clinical presentations that indicate the need for therapy of VAs in patients with CHD include arrhythmia-related symptoms and deterioration of ventricular function. In patients with CHD who have an implanted ICD, frequent appropriate shocks often require prevention of recurrences. Strategies for management include suppressive antiarrhythmic therapy, ablation (catheter or surgical), and ATP. There are no prospective studies of sufficient power to be directive of therapy in this group of patients. Thus, recommendations regarding management of VA in this patient group are based on expert consensus.

Antiarrhythmic agents are often used to suppress PVCs and NSVT of lower grades. Efficacy is usually defined as symptomatic improvement or reduction in ectopic events, but suppression of PVCs is not known to be associated with change in mortality. Evidence for safety and efficacy of AAD therapy (e.g. mexiletine, propafenone, sotalol, and amiodarone)[284–286] is derived from case series in populations with mixed arrhythmia mechanisms, or is inferred from studies performed in adult populations, although amiodarone has also been prospectively studied in an acute setting in a small number of paediatric patients with VT.[287] These advanced antiarrhythmic agents are largely reserved for suppressing excessive arrhythmia in patients with ICD therapy or those where ICD therapy is deferred for anatomical reasons. Programming ICDs to high VF detection rates and long VT detection times is important to minimize unnecessary ATP or shocks for NSVT that would have been self-terminating without device intervention. While there are similarly no prospective data on beta-blockers in patients with CHD who have VAs, their broad safety profile results in them being a popular choice to suppress ectopy.

Several studies have documented the feasibility of using catheter ablation to treat MMVT in patients with CHD.[288–291] Success rates in these studies have ranged from "60 to .90% case series of 11 – 20 patients and in one case ablation has been proposed in conjunction with use of Class III antiarrhythmic agents.[292] Access to the ventricular endocardium may be limited by some anatomical abnormalities or surgical

corrections. Extrapolating from adult data with normal cardiac anatomy, in patients with frequent (.15% or more) monomorphic ventricular ectopy and newly recognized or progressive ventricular dysfunction, ablation of PVCs may be a useful adjunct if suppressive AAD therapy fails.[23,293] The European Society of Cardiology guidelines for adults with CHD[6] suggest the ablation may be reasonable as monotherapy for SMVT.

Recent mapping studies suggest predictable anatomical substrates for reentry in many patients with typical biventricular anatomy (i.e. that seen after repair of tetralogy of Fallot).[294] These include the corridor between the tricuspid annulus and the RVOT, and the infundibular septum. While surgical ablation based on this anatomical template can be added to surgical repairs,[295] the efficacy of this approach remains uncertain.

A recent, small study has suggested that ATP may be efficacious in paediatric and congenital patients with ICDs.[296] The relative simplicity of this approach in combination with the more compelling evidence derived from adult studies suggest that this should be considered in all implanted patients.

Ventricular arrhythmias occur more frequently in patients with significant haemodynamic burden. New or increasing VAs should always trigger a careful evaluation of the underlying haemodynamic issues.[297] However, correction of haemodynamic problems alone does not eliminate VAs.[298–300]

Younger children and infants

The writing group has focused on the adult patient. These data are reasonably extrapolated to the older adolescent. For the younger adolescent, the school age child and particularly for infants both the natural history, the risk/benefit calculations for drugs, ablation, and device therapy may be different. Therefore, consultation with centres experienced in the management of children is appropriate. Recent guidelines focus on this particular population.[301]

Evidence gaps and future research directions

The writing group acknowledges the lack of randomized controlled clinical trials to support many of the recommendations put forward in this document. While we acknowledge the historical reasons (see the Introduction section), the writing committee strongly supports controlled trials in adequately diagnosed contemporary patient cohorts. There is ample evidence to support the use of defibrillators in patients at highest risk for sudden death. While the initial approach to these patients was done in high-risk patients, the available data suggest that ECG parameters and/or cardiac imaging could better define those patients who will benefit from a defibrillator, and possibly delineate patient groups at lower risk who will not. The use of AADs for the suppression and symptomatic improvement of patients with VAs is in clear need of controlled trials. Such trials, possibly aiming for symptomatic improvement, e.g. measured by patient-reported outcomes in addition to monitoring of arrhythmia recurrence, seem feasible in relatively small patient cohorts. Ongoing studies are evaluating whether early interventional treatment of VAs by catheter ablation can improve outcomes in patients with an implanted defibrillator. Furthermore, long-term outcomes after catheter ablation in specific disease entities, e.g. RVOT tachycardia or fascicular tachycardia are available and support the use of ablation in these patients. The role of specific antiarrhythmic interventions (by AADs or catheter ablation) in addition to treatment of the underlying heart disease warrants further clinical research. Furthermore, a contemporary description and characterization of the causes and underlying cardiovascular diseases, including inherited arrhythmogenic syndromes, would allow better strategies to earlier identify patients at risk for sudden death, thus setting the stage for intervention trials aimed at reducing sudden death.

Conflict of interest: none declared.

Appendix A

See Table A1.

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Table A1 EHRA/HRS/APHRS Expert Consensus Statement on Ventricular Arrhythmias – 2014

Expert	Type of relationship with industry
Alexander, Mark E	None
Borggrefe, Martin	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. St Jude Medical : Catheters, ICD (2013) Boehringer-Ingelheim : Drugs (2013) Novartis : Drugs (2013) Sanofi Aventis : Drugs (2013) Bayer Healthcare : Drugs (2013) Medtronic : Medical devices (2013) Impulse Dynamics : Medical devices (2013) Zoll Medical : Medical devices (2013) Boston Scientific : Stents, Catheter (2013) B - Payment to your Institution: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Boehringer-Ingelheim : Drugs (2013) Pfizer : Drugs (2013) Sanofi Aventis : Drugs (2013) Medtronic : Medical devices (2013) St Jude Medical : Medical devices (2013) Impulse Dynamics : Medical devices (2013) Zoll Medical : Medical devices (2013) C - Receipt of royalties for intellectual property. Thieme Verlag : Authorship (2013)
Della Bella, Paolo	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. St Jude Medical : Cardiac electrophysiology (2013) Biotronik : Cardiac electrophysiology (2013) Biosense Webster : Cardiac electrophysiology (2013) D - Research funding (departmental or institutional). Boston Scientific : Cardiac electrophysiology (2013) Medtronic : Cardiac electrophysiology (2013) St Jude Medical : Cardiac electrophysiology (2013) Biotronik : Cardiac electrophysiology (2013) Biosense Webster : Cardiac electrophysiology (2013)
Dickfeld, Timm	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Biosense Webster : VT (2013) D - Research funding (departmental or institutional). GE Healthcare : VT (2013) Biosense Webster : VT (2013)
Dimarco, John Philip	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Medtronic : Devices (2013) Novartis : DSMB member (2013) St Jude Medical : DSMB member (2013) Boston Scientific : Speaker (2013)
Dorian, Paul	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Servier : arrhythmias (2013) Bayer : atrial fibrillation (2013) Boehringer-Ingelheim : atrial fibrillation (2013) Pfizer : atrial fibrillation (2013) Bristol Myers Squibb : atrial fibrillation (2013) D - Research funding (departmental or institutional). Boehringer-Ingelheim : atrial fibrillation (2013) Bristol Myers Squibb : atrial fibrillation (2013)
Exner, Derek	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Analytics for Life : ECG (2013) Spectranetics : Extraction (2013) Boston Scientific : ICD, CRT (2013) Medtronic : ICD, CRT, Extraction (2013) Heartforce Medical : Research (2013) B - Payment to your Institution: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc.

Table A1 (*continued*)

Expert	Type of relationship with industry
	Boston Scientific : Fellowships (2013) Medtronic : Fellowships (2013) C - Receipt of royalties for intellectual property. GE Healthcare : Patents (2013) Analytics for Life : Patents (2013) E - Research funding (personal). Heartforce Medical : CRT (2013) Medtronic : ICD, CRT (2013) St. Jude Medical : ICD, CRT, PM (2013)
Haines, David	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. None B - Payment to your Institution: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Boston Scientific : catheter ablation (2013) Medtronic : catheter ablation (2013) St Jude Medical : catheter ablation (2013) Biotronik : catheter ablation (2013) Biosense Webster : catheter ablation (2013) Zoll Medical : defibrillation (2013) D - Research funding (departmental or institutional). Boston Scientific : catheter ablation (2013) Medtronic : catheter ablation (2013) Toray Medical : catheter ablation (2013) ARCA Biopharma, Inc : Pharmaceutical (2013)
Huikuri, Heikki	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. None D - Research funding (departmental or institutional). Boehringer Ingelheim - Ingelheim; Daiichi-Sankyo/Eli Lilly; Nycomed Pharma : Refine-ICD study, prophylctic implantable cadioverter defibrillator (2013)
Iesaka, Yoshito	None
Indik, Julia	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. None E - Research funding (personal). National Institutes of Health : Role: Image Analyst, (RO1 grant for the study of Arrhythmogenic Cardiomyopathy) (2013)
Kalman, Jonathan	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Biotronik : Speakers fees (2013) D - Research funding (departmental or institutional). St Jude Medical : Fellowship and research support (2013) Medtronic : Fellowship support (2013) Biosense Webster : Fellowship support (2013) Boston Scientific : Research support (2013)
Kay, Neal	None
Kim, Young-Hoon	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Bayer Schering Pharma : Advisory Board fees, (2013) Boston Scientific : Honoraria (2013) St Jude Medical : Speaker fees, Honoraria (2013)
Kirchhof, Paulus	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Boehringer-Ingelheim : cardiovascular (2013) Daiichi Sankyo : cardiovascular (2013) Medtronic : cardiovascular (2013) Pfizer : cardiovascular (2013) St Jude Medical : cardiovascular (2013) Sanofi Aventis : cardiovascular (2013) Meda pharma : cardiovascular (2013) Bristol Myers Squibb : cardiovascular (2013) Merck Sharp & Dohme : cardiovascular (2013) Otsuka Pharmaceuticals Development and Commercialization (consultancy) : cardiovascular (2013)

Table A1 (*continued*)

Expert	Type of relationship with industry
	B - Payment to your Institution: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Boehringer-Ingelheim : cardiovascular (2013) Bayer Healthcare : cardiovascular (2013) Gilead : cardiovascular (2013) BMS / Pfizer alliance : cardiovascular (2013) D - Research funding (departmental or institutional). St Jude Medical : cardiovascular (2013) Sanofi Aventis : cardiovascular (2013) Meda pharma : cardiovascular (2013)
Knight, Bradley	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Biosense Webster : ablation system (2013) Boston Scientific : implantable devices (2013) Medtronic : implantable devices (2013) Biotronik : implantable devices (2013) St. Jude : implantable devices (2013)
Kuck, Karl-Heinz	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Edwards Lifesciences : Speaker Fees, Honorary, Consultancy (2013) Stereotaxis : Speaker Fees, Honorary, Consultancy (2013) Medtronic Foundation : Speaker Fees, Honorary, Consultancy (2013) Biosense Webster : Speaker Fees, Honorary, Consultancy (2013) St. Jude Medical : Speaker Fees, Honorary, Consultancy (2013)
Lip, Gregory Y H	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Biotronik : atrial fibrillation (2013) Boehringer-Ingelheim : atrial fibrillation, thrombosis (2013) Daiichi Sankyo : atrial fibrillation, thrombosis (2013) Pfizer : atrial fibrillation, thrombosis (2013) Bayer Healthcare : atrial fibrillation, thrombosis (2013) Bristol Myers Squibb : atrial fibrillation, thrombosis (2013) Astellas : atrial fibrillation, thrombosis (2013) D - Research funding (departmental or institutional). Bayer : atrial fibrillation, thrombosis (2013)
Marchlinski, Francis	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Boston Scientific : Electrophysiology (2013) St Jude Medical : Electrophysiology (2013) Biotronik : Electrophysiology (2013) Biosense Webster : Electrophysiology (2013) CardioInsight : Electrophysiology (2013) Medtronic : VT ablation (2013) D - Research funding (departmental or institutional). Boston Scientific : Electrophysiology (2013) Medtronic : Electrophysiology (2013) Biotronik : Electrophysiology (2013) Biosense Medical : Electrophysiology (2013) St Jude Medical : Eletrophysiology (2013)
Mont, Lluis	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. St Jude Medical : Atrial Fibrillation, Resynchronization Therapy. (2013) Biosense Webster : Atrial Fibrillation. (2013) Boston Scientific : Resynchronization Therapy. (2013) Medtronic : Resynchronization Therapy. (2013) Sorin Group : Resynchronization Therapy. (2013) Biotronik : Resynchronization Therapy. (2013) D - Research funding (departmental or institutional). St. Jude Medical : Atrial Fibrillation, Resynchronization Therapy. (2013) Biosense Webster : Atrial Fibrillation. (2013) Boston Scientific : Devices, Resynchronization Therapy. (2013) Medtronic : Resynchronization Therapy. (2013) Sorin Group : Resynchronization Therapy. (2013) Biotronik : Resynchronization Therapy. (2013)

Table A1 (*continued*)

Expert	Type of relationship with industry
Ross, David L	None
Sacher, Frederic	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Medtronic : Medical material (2013) Sorin Group : Medical material (2013) Biotronik : Medical material (2013) Biosense Webster : Medical material (2013) saint Jude medical : Medical material (2013) Boehringer-Ingelheim : Pharmaceutical (2013) Bayer Healthcare : Pharmaceutical (2013) Bristol Myers Squibb : Pharmaceutical (2013) B - Payment to your Institution: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Boston Scientific : medical material (2013) D - Research funding (departmental or institutional). Medtronic : medical material (2013)
Sapp, John Lewis	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. None D - Research funding (departmental or institutional). Philips : Arrhythmia Research (2013) St Jude Medical : Ventricular Tachycardia Research (2013) Biosense Webster : Ventricular Tachycardia Research (2013)
Shivkumar, Kalyanam	None
Soejima, Kyoko	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. St Jude Medical Japan : ablation, device (2013) Boston Scientific Japan : ablation, device (2013) Medtronic Japan : cardiac rhythm device (2013) D - Research funding (departmental or institutional). DVX Japan : clinical electrophysiology (2013) Biotronik Japan : clinical electrophysiology (2013)
Tada, Hiroshi	None
Torp-Pedersen, Christian Tobias	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Sanofi Aventis : Antiarrhythmics (2013) Merck Sharp & Dohme : Antiarrhythmics, diabetes (2013) Cardiomems : atrial fibrillation (2013) B - Payment to your Institution: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Sanofi Aventis : Investigator various drugs (2013) Merck Sharp & Dohme : Investigator various drugs (2013) Bristol Myers Squibb : Investigator, various drugs (2013) D - Research funding (departmental or institutional). Bristol Myers Squibb : Atrial fibrillation (2013)
Triedman, John	A - Direct Personal payment: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. None B - Payment to your Institution: Speaker fees, Honoraria, Consultancy, Advisory Board fees, Investigator, Committee Member, etc. Boehringer-Ingelheim : Anticoagulants (2013) American Heart Association : Editorial (2013) C - Receipt of royalties for intellectual property. UpToDate : Editorial (2013) E - Research funding (personal). NIH : Clinical research network (2013)
Yamada, Takumi	None

This table represents the relevant relationships of the above experts with Industries and other entries that were reported to us at the time of publication of the guidelines.