VENTRICULAR TACHYCARDIA

MANAGEMENT GUIDELINES

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Ventricular Tachycardia - Management Guidelines

ANCC Accredited NCPD Hours: 1.4 hrs

Target Audience: RN/APRN

Need Assessment

Practice guidelines provide recommendations applicable to patients with or at risk of developing cardiovascular disease. Guidelines are intended to define practices meeting the needs of patients and should not replace clinical judgment. It can be effective only when followed by nurses and practitioners. Effeciency can be enhanced by proper knowledge and practice of guidelines, shared decision-making between healthcare providers and patients and interventions based on individuals.

Objectives

- Discuss the mechanisms in pathophysiology of ventricular tachycardia.
- Recognise the assessment procedure in Ventricular Arrhythmias
  Adapt to the AHA guidelines on Acute
- Management of ventricular tachycardia.
- Discuss the medication therapy for Ventricular Arrhythmias.
- Describe ICD therapy and Catheter ablation in VT management.
- Describe ventricular tachycardia management in children.

Goal

The goal of this article is to highlight the advances in the field of cardiology in the management of V Tach in both acute and long-term settings.

Introduction

Ventricular arrhythmias are an important cause of late morbidity and sudden cardiac death in the growing population of adults with repaired congenital heart disease. Risk stratification remains challenging because of the heterogeneity of the malformations and the surgical approaches. Therapeutic interventions depend on the type of ventricular arrhythmia, which can be polymorphic ventricular tachycardia (VT) or ventricular fibrillation in patients without ventricular scars, but also potentially fatal monomorphic reentrant Ventricular Tachycardia, typical for patients with ventricular scars or obstacles. Advances in surgical techniques have improved survival and have important implications for the arrhythmia substrates and prognosis. Over the past few decades, progress has been made to determine the anatomical basis for monomorphic Ventricular Tachycardia in patients with ventricular surgical scars and patch material. These substrates can be currently identified and targeted during sinus rhythm by radiofrequency catheter or surgical ablation without the need for Ventricular Tachycardia induction. [1, Rank 4]

Ventricular Tachycardia-Mechanisms

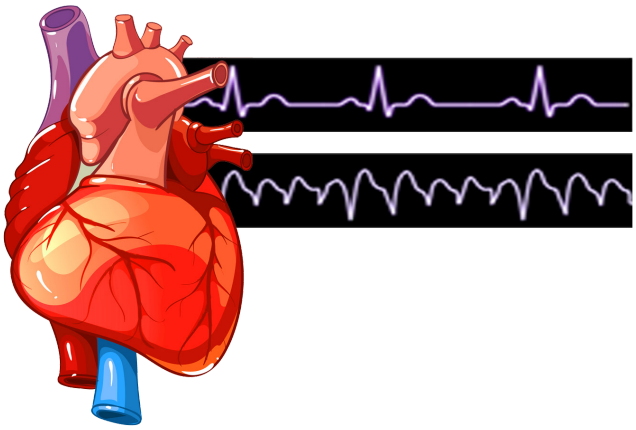

Figure 1: Ventricular tachycardia

Automaticity

Normal automaticity results from phase 4 spontaneous depolarization of the transmembrane action potential arising from a normal resting potential, reaching threshold and initiating an action potential. An initiating current is responsible for spontaneous phase 4 depolarization in the sinus node. The rate is determined by the integration of the maximum diastolic potential at the end of repolarization.

Triggered Activity

Early afterdepolarizations occur during late phase 2 or early phase 3 of the action potential, usually in the setting of action potential prolongation due to an increase in inward currents and early after

depolarizations may be initiated. Spontaneous calcium release from the sarcoplasmic reticulum may also result in activation of a depolarizing sodium/calcium exchange current.

Delayed afterdepolarizations are the underlying mechanism for Ventricular Tachycardia in the setting of digoxin toxicity, catecholaminergic polymorphic Ventricular Tachycardia, and idiopathic outflow tract Ventricular arrhythmia. Delayed afterdepolarizations may be an important mechanism for some Purkinje fiber-related ventricular arrhythmia.

Re-entry

Reentry is the underlying mechanism for most sustained ventricular arrhythmia in the presence of structural heart disease. Reentry may occur around a fixed anatomical obstacle, such as scar after an MI or surgically repaired congenital heart disease.

Functional reentry around areas of functional block without anatomical obstacles can also occur.

- The leading circle model has a functionally refractory core and no excitable gap.
- Spiral wave reentry is driven by a rotor with a curved wavefront and wavetail pivoting around an excitable but unexcited core.

> **"Early afterdepolarizations are the trigger for torsades de pointes VT associated with QT prolongation either induced by medications or other acquired factors or due to mutations of ion channels causing the long QT syndrome. The early afterdepolarization is the trigger that culminates in polymorphic VT/VF."**

Electrotonic currents may flow from endocardial sites with longer action potential durations to the epicardium with shorter action potential durations which can result in reexcitation.

Assessment of Ventricular Tachycardia

Symptoms

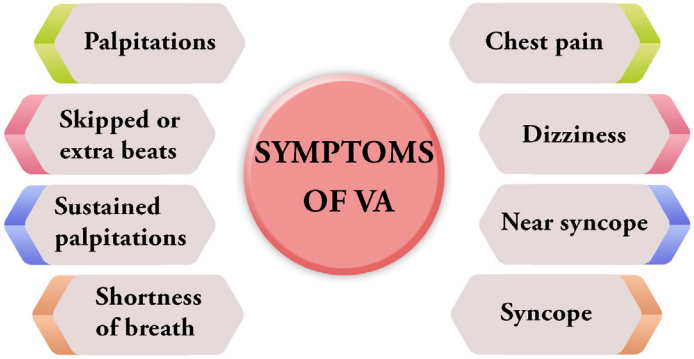

Figure 2: Symptoms of Ventricular Arrhythmia

Assessment

Figure 3: Assessment relevant for VA

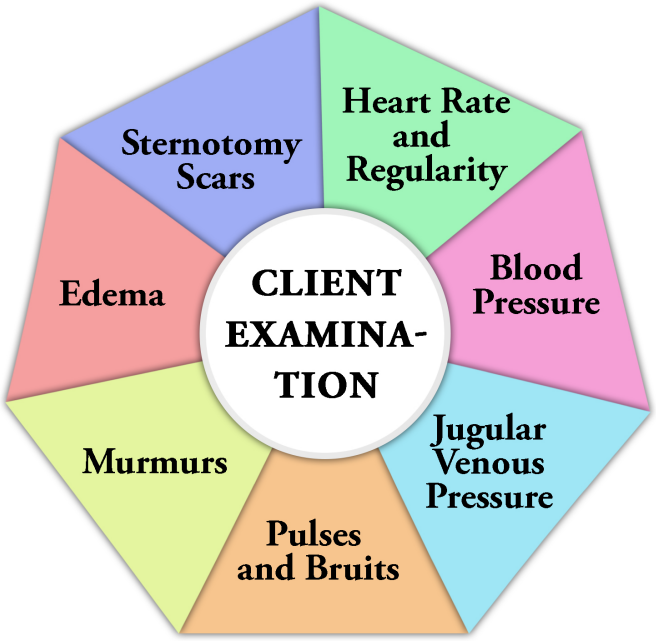

Figure 4: Examination of the client

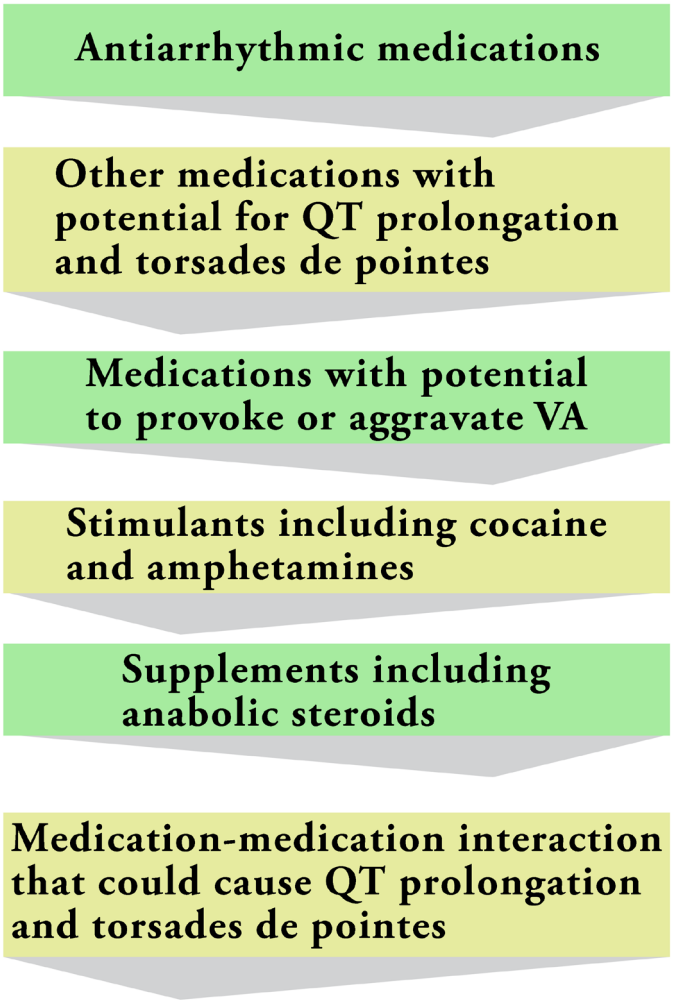

Figure 5: Assessment points in Medication History

Management Guidelines for Ventricular Tachycardia

Ventricular Tachycardia management should focus on concerted attempts to eliminate or control the arrhythmia, with the goal of improving symptoms, reversing left ventricular dysfunction, and preventing arrhythmia recurrence. A favorable response to arrhythmia elimination/ control establishes the diagnosis of arrhythmia induced cardiomyopathy. Along with arrhythmia control, use of neurohormonal antagonists can result in favorable ventricular remodeling. Controversy remains about the need to continue these medications if there is complete recovery of Left ventricular ejection fraction (LVEF) with arrhythmia control. [3, Rank 4]

Atrial fibrillation(AF)

Atrial fibrillation is the most common cause of arrhythmia induced cardiomyopathy (AIC) in adults. Of patients presenting with HF, 10% to 50% have Atrial fibrillation and many such patients likely have a component of arrhythmia induced cardiomyopathy. The mechanisms underlying development or progression of cardiomyopathy in patients with persistent Atrial fibrillation are not clearly elucidated. Rapid heart rates, loss

of atrial contraction, and rhythm irregularity may contribute. ***Persistent tachycardia can impair myocardial contractility, either directly or through alterations in cellular and neurohormonal mechanisms. Resting tachycardia, as well as a rapid increase in heart rate with exercise, can impair diastolic filling. Lack of an atrial contribution to ventricular filling can further worsen diastolic function.*** A vicious cycle can thus develop, with heart failure and the associated increases in left-sided filling pressures and functional mitral regurgitation resulting in mechanoelectrical changes in the left atrium, perpetuating Atrial fibrillation and cardiomyopathy. [4, Rank 3]

Management of Atrial fibrillation consists of rate and/or rhythm control. In those with AF and cardiomyopathy, the ideal target heart rate remains uncertain. For those with permanent Atrial fibrillation, lenient rate control (resting heart rate <110 beats/min) has been advocated over strict rate control (resting heart rate <80 beats/min and heart rate with moderate exercise <110 beats/min). However, in the RACE II trial, most patients were rate controlled before enrollment (baseline heart rate 96 beats/min), and were asymptomatic without cardiomyopathy. Follow-up was short and development of AIC was not specifically considered. [5, Rank 5]

Several methods are available for Atrial fibrillation rate control. Achieving adequate rate control may require drug combinations and frequent regimen changes. However, these data may not directly apply to AF-mediated arrhythmia induced cardiomyopathy, as rate irregularity may contribute to symptoms and facilitate development of AIC. Although AV nodal ablation with pacemaker implantation can provide effective rate control and regularize the rate, this strategy changes ventricular activation, even if cardiac resynchronization therapy is used, and therefore should only be considered if rhythm and/or rate control cannot be established. In contrast, electrical or pharmacologic cardioversion, antiarrhythmic drugs, and catheter ablation can achieve rhythm control. ***In AF-mediated cardiomyopathy, restoration and maintenance of sinus rhythm can hasten clinical recovery and reverse cardiomyopathy over several months.*** [6, Rank 3]

The AF-CHF trial randomized 1,376 patients with AF (70% persistent) and HF to either a rhythm control (amiodarone with cardioversion) or a rate control strategy. The mean Left ventricular ejection fraction was 27% and patients were followed for 37 months. A rhythm control strategy using antiarrhythmics did not improve all-cause mortality or prevent worsening HF. However, the AF-CHF patient

population may not fully represent the arrhythmia induced cardiomyopathy population, as 40% of patients in the rate control arm were in sinus rhythm during follow-up. The CAFÉ-II study randomized 61 patients with persistent AF (median duration of 14 months) and moderate LV dysfunction to a rate control and rhythm control strategy (amiodarone with cardioversion). During a follow-up of 1.2 years, 66% of patients maintained sinus rhythm, whereas 90% achieved target rate control (<80 beats/min at rest and <110 beats/min with 6-minute walk). Rhythm control was superior to rate control in improving LV function, pro-BNP levels, and quality of life. Attempts to control rate might not be as aggressive or carefully monitored in the real world as in clinical trials. It is also possible that side effects and proarrhythmic risks from antiarrhythmic drugs may offset any salutary effects from restoring and maintaining sinus rhythm. [7, Rank 4]

Restoring and maintaining sinus rhythm by catheter ablation of AF can improve and reverse Arrhythmia induced cardiomyopathy. Pulmonary vein isolation appears superior to AV node ablation and biventricular pacing in patients with drug-refractory AF and HF. A systematic review of 19 studies (914 patients) evaluating AF ablation in patients with concomitant LV dysfunction showed that sinus rhythm was maintained in 57% after a single procedure, with an increase to 82% with >1 procedure and/or use of antiarrhythmic drugs. LVEF increased by 13.3% (95% CI: 11% to 16%), suggesting the effectiveness of catheter ablation for maintaining sinus rhythm and reversing AIC. [8, Rank 3]

> **"In the acute phase of an MI or during transient ischemia, increased extracellular potassium causes partial depolarization of the resting membrane potential creating injury currents between the infarcted/ischemic tissue and healthy myocardium. These injury currents may initiate spontaneous activity. In ischemia, abnormal automaticity may occur in both ventricular myocytes and Purkinje fibers, and may also enhance normal automaticity in Purkinje fibers in the ischemic zone."**

The recent AATAC-AF trial randomized 203 persistent AF patients with HF and cardiomyopathy (LVEF <40%) to either amiodarone or catheter ablation. During a 24-month follow-up, 70% of patients in the ablation arm were free of AT/AF (vs. 34% in the amiodarone arm

[p < 0.001]) and had significant improvements in mortality, hospitalization rates, and quality of life. LVEF improved 9.6 ± 7.4% in the ablation arm versus 4.2 ± 6.2% in the amiodarone arm (p < 0.01). Catheter ablation thus offers an effective rhythm control strategy and avoids potentially toxic long-term antiarrhythmic therapy. The available data argues for catheter ablation as the best choice for rhythm control in the patient with AF-mediated AIC. [9, Rank 1]

Atrial Flutter

Atrial flutter is more difficult to rate control than Atrial fibrillation, given less concealed conduction into the AV node. Therefore, despite intense efforts at pharmacological rate control minimal exertion can lead to rapid ventricular rates. Given the inherent difficulty with rate control and the high success rate and low risk of complications with catheter ablation, ablation to eliminate atrial flutter is recommended when Arrhythmia induced cardiomyopathy is suspected. For those in whom catheter ablation is not feasible or desired, cardioversion with antiarrhythmic therapy or aggressive rate control should be employed. [10, Rank 2]

Persistent supraventricular tachycardias can result in Arrhythmia induced cardiomyopathy by several mechanisms. Near simultaneous AV relationships can have a negative hemodynamic effect. A curative strategy by catheter ablation should be pursued whenever possible as first-line therapy for supraventricular tachycardia-mediated Arrhythmia induced cardiomyopathy. Successful catheter ablation can normalize LVEF and is usually associated with excellent long-term outcomes. [11, Rank 5]

Premature Ventricular Contractions(PVCs) and Ventricular Tachycardia

Idiopathic ventricular tachycardia and, more commonly, frequent PVCs, can lead to AIC in patients without structural heart disease and can exacerbate cardiomyopathy in patients with structural disease. Premature ventricular contractions associated with cardiomyopathy usually arise in the right or left ventricular outflow tract, but premature ventricular contractions from non-outflow tract sites can also result in AIC. [11, Rank 3]

The mechanism of premature ventricular contractions - mediated arrhythmia induced cardiomyopathy is not fully understood. A large animal model using a pacing protocol to simulate paroxysmal premature ventricular contractions produced an arrhythmia induced cardiomyopathy phenotype that resolved completely within 2 to 4 weeks after pacing cessation. Tissue

analysis did not show evidence of inflammation, fibrosis, or apoptosis, suggesting that Premature ventricular contractions induced cardiomyopathy in structurally normal hearts could be a functional abnormality. Potential mechanisms postulated include ventricular dyssynchrony, especially related to left bundle branch block premature ventricular contractions morphology, abnormal calcium handling from the short coupling intervals, and abnormal ventricular filling from the post- premature ventricular contractions pause. [12, Rank 4]

The development of a myopathy with atrial premature depolarizations and the absence of convincing site-specific association in premature ventricular contractions mediated arrhythmia induced cardiomyopathy suggest that it may not be a simple matter of LV dyssynchrony. The causal relationship between premature ventricular contractions and arrhythmia induced cardiomyopathy has been firmly established on the basis of reversal of the cardiomyopathy with suppression and/or elimination of PVCs. [13, Rank 5]

The most prominent predictor of cardiomyopathy in patients with frequent PVCs appears to be the daily burden of premature ventricular contractions. A high PVC burden has been variably defined as ranging from >10,000 to 25,000 PVCs/day and as >10% to 24% of total heartbeats/-day. There appears to be a threshold burden of ~10,000 PVCs/day for developing AIC. Ventricular function can improve if the Premature ventricular contractions burden is reduced to <5,000/day. This is an important target when elimination of all premature ventricular contractions may not be possible, especially in the setting of multiform premature ventricular contractions. [14, Rank 1]

> **"Mechanisms of Ventricular Arrhyth miainclude enhanced normal automaticity, abnormal automaticity, triggered activity induced by early or late afterdepolarizations, and reentry."**

Retrospective studies suggest multiple potential patient and premature ventricular contractions characteristics associated with the development of arrhythmia induced cardiomyopathy. These characteristics include male sex, increased body mass index, asymptomatic premature ventricular contractions, and higher premature ventricular contractions coupling interval dispersion, interpolated PVCs, and presence of retrograde P waves. Importantly, most patients with frequent premature ventricular contractions will not develop

cardiomyopathy. Currently, although an important goal of future investigation, no risk profile defines a group of patients requiring prophylactic premature ventricular contractions (PVC) elimination to prevent arrhythmia induced cardiomyopathy. However, it is advisable for patients with a high PVC burden to have periodic echocardiographic assessment to confirm stable LV chamber size and function. [15, Rank 2]

Therapy for Premature ventricular contractions - mediated AIC should be targeted at suppressing or eliminating the Premature ventricular contractions and include antiarrhythmic therapy and catheter ablation. Beta-blockade and non-dihydropyridine calcium channel blockade are low-risk therapies, but with limited effectiveness. Beta-blockers are frequently considered first-line treatment because of the benign nature of the treatment. Dofetilide, mexiletine, sotalol, or amiodarone may be more effective, although with greater risk of side effects and proarrhythmia. Antiarrhythmic drug use is frequently reserved for patients who fail or are reluctant to undergo catheter ablation. [16, Rank 3]

Catheter ablation has emerged as the definitive therapy for premature ventricular contractions -mediated arrhythmia induced cardiomyopathy with success rates ranging from 70% to 90%. Elimination of Premature ventricular contractions with ablation has been shown to improve LVEF, ventricular dimensions, mitral regurgitation, and functional status. In an observational series, ablation was superior to antiarrhythmic therapy in reducing premature ventricular contractions and improving LVEF. Successful ablation of PVCs can improve the efficacy of cardiac resynchronization therapy in non-responders. The elimination of high Premature ventricular contractions burden (>10%) in patients with impaired LVEF can be associated with improvement of function, even when structural cardiac abnormalities are present. [17, Rank 4]

Medication Therapy

Beta blockers reduce all-cause mortality in patients with HF with reduced ejection fraction. With the exception of beta blockers (eg, metoprolol succinate, carvedilol), there is no evidence from RCTs that antiarrhythmic medications for ventricular tachycardia improve survival when given for the primary or secondary prevention of sudden cardiac death. However, the use of these medications is essential in some patients to control arrhythmias and improve symptoms.

Vaughn Williams 4-level Schema	
Class I	Fast sodium channel blockers
Class II	Beta blockers
Class III	Repolarization potassium current blockers
Class IV	Nondihydropyridines calcium channel blockers

Table 1: Classification of Anti- arrhythmic Medications

Vaughan Williams system does not address the complexities in antiarrhythmic medications, since nearly every agent has multiple effects.

One newer medication of potential benefit, based on very limited data, is ranolazine. This medication, developed and FDA-approved as an antianginal agent, provides relatively specific late sodium channel current blockade in addition to less potent blockade of the phase 3 repolarizing potassium current

Administration of potassium and magnesium has been proposed as helpful adjuncts in the prevention of Ventricular Arrhythmias. Hypokalemia and hypomagnesemia are common consequences of diuretic therapy in heart failure; both have been associated with Ventricular Arrhythmias during an acute MI. [31]

> **"Except in specific circumstances, sodium channel blockers (Vaughn-Williams class I agents) have a limited role in the prevention of VT and sudden cardiac death; this is based on a lack of survival benefit and increased mortality observed during chronic therapy in patients with ischemic heart disease"**

Defibrillators for Treatment of Ventricular Arrhythmias

These devices monitor the heart rhythm continuously and deliver therapy in response to a tachycardia that meets preprogrammed detection rates and arrhythmia duration. The vast majority of transvenous implantable cardioverter-defibrillator are implanted in the subclavicular area under fluoroscopy guidance. Subcutaneous implantable

cardioverter-defibrillators are implanted in the left side of the chest over the sixth rib between the left midaxillary and left anterior axillary lines. Implantable cardioverter-defibrillator with epicardial sensing and pacing leads is still being implanted in some patients especially those with certain forms of congenital heart disease.

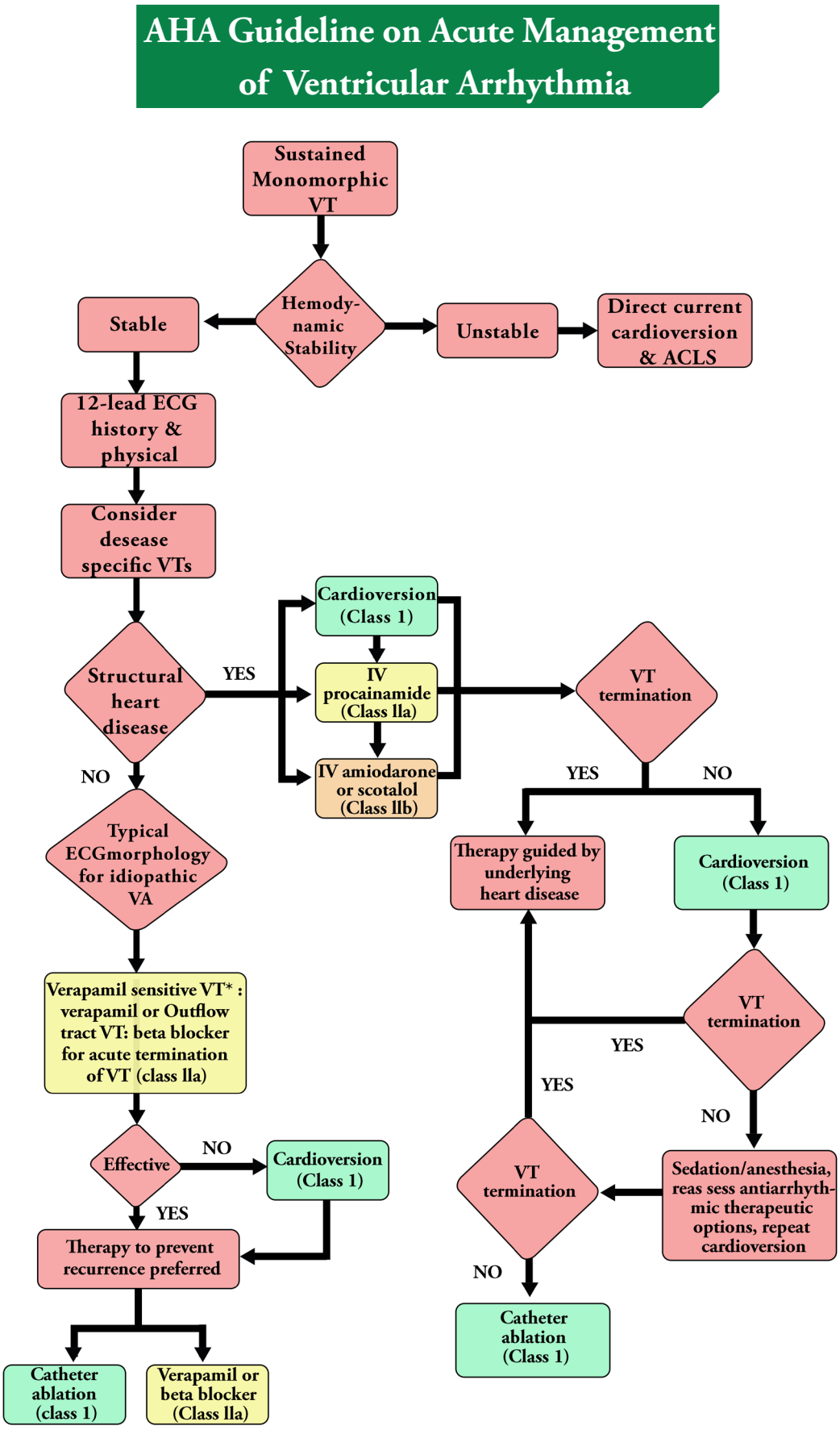

Figure 6: AHA guideline on Ventricular Arrhythmia Management

COMMON DRUGS FOR VENTRICULAR ARRHYTHMIA

NAME OF DRUG	*EFFECT OF DRUG*
Acebutolol	Sinus rate slowed, AV nodal refractoriness increased
Amiodarone	Sinus rate slowed, QRS prolonged, QTc prolonged, AV nodal refractoriness increased; increased DFT
Atenolol	Sinus rate slowed, AV nodal refractoriness increased
Bisoprolol	Sinus rate slowed, AV nodal refractoriness increased
Carvedilol	Sinus rate slowed, AV nodal refractoriness increased
Diltiazem	Sinus rate slowed, PR prolonged, AV nodal conduction slowed
Esmolol	Sinus rate slowed, AV nodal refractoriness increased
Flecainide	PR prolonged, QRS prolonged; increased defibrillation threshold (DFT) testing.

Lidocaine	No marked effect on most intervals; QTc can slightly shorten
Metoprolol	Sinus rate slowed, AV nodal refractoriness increased
Mexiletine	No marked effect on most intervals; QTc can slightly shorten
Nadolol	Sinus rate slowed, AV nodal refractoriness increased
Procainamide	QRS prolonged, QTc prolonged; increased defibrillation threshold (DFT) testing
Propafenone	PR prolonged, QRS prolonged; increased defibrillation threshold (DFT) testing
Propranolol	Sinus rate slowed, AV nodal refractoriness increased
Quinidine	QRS prolonged; QTc prolonged; increased defibrillation threshold (DFT) testing
Ranolazine	Sinus rate slowed ; Tc prolonged
Sotalol	Sinus rate slowed; QTc prolonged ;AV nodal refractoriness increased; decreased defibrillation threshold (DFT) testing
Verapamil	Sinus rate slowed, PR prolonged; AV nodal conduction slowed

Table 2: Drugs used for Ventricular Arrhythmias

> "Defibrillation is highly effective in terminating life-threatening Ventricular Arrhythmias. This therapy can be delivered by a transvenous ICD, a subcutaneous implantable cardioverter-defibrillator, a wearable cardioverter-defibrillator or an external defibrillator."

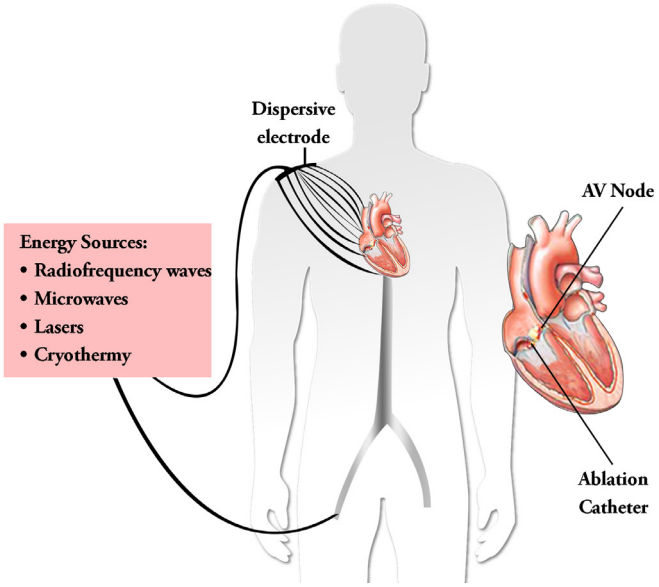

Figure 7: Catheter Ablation

The transvenous ICD has been in clinical use for >3 decades, and robust data from high-quality RCTs support its use in various patient populations including survivors of cardiac arrest, patients with ventricular tachycardia and structural heart disease, and patients with significant left ventricular dysfunction. [31]

Catheter Ablation

Catheter ablation is an important treatment option for patients with Ventricular Arrhythmias when antiarrhythmic medications are ineffective, not tolerated, or not desired by the patient. Monomorphic Ventricular Arrhythmias usually has an origin or substrate that can be targeted for ablation. Ablation is an option for selected patients with polymorphic VT/VF only if an initiating premature ventricular contraction focus or substrate can be identified.The ablation strategy, risks and outcomes are related to the mechanism and location of the Ventricular Arrhythmias. Most Ventricular Arrhythmias originate close to the sub-endocardium and are approached through a transvenous or transaortic/ transeptal catheterization. Some diseases give rise to Ventricular Arrhythmias from the subepicardium, which may be approached by epicardial mapping and ablation. Pericardial access is usually achieved by a percutaneous subxiphoid puncture. The catheter ablation procedure usually involves attempts to induce VT by programmed electrical stimulation to confirm the diagnosis and guide ablation.

Epicardial Mapping and Ablation

In patients with ischemic heart disease substrates, an epicardial approach is often favored after previous failed endocardial approach. This is in contrast to other substrates such as Chagasic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy (ARVC), or idiopathic dilated cardiomyopathies where epicardial Ventricular Tachycardia substrates are encountered more frequently. In most cases, use of angled sheaths and deflectable catheters enables access to all aspects of the epicardium. In patients who have had prior cardiac surgery, prior epicardial access, or prior pericarditis, focal or global adhesions may be present, restricting access to the pericardial space. Limited surgical exposure can be utilized to gain epicardial access in these cases. [18, Rank 4]

The true incidence of epicardial Ventricular Tachycardia in ICM remains unknown. As circuits may be transmural, termination of Ventricular Tachycardia on a given surface is an imperfect gold standard. Additionally, 12-lead ECG localization only assists in determining the exit site, which can be spatially remote from the critical isthmus.

Risks of epicardial access include cardiac perforation and/or tamponade, phrenic nerve palsy, hepatic laceration, bowel perforation, pericarditis, and epicardial coronary artery injury. Of 95 patients who underwent epicardial access, complications were seen in 8.8% of cases (eight patients), including six (6.7%) cases of epicardial bleeding (one confirmed RV puncture), and two patients with phrenic nerve palsy. These complication rates are in line with multicenter experience detailing the safety of epicardial mapping and ablation of Ventricular Tachycardia. [11, Rank 3]

Identification and Ablation of Channels

Channels have been alternatively identified by electroanatomic mapping during hemodynamically tolerated MMVT. Channel characteristics identified include a mean length and width of 31 ± 7 mm and 16 ± 8 mm respectively. In addition, the location of the circuit was associated with channel orientation, with perimitral circuits demonstrating channels parallel to the mitral annulus, while all other channels were oriented perpendicular in 21 studied patients. Confirming the concept, ablation lesions transecting the narrowest portion of a common channel terminated Ventricular Tachycardia in 97% of cases. In contrast to these studies, others have failed to find strong associations between

> "Because of their excellent safety profile and effectiveness in treating ventricular arrhythmia and reducing the risk of sudden cardiac death, beta blockers are often first-line antiarrhythmic therapy. Their antiarrhythmic efficacy is related to the effects of adrenergic-receptor blockade on sympathetically mediated triggering mechanisms, slowing of the sinus rate, and possibly inhibition of excess calcium release by the ryanodine receptor."

channels and critical isthmuses of Ventricular Tachycardia. [18, Rank 4]

Surgery and Revascularization Procedures

Myocardial ischemia is a cause of sustained polymorphic VT/VF, and revascularization is an effective treatment to prevent myocardial ischemia. For patients with life-threatening VA, observational studies show that patients undergoing coronary artery bypass graft (CABG) had substantially better survival after accounting for other predictors.

Cardiac surgery for Ventricular Tachycardia is rarely performed, but has a role in some highly symptomatic patients, when antiarrhythmic medications and catheter ablation fails or are not possible, particularly if the failure of ablation is due to an arrhythmia arising from an area that is inaccessible to catheter ablation, such as deep in the myocardium, beneath epicardial fat, or near the coronary arteries. Surgical ablation of tachycardia can also be performed at the time of other cardiac surgical interventions, such as during surgical resection of large aneurysms due to prior MI in which the border zone is often a substrate for Ventricular Tachycardia, or placement of an LV assist device (LVAD).

Autonomic Modulation

Sympathetic activation is proarrhythmic and parasympathetic activation is generally antiarrhythmic in VT/VF. ***Modulating the autonomic nervous system for the purpose of preventing arrhythmias is an emerging therapeutic modality. It can be done either through interruption of sympathetic outflow to the heart, pharmacological beta blockade, or through stimulation of the parasympathetic pathway.*** Evidence is limited for its applicability to the broader group of VA, but studies are ongoing. Currently, there are limited data on the

role of vagal nerve stimulators and spinal cord stimulators for the prevention of VA/SCD in humans, and thus no formal recommendation could be supported.

Management in Children

Nearly 40% of children with cardiomyopathy undergo heart transplantation or die within 2 years of presentation. Arrhythmia induced cardiomyopathy must be considered in this setting. In the largest pediatric series of arrhythmia induced cardiomyopathy, AET (Atrial ectopic tachycardia) (59%) and permanent junctional reciprocating tachycardia (PJRT; 23%) were the most common arrhythmias represented. Ventricular arrhythmias were uncommon. [18, Rank 4]

Tachyarrhythmias are a reversible cause of cardiomyopathy from fetal life onward. Children often present late because they fail to recognize palpitations or are unable to verbalize symptoms and come to medical attention only after the development of HF. Compared with adults, different arrhythmia mechanisms are represented in pediatric arrhythmia induced cardiomyopathy.

Supraventricular arrhythmias are more common than ventricular arrhythmias in children and therefore are more frequently associated with arrhythmia induced cardiomyopathy. In the newborn, a single, sustained episode of typical supraventricular tachycardia may be unrecognized until heart failure symptoms emerge; thus, neonates may present with decreased left ventricular function, or even shock. In this group, prognosis and recovery of cardiac function are excellent after control of supraventricular tachycardia. This is in contrast to the more incessant tachycardias, where control is more challenging and recovery less rapid. [19, Rank 5]

Etiologically, sustained rapid rates, QRS duration, AV dys-synchrony and heart rate irregularity all could contribute to arrhythmia induced cardiomyopathy, yet not all children with incessant tachycardia develop arrhythmia induced cardiomyopathy. In children, the tachycardias most often associated with arrhythmia induced cardiomyopathy have a narrow QRS complex and 1:1 AV conduction. Heart rate irregularity occurs in pediatric arrhythmia induced cardiomyopathy, but as salvos of tachycardia interspersed with periods of sinus rhythm, rather than as the persistent heart rate irregularity seen in AF. [20, Rank 3]

As evident in many cardiac conditions, genetic factors may underlie the development of arrhythmia induced cardiomyopathy. Serum- and glucocorticoid-regulated kinase-1 (SGK1), a component of the cardiac phosphatidylinositol 3-kinase signaling pathway has proarrhythmic effects and has

been linked to biochemical and functional changes in the cardiac sodium (Na+) channel. These effects are reversed by treatment with ranolazine, which blocks the late Na+ current. Conversely, inhibition of SGK1 in the heart protects against fibrosis, heart failure, and Na+ channel alterations after hemodynamic stress. [21, Rank 5]

Management of tumor-induced Ventricular Tachycardia

Ventricular tachycardia from cardiac tumors can be managed initially like Ventricular Tachycardia from other origins, with use of defibrillation for unstable Ventricular Tachycardia and antiarrhythmic therapy for hemodynamically stable patients. Various long-term management approaches have yielded mixed results in suppressing or eliminating recurrent Ventricular Tachycardia associated with cardiac tumours.

Conservative Therapy

When Ventricular Tachycardia is associated with rhabdomyoma, the tumor's spontaneous resolution usually results in elimination of the Ventricular Tachycardia; accordingly, conservative therapy can be considered. Therapy with β-blockers has been reported to suppress Ventricular Tachycardia in one such instance, as well as in VT associated with other tumors.

Antiarrhythmic Therapy

Amiodarone suppressed recurrent Ventricular Tachycardia in our patient, as well as in others. However, aggressive antiarrhythmic therapy, although often necessary, is not always successful: amiodarone and tocainide failed to prevent sudden cardiac death in a patient who had osteosarcoma.

Resection

When feasible, resection especially of benign primary tumors is preferred, and it usually results in complete remission of VT. Resectability depends on the tumor's location and its proximity to the coronary arteries and other vital structures. In patients with lipoma and recurrent VT, additional cryoablation at the resection border is necessary. When malignant primary tumors do not cause death secondary to ventricular arrhythmia, they generally have poor prognoses. The median survival period of patients without metastases is 15 months. Complete excision has extended the median survival period to 17 months, compared with 6 months in incomplete resections.

Chemotherapy

Chemotherapy targeting the tumor itself has been of benefit. Combined cyclophosphamide, adriamycin, vincristine, and prednisolone chemotherapy, the mainstay of treatment for non-Hodgkin lymphoma, has eliminated ventricular arrhythmias through tumor regression. Nevertheless, despite adequate treatment of lymphomas, residual necrosis secondary to tumor regression can still create a nidus for continued ventricular arrhythmias.

Ablation

Radiofrequency ablation has been used to treat unresectable tumors that cause VT, in one instance eliminating incessant Ventricular Tachycardia in a 3-month-old girl who had rhabdomyoma. The only reported case in an adult involved a man who had metastatic gluteal sarcoma involving the left ventricular anterolateral wall. The patient was burdened by multiple episodes of drug-refractory Ventricular Tachycardia and Ventricular Fibrillation. Pace mapping and activation mapping were used, and catheter ablation at the site of earliest activation eliminated the Ventricular Tachycardia

Defibrillation

Cardiac defibrillators should be reserved for patients with recurrent episodes of unstable Ventricular Tachycardia, a reasonable quality of life, and a life expectancy longer than one year. A portable external defibrillator, such as the Life-Vest, might be an option for patients who have potentially unstable arrhythmias and a poor prognosis but an otherwise reasonable quality of life. [22, Rank 3]

Management of Ventricular Tachycardia in Adult Congenital Heart Disease

There are no randomised clinical trials evaluating the efficacy and safety of antiarrhythmic drugs (AADs) in patients with ACHD (Adult Congenital Heart Disease). Medication with beta-blocking agents may protect from rapid 1:1 AV conduction and tachycardia-mediated hypotension, but their preventive efficacy in SVT is uncertain. Non-use of beta-blockers was an independent predictor of appropriate implantable cardioverter defibrillator shocks in a multicentre cohort study of patients with TGA (Transposition of the great arteries) and intra-atrial baffle repair (hazard ratio 16.7; P=0.030). All

Antiarrhythmic drugs have an increased risk for proarrhythmia and many also aggravate sinus node dysfunction as well as heart failure and require in-hospital observation. Sinus node dysfunction may require pacemaker implantation prior to initiation of Antiarrhythmic drugs [23, Rank 4]

Catheter and Surgical Ablation

Catheter ablation of supraventricular tachycardia is more complicated in patients with Adult Congenital Heart Disease due not only to the nature of the MRAT (macro-reentrant atrial tachycardias), but also to the challenge with limited venous access to the heart, fibrotic atrial tissue, multiple atrial reentrant circuits, and atrial baffles separating the coronary sinus and CTI to the systemic venous atrium. Patients should preferably be referred to experienced centres with respect to complex macro-reentrant atrial tachycardias and with access to advanced mapping systems as special expertise and knowledge of complex tachyarrhythmias and scar-related ablation procedures is required for a successful outcome.

Catheter ablation is further challenged by the difficult access to the pulmonary venous atrium in patients who have undergone Fontan or atrial switch procedures. Trans-baffle access was reported to be successful in 96 % of 74 attempted cases without indications of higher incidence of adverse events. Trans-conduit puncture for patients who have undergone extra-cardiac Fontan procedures has more recently been reported without complication related to the puncture procedure. [24, Rank 4]

The acute success rates of catheter ablation of SVT in patients with Adult Congenital Heart Disease ranges from 65 to 100 %, with a higher recurrence rate (20–60 %) within 2 years than seen in other cohorts of routine SVT ablation. Lower success rates (65–82 %) have been reported for atrial tachycardia or macro-reentrant atrial tachycardias ablations as compared with those observed in the absence of Adult Congenital Heart Disease, although better outcomes have been achieved with the advent of advanced mapping and ablation techniques. Although ablation of CTI-dependent atrial flutter has a high acute success rate of 96 %, depending on the type of anomaly, the recurrence rate after 45±15 months' follow-up is as high as 18 %. ***The main factors related to higher success rates of catheter ablation in adult patients are:***

- ***Severity of Adult Congenital Heart Disease (patients with single ventricle or dextro- Transposition of the great arteries [d-TGA] with poorer outcomes);***

- ***Age (worse outcomes with older age at repair); and***
- ***Anatomical mapping systems and irrigated tip ablation catheters (higher success rates if used).***

Arrhythmia surgery can be integrated into a corrective surgical procedure with high efficacy and with no obvious signs of increased surgical morbidity. A 5 % mortality rate was, however, reported with Fontan conversion when surgery was performed purely for refractory supraventricular arrhythmia [25, Rank 5]

Specific Disease Conditions

Atrial Septal Defect

Most macro-reentrant atrial tachycardias (MRATs) occurring in patients without prior closure of the Atrial Septal Defect are cavo-tricuspid isthmus (CTI) dependent and susceptible to catheter ablation.

The Atrial Septal Defect closure unlikely eliminates the atrial flutter and catheter ablation of the cavo-tricuspid isthmus is therefore the recommended approach. If the Atrial Septal Defect mandates a closure, macro-reentrant atrial tachycardias) ablation prior to closure should be considered. Significant Atrial Septal Defects

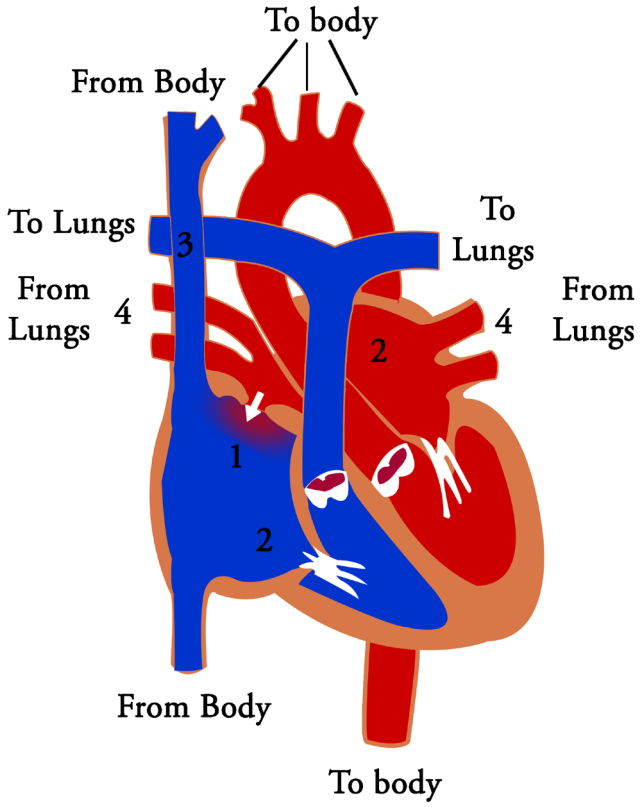

Figure 8: Atrial Septal Defect

in adults can even be closed later in life and result in improved morbidity and survival rates, although new or recurrent atrial tachycardias are frequent. It is therefore preferable to perform both catheter ablation of the atrial tachycardias and closure of the Atrial Septal Defect in patients with significant Atrial Septal Defect and tachyarrhythmia. The anatomical features of the Atrial Septal Defect determine the most suitable choice between catheter and surgical treatment approach. No randomised trials have compared catheter-based versus surgical closure of Atrial Septal Defect combined with arrhythmia intervention. [26, Rank 4]

Ebstein's Anomaly

Accessory pathways are frequent (15–30 %), more often right sided and multiple in patients with ACHD than in other patients, and other ***SVTs that can occur include Atrial fibrillation, atrial flutter and focal atrial tachycardia.***

The haemodynamic consequences of supraventricular tachycardias depend on the degree of malformation, varying from mild variants without any symptoms to severe haemodynamic compromise and cyanosis in cases of tricuspid regurgitation and large Atrial Septal Defect. Preexcited atrial fibrillation or rapidly conducting macro-reentrant atrial tachycardias) may result in sudden cardiac death. Catheter ablation of accessory pathways is challenging and associated with lower success rates (80 %) and higher recurrences (40 %) than in other patients, also depending on accessory pathway location. When surgical corrections are warranted and supraventricular tachycardias are present ablation is still recommended prior to surgery. Surgical ablation of accessory pathways is successful in 92–100%. Preoperative electrophysiological evaluation has a high diagnostic and therapeutic yield and is recommended as a routine preoperative test for this population. Patients who underwent corrective

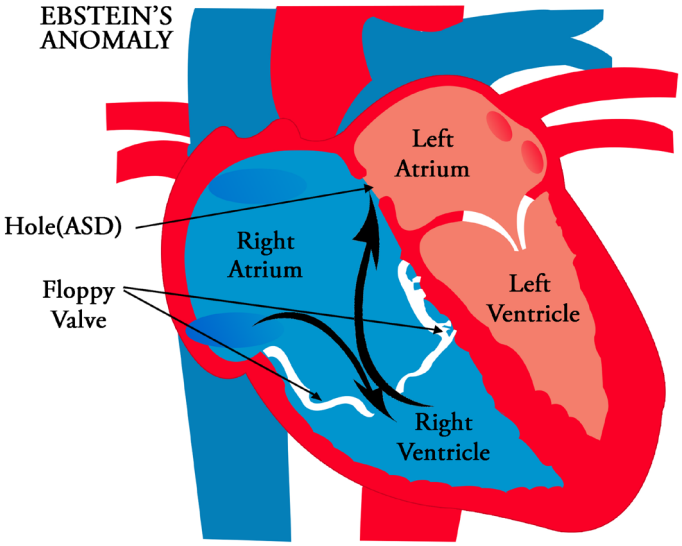

Figure 9: Ebsteins's Anomaly

surgery for ***Ebstein's anomaly with preoperative electrophysiological study and intraoperative arrhythmia ablation had a lower risk of sudden cardiac death than patients without arrhythmia intervention, in a small series.*** Catheter ablation procedures should be performed by experienced physicians related to the complex anatomy and the more complex arrhythmias. [27, Rank 4]

Arrhythmia-Induced Cardiomyopathy

Arrhythmia-induced cardiomyopathy (AIC) is a potentially reversible condition in which left ventricular dysfunction is induced or mediated by atrial or ventricular arrhythmias. Cellular and extracellular changes in response to the culprit arrhythmia have been identified,

but specific pathophysiological mechanisms remain unclear. ***Early recognition of AIC and prompt treatment of the culprit arrhythmia using pharmacological or ablative techniques results in symptom resolution and recovery of ventricular function. Although cardiomyopathy in response to an arrhythmia may take months to years to develop, recurrent arrhythmia can result in rapid decline in ventricular function with development of heart failure,*** suggesting residual ultrastructural abnormalities. Reports of sudden death in patients whose left ventricular ejection fraction have normalized cast doubt on the complete reversibility of this condition. ***Several aspects of AIC, including specific pathophysiological mechanisms, predisposing factors, optimal therapeutic strategies to prevent ultrastructural changes, and long-term risk of sudden death remain unresolved and need further research.*** [2, Rank 3]

Myocardial Infarction

Structural Remodelling

The healing phase of infarcted myocardium is characterized by infiltration of the infarcted myocardial tissue by inflammatory cells. Necrotic myocytes are cleared by macrophages, and replacement fibrous tissue, consisting of collagen, is deposited by fibroblasts over the next days, weeks, and months. The ischemic wavefront of necrosis proceeds from the subendocardium to epicardium during myocardial ischemia, and scar deposition parallels this sequence. Critical elements arise during this process, which permit the reentrant circuits that characterize monomorphic ventricular tachycardia (MMVT) [28, Rank 3]

Channels that facilitate or sustain Monomorphic Ventricular Tachycardia, consist of an entry site, a protected isthmus, and a breakthrough exit site that activates the ventricles. Functional or fixed conduction slowing and block in a channel can result in an excitable gap for reentry. These localized regions of slow conduction within scar exhibit "zig-zag" conduction during normal sinus rhythm through heterogeneously connected myocytes traversing dense unexcitable scar. Post-infarct structural remodeling may also involve deposition of adipose tissue in the infarcted bed. A recent report showed that electrophysiologic consequences of post-infarct myocardial fatty replacement in ovine Myocardial infarction included decreased conduction velocity, and reduced bipolar electrogram amplitude. The presence of inducible ventricular tachycardia in Myocardial infarction animals was associated with greater adipose

content and slower conduction velocity in the border zones of infarcts. [29, Rank 4]

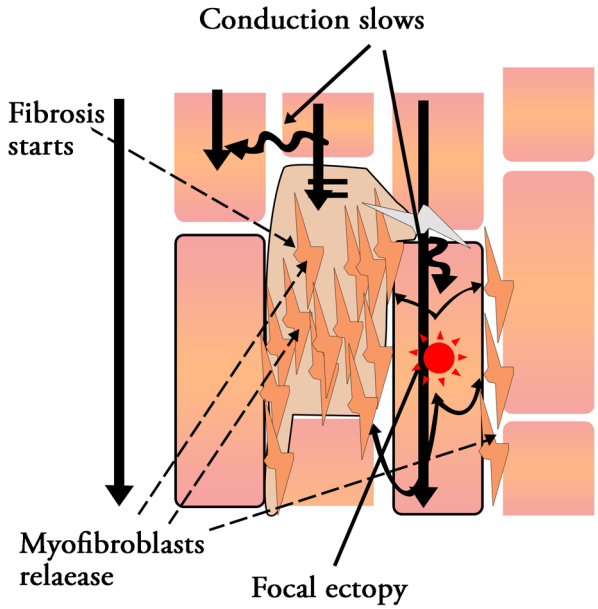

Figure 10: Structural Remodelling

Functional Cellular Remodelling

Remodeling of other important elements within and beyond the infarcted myocardial bed also occur, and add further complexity to the post- Myocardial infarction substrate. These include remodeling of myocyte ionic currents and gap junctions, direction of activation propagation, and intra-myocardial nerve fibers. Although human data are lacking, studies in animal models have provided insight into how ventricular myocyte action potential (AP) remodel in cardiomyocytes adjacent to a healed Myocardial infarction. These include reduction in the duration, upstroke amplitude, and velocity of border zone myocyte action potential. Reductions have also been reported in peak calcium currents in surviving border zone cells. In addition, refractoriness in the infarcted animal heart is known to be more nonuniform compared to normal hearts, with varying degrees of AP prolongation exhibited by individual surviving myocytes adjacent to and remote from the infarcted myocardium. In the border zones of infarcts, this worsens heterogeneity in refractorinesss, and facilitates the development of unidirectional block, critical to genesis and perpetuation of ventricular tachycardia.

The distribution of connexin 43 gap junctions in the border zone of the infarcted human heart is also aberrant. Fewer gap junctions are organized into transverse (side-to-side) connections, rather the gap junctions are redistributed in a longitudinal fashion. Detailed animal studies support light microscopy findings in humans, with altered anisotropic conduction in the healed infarct heart. In addition, interstitial fibrosis results in displacement of myocytes from each other, and a significant decrease in the syncytial connection of myocytes in the infarct border zone.

Another component of post- Myocardial infarction functional change is neural remodeling. Nerve endings in the infarcted bed are resorbed, however, since the neuronal cell body from which these nerves originate is removed from the infarcted territory, plastic growth is driven

at the most distal intact endings adjacent to the infarcted tissue. This nerve sprouting in the border zone is heterogeneous, and is unable to penetrate scar tissue. The presence of these sprouts has been associated with ventricular arrhythmias and sudden death in humans, likely related to local heterogeneity in myocyte electrophysiological properties. Remodeling within stellate ganglia, which partly control myocardial excitability, has also been reported, and likely contributes to enhanced sympathetic tone and electrical heterogeneity seen after Myocardial infarction. [30, Rank 3]

Specific Management of Ventricular Tachycardia in Ischemic Substrates

Pharmacologic Therapy

Despite decades of intense research and development, few effective drugs with minimal side effects are available for the treatment of recurrent MMVT (Monomorphic Ventricular Tachycardia). Beta-adrenergic receptor blockers have been studied in a variety of post-myocardial infarction trials, demonstrating substantial reduction in the risk of sudden death and recurrent Ventricular Tachycardia. The efficacy of beta blockers in stable Monomorphic Ventricular Tachycardia is however limited. Sotalol demonstrates greater efficacy compared to beta blockers, however, the risk of prolonged QT and Polymorphic ventricular tachycardia (PMVT) restricts its use. The proarrhythmic risk of anti-arrhythmics drugs in the post-infarct setting have long been recognized, with amiodarone demonstrating a safer risk profile. Given the long-term risk of side effects, amiodarone is a less favorable choice for long-term management of Ventricular Tachycardia in Ischemic cardiomyopathy (ICM) patients. Newer agents such as ranolazine have shown some promise in reducing Ventricular Tachycardia and implantable cardioverter-defibrillator shocks in Ischemic cardiomyopathy patients without significantly increased risk profile. [25, Rank 4]

Defibrillator Therapy

Implantable cardioverter-defibrillators have been demonstrated in multiple trials to reduce the risk of sudden death in patients with ischemic heart disease substrates. Although defibrillators save lives, they do not prevent the initiation of Ventricular Tachycardia, and patients frequently present to medical attention with repetitive implantable cardioverter-defibrillator shocks. Defibrillator shocks are associated with significant medical and psychiatric

morbidity. Post hoc analysis of implantable cardioverter-defibrillator studies demonstrate that patients who receive appropriate implantable cardioverter-defibrillator shocks have clinical outcomes that are less favorable than those patients without Ventricular Tachycardia and who do not receive implantable cardioverter-defibrillator shocks. While the underlying reason for this phenomenon is not clear, it emphasizes that although defibrillators have a role in preventing sudden death from ventricular arrhythmias, adjunctive therapies are required to mitigate arrhythmogenesis. [24, Rank 4]

Surgical Treatment

In contemporary management of recurrent MMVT, surgical therapy has a limited role. Although intraoperative mapping studies provided substantial insights into the mechanisms underlying scar-related Ventricular Tachycardia, it has fallen out of favor due to the morbidity of surgical exposure of the heart for mapping and ablation. This is especially true in the era of minimally based access to the endocardium and epicardium, and mini-thoracotomy for epicardial access, which is increasingly implemented. However, it is important to note that the advent of border zone ablation was an attempt to mimic encircling ventriculotomy and subendocardial resection. [22, Rank 5]

Catheter Ablation

Catheter-based management of MMVT is an increasingly adopted strategy, with a number of studies supporting its role over antiarrhythmic drugs. It requires careful patient selection, pre-procedural planning and imaging, procedural substrate characterization, induction and mapping of tolerable MMVTs, ablation of electrophysiologic and substrate targets, and careful post-procedural care, while minimizing risks of complications. Catheter ablation is often reserved for patients with ischemic heart disease who suffer implantable cardioverter-defibrillator shocks or recurrent arrhythmias (including electrical storm), although a growing trend is the early introduction of catheter ablation of Ventricular Tachycardia. [20, Rank 5]

Conclusion

After infarction, the myocardial substrate undergoes significant structural and functional alterations, from a molecular to macroscopic level, resulting in substrates capable of facilitating MMVT. The morbidity and mortality associated with VT in this substrate cannot be overstated. Pharmaco-

logic, and catheter-based approaches to treating VT specific to this substrate have evolved since the initial intraoperative mapping studies detailing critical elements of the ischemic substrate. While the structural elements of the ischemic heart disease substrate are well understood, the chronic functional changes that permit unidirectional block and other key electrophysiologic phenomena, as well as the acute functional changes that initiate MMVT remain poorly understood. Improving our understanding of this new frontier will undoubtedly improve or ability to prevent and care for patients with ischemic heart disease substrates suffering from recurrent MMVT. [14, Rank 5]

***Important information for post-test is highlighted in red letters, boxes and diagrams.**

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