Overdrive Pacing for Ventricular Tachyarrhythmias: A Reassessment

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Overdrive pacing was used for many years to prevent ventricular tachycardia and there are many reports of its effectiveness. Nevertheless, the use of overdrive pacing for most types of ventricular tachyarrhythmia has been abandoned. One notable exception is torsades de pointes, in which interventions that increase heart rate, including pacing, at least temporarily protect against recurrence. Overdrive may work by narrowing dispersion of ventricular refractoriness, and measurement of the latter could provide a marker to selectively apply overdrive pacing, thus increasing its usefulness.

THE RATIONALE FOR the use of overdrive pacing to prevent ventricular tachyarrhythmias is based on the observation made early in this century that heart rate is critical to the genesis of some arrhythmias. It was noted that severe bradycardia was frequently accompanied by complex ventricular ectopic activity. Syncope and sudden death in patients with complete heart block often resulted from ventricular tachycardia or fibrillation. It was assumed that increasing heart rate would not only alleviate the symptoms of bradycardia but also prevent the emergence of potentially lethal ventricular arrhythmias. The literature reporting the prevention of tachyarrhythmias by pacing consists principally of many anecdotal case reports. Table 1 summarizes several studies in which more than one representative case was reported.

The initial experience with overdrive pacing focused on patients with atrioventricular block in an effort to maintain heart rate to prevent recurrent ventricular tachycardia and fibrillation. Schnur (1) reported in 1948 that recurrent ventricular tachycardia and fibrillation were prevented in a patient with complete heart block by using epinephrine and ephedrine treatments to increase the ventricular escape rate. Zoll and associates (2) in 1960 reported their experience with external cardiac pacing for the prevention of ventricular tachyarrhythmias after successful defibrillation. Four of their patients were maintained in a regular rhythm for several hours to days, driving the heart at a rate of 40 to 60 beats/min. Slowing the ventricular paced rate to less than 40 beats/min resulted in ectopic activity that degenerated into ventricular fibrillation. Their technique was painful, precluding continued pacing, and many of these early patients eventually died. The next development was the use of electrodes affixed directly to the heart at thoracotomy, using an external power source, but the major breakthrough was implantation of the power source. Dressler (3) reported his experience with such a system in 1964. He noted that Adams-Stokes syndrome resulted from ventricular tachycardia in 19 of 28 patients with the syndrome. Permanent ventricular pacing at 60 to 80 beats/min prevented seizures in all of the 19 patients, preventing further episodes of ventricular tachycardia in 15. Sowton and colleagues (4), in the same year, reported 2 patients similarly benefiting from chronic ventricular pacing. One of these patients needed both drug therapy and a pacemaker, whereas the other had incessant episodes of ventricular fibrillation that were controlled for 14 days by ventricular pacing.

Ventricular pacing of patients in sinus rhythm for suppression of ventricular tachyarrhythmias (overdrive pacing) was pioneered by Eraklis and colleagues (5) and by Heiman and Helwig (6) in the mid-1960s. Eraklis and colleagues (5) reported the case of a patient temporarily responding to atrial overdrive pacing during a stormy postoperative course after mitral commissurotomy. Heiman and Helwig (6) treated two patients with overdrive. The first was a 42-year-old woman who, in retrospect, was considered to have torsades de pointes secondary to quinidine sulfate. Her torsades was resistant to all antiarrhythmic agents but responded to atrial pacing at 155 beats/min. Over the next week, the pacing rate was progressively lowered to 110 beats/min, but rechallenge with quinidine caused recurrence of torsades. The patient was weaned from the pacer after the quinidine was stopped, but she died 3 months later. Their second patient had a similar syndrome and needed permanent ventricular pacing (110 to 130 beats/min). This patient had a functioning pacemaker at the time of discharge but died suddenly 6 months later.

Kastor and coworkers (7) reported the successful use of temporary pacing to treat ventricular tachyarrhythmias in two patients, one of whom required pacing at 100 beats/min. Both patients needed only temporary pacing and were well at discharge. Wellens and associates (8)

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Table 1. Representative Reports of Overdrive Pacing

Reference	Patients Reported	Arrhythmia Treated	Pacing Mode			Results	
			Duration	Site	Rates	Patients Responding	Duration of Pacing
	n				*beats/min*	*n*	
Zoll and associates (2)	5	Ventricular fibrillation related to atrioventricular block	Temporary	External	40-80	4	2 h to 4 d
Dressler (3)	19	Ventricular tachycardia related to atrioventricular block	Permanent	Ventricular	60	15	6-25 mos
Sowton and associates (4)	2	Ventricular tachycardia	Temporary ($n = 1$), permanent ($n = 1$)	Ventricular	120	2	14 d and 14 mos
Heiman and Helwig (6)	2	Ventricular tachycardia related to antiarrhythmic drug	Temporary ($n = 1$), permanent ($n = 1$)	Atrial ($n = 1$), ventricular ($n = 1$)	110-155	2	5 d
Kastor and associates (7)	2	Ventricular tachycardia and ventricular fibrillation	Temporary	Atrial	100-110	2	2 and 3 d
Hornbaker and associates (9)	5	Ventricular tachycardia (2 cases related to bradycardia)	Permanent	Ventricular	70-130	5	2-16 mos
Friedberg and associates (16)	7	Ventricular tachycardia (4 cases related to antiarrhythmic drugs)	Temporary ($n = 3$), permanent ($n = 4$)	Ventricular	95-120	4	1-14 mos
Johnson and associates (21)	11	Ventricular tachycardia and ventricular fibrillation	Permanent	Atrial ($n = 6$), ventricular ($n = 5$)	70-110	9	16-72 mos
Lopez and Sowton (22)	6	Ventricular tachycardia (3 cases related to atrioventricular block)	Temporary	Ventricular	83-120	4	2 h to 14 d

have supported the use of atrial rather than ventricular overdrive pacing in selected patients, explaining that the pattern of ventricular activation may be an important factor in facilitation of the arrhythmia. However, there have been no controlled comparisons of efficacy of atrial versus ventricular overdrive. Other reports are difficult to assess because overdrive was combined with pharmacologic therapy (9) or surgical suppression of sympathetic tone (10). For example, Hornbaker and coworkers (9) reported increased effectiveness of permanent ventricular overdrive pacing in two of five patients when a beta-adrenergic blocking drug was added, and Zipes and associates (10) used beta-blockade and cardiac sympathectomy in conjunction with ventricular overdrive pacing. The rationale for combined therapy has not always been clear; in some reports, a drug shown to be ineffective was continued even after successful pacemaker therapy was initiated (11).

Mechanisms of Overdrive Suppression

Overdrive pacing to prevent ectopy is different from the pacemaker techniques currently used in the electrophysiology laboratory to terminate ventricular tachycardia. Termination probably results from entrance of a critically timed impulse into a reentrant pathway, disrupting the circuit of an established tachycardia. Overdrive pacing presumes a rate-related physiologic substrate for tachyarrhythmia and that the arrhythmia is prevented by changing that substrate. Exactly how overdrive works is speculative. In a patient with bradycardia, increased heart rate and cardiac output may increase coronary flow and thereby reduce myocardial ischemia. Likewise, increased heart rate causes diminished diastolic filling time and decreases ventricular volume and myocardial stretch, and stretch enhances automaticity of spontaneously depolarizing cells. However, many patients benefiting from overdrive suppression have neither symptoms nor signs of myocardial ischemia when they are bradycardic and susceptible to arrhythmia. Pacing at the high rates frequently required would likely cause a fall in cardiac output and coronary flow by shortening the relative time spent in diastole. However, the hemodynamic response to atrial or ventricular pacing is variable and unpredictable, in part depending on myocardial compliance determined by the presence of the underlying heart disease. We suspect that overdrive pacing has a nonhemodynamic mechanism of action, although studies that controlled for changes in cardiac output or coronary flow are lacking.

Overdrive pacing may benefit those arrhythmias with an automatic mechanism by effecting activation of Purkinje cells. Changes in membrane potential alter extracellular concentration of potassium ion, so that the cell cannot fully or rapidly depolarize on subsequent excitation (phase 0). Rapid pacing also increases the intracellular concentration of sodium. This increase, in turn, reduces the activity of ectopic pacemakers by reducing the net inward current that would otherwise lead to spontaneous diastolic depolarization (12). In reentrant ventricular arrhythmias, pacing changes the pattern of ventricular activation, which may prevent perpetuation of reentry. However, we suspect that overdrive pacing suppresses tachyarrhythmias mainly by causing more uniform ventricular refractoriness. This suspicion is based on the effect of heart rate on ventricular refractoriness. The duration of repolarization and refractoriness, measured by either the QT interval or by the effective refractory period, is shortened as the heart rate is increased (13). However, refractoriness becomes progressively more uniform as cycle length is shortened, and narrowing the dispersion of refractoriness decreases the susceptibility to ventricular tachyarrhythmias (14). Dispersion of refractoriness will be considered in more detail in the discussion of torsades de pointes.

Efficacy of Overdrive Pacing

Overdrive pacing is effective therapy for patients with ventricular tachyarrhythmias arising in severe bradycardia (1-4) and has been advocated for use in patients with incessant or refractory tachycardias until a more permanent drug regimen is designed (15-17). Preston (15) claimed that "arrhythmias almost always can be suppressed by pacing the ventricle or atrium at a rate greater than that of the arrhythmia" and that overdrive pacing "is best suited to the acute recurrent arrhythmia which can be suppressed or prevented by short-term pacing." Friedberg and associates (16) studied seven patients with recurrent ventricular tachycardia and found that most responded to temporary pacing.

However, more chronic use of ventricular overdrive pacing for patients with normal rates of sinus rhythm has not gained favor, presumably because of theoretical objections. There is an undefined incidence of breakthrough tachycardias during pacing, requiring progressive increases in the pacing rate. In Friedberg and associates' study (16), three patients with an initial response to ventricular overdrive needed an escalation in rate, and in one, pacing was discontinued because the patient could not tolerate the faster rates required. Escalation of rate may be accompanied by increasing atrioventricular block in the case of atrial pacing, by a fall in cardiac output in the case of ventricular pacing, or by myocardial ischemia. Pacing could accentuate afterpotentials that result in triggered automaticity, as it does in patients with digitalis excess. Finally, tachyarrhythmias are more easily induced by ventricular extrasystoles if the extrasystoles occur during rapid ventricular pacing, the standard clinical technique for ventricular tachycardia induction.

These objections to overdrive pacing are based on validated hemodynamic and electrophysiologic observations. However, clinical documentation of the inadequacy of overdrive is difficult to find. In a review of more than 30 reports of atrial and ventricular overdrive, we found only one report in which overdrive consistently failed. Lown and coworkers (18) attempted overdrive suppression in 12 patients with ventricular tachycardia and found none in whom it was more than transiently effective. Nevertheless, reports as recently as the late 1970s continue to detail its efficacy in small, selected groups of patients (15-17). In 1974, Haft (19) cited 21 reports describing successful overdrive pacing, which included case reports of 127 patients. He concluded that "... the beneficial effect of pacing to inhibit ventricular irritability. . .has been amply demonstrated clinically in patients with underlying bradycardias or heart block. In addition, there have now appeared many demonstrations of the efficacy of electrical pacing in the management of patients with ventricular arrhythmias but with underlying normal sinus rhythm." Batchelder and Zipes (20) concluded in 1975 that "temporary pacing may be quite useful in the treatment of recurrent ventricular tachycardia that is refractory to pharmacologic agents. . .". These authors add that "... the overall success rate of electrical pacing. . .is quite variable. . .". However, neither specific instances of failure nor guidelines for establishing efficacy were provided. Other reviews (11, 16, 21, 22) have also indicated that pacing is effective in most patients in whom it is attempted.

In summary, both atrial and ventricular overdrive pacing have often been useful for the treatment of ventricular tachycardia. The total number of cases reported in the literature in which overdrive has been successful is less than 150. Furthermore, it is conceivable that most published reports are favorable because investigators are more likely to report positive results. Nevertheless, advocates of overdrive pacing have stressed that its failures may be explained by a reluctance to pace at rates greater than 110 beats/min (16) and that nonelectrophysiologic factors, such as a fall in cardiac output and precipitation of ischemia, limit its usefulness. Its abandonment may have been due, in part, to the development of investigational drugs, surgical therapy, and pacing techniques for terminating arrhythmia. It is also possible that overdrive has been misapplied and that more precise measurements of repolarization abnormalities may permit selection of those patients who will benefit from overdrive pacing. This last point particularly applies to a unique form of ventricular tachycardia that is best prevented by overdrive: torsades de pointes (23, 24).

Treatment of Torsades de Pointes

Torsades de pointes has been described as three syndromes. Horowitz and colleagues (25) used the term to describe the pleomorphic ventricular tachycardia that they induced in the electrophysiology laboratory in patients with structural heart disease and normal QT intervals. The tachycardia generally responded to treatment with type I antiarrhythmic drugs. This arrhythmia may not represent true torsades, but may be a polymorphic variety of the ventricular tachycardia that is regularly seen in the electrophysiology laboratory (26). The torsades or "cardiac ballet" described by Dessertenne (27) is typically seen in patients with congenitally prolonged QT intervals and structurally normal hearts, and is sometimes associated with deafness. This torsades is characterized by alternating electrical polarity; the peaks of the QRS complexes appear to rotate about an isoelectric line in a sinusoidal fashion. This torsades commonly ends spontaneously, with brief and sometimes frequent recurrences, although it may persist and have a fatal outcome. A similar sinusoidal tachycardia has been described with increasing frequency in patients treated with drugs that prolong the QT interval or with QT prolongation from metabolic abnormalities such as hypokalemia or hypomagnesemia (28). This arrhythmia is associated with sudden death, especially in patients with structural heart disease (29), and can recur after the removal of the cause. This torsades is likely to emerge in the setting of QT prolongation from bradycardia (complete heart block or severe sinoatrial disease) (27).

A critical factor in the pathogenesis of torsades appears to be the manner of ventricular repolarization, because QT prolongation is present in almost all spontaneous cases. The label torsades is perhaps misapplied in cases in which the QT interval is normal (26). This potential misclassification is of critical importance, because a normal QT interval indicates a response to agents such as type I drugs that are etiologic or that would be avoided in patients with prolonged QT intervals.

Management of congenital torsades, or of torsades that persists after withdrawal of an etiologic factor, has been directed toward alteration of the QT interval by treatment with antiarrhythmic drugs such as phenytoin or bretylium tosylate (30-32), by stellate ganglionectomy (33, 34), or by adrenergic blockade (35, 36) and stimulation (37). However, the treatment of choice for torsades is generally considered to be cardiac pacing (23, 24, 38-43). Reports of successful pacing therapy in torsades principally have used temporary pacing to stabilize the patients while etiologic factors have been corrected, such as withdrawal of an antiarrhythmic medication. Sclarovsky and associates (41) studied 34 patients with torsades caused by a drug that prolonged the QT interval. Lidocaine therapy and electrical cardioversion were used in all patients but were effective in only 7. The most useful treatment was increasing the heart rate either by temporary ventricular pacing (17 patients) or intravenous isoproterenol (10 patients). Khan and coworkers (40) treated 11 patients with acquired QT prolongation and torsades. In 4, tachyarrhythmias ceased when the causative agents were withdrawn. In the other 7, ventricular tachyarrhythmias were abolished only by overdrive ventricular or atrioventricular sequential pacing. Keren and colleagues (43) diagnosed torsades in 10 patients, 9 who were receiving antiarrhythmic drug therapy to prolong the QT interval. Ventricular pacing or isoproterenol therapy prevented torsades while the causative agents were withdrawn.

One rationale for overdrive suppression is that faster rates limit repolarization time, reducing the vulnerable period during which ventricular premature beats initiate the arrhythmia (38). However, Fontaine and associates (44) found the coupling intervals of extrasystoles that initiate torsades to be variable. Moreover, changes in the QT_c (the QT interval when corrected for heart rate) (45) may not correspond to changes in the absolute QT interval (46). This latter point is corroborated by Keren and colleagues (43), who increased the heart rate in 10 patients with torsades with prolonged QT and QT_c (average, 0.60 s) by ventricular pacing or treatment with isoproterenol or atropine. Torsades did not recur in any patient. Nevertheless, the mean QT_c remained prolonged (0.61 s), whereas the QT intervals were significantly shortened.

The Role of Dispersion

Dispersion of refractoriness may be critical to torsades de pointes, as suggested by the accompanying repolorization abnormality. However, there has only been preliminary measurement of dispersion, even in the normal heart. Han and coworkers (14) measured dispersion of refractoriness in dogs and found it to decrease as cycle length was decreased. Longer cycle lengths yielded not only greater dispersion but also enhanced vulnerability to ventricular fibrillation. Han and coworkers inferred that bradycardia-enhanced dispersion increased susceptibility to ventricular arrhythmias. However, the cycle lengths used for pacing the dogs were 200 to 700 ms, rates not used in human studies. Han and Moe (47) showed increased dispersion in two preparations with prolonged QT interval (bradycardia and stellate ganglion stimulation) and showed that epinephrine decreased dispersion while increasing the rate. Olson and associates (48) measured refractory periods in ten patients with various rhythm disturbances at 2 right-ventricular sites in sinus rhythm and found that the refractory periods were within 25 ms in nine patients. Spielman and colleagues (49), in a preliminary report of the cases of ten patients, found that the mean dispersion of refractoriness at 12 sites in the left ventricle was 43 ms (35 to 60 ms). Gavrilescu and Luca (50) measured refractoriness in three patients with long QT interval and ventricular tachycardia and found dispersion of 105 and 90 ms among 3 right-ventricular sites in two patients measured during pacing. When measuring the effective refractory period at right- and left-ventricular sites, we have not found more than 40 ms of dispersion in normal persons. In three patients with torsades and prolonged QT intervals, chronic overdrive pacing prevented recurrence. Dispersion of refractoriness before therapy ranged from 60 to 130 ms and had been consistently reduced by atrial pacing in one patient and ventricular pacing in the other two. There was no consistent change in QT_c in these patients, although all three had a reduction in absolute QT interval with pacing. There have been no recurrences of arrhythmia in 42 patient-months of follow-up.

Conclusion

Overdrive pacing for the prevention of ventricular arrhythmias has lost favor among clinicians. We explored the literature to find the reasons for its demise and instead found reports detailing its efficacy not only for acute suppression of ventricular tachycardia but also for long-term therapy. Perhaps its abandonment is explained by the hemodynamic disadvantages of rapid pacing and by the advent of alternative antiarrhythmic measures, including investigational surgery and drug therapy. More recently, atypical ventricular tachycardia (torsades de pointes) has been successfully treated with temporary overdrive pacing. It is tempting to speculate that many patients described in earlier studies who responded to overdrive pacing actually had torsades. Indeed, some records of the tachyarrhythmias illustrated in those reports have the characteristic morphologic features of torsades (6, 7, 9, 11). The mechanism for the salutary effect of pacing in torsades has not been identified, but a narrowing of ventricular dispersion appears to be likely. Demonstration of such an electrophysiologic abnormality as the basis for torsades and correlation of successful therapy with correction of that abnormality will allow better application of overdrive pacing. A systematic comparison of atrial and ventricular pacing and tests of the persistent efficacy of permanent pacing on dispersion and torsades should be done in clinical trials.

A prolonged QT interval has been associated with sudden death (51) or ventricular tachycardia (52) in patients after myocardial infarction. Measurement of dispersion, or of focal abnormalities of refractoriness at the site of previous infarction, may some day be used to provide an index of risk that can be treated with pacing. Now, at least, there is inadequate evidence that temporary overdrive pacing is not useful in the management of ventricular tachycardia, especially atypical ventricular tachycardia or torsades de pointes.

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