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Radiofrequency Catheter Ablation for Treatment of Bundle Branch Reentrant Ventricular Tachycardia: Results and Long-Term Follow-Up

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Seven of 120 consecutive patients with inducible sustained ventricular tachycardia (from September 1, 1988 to January 1, 1991) had bundle branch reentrant tachycardia and underwent percutaneous radiofrequency ablation of the right bundle branch. The seven patients had been unsuccessfully treated with a mean of 3 ± 1 drugs. Four patients presented with syncope and three with aborted sudden death. The baseline electrocardiogram revealed a left bundle branch block pattern in three patients and an intraventricular conduction defect in four.

The baseline HV interval was prolonged in each case (79 ± 2 ms). With use of programmed ventricular extrastimuli, sustained bundle branch reentrant tachycardia was inducible in all patients at a mean cycle length of 283 ± 17 ms (range 230 to 350). Bundle branch reentrant tachycardia characteristics included atrioventricular dissociation, a His deflection that preceded each QRS complex and spontaneous His to His variation that preceded changes in ventricular tachycardia cycle length.

A quadripolar catheter was positioned across the tricuspid valve with the distal electrode tip of the catheter near the right bundle branch. One to three applications of continuous unmodulated radiofrequency current at 300 kHz between the distal electrode and a large posterior skin patch resulted in complete right bundle branch block in all patients, after which none had inducible bundle branch reentrant tachycardia on restudy. On restudy, three of the seven patients had ventricular tachycardia of myocardial origin (not bundle branch reentry). One patient required no therapy; drug or defibrillator therapy was used in the others. After a mean follow-up interval of 12 ± 3 months (range 6 to 29) complete right bundle branch block persisted, there were no spontaneous episodes of ventricular tachycardia and no patient required a permanent pacemaker.

Radiofrequency catheter ablation of the right bundle branch is easily performed and is a safe and effective treatment for bundle branch reentrant tachycardia. It is probably the procedure of choice for these highly symptomatic patients.

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In 6% of patients with inducible ventricular tachycardia (1), bundle branch reentry has been reported as the mechanism. Direct current catheter ablation of the right bundle branch has been successful in interrupting the macroreentrant circuit (2–4). Recently, Langberg et al. at our institution described a case in which radiofrequency ablation produced right bundle branch block and eliminated bundle branch reentrant tachycardia. In the present study, we report a long-term follow-up of seven patients who underwent radiofrequency catheter ablation of the right bundle branch to cure ventricular tachycardia due to bundle branch reentry.

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Methods

Study patients. Between September 1, 1988 and January 1, 1991, 7 of 120 consecutive patients were identified as having inducible sustained ventricular tachycardia due to a bundle branch reentrant mechanism. Table 1 shows the incidence of bundle branch reentrant tachycardia in various patient categories with inducible sustained ventricular tachycardia over this period. Table 2 shows the characteristics of our seven patients with bundle branch reentrant tachycardia. Patient 1 was described in a previous report (5). The mean age of the group was 62 ± 6 years (34 to 72) and the mean left ventricular ejection fraction was 23 ± 3% (9% to 35%). All were male. Four patients were admitted with syncope and three with aborted sudden death (ventricular tachycardia or ventricular fibrillation requiring cardioversion or defibrillation). Four patients had ischemic cardiomyopathy with severe three-vessel coronary disease with prior myocardial infarction, one had alcoholic cardiomyopathy, one had idiopathic dilated cardiomyopathy and one had hypertrophic

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Table 1. Cardiac Diagnosis in 120 Consecutive Patients With Inducible Sustained Ventricular Tachycardia

Cardiac Substrate	Patients (no.)	Incidence of BBRT (%)
Coronary artery disease	88	4.5
Cardiomyopathy	18	16.7
Normal ventricle*	5	0
Aortic valve replacement	3	0
Congenital heart disease	3	0
Right ventricular dysplasia	3	0
Total	120	5.8

*Septal, right ventricular outflow tract and catecholamine-induced ventricular tachycardia. BBRT = bundle branch reentrant tachycardia.

cardiomyopathy. Two (Patients 3 and 6) had a pacemaker that had been implanted because of syncope or intermittent trifascicular block, or both. In all patients the arrhythmias proved refractory to a mean of 3 ± 1 antiarrhythmic drugs (range 1 to 7).

Baseline electrophysiologic study. Each patient underwent electrophysiologic study with programmed electrical stimulation to assess the inducibility and the mechanism of tachycardia. Three electrode catheters were inserted through the femoral vein into the right atrium, low right atrial septum and against the right ventricular apex, respectively. Standard programmed electrical stimulation was performed with use of up to three extrastimuli from two right ventricular sites. An induction protocol with use of pauses (6) (short-long-short induction sequence) was required for tachycardia induction only in Patient 7. Bundle branch reentry was searched for during each study.

Bundle branch reentrant tachycardia was identified on the basis of the following criteria: 1) atrioventricular (AV) dissociation occurred during ventricular tachycardia; 2) a His or right bundle branch deflection, or both, preceded each QRS complex; 3) spontaneous His to His and right bundle branch to right bundle branch cycle length variations preceded a change in ventricular tachycardia cycle length; 4) the duration of the HV interval was the same or longer during tachycardia compared with conducted complexes; and 5) in selected cases premature right ventricular apical depolarizations delivered during inscription of the His bundle resulted in termination of the tachycardia (1,7). In addition, the His to right bundle branch conduction time during tachycardia was the same or shorter than His to right bundle branch conduction time at baseline.

The following tachycardias were differentiated from bundle branch reentrant tachycardia (1): 1) supraventricular tachycardia with aberrancy; 2) tachycardia originating from ventricular muscle; 3) fascicular tachycardia; and 4) antidromic tachycardia using a Mahaim tract.

Technique of radiofrequency ablation of the right bundle branch. This study was approved by the Institutional Review Board of the University of California, San Francisco and each patient gave informed consent. A 6F or 7F steerable quadripolar catheter with a 3-mm distal tip and 1-cm interelectrode spacing (Mansfield Scientific) or a custom-designed steerable bipolar catheter with a distal tip 4 mm in length and 2-mm interelectrode spacing (USCI) were used for right bundle branch ablation. The catheter was positioned across the tricuspid valve to record a His bundle electrogram. It was then advanced to record a right bundle branch potential from the distal two poles.

Criteria for detection of a right bundle branch potential included 1) a sharp deflection occurring ≥20 ms after the His deflection, and 2) no atrial electrogram present on the right bundle branch electrogram recording (see Fig. 2) (8). Continuous unmodulated radiofrequency current at 300 kHz, delivered by a radiofrequency generator (model RFG-3B, Radionics) was applied to the region of the right bundle branch during the baseline rhythm (sinus rhythm in six patients and atrial fibrillation in one). Applications of radiofrequency were administered at 15 to 20 W and for up to 60 s or until an increase in impedance occurred. The radiofrequency energy was applied between the distal electrode in the right ventricle and a large posterior skin patch. A repeat electrophysiologic study was performed in each patient after ablation during the same procedure.

Table 2. Characteristics of Seven Men With Bundle Branch Reentrant Tachycardia

						Bundle Branch Reentrant Tachycardia*				
Pt No.	Age (yr)	Symptom	Diagnosis	EF (%)	ECG	CL (ms)	Axis	Drugs Failed (No.)	RF No.	F/U
1	63	ASD	CAD	9	IVCD	270	Sup	1	2	29 mo†
2	77	Syncope	Alc CM	20	IVCD	230	Sup	1	3	A/W, 14 mo
3	79	Syncope	CAD	20	LBBB	330	Inf	4	2	3 mo†
4	55	Syncope	CAD	25	LBBB	230	Inf	1	1	A/W, 14 mo
5	53	Syncope	CAD	25	IVCD	280	Inf	5	1	A/W, 10 mo
6	72	ASD	IDCM	25	LBBB	350	Inf	7	1	A/W, 7 mo
7	34	ASD	HCM	35	IVCD	290	Sup	1	1	A/W, 6 mo

*All of these tachycardias had a left bundle branch block configuration. †Died of causes unrelated to the procedure. Alc CM = alcoholic cardiomyopathy; ASD = aborted sudden death; A/W = alive and well; CAD = coronary artery disease; CL = cycle length; ECG = electrocardiogram; EF = ejection fraction; F/U = follow-up; HCM = hypertrophic cardiomyopathy; IDCM = idiopathic dilated cardiomyopathy; Inf = inferior; IVCD = intraventricular conduction defect; LBBB = left bundle branch block; M = male; Pt = Patient; RF = radiofrequency ablation procedures; Sup = superior.

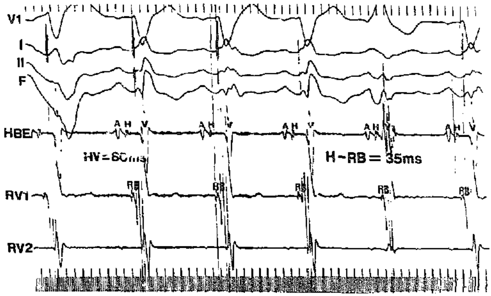

Figure 1. Patient 4. Baseline body surface electrocardiograms (ECGs) and intracardiac electrograms. His bundle potential (H) and right bundle branch (RB) potentials are simultaneously recorded. The HV interval was prolonged at 80 ms. A right bundle branch potential (V) is recorded 35 ms after the His bundle potential (H). A = atrial electrogram; HBE = His bundle electrogram; RV = right ventricular electrogram; V = ventricular electrogram.

Patient follow-up. After ablation, each patient had a 24-h Holter ambulatory electrocardiographic (ECG) monitor before hospital discharge. In addition, each patient was instructed to contact our clinic immediately for any recurrence of arrhythmia symptoms. All patients were seen in our arrhythmia clinic at 1 month follow-up and then followed up at 3 month intervals. A history, physical examination and 12-lead ECG were obtained at that time. The patients were recontacted by phone and their current medical status reviewed.

Statistical analysis. The chi-square test was used to compare the incidence of bundle branch reentrant tachycardia in patients with coronary artery disease with that in patients with cardiomyopathy. A Student's unpaired *t* test was used to compare the electrophysiologic characteristics after radiofrequency ablation of the right bundle branch with those at baseline. A p value < 0.05 was considered statistically significant. All data are presented as mean values ± SE.

Results

Summary of seven cases. Baseline ECGs showed a left intraventricular conduction defect in four patients and a complete left bundle branch block pattern in three. The baseline HV interval was prolonged in all patients (mean 79 ± 2 ms, range 65 to 85). Sustained bundle branch reentrant tachycardia was inducible with use of standard programmed ventricular stimulation in all patients. In Patient 7 a pause protocol facilitated induction of bundle branch reentrant tachycardia. The mean tachycardia cycle length was 283 ± 17 ms (range 230 to 350).

A typical case (Patient 4) is illustrated in Figures 1 and 2. Figure 1 shows simultaneous recordings of surface ECG and intracardiac electrograms. Figure 2 shows intracardiac recordings during bundle branch reentrant tachycardia in this patient. Note the presence of AV dissociation and His to His variation that preceded a change in ventricular tachycardia

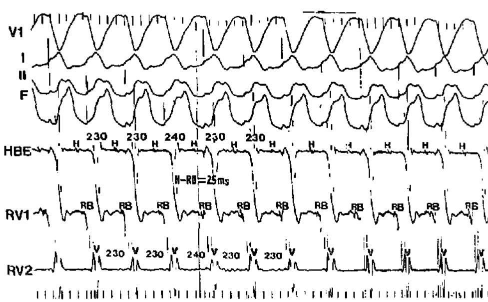

Figure 2. Patient 4. Bundle branch reentrant tachycardia was induced at a ventricular cycle length of 240 ms. Atrioventricular dissociation was present (not illustrated) and His to His (H-H) variation precedes changes in tachycardia cycle length. In addition, the His to right bundle branch (H-RB) conduction time shortened during bundle branch reentrant tachycardia (from 35 to 25 ms). Abbreviations as in *Figure 1*.

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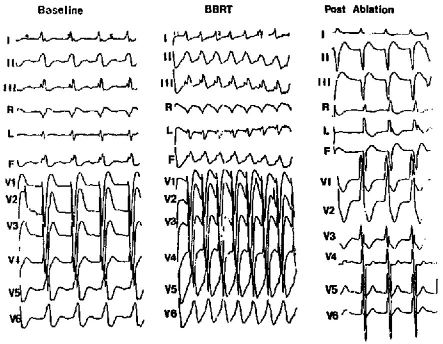

Figure 3. Patient 3. The baseline 12-lead electrocardiogram (ECG) shows a left bundle branch block pattern. Bundle branch reentrant tachycardia (BBRT) was inducible with a right inferior axis and left bundle branch block configuration at a ventricular cycle length of 330 ms. Radiofrequency ablation (Post Ablation) resulted in complete right bundle branch block, after which bundle branch reentrant tachycardia was no longer inducible.

cycle length. His to right bundle branch conduction time during bundle branch reentrant tachycardia was less than at baseline.

It is important to emphasize that multiple forms of tachycardia may be present in any given patient with only one configuration representing bundle branch reentrant tachycardia. In Patient 3 the baseline ECG showed a complete left bundle branch block pattern (Fig. 3). Bundle branch reentrant tachycardia had a left bundle branch block configuration and an inferior axis at a cycle length of 330 ms. Radiofrequency ablation resulted in complete right bundle branch block after which bundle branch reentrant tachycardia was no longer inducible. However, this patient also had ventricular tachycardia of myocardial origin with a different configuration. Right bundle branch ablation succeeded in control of the tachycardia with an inferior axis (bundle branch reentrant tachycardia) but not that with a superior axis (myocardial ventricular tachycardia). The latter arrhythmia was never documented clinically and was not treated.

Patient 6 had a long history of recurrent ventricular tachycardia treated elsewhere with amiodarone. He underwent AV junction ablation at our institution for symptomatic atrial fibrillation (Fig. 4A) followed by pacemaker implantation. He was referred back for possible recurrence of AV conduction with presumed atrial flutter and, at electrophysiologic study, was found to have complete AV block and bundle branch reentrant tachycardia (Fig. 4B). This case demonstrates that bundle branch reentrant tachycardia may resemble wide complex supraventricular tachycardias (such as atrial flutter with aberrant conduction) and can occur even in the presence of complete AV block.

Catheter ablation of the right bundle. One to three applications of radiofrequency energy (15 to 20 W for up to 60 s) resulted in complete right bundle branch block in all patients. Table 3 shows the electrophysiologic characteristics before and immediately after radiofrequency ablation of the right bundle branch. The His bundle deflection could not be recorded after right bundle branch ablation in Patient 6. The HV interval remained unchanged after ablation in all other patients except Patient 3, who showed marked HV prolongation (from 80 to 170 ms) but who already had a permanent pacemaker. AH and HV intervals and QRS durations were statistically unchanged after ablation. Infranodal block was not present during either atrial overdrive pacing or during programmed atrial extrastimuli. Repeated attempts at induction after ablation (and during the same procedure) were unsuccessful in initiating bundle branch reentrant tachycardia in all patients.

All patients underwent an additional repeat electrophysiologic study either before discharge or at 6-month follow-up. Three patients (Patients 3, 5 and 7) still had inducible sustained monomorphic ventricular tachycardia originating from ventricular myocardium. In Patient 3 ventricular tachycardia was slow (430 ms cycle length) and not associated with hemodynamic compromise. He was discharged without antiarrhythmic therapy and never had spontaneous recurrence. The "myocardial" ventricular tachycardia of Patient 5 recurred spontaneously and is currently controlled with amiodarone therapy. Patient 7 had an inducible, rapid, hemodynamically unstable myocardial ventricular tachycardia at restudy and underwent implantation of an automatic cardioverter-defibrillator.

Follow-up. At a mean follow-up period of 12 ± 3 months (range 6 to 29), complete right bundle branch block persisted in all patients and there were no recurrences of bundle branch reentrant tachycardia. Patient 1 died of end-stage

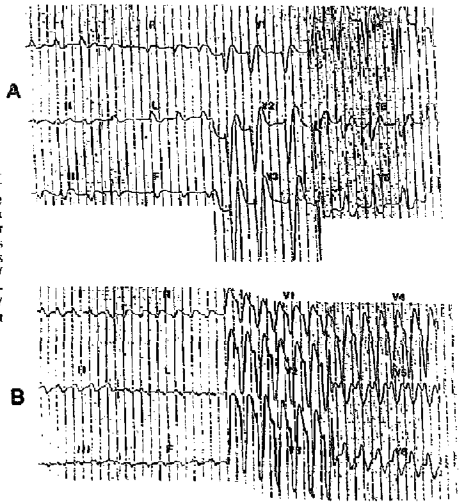

Figure 4. Patient 6. **A,** the baseline 12-lead ECG. Atrial fibrillation is present (before atrioventricular [AV] junction ablation) with a complete left bundle branch block pattern. **B,** a regular wide complex tachycardia at a rate of 150 beats/min is present after AV junction ablation with a configuration and axis similar to those observed on the baseline ECG. This patient was thought to have a recurrence of AV conduction with atrial flutter and 2:1 AV conduction. At electrophysiologic study, complete AV block was present and bundle branch reentrant tachycardia was identified.

congestive heart failure and uremia 29 months after the ablation procedure. Patient 3 died of an unrelated cause (sepsis post-herniorrhaphy). Patient 4 returned for treatment of atrial fibrillation with aberrant conduction that was controlled with propafenone. Two patients already had a pacemaker before right bundle branch ablation but none of the others required pacemaker placement.

Discussion

Long-term efficacy of radiofrequency ablation in bundle branch reentrant tachycardia. In 1989 Langberg et al. (5) at our institution reported the first successful bundle branch reentrant tachycardia ablation with use of radiofrequency energy (Patient 1). This patient lived for 29 months after the procedure without arrhythmia recurrence, then died of un-

Table 3. Atrioventricular Conduction Before and After Ablation in Seven Cases

Pt No	Baseline			After Ablation		
	AH (ms)	HV (ms)	QRS (ms)	AH (ms)	HV (ms)	QRS (ms)
1	65	80	180	90	80	180
2	130	80	140	115	80	160
3	180	80	180	190	170	180
4	70	80	130	90	80	130
5	70	65	100	90	65	170
6	*	80	160	*	†	200
7	110	85	100	125	85	170
Mean ± SE	104 ± 19	79 ± 2	141 ± 13	102 ± 16	93 ± 16	170 ± 8‡

*Atrial fibrillation present; †not recorded; ‡there were no significant differences between values at baseline and after ablation.

related causes. Subsequently, six additional patients were identified as having this form of tachycardia and were successfully treated with this approach. Each patient was highly symptomatic (syncope or aborted sudden death), although only two had 12-lead ECG documentation of spontaneous episodes with a configuration identical to that of bundle branch reentrant tachycardia induced in the electrophysiology laboratory (Patients 2 and 6). We can only infer that bundle branch reentrant tachycardia was the clinical arrhythmia in the other five patients because 1) induction of bundle branch reentrant tachycardia reliably replicated the clinical presentation and 2) after right bundle branch ablation there was no recurrence of these symptoms. To our knowledge, this is the first study to demonstrate long-term efficacy of radiofrequency ablation in the treatment of bundle branch reentrant tachycardia. In seven patients no complications or arrhythmia recurrences were observed (immediate or long-term) over 83 months combined follow-up; two patients died of unrelated causes.

Previous studies. Previous studies demonstrated that direct current catheter ablation may successfully interrupt the macroreentrant circuit and cure patients with bundle branch reentrant tachycardia. Successful direct current ablation has been reported (2–4) in 12 patients with bundle branch reentrant tachycardia (and at least 8 of these received a prophylactic permanent pacemaker). Radiofrequency energy appears preferable to direct current for ablation because it can be delivered without general anesthesia or barotrauma and produces more shallow and more uniform and smaller zones of myocardial damage (9–11). It is conceivable that radiofrequency ablation may be more likely than other procedures to interrupt the right bundle branch alone without more diffuse effects on the specialized ventricular conduction system. Only one of our patients showed significant prolongation of infranodal conduction after ablation. Five patients who showed no significant changes in the HV interval are currently being followed up without a pacemaker.

The incidence of bundle branch reentrant tachycardia in our patients with ventricular tachycardia is similar to that reported by Caceres et al. (1). Four of our seven patients with this arrhythmia had coronary artery disease and three had cardiomyopathy. Although our incidence of bundle branch reentrant tachycardia (16.6%) for patients with cardiomyopathy was lower than that previously reported (36%) (1), it was nevertheless significantly greater than in those with coronary artery disease (4.5%).

The pause protocol. In the previously reported largest series of bundle branch reentrant tachycardia (1), a pause protocol was used to induce the tachycardia. In the present series the tachycardia was inducible in all patients with use of a standard protocol. It was appreciated, however, that the tachycardia could be induced more easily with use of a pause protocol in Patient 7. We cannot exclude the possibility that this protocol might have improved the sensitivity of diagnosing bundle branch reentrant tachycardia in our study, nevertheless, our overall incidence of bundle branch reentrant tachycardia is similar to the reported incidence of this entity (1).

Significance of left bundle branch block on a baseline ECG. Three of our seven patients had a baseline 12-lead ECG consistent with a complete left bundle branch block pattern. This pattern is obviously due to a conduction delay rather than to complete block in the left bundle because induced block in the right bundle forced exclusive conduction over the left bundle. Thus, the presence of a complete left bundle branch block pattern on baseline ECG or even complete AV block (Patient 6) does not exclude a bundle branch reentrant mechanism. Three patients had both inducible sustained monomorphic ventricular tachycardia of a bundle branch and a myocardial reentrant mechanism. This emphasizes the importance of a thorough investigation of a bundle branch reentrant mechanism even if other etiologies are identified (and vice versa). In addition, bundle branch reentrant tachycardia mimicked supraventricular tachycardia with aberration in one patient.

Conclusions. The possibility of bundle branch reentrant tachycardia must be carefully evaluated in all patients with known or suspected ventricular tachycardia. All patients in our study presented with either syncope or aborted sudden death. Radiofrequency ablation of the right bundle branch appears to be a safe and effective treatment modality. We found a high incidence (three of seven patients [43%]), of coexisting ventricular tachycardia of myocardial origin, which required active therapy in two patients. Despite the presence of an intraventricular conduction defect or left bundle branch pattern, there was no progression to complete AV block during follow-up in the five patients without a permanent pacemaker. One patient did show marked prolongation of the HV interval after ablation; therefore, these patients must be carefully observed with regard to development of progressive disease of the specialized ventricular conduction system. We conclude that radiofrequency ablation is a safe and effective treatment for bundle branch reentrant tachycardia and probably the procedure of choice for these highly symptomatic patients.

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