PROPER MANAGEMENT of ventricular tachycardia (VT) should take into consideration: (1) the type of VT (nonsustained or sustained, monomorphic or polymorphic), (2) the probable electrophysiologic mechanism, (3) the anatomic and functional substrates (minimal or no structural heart disease or organic heart disease, normal or depressed ventricular function), and (4) the clinical presentation (palpitation, presyncope/ syncope, in other words, hemodynamically stable or unstable). While nonsustained VT in the presence of minimal or no structural heart disease may be benign and requires no further management, a hemodynamically unstable VT is potentially lethal and requires specific management steps.

Electrophysiologic Mechanisms of VT

VT can be caused by either abnormal pacemaker activity or by reentrant excitation! Pacemaker activity occurs when a cell or a group of closely knit cells begins to generate impulses. The mechanism can be abnormal automaticity or triggered activity, the latter is subdivided into activity arising from delayed or early afterdepolarizations. Triggered activity from delayed afterdepolarizations may be the mechanism of idiopathic VT seen in patients with minimal or no structural heart disease. Triggered activity from early afterdepolarizations is probably the mechanism of polymorphic VT, known as torsades de pointes (TdP), seen in patients with congenital or acquired long QTU syndrome. On the other hand, reentrant excitation occurs when the propagating impulse does not die out after complete activation of the heart, as is normally the case, but persists to reexcite the ventricles after the end of the refractory period. A figure-eight circus movement reentry is the most common basis of VT in patients with organic heart disease, especially coronary artery disease with recent or old myocardial infarction.

Sustained Monomorphic VT

Sustained monomorphic VT is commonly seen in patients with coronary artery disease especially in those with previous myocardial infarction. The arrhythmia is rather uncommon in other forms of organic heart disease like idiopathic dilated cardiomyopathy, hypertrophic cardiomyopathy, and valvular heart disease. Symptoms range from palpitation to syncope, the latter due to hemodynamic compromise. A hemodynamically unstable VT is usually fast and is associated with poor left ventricular systolic function. Another important but less understood factor is the integrity of the autonomic nervous system which characterizes the response of the systemic peripheral vascular resistance to the decrease in cardiac output. In some patients with hypotensive VT, the expected peripheral vasoconstrictive response to the decrease in cardiac output is inadequate and sometimes paradoxical. Hypotensive VT can rapidly degenerate into ventricular fibrillation (VF) and hypotensive VT/VF is the arrhythmia most commonly seen in sudden cardiac death.

Management of patients resuscitated from a hypotensive VT and those with recurrent and/or
less symptomatic sustained monomorphic VT requires evaluation of the underlying anatomic and functional substrates. In patients with coronary artery disease this means evaluation of coronary artery anatomy, left ventricular systolic function, evidence of myocardial ischemia, and the presence of a myocardial aneurysm. Therapeutic options include (1) coronary revascularization, (2) antiarrhythmic drug therapy guided by electrophysiologic (EP) testing or Holter monitoring, (3) surgical or electrode catheter ablative techniques, and (4) arrhythmia control electrical devices.

Coronary Revascularization
Several reports suggest that survival is excellent after revascularization in coronary artery disease patients with cardiac arrest who have no inducible arrhythmia at EP study.4,5 Other reports have indicated that the effects of revascularization in cardiac arrest patients with inducible arrhythmias may depend on the type of arrhythmia initiated. Patients who manifest only polymorphic VT or VF at EP study will often have no inducible arrhythmia at a postoperative study.6 In contrast, patients who have a sustained monomorphic VT will only rarely have their inducible arrhythmia suppressed when restudied after an otherwise successful revascularization. However, even in patients with monomorphic VT, surgical revascularization may improve survival by decreasing the frequency of arrhythmia or by preventing the appearance of new arrhythmias due to uncontrolled or progressive ischemia.7

Antiarrhythmic Drug Therapy
Invasive EP study8 and noninvasive Holter monitoring9 in conjunction with exercise testing have both been used to evaluate the efficacy of antiarrhythmic drugs in patients with sustained VT and in survivors of cardiac arrest. Sustained VT can be reproduced by EP study in a large majority of patients who present with this arrhythmia.10,11 In patients with coronary heart disease, the rate of induction of VT exceeds 90%. This rate is somewhat lower in patients with cardiomyopathy, valvular heart disease, and idiopathic VT. VT is rarely induced by programmed electrical stimulation in patients with the long QTU syndrome and TdP VT.

In patients with sustained monomorphic VT, an antiarrhythmic drug regimen that prevents induction of the clinical arrhythmia during serial EP testing can be found in approximately 20% to 50% of patients.12,13 Patients treated with drugs that have been shown to suppress inducible VT are at significantly lower risk for recurrent spontaneous VT and sudden death than patients in whom a suppressive drug regimen cannot be identified.8 Successful suppression of inducible VT is more likely in patients with well-preserved left ventricular function and in patients with fewer previously unsuccessful empirical drug trials. Suppression of inducible VT during serial EP testing has been found to be a powerful independent predictor of recurrence and survival in this patient population. 8

The comparative efficacy of invasive EP testing and ambulatory electrocardiographic monitoring as end points for the selection of antiarrhythmic drug regimens in patients with recurrent sustained VT have been recently addressed by the Electrophysiology Study Versus Electrocardiographic Monitoring (ESVEM) study.14 There was no significant difference in the probability of recurrence of ventricular tachyarrhythmia between patients who received antiarrhythmic drugs predicted to be effective on the basis of EP study and those who received drugs predicted to be effective on the basis of Holter monitoring combined with exercise testing. The principal difference between the two methods was a longer yield of prediction of drug efficacy with Holter monitoring. At present, however, invasive EP testing is generally recommended in patients with sustained VT that has been associated with life-threatening sequelae, such as hemodynamic compromise during VT or degeneration of VT to VF. Even in patients in whom sustained VT, in the absence of drugs, is relatively stable, EP testing may be preferable to empirical or Holter-guided therapy if the episodes of spontaneous VT are rare and ambulatory monitoring fails to reveal frequent nonsustained VT. In patients in whom antiarrhythmic drug therapy is ineffective in preventing VT, EP testing is mandatory in the selection, implementation, and evaluation of nonpharmacological therapies, such as mapguided antiarrhythmic surgery, catheter ablation.
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Surgical and Electrode Catheter Ablative Techniques

Map-guided endocardial resection of the arrhythmogenic substrate is the most commonly utilized antiarrhythmic surgical technique. Alternative ablation techniques that could be used instead of, or in addition to, endocardial resection are cryoablation and laser photocoagulation. Currently, the operative mortality in experienced centers may be less than 5% in stable patients undergoing elective procedures, with 85% to 95% of operative survivors free of inducible and spontaneous VT after operation. Among those patients in whom VT is still inducible after surgery, drug therapy is often successful. Long-term mortality also continues to improve. This probably is due to the combined effects of greater experience by the medical and surgical teams, more effective operative techniques, and better patient selection. Both direct current shock and radiofrequency electrode catheter ablative techniques have been less successful compared to antiarrhythmic surgery. Approximately 25% of patients remained free of recurrent VT with no antiarrhythmic drug therapy. Ablation results are more successful if a specific area with slow conduction is found, as identified by pace mapping and/or the recording of mid-diastolic potentials. An important exception is patients with VT due to bundle branch reentry in whom ablation of the right bundle is highly successful in interrupting the arrhythmia. A more recently described procedure for transcoronary chemical ablation requires precise mapping during tachycardia.

Arrhythmia Control Electrical Devices

Patients with symptomatic hypotensive VT who failed antiarrhythmic therapy and who are not candidates for ablative therapy should receive an implantable cardioverter defibrillator (ICD). The clinical efficacy of ICD in terminating VTNS has been proven repeatedly both at the time of implantation and at the time of subsequent ICD shocks during electrocardiographic monitoring. Although it is difficult to compare relative efficacy of various therapeutic modalities because of selection bias, the overall mortality seems to be the lowest with ICD and only surgical ablative therapy for VT achieves comparable sudden cardiac death rates. VT can be interrupted by an automatic anti tachycardia pacemaker that delivers various sequences of programmed stimulation and different forms and combinations of rapid overdrive stimulation such as those used during EP studies. The risk of acceleration of VT or degeneration into VF prohibits the use of this therapeutic modality without a backup defibrillator. New generations of ICD promise to have a tiered antitachycardia algorithm that includes various programmed stimulation modalities, low-energy cardioversion shocks, and high-energy cardioversion shocks.

Idiopathic VT

VT in patients with minimal or no structural heart disease is an uncommon clinical entity. Clinical presentations range from incessant (repetitive) runs of non sustained monomorphic VT to infrequent episodes of sustained VT. Two types have been recognized based on the QRS morphology of the VT. VT with left bundle branch block and inferior QRS axis morphology originates from the right-ventricular outflow tract while VT with right bundle branch and left-axis deviation originates from the left posterior fascicle. However, idiopathic VT does not constitute a homogenous group. Attempts to classify tachycardia mechanism by the response to programmed stimulation and pharmacological manipulation suggest diverse potential EP mechanisms including reentry, triggered activity, and catecholamine-mediated automaticity.

Right-ventricular outflow VT can be induced by exercise or infusion of catecholamine and terminated by vagotonic measures (valsalva maneuver), specifically by adenosine. On the other hand, idiopathic left ventricular fascicular VT was shown to be verapamil-sensitive and the drug is effective in both short- and long-term treatment of VT. Detailed mapping and pacing studies have demonstrated that both types of VT arise from discrete foci, and catheter ablation at...
these sites can result in long-term abolition of spontaneous VT. 26,29

Polymorphic VT

Polymorphic VT is VT with unstable, continuously varying QRS complex morphology in any recorded electrocardiographic lead. Compared to sustained monomorphic VT, polymorphic VT is usually viewed as having a more ominous prognosis. Although many prolonged episodes of very fast polymorphic VT (~ 200 beats/min) are associated with hemodynamic collapse and usually degenerate into VF, a majority of episodes of polymorphic VT terminates spontaneously. It is important to remember that spontaneous polymorphic VT and polymorphic VT induced in the electrophysiology laboratory by programmed stimulation have different prognostic significance.

There is more than one electrophysiologic mechanism for polymorphic VT, and an understanding of these mechanisms can be of valuable help in the proper management of individual patients. The most appropriate way to classify polymorphic VT is whether it is associated with normal or prolonged QT (or QTU) segment (Figure 1). With few exceptions the EP mechanisms of these two types of polymorphic VT are different. There is also unnecessary confusion regarding the use of the term polymorphic VT and TdP VT. The latter is simply a descriptive term of polymorphic VT with a characteristic undulating QRS configuration.30 The term TdP should be reserved for use with the long QTU syndrome. However, not all patients with the long QTU syndrome have polymorphic VT with a characteristic TdP configuration, and this classic configuration can be seen in some cases without a prolonged QTU.

Clinical Syndrome of Long QTU and TdP

The clinical syndrome of long QTU and TdP can be either congenital, idiopathic, or acquired.31,32 Congenital long QTU syndrome differs from the acquired type, especially in response to cycle-length changes and sympathetic activity. The onset of TdP in the congenital long QTU syndrome is not necessarily bradycardiodependent, as is frequently the case in the acquired type. Patients with congenital long QTU syndrome characteristically develop TdP during periods of increased adrenergic activity. Several observations, however, suggest a common underlying mechanism for both congenital and acquired forms with a greater predominance of adrenergic influence in the congenital and idiopathic long QTU syndrome.

An international prospective registry has provided significant insight into the clinical presentation and long-term follow-up of patients with the congenital long QTU syndrome.33 In a study of 343 individuals from 328 families in which one or more members were affected by the long QTU syndrome, the syndrome was familial in 85% of patients. The disorder primarily affected children and young adults with structurally normal hearts. The development of lifethreatening ventricular tachyarrhythmias was quite variable among affected individuals. The first patient from a family to be identified with the syndrome, the proband, was more likely to be female (69%). Other findings included symptoms
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provoked by emotional or physical stress (47%), congenital deafness (7%), a resting heart rate less than 60 beats/min (31%), and corrected QT interval greater than 500 ms (52%). The average age at presentation was 21 years. As many as 50% of the probands had experienced a syncopal episode or aborted sudden death by the age of 12 years. Because the patients had recurrent syncope, many had been misdiagnosed as having seizure disorders. The rates of sudden death and syncope after enrollment into this longitudinal study were 0.9% and 5% per year, respectively. Patients with congenital long QTU syndrome have been managed by one of four different modalities: (1) beta-adrenergic blocking agents have been the cornerstone of therapy since these agents counteract the excess sympathetic activity that frequently triggers the polymorphic VT in these patients. Beta-adrenergic blocking agents frequently suppress symptoms but have little effect on the prolonged QTU interval; (2) left cervicothoracic sympathectomy has been recommended for patients with symptoms refractory to beta-adrenergic blocking agents or with intolerable side effects to the drugs; (3) an interesting therapeutic modality in patients with congenital long QTU syndrome is the combined use of maximal tolerated doses of beta-adrenergic blocking agents and permanent cardiac pacing, the latter to prevent excessive bradycardia and cardiac pauses which could trigger ventricular tachyarrhythmias; and (4) in symptomatic patients who failed the above management techniques, an ICD device is recommended.

The acquired long QTU and TdP is characteristically associated with bradycardic pauses and a prominent late diastolic U wave that results in a prolonged QTU interval. A few reports of monophasic action potential recordings in patients with congenital or acquired long QTU and TdP have shown deflections on late phase 2 or phase 3 repolarization consistent with early afterdepolarization. The clinical syndrome occurs in association with certain pharmacologic agents, electrolyte abnormalities, and bradycardic states. Literally, any pharmacologic agent that can result in prolonged QTU interval may be associated with TdP. A combination of predisposing factors is not uncommon in clinical practice. The most notable examples are patients on quinidine who also develop hypokalemia from potassium-wasting diuretics and have a slow cardiac rhythm and/or long bradycardic pauses (e.g., during atrial fibrillation or postextrasystolic pauses). In the majority of patients, the plasma concentration of the drug is within or below the accepted therapeutic range. The question of whether associated predisposing factors like hypokalemia and bradycardia, individual susceptibility (possible subclinical abnormality of an ionic channel protein or a regulatory G protein), or both could explain the occurrence of TdP in a small percentage of patients who receive quinidine or one of the other pharmacological agents associated with the syndrome has not been adequately investigated.

Management of patients with acquired long QTU and polymorphic VT requires immediate measures to suppress the tachyarrhythmia. Intravenous magnesium sulfate was shown to suppress the polymorphic VT without shortening of the prolonged QTU interval. Increasing the heart rate by either atropine or isoproterenol or preferably in a controlled fashion by temporary ventricular pacing is usually successful in suppressing the arrhythmia. Fast pacing results in shortening of the action potential duration, QT interval, and suppression of early afterdepolarization. Long-term measures include correction of underlying electrolyte abnormalities and discontinuation of the offending agent.

Polymorphic VT with Normal QTU Interval

Polymorphic VT is uncommon in the course of acute myocardial infarction and is usually associated with normal QTU interval. The appropriate management of this arrhythmia is not well defined. The arrhythmia had a variable response to Class I antiarrhythmic agents but could be suppressed in some patients by intravenous amiodarone. Coronary revascularization appeared to be effective in preventing the recurrence of polymorphic VT when associated with recurrent postinfarction angina. There are few reports of polymorphic VT/VF in patients with no significant structural heart disease. Because these patients are at high risk for sudden death, an ICD device may have to be considered in some cases.
Nonsustained VT

The prognostic significance of nonsustained VT depends on the underlying anatomic substrate. In asymptomatic healthy subjects, the presence of complex ventricular ectopy and nonsustained VT is not associated with an increased risk of sudden death.\(^4^1\) On the other hand, the occurrence of spontaneous nonsustained VT in patients with organic heart disease is considered a poor prognostic index.\(^4^2,4^3\) However, the likelihood of sudden death may not be the same for all patients with organic heart disease and nonsustained VT. Different methods have been proposed for risk stratification in this group. The electrocardiographic characteristics of the arrhythmia have shown little value in identifying patients at higher or lower risk of serious arrhythmic events. The use of EP study for prognostic purposes has produced inconclusive results. A majority of studies,\(^4^4,4^5\) including one from this laboratory, \(^4^6\) has reported that patients with spontaneous nonsustained VT in whom ventricular tachyarrhythmias are not inducible are at low risk of sudden death and may not warrant antiarrhythmic therapy. On the other hand, in patients with coronary artery disease, spontaneous nonsustained VT and inducible sustained monomorphic VT, EP-guided therapy can result in a good clinical outcome if an appropriate drug is identified that fully suppresses the induced VT or results in a slower and well-tolerated arrhythmia.\(^4^5\) In this group of patients the two noninvasive tests of signal-averaged electrocardiogram and left ventricular ejection fraction as well as the invasive test of programmed stimulation could be used for risk stratification and management according to the following guidelines (Figure 2).\(^4^6\) Patients with an ejection fraction of 40% or greater and no late potentials on the signal-averaged electrocardiogram do not require EP testing or long-term antiarrhythmic therapy because the incidence of inducible sustained monomorphic VT and the risk of sudden death are very low in this group of patients. On the other hand, patients with late potentials as well as patients with no late potentials but with an ejection fraction less than 40% may be recommended for EP testing. Patients with no inducible tachyarrhythmia as well as those with inducible nonsustained VT or VF could be followed on no antiarrhythmic therapy, with a low risk of sudden death. If sustained monomorphic VT is induced, those patients could receive antiarrhythmic therapy guided by EP testing. However, the recommendation for the use of EP testing to guide therapy should be tempered by the fact that the value of antiarrhythmic treatment of induced sustained VT in patients with coronary artery heart disease and spontaneous nonsustained VT has not been definitely established. This could only be achieved through randomization of therapy in a large multicenter study. Such a study is currently under way entitled "The Multicenter Unsustained Tachycardia Trial, MUSTI" and sponsored by the National Institutes of Health\(^4^7\) in the United States.

Finally, risk stratification and management of nonsustained VT in patients with nonischemic dilated cardiomyopathy remains controversial. A recent study suggests that a normal signal averaged electrocardiogram as well as failure to induce VT in those group of patients do not imply a benign outcome.\(^4^8\) Other risk stratification strategies should be implemented in this group.
References