Case reports

Triggered activity as a mechanism of recurrent ventricular tachycardia

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SUMMARY   Triggered activity was shown to be the likely mechanism of recurrent tachycardia in a 28 year old Vietnamese man. During baseline electrophysiological testing the tachycardia was induced consistently by prolonged atrial or ventricular pacing but not by premature extrastimuli. Moreover, the tachycardia coupling intervals varied directly with the cycle length of the initiating drive. Procainamide and propranolol did not suppress tachycardia, but verapamil terminated it and prevented its reinitiation. The origin of the tachycardia was localised to the left ventricular inferoapical segment and four direct current countershocks of 200 J each delivered via an electrode catheter abolished the tachycardia. During 12 months of follow up the patient was not treated with antiarrhythmic agents and the tachycardia did not recur.

Triggered activity resulting from delayed after-depolarisations has been demonstrated in isolated human or canine cardiac tissue under conditions of digitalis toxicity,[1][2] catecholamine superfusion,[3][4] and acute myocardial infarction.[5] In these preparations, pacing can induce sustained rhythmic activity that results from repetitive triggered activity in which the mechanism is not reentry. Although sporadic case reports have attempted to implicate triggered activity as a mechanism of cardiac arrhythmias in man,[6–10] convincing proof that it causes arrhythmias is still lacking.

We report a young patient in whom recurrent ventricular tachycardia was probably caused by triggered activity and was successfully controlled by ablation with an electrode catheter.

Case report

A 28 year old Vietnamese man with chronic schizophrenia was admitted to our medical centre in September 1986 because he had had recurrent palpitation since the age of 24. Palpitation occurred one to three times a month and was associated with dizziness, vomiting, and presyncope. Repeated electrocardiograms during palpitation showed a wide complex tachycardia at a rate of 180—200 beats/minute with a QRS configuration of right bundle branch block and a frontal plane axis of −45°. The patient was not taking cardiac or psychotropic medications. An electrophysiological study in 1983 showed that the tachycardia was ventricular in origin. Propranolol, lignocaine, and procainamide did not prevent the induction of ventricular tachycardia, but intravenous verapamil suppressed it. Despite maintenance treatment with high dose verapamil (480 mg/day) and then with diltiazem (360 mg/day) the patient had several recurrences of symptomatic ventricular tachycardia over the next two years and required frequent admissions to hospital. Therefore, he was admitted electively so that he could be assessed for ablation of ventricular tachycardia by percutaneous electrode catheter. The patient was a well developed young man with a heart rate of 70 beats/minute and systemic arterial blood pressure of 110/70 mm Hg. Physical examination was normal. The baseline electrocardiogram was normal except for minor T-wave inversion in leads

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III and aVF. An M mode and cross sectional echocardiogram, radionuclide angiography, and a right heart catheterisation showed no abnormality.

ELECTROPHYSIOLOGICAL STUDY

After he gave his informed consent, an electrophysiological study was performed while he was fasting and unsedated. Four quadripolar electrode catheters were positioned at the high lateral right atrium, His bundle region, coronary sinus, and right ventricle. Surface leads V1, I, and aVF and the intracardiac electrograms were displayed on a VR-12 oscilloscope (Electronic for Medicine) and recorded at a paper speed of 100 mm/s. Programmed stimulation was performed with a programmable stimulator (Bloom and Associates) with pulse duration of 2 ms and a current strength of twice diastolic threshold.

The coupling interval for ventricular tachycardia was defined as an interval from the earliest ventricular activation of the last paced QRS complex to that of the first beat of induced ventricular tachycardia. The relation between ventricular tachycardia coupling intervals and the initiating drive length was analysed by linear regression.

Results

The baseline atrio-His (AH) interval was 90 ms and the His-ventricle (HV) interval was 40 ms. There was no evidence of dual atrioventricular nodal pathways or nodoventricular accessory pathways. Programmed stimulation induced a sustained ventricular tachycardia that had the same configuration as the clinical ventricular tachycardia. The diagnosis of ventricular tachycardia was confirmed by the presence of fusion beats and complete atrioventricular dissociation, and by the absence of a His deflection preceding the QRS complexes.

INDUCTION AND TERMINATION
CHARACTERISTICS

The ventricular tachycardia was induced consistently after or during 10–20 seconds of atrial pacing at cycle lengths ranging from 400 to 340 ms (fig 1). Pacing at shorter cycle lengths resulted in atrioventricular nodal Wenckebach block and failed to induce ventricular tachycardia. After administration of intravenous atropine 0·4 mg, atrioventricular nodal Wenckebach cycle length decreased from 330 to 270 ms, and ventricular tachycardia could now be induced by atrial pacing at cycle lengths of 330–270 ms (fig 1). Induction of ventricular tachycardia was never preceded by the development of fascicular or right bundle branch block, which makes the involvement of bundle branches in the tachycardia circuit unlikely. Incremental right ventricular pacing

(pre-atropine) at cycle lengths from 350 to 220 ms also consistently induced clinical ventricular tachycardia. In contrast, atrial extrastimuli never initiated ventricular tachycardia. A single ventricular extrastimulus induced ventricular tachycardia on only two occasions with a V_1V_2 of 320 ms and 280 ms, respectively and ventricular tachycardia was never induced with two or three double ventricular extrastimuli.

The coupling intervals of induced ventricular tachycardia seemed to vary directly with the initiating paced cycle lengths. As the atrial drive length decreased from 400 to 270 ms, the coupling intervals shortened from 330 ms to 235 ms. A similar shortening was seen during ventricular overdrive pacing but did not reach statistical significance (fig 2). The cycle length of induced ventricular tachycardia ranged from 270 to 310 ms and seemed to depend upon the initiating drive length. A precise determination of this relation, however, could not be obtained because of spontaneous variations of 10 to 30 ms in the cycle length of induced ventricular tachycardia. The average cycle length of ventricular tachycardia was 310 ms at initiating (atrial or ventricular) drive lengths of 300 to 400 ms, 290 ms at drive lengths of 260 to 290 ms, and 270 ms at drive lengths of 250 ms or less (fig 1).

Right ventricular overdrive pacing (cycle lengths 260 to 220 ms) consistently terminated ventricular tachycardia but single and double ventricular extrastimuli failed to terminate or reset the ventricular tachycardia. Rapid atrial pacing had no effect on the tachycardia. Ventricular tachycardia was never entrained during atrial or ventricular pacing.

After isoproterenol infusion (2 µg/min) the sinus cycle length decreased from 560 to 340 ms and there was a spontaneous induction of clinical ventricular tachycardia with a cycle length of 250 ms. The ventricular tachycardia could not be terminated by overdrive pacing and the termination required discontinuation of isoproterenol and administration of 10 mg of intravenous verapamil. After verapamil sustained ventricular tachycardia could still be induced, but its cycle length had lengthened from 250 ms to 420 ms. The ventricular tachycardia could no longer be induced after infusion of an additional 10 mg of intravenous verapamil.

TACHYCARDIA MAPPING AND ABLATION

Electrode catheter mapping[11] during induced ventricular tachycardia localised the site of earliest endocardial activation to the left ventricular inferoapical region. At this site endocardial activation occurred 20 ms before the onset of ventricular activation on the surface electrocardiographic leads. Fragmented electric potentials were not noted at any
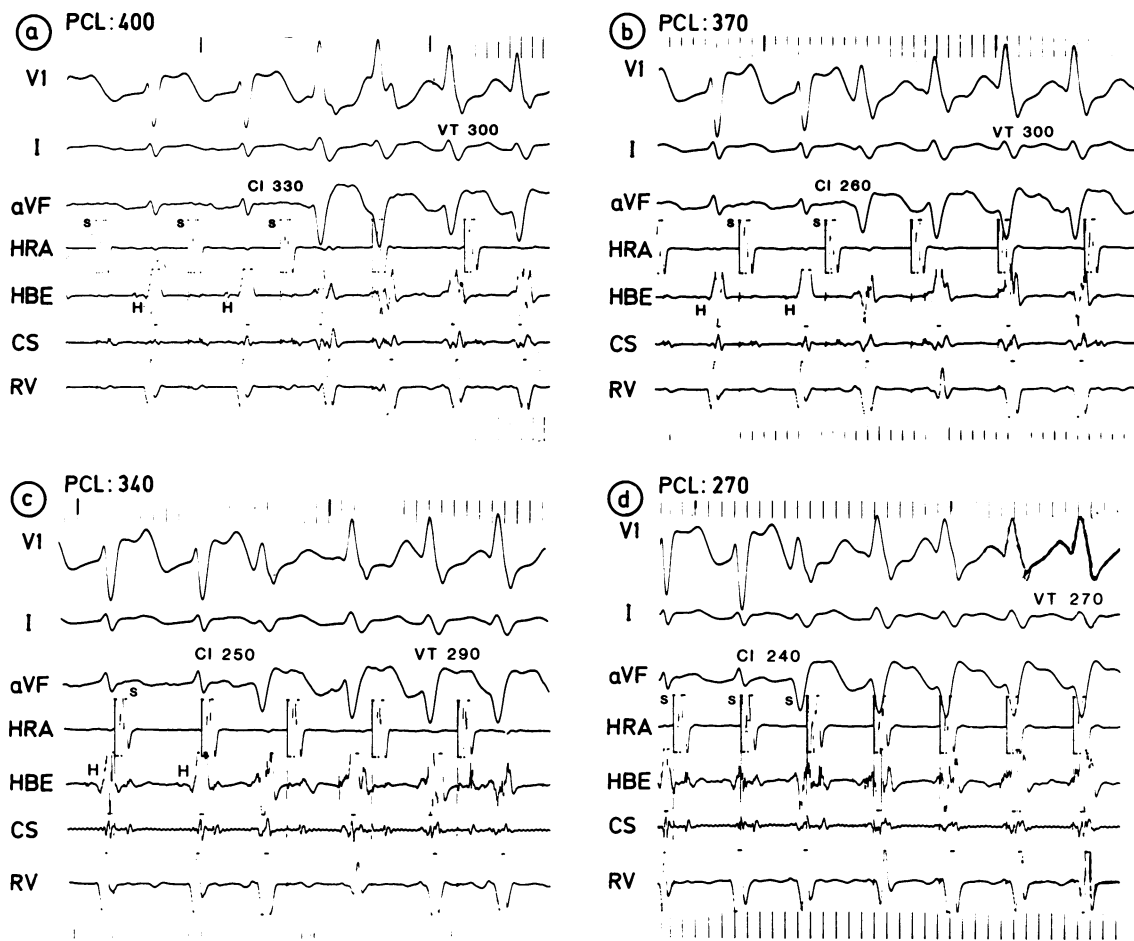
Fig 1 *Atrial induction of ventricular tachycardia (VT). VT was induced during atrial pacing at cycle lengths of 400, 370, 340, and 270 ms (a–d). During induced VT the QRS complexes were not preceded by His deflection, and there was complete atrioventricular dissociation. Note that the VT coupling intervals (CI) vary directly with the atrial paced cycle length (PCL). The CI was 330 ms at PCL of 400 ms (a), 260 ms at PCL of 370 ms (b), 250 ms at PCL of 340 ms (c), and 240 ms at PCL of 270 ms (d). The recordings also show the dependency of VT cycle length on the initiating drive length. The VT cycle length was 300 ms at PCL of 370 ms (b), 290 ms at PCL of 340 ms (c), and 270 ms at PCL of 270 ms (d). Recordings include surface leads V1, I, and aVF and bipolar electrograms from the high right atrium (HRA), the region of the His bundle (HBE), the coronary sinus (CS), and right ventricle (RV). Heavy time lines represent 1 s. S, atrial stimulus; H, His bundle deflection.*

site in the ventricles. Catheter ablation of the ventricular tachycardia was achieved under thiopentone sodium (pentothal) anaesthesia with four direct current countershocks of 200 J each at the site of the earliest endocardial activation. The distal catheter pole acted as a cathode and the posterior electrode pad (R–2 industries) as an anode. This did not suppress the inducibility of ventricular tachycardia but the cycle length of induced ventricular tachycardia lengthened from 310 to 420 ms.

After ablation creatine kinase peaked at 1515 U/l with a 14% MB isoenzyme fraction. The electrocardiogram showed 3–5 mm ST-segment elevation in leads II, III, and aVF, and a cross sectional echocardiogram showed moderate hypokinesia of the left ventricular inferior wall; both abnormalities resolved three days later. Subsequently, he had an uncomplicated hospital course. One week later, repeat electrophysiological testing was performed, during which ventricular tachycardia could no longer be
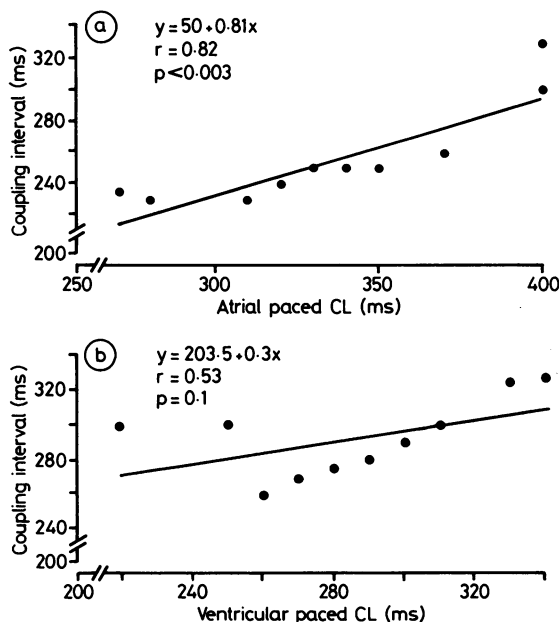
Fig 2 *Relation of paced cycle lengths with the coupling intervals of ventricular tachycardia induced during atrial (a) and ventricular (b) overdrive pacing. See text for explanation.*

induced either before or after administration of isoproterenol (1 to 4 μg/minute), despite the use of incremental pacing and three extrastimuli at two right ventricular sites.

The patient was discharged home without antiarrhythmic treatment, and he has not had palpitation during a follow up of 12 months.

Discussion

MECHANISM OF VENTRICULAR TACHYCARDIA

Tachycardias reproducibly initiated and terminated by programmed stimulation may be caused by reentry or triggered activity. Several findings suggest that triggered activity was the mechanism of ventricular tachycardia in our patient. First, the ventricular tachycardia was induced consistently by atrial and ventricular incremental pacing, but not by premature stimuli. Second, the ventricular tachycardia coupling intervals varied directly with the cycle length of the initiating paced drives. Third, the ventricular tachycardia showed considerable sensitivity to the effects of catecholamines: ventricular tachycardia became easier to induce, faster in rate, and more difficult to terminate after administration of isoproterenol. Fourth, the rate of ventricular tachycardia seemed to depend upon the cycle length

of the initiating drive. This relation was seen for ventricular tachycardia induced by both atrial and ventricular pacing. Finally, the ventricular tachycardia was successfully terminated and suppressed by verapamil, whereas procainamide and propranolol were ineffective.

These findings are atypical of reentry and when taken together are best explained by triggered activity.[2-4] Under experimental conditions, sustained tachycardias caused by triggered activity have been shown to be induced more readily by prolonged incremental pacing than by extrastimuli.[34] Triggered activity was induced by prolonged overdrive pacing in 83% of ouabain perfused isolated canine Purkinje fibres, in 39% of fibres by a single extrastimulus, and in 48% of fibres by double extrastimuli.[3] Unlike reentrant arrhythmias in which the ventricular tachycardia coupling intervals are inversely related to the initiating drive length,[12] the coupling intervals of triggered tachycardias have been demonstrated to vary directly with the cycle length of the initiating drive.[34] This relation may be more complex when triggered arrhythmias are induced by short drive lengths. Under these conditions, the coupling intervals may shorten or lengthen, depending on whether the first or second delayed afterdepolarisation attains threshold and initiates sustained tachycardia.[2] The responsiveness of ventricular tachycardia to verapamil also accords with the ionic mechanism of triggered activity, which is thought to be mediated by an enhanced inward slow channel current carried by calcium.[13] None the less, none of the above criteria is specific enough reliably to differentiate triggered rhythm from other mechanisms and, therefore, a reentrant mechanism, although unlikely, cannot be excluded in our patient.

Previous data on triggered activity causing clinical arrhythmias are scarce. Zipes et al reported three patients in whom atrial pacing consistently induced ventricular tachycardia; triggered activity was the suspected mechanism in one patient.[6] Belhassen et al suspected triggered activity in a patient with recurrent sustained ventricular tachycardia in whom verapamil terminated ventricular tachycardia and prevented its reinitiation.[7] Similarly, Lin et al reported four patients[8] and Ward et al five patients[9] with recurrent ventricular tachycardia in whom ventricular tachycardia was induced by overdrive pacing, extrastimuli, or both, and was terminated or slowed by calcium antagonists. Like our patient, these patients had no identifiable heart disease, and the QRS complexes during ventricular tachycardia had a right bundle branch block configuration and left axis. In most of these patients, the tachycardia characteristics seemed to be those of reentry rather than the triggering. In no patient did the ventricular

tachycardia coupling intervals progressively decrease or the ventricular tachycardia rate increase as the initiating drive length was shortened. The patient reported by us is the first who met the proposed electrophysiological criteria for triggered activity.[14] There is also controversy on whether this form of verapamil-sensitive ventricular tachycardia originates in the region of left posterior fascicle or in the ventricular myocardium. In the five patients reported by Ward *et al*, the HV intervals ranged from + 15 to − 20 ms, and they suggest a fascicular origin for the tachycardia.[9] In our patient, the ventricular tachycardia was probably myocardial in origin because His deflections could not be recorded during ventricular tachycardia, and the mapping studies localised the tachycardia in the inferoapical segment of the left ventricle.

Percutaneous catheter ablation has been reported to be an effective treatment in patients with drug resistant ventricular tachycardia, which has a reentrant mechanism.[15 16] The case we report shows that sustained ventricular tachycardia caused by a triggered mechanism may also be responsive to this technique. For reasons that are unclear, the ventricular tachycardia could be induced immediately after delivery of four direct current counter shocks, but could no longer be induced during repeat electrophysiological testing one week later. Moreover, the patient has stayed free of recurrent palpitation during a follow up of 12 months. It could be that healing at the site of catheter ablation in the first week led to a late resolution of the inducibility of ventricular tachycardia. This, however, could not be confirmed.

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