Mechanisms of Sustained Ventricular Tachycardia in Myotonic Dystrophy
Implications for Catheter Ablation

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Background—Ventricular arrhythmias have been documented and linked to the high incidence of sudden death seen in patients with myotonic dystrophy. However, their precise mechanism is unknown, and their definitive therapy remains to be established.

Methods and Results—We studied 6 consecutive patients with myotonic dystrophy and sustained ventricular tachycardia by means of cardiac electrophysiological testing. Particular attention was paid to establish whether bundle-branch reentry was the tachycardia mechanism, and when such was the case, radiofrequency catheter ablation of either the right or left bundle branch was performed. Clinical tachycardia was inducible in all patients and had a bundle-branch reentrant mechanism. In 1 patient, 2 other morphologies of sustained tachycardia were also inducible, neither of which had ever been clinically documented, and both had a bundle-branch reentrant mechanism. Ventricular tachycardia was no longer inducible after bundle-branch ablation, except for a nonclinically documented and nonsustained ventricular tachycardia in the only patient who had apparent structural heart disease.

Conclusions—A high clinical suspicion of bundle-branch reentrant tachycardia is justified in patients with myotonic dystrophy who exhibit wide QRS complex tachycardia or tachycardia-related symptoms. Because catheter ablation will easily and effectively abolish bundle-branch reentrant tachycardia, myotonic dystrophy should always be considered in patients with sustained ventricular tachycardia. This is especially true if no apparent heart disease is found. (Circulation. 1998;98:541-546.)

Key Words: ablation • bundle-branch block • electrophysiology • myotonia atrophica • tachycardia

Myotonic dystrophy is the commonest muscular dystrophy occurring in adult life, with a prevalence of 1 in 8000.¹ Cardiac involvement is frequent and is manifested as a selective and extensive impairment of the conducting system, which typically is not associated with apparent structural heart disease.¹⁻⁴ There is also a high incidence of sudden death, which makes it a significant unsolved clinical problem. Although commonly attributed to conduction block, sudden death has been seen in patients with pacemakers. This observation, together with reports of spontaneous ventricular tachycardia,⁵⁻⁹ raises the possibility that ventricular arrhythmias play a major role in the mortality of these patients.¹,²,⁵⁻⁶ However, the mechanism of ventricular arrhythmias in this setting has not been determined, and reentry related to areas of damaged myocardium is thought to be the most plausible explanation.¹⁰¹¹ In addition, no standard therapy for these arrhythmias has been established. We postulated that cardiac involvement in myotonic dystrophy is an ideal substrate for bundle-branch reentry. To this end, we tested the relationship of this mechanism with clinical monomorphic sustained ventricular tachycardias in 6 consecutive patients with myotonic dystrophy, 5 of whom had no apparent valvular or myocardial dysfunction.

Methods

Patients

Six consecutive patients with myotonic dystrophy were referred to our centers for evaluation and treatment of sustained wide QRS complex tachycardia. Their main clinical characteristics are displayed in the Table. Two patients had a family history of sudden death. They had no other history of interest, and none of them presented cardiac symptoms, apart from those related to tachycardia episodes.

All patients showed the characteristic phenotype of frontal baldness and distal and parietal muscle atrophy. All had myotonia, distal muscular weakness, and hyporeflexia, and except for patient 2, all had cataracts. In all cases, the first clinical suspicion of myotonic dystrophy arose in our centers, except for patients 5 and 6, who both had myotonia recognized several years before the onset of tachycardia. All 6 patients showed myotonia at electromyography.
and pathological expansion of the nucleotide triplet CTG in locus 19q13.3 in the genetic study. Cardiac examination was unremarkable in all cases. All ECGs showed sinus rhythm, PR-interval prolongation, and, except for patient 6, a QRS complex displaying intraventricular conduction defects (the Table). No apparent heart disease was revealed in 5 of the patients by chest x-ray, echocardiography, right and left ventriculography, or coronary angiography examinations. Patient 5 had a nondilated, mild, hypertrophied left ventricle with mild systolic dysfunction.

Four patients presented with tachycardia with paroxysmal episodes of palpitations, dyspnea, chest pain, dizziness, and near syncope. Patients 2 and 5 only had palpitations and chest pain, respectively. All patients except patient 3 had had multiple episodes of tachycardia for ≤8 years before referral. Patient 3 was referred within 1 month of her single episode of tachycardia. Patient 1 had previously been studied in another hospital, where idiopathic myocardial ventricular tachycardia had been diagnosed and an unsuccessful attempt at radiofrequency ablation had been made. Initially, a misdiagnosis of paroxysmal supraventricular tachycardia had been made in patients 2 and 4. After many episodes and several unsuccessful antiarrhythmic drug trials, patients 5 and 6 were referred to one of our centers. Invasive cardiac electrophysiological studies were performed, the clinical tachycardias were repeatedly induced, and a diagnosis of ventricular tachycardia related to myocardial reentry was established in both cases. Eventually, both patients had an automatic defibrillator implanted. At 4- and 5-year follow-up, respectively.

Most episodes of clinical tachycardia were hemodynamically tolerated and were terminated by intravenous antiarrhythmic drugs in the majority of patients. However, these episodes were poorly tolerated and required electrical cardioversion in patients 3 and 6. Antiarrhythmic drug therapy was attempted with patients 1 (propranolol, amiodarone, mexiletine, and flecainide), 2 (amiodarone), 5 (amiodarone, sotalol, and atenolol), and 6 (propranolol, quinidine, amiodarone, propafenone, sotalol, and atenolol), which in all cases proved unsuccessful at preventing recurrence of tachycardia.

**Electrophysiological Testing**

Cardiac invasive electrophysiological studies were performed with patients in the unsedated postabsorptive state after informed consent was obtained from the patients and all antiarrhythmic drugs were withdrawn. Three quadrupolar electrode catheters were introduced percutaneously through the right femoral vein, the right subclavian vein, or both and were placed under fluoroscopic guidance in the high right atrium, His bundle area, and right ventricular apex. Patients 2, 3, 5, and 6 had a catheter inserted through the right femoral artery and placed in the left bundle-branch area. Three or 4 surface ECG traces and 3 or 4 bipolar intracardiac recordings filtered between 30 and 500 Hz were simultaneously displayed on a multichannel oscilloscope (LabSystem, Bard Electrophysiology or VR12, Electronics for Medicine) and printed on paper (Minograf 7, Siemens-Elema) at 100 mm/s or stored on an optical disk for later reproduction at 200 mm/s. Programmed ventricular extrastimulation was performed at not less than 2 constant basic cycle lengths and from 2 ventricular sites (right ventricular apex and right ventricular outflow tract) with ≤3 extrastimuli, both at baseline and under isoproterenol infusion. The correct positioning of the His bundle area catheter was verified whenever a tachycardia was induced, to avoid the possibility of failure to record the His bundle electrogram because of catheter displacement. Bundle-branch reentrant tachycardia diagnosis was established according to previously published criteria13,14: (1) QRS complex morphology with typical bundle-branch block pattern consistent with ventricular depolarization through the appropriate bundle branch; (2) AV dissociation during tachycardia; (3) exclusion of a tachycardia from supraventricular origin by established criteria; (4) prolonged HV interval during sinus rhythm; (5) a stable His or bundle-branch electrogram preceding each ventricular activation during tachycardia with an HV interval equal to or longer than that during sinus rhythm; (6) spontaneous changes in the bundle potential cycle length preceding similar changes in the ventricular cycle length; and (7) suppression of ventricular tachycardia inducibility after right or left bundle-branch ablation.

Radiofrequency catheter ablation of the right or left bundle branch was attempted whenever a diagnosis of bundle-branch reentrant tachycardia was established. Unmodulated radiofrequency current was delivered under temperature control mode by standard means. Ablation success was defined as the recording of an ECG concordant with bundle-branch block ipsilateral to the ablation site and the absence of spontaneous or inducible tachycardia after the complete ventricular stimulation protocol, both at baseline and under isoproterenol infusion.

**Results**

A sustained tachycardia with a QRS complex morphology identical to the clinical tachycardia was induced in all patients (Figures 1, 2, and 3). It was induced with a single extrastimulus after a basic pacing train from the right ventricular apex in 3 patients. In patients 2 and 6, it was only induced with atrial pacing, and in patient 3, only with atrial pacing under isoproterenol infusion. In patient 5, the only patient with apparent structural heart disease, a nonsustained ventricular tachycardia was also inducible before and after left bundle-branch ablation. This arrhythmia was never clinically documented, and after the exclusion of a bundle-branch reentry mechanism, no attempt at ablation was made. No other forms of sustained or nonsustained ventricular tachycardia (defined as runs of >3
premature ventricular beats) were induced in the remaining patients, with the exception of patient 6. This patient had 2 additional sustained tachycardias, which were never documented clinically (Figure 3); 1 was induced with ventricular pacing during sinus rhythm, and the other occurred spontaneously during the clinical tachycardia. The QRS complex had a left bundle-branch block morphology in the former instance and a right bundle-branch block morphology with a QRS complex superior axis in the latter, and both had a cycle length similar to the clinical tachycardia.

The clinical tachycardia fulfilled all the criteria of bundle-branch reentrant tachycardia in all patients (Table and Figures 1, 2, and 3). There was a stable His bundle electrogram preceding each ventricular activation during tachycardia, with an HV interval longer than that during sinus rhythm and with spontaneous changes in the bundle potential cycle length preceding similar changes in the ventricular cycle length. AV reentry through an accessory pathway was ruled out as the tachycardia mechanism through the observation of AV dissociation during tachycardia in all patients. Automatic junctional tachycardia and intranodal, or intrahisian, reentry were also excluded by the observation of manifest QRS complex fusion during transient entrainment pacing from the right ventricle in 5 patients or a change in the activation sequence of the His bundle and its main branches in the case of patient 2 (Figure 2). Other mechanisms, such as a concealed nodoventricular accessory pathway with nodal-atrial retrograde block and bundle-branch conduction aberrancy, were considered highly unlikely.

Both of the tachycardias that were never clinically documented in patient 6 fulfilled all the criteria of bundle-branch reentrant tachycardia except for the criterion of spontaneous changes in the His bundle potential cycle length in the tachycardia with right bundle-branch block morphology of the QRS complex. In this latter tachycardia, spontaneous changes in His bundle potential cycle length followed instead of preceded similar changes in ventricular cycle length.

Radiofrequency catheter ablation was performed in all patients (left bundle branch in patient 5 and right bundle

Figure 1. Ventricular tachycardia of patient 1. Simultaneous 100-mm/s tracings, from top to bottom, are 20-ms time lines; surface ECG leads aVF, V1, V5, and V6; and bipolar intracardiac recordings from the high right atrium (hRA), proximal (3–4) and distal (1–2) His bundle area (HBE), and right ventricular apex (RVa). Pertinent intervals are labeled in milliseconds. Note the AV dissociation and note the small HBE (H) that precedes each QRS complex by 120 ms. Spontaneous changes in the His-His (HH) interval precede those of the ventriculogram-ventriculogram interval (VV).

Figure 2. Ventricular tachycardia of patient 2. Simultaneous 100-mm/s tracings, from top to bottom, are surface ECG leads I, II, III, and V1, and bipolar intracardiac recordings obtained from the high right atrium (hRA), right bundle-branch area (RB), and His (panel A) or left bundle-branch (panels B and C) areas (BE). Pertinent intervals are labeled in milliseconds. Note in A and B that a right bundle-branch electrogram (RB), a His bundle electrogram (H), and a fractionated left bundle-branch electrogram (LB) precede each QRS complex by 140, 120, and 80 ms, respectively. Note also in C that RB spontaneous cycle length oscillations precede those of the QRS complex and a more distal LB.
In our experience, only 1 patient was found not to have myotonic dystrophy, which, as in our patients, is often an unrecognized disease. In our patient, myotonic dystrophy was ruled out as a cause of His-Purkinje disease. It was mentioned, however, that 2 patients bore mild intellectual retardation, a common finding in myotonic dystrophy, which, as in our patients, is often an unrecognized disease. In our experience, only 1 patient was found not to have myotonic dystrophy (this condition was ruled out by electromyography and genetic study) from among those who presented with clinical ventricular tachycardia due to bundle-branch reentry but who did not have apparent structural heart disease (J.L. Merino, MD, et al, unpublished data, 1997).

Berger et al reported on a patient with myotonic dystrophy, dilated cardiomyopathy, and ventricular tachycardia secondary to bundle-branch reentry. These authors attributed this mechanism to the dilated cardiomyopathy but pointed out that in their patient, myotonic dystrophy probably contributed to the mechanism through His-Purkinje system impairment. Five of our patients had no obvious heart disease; therefore, it would appear that no factor other than His-Purkinje conduction delay was responsible for bundle-branch reentrant tachycardia, and no mechanism other than bundle-branch reentry was found to be responsible for ventricular tachycardia.

Without the clinical suspicion of bundle-branch reentrant tachycardia, its recognition, as in patients 1 and 5 in the present study, can be easily missed for several reasons. First, in myotonic dystrophy, a proposed myocardial reentry ventricular tachycardia mechanism and the common absence of apparent heart disease may lead to the introduction of fewer catheters and to the His bundle area catheter being relocated to a ventricular position after AV conduction is studied. Second, as in patients 2 and 3 in the present study, bundle-branch reentrant tachycardia may be difficult to induce and could require the use of different pacing protocols or the infusion of isoproterenol or type I antiarrhythmic drugs. Third, as in patients 4 and 5 in the present study, catheter displacement during tachycardia often makes the recording of a good quality, stable His bundle electrogram difficult. Finally, a severely diseased conducting system may also make the recording of a good quality His bundle electrogram difficult or impossible during tachycardia.

Changes in the HH interval preceding those of the VV interval represent variations of conduction in the retrograde conducting bundle branch and establish the diagnosis of
bundle-branch reentrant tachycardia.13 However, observations of changes in the HH interval that follow rather than precede those of the VV interval do not exclude bundle-branch reentry. It is possible that conduction oscillations can also occur in the antegrade conducting bundle branch,20 which is also commonly affected by conduction disease. Interestingly, patient 6 exhibited this pattern during the episode of nonclinical tachycardia with right bundle-branch block morphology. Although intramyocardial reentry with passive His activation had to be considered in this tachycardia, bundle-branch reentry was more plausible because after right bundle-branch ablation, the tachycardia was no longer inducible by the described programmed ventricular extrastimulation protocol or by an additional protocol with up to 2 extrastimuli following an abrupt short-to-long cycle length change. Both protocols were performed at baseline and under isoproterenol infusion.

Study Limitations and Clinical Implications
This study does not demonstrate a definitive link between bundle-branch reentrant tachycardia and sudden death in myotonic dystrophy. However, the fact that this type of ventricular tachycardia is often poorly tolerated, is suspected to be responsible for sudden death in other clinical settings,26 and has an ideal arrhythmogenic substrate to be induced in this disease makes this hypothesis very likely.

The precise population of patients with myotonic muscular dystrophy from whom this sample is drawn is not known; this is a weakness that prevents estimation of the incidence of bundle-branch reentry in this disease.

The recognition of bundle-branch reentrant tachycardia has important clinical implications in myotonic dystrophy. Catheter ablation of either the right or left bundle branches may abolish the tachycardia.27,28 In addition, the use of antiarrhythmic drugs to ameliorate myotonia29 should be avoided whenever possible because these drugs are capable of inducing bundle-branch reentrant tachycardia.26

Conclusions
Our study indicates that a high clinical suspicion of bundle-branch reentrant tachycardia is justified in patients with myotonic dystrophy exhibiting wide QRS complex tachycardia or tachycardia-related symptoms. Such patients should undergo a complete electrophysiological study with different pacing and pharmacological strategies. Whenever a tachycardia is induced, the correct location of the His bundle area catheter should be ensured, and bundle-branch record-

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