

Catheter Ablation of Fascicular Ventricular Tachycardia Long-Term Clinical Outcomes and Mechanisms of Recurrence

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Background—Fascicular ventricular tachycardia (FVT) is a common form of sustained idiopathic left ventricular tachycardia with an Asian preponderance. This study aimed to prospectively investigate long-term clinical outcomes of patients undergoing ablation of FVT and identify predictors of arrhythmia recurrence.

Methods and Results—Consecutive patients undergoing FVT ablation at a single tertiary center were enrolled. Activation mapping was performed to identify the earliest presystolic Purkinje potential during FVT that was targeted by radiofrequency ablation. Follow-up with clinic visits, ECG, and Holter monitoring was performed at least every 6 months. A total of 120 consecutive patients (mean age, 29.3±12.7 years; 82% men; all patients with normal ejection fraction) were enrolled. FVT involved left posterior fascicle and left anterior fascicle in 118 and 2 subjects, respectively. VT was noninducible in 3 patients, and ablation was acutely successful in 117 patients. With a median follow-up of 55.7 months, VT of a similar ECG morphology recurred in 17 patients, and repeat procedure confirmed FVT recurrence involving the same fascicle. Shorter VT cycle length was the only significant predictor of FVT recurrence ($P=0.03$). Six other patients developed new-onset upper septal FVT that was successfully ablated.

Conclusions—Ablation of FVT guided by activation mapping is associated with a single procedural success rate without the use of antiarrhythmic drugs of 80.3%. Arrhythmia recurrences after an initially successful ablation were caused by recurrent FVT involving the same fascicle in two thirds of patients or new onset of upper septal FVT in the remainder. (*Circ Arrhythm Electrophysiol.* 2015;8:1443-1451. DOI: 10.1161/CIRCEP.115.003080.)

Key Words: bundle of His ■ catheter ablation ■ follow-up studies ■ recurrence ■ tachycardia, ventricular

Since the first description of fascicular ventricular tachycardia (FVT) involving the left posterior fascicle (LPF) in 3 patients by Zipes et al¹ in 1979, our understanding of this common form of idiopathic left ventricular (LV) tachycardia has expanded particularly during the past 2 decades. Through detailed electrophysiological studies (EPS), FVT has been determined to be reentrant in mechanism, can be responsive to verapamil, involves various branches of Purkinje network emanating from left fascicles with differential conduction properties participating in the tachycardia, and can be successfully treated by localized ablation in the LV septum.²⁻¹⁴ On the basis of reports of small single-center cohorts undergoing ablation, acute success rates are generally high although limited data exist about electrophysiological findings and clinical outcomes in the few patients who do develop arrhythmia recurrence. More recently, case reports have described patients with FVT representing years after ablation with different variants of FVT.^{15,16}

This study aimed to prospectively investigate long-term clinical outcomes of a large cohort of patients undergoing catheter ablation of FVT in a regional referral center in China, analyze mechanisms of arrhythmia recurrence, and identify electrophysiological or clinical predictors of FVT recurrence.

Methods

Population

This study was approved by an institutional ethics committee, and all subjects gave informed consent. From January 2008 to December 2012, consecutive patients undergoing clinically indicated EPS and ablation for FVT at the Affiliated Hospital of Nanjing Medical University, China, were enrolled into a prospective clinical database. All patients fulfilled all of the following criteria:

1. Symptomatic sustained VT
2. Documented clinical VT with right bundle branch block-like morphology

Received April 14, 2015; accepted September 3, 2015.

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The Data Supplement is available at <http://circep.ahajournals.org/lookup/suppl/doi:10.1161/CIRCEP.115.003080/-DC1>.

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Circ Arrhythm Electrophysiol is available at <http://circep.ahajournals.org>

DOI: 10.1161/CIRCEP.115.003080

WHAT IS KNOWN

- Fascicular ventricular tachycardia (FVT) is an idiopathic left ventricular tachycardia with an Asian preponderance.
- On the basis of small single-center series of patients undergoing catheter ablation of FVT, acute success rates are generally high although limited data exist on long-term outcomes.

WHAT THE STUDY ADDS

- This study reports long-term clinical outcomes of a large cohort of 120 patients with FVT with a median follow-up in excess of 4.5 years. Activation mapping-guided FVT ablation is associated with high acute procedural success (100%) when FVT is inducible. Approximately 15% (17/117) of patients subsequently developed arrhythmia recurrence.
- Two thirds of FVT recurrence were caused by FVT involving the same fascicle that was targeted during the index ablation, whereas the rest was caused by new-onset upper septal VT. Shorter tachycardia cycle length was the sole independent predictor of left posterior FVT recurrence.
- The development of new left posterior fascicular block after FVT ablation was associated with more basal ablations and did not protect against left posterior FVT recurrence.

3. The absence of ischemic or structural heart disease based on transthoracic echocardiography and clinical evaluation

Electrophysiological Study

Antiarrhythmic medications were withdrawn for at least a period of 5 half-lives. After written informed consent was obtained, the EPS was performed in the fasting state under conscious sedation. Six French quadripolar catheters were positioned at the bundle of His and right ventricular (RV) apex. AH and HV intervals and ECG frontal axis during sinus rhythm were recorded at baseline and at the end of the procedure. Particular attention was paid to the development of fascicular block after ablation. Specifically, LPF block was defined as frontal axis between 90° and 180°, rS pattern in leads I and aVL, qR pattern in leads III and aVF, and QRS duration of <120 ms as per the most recent international guidelines.¹⁷

In patients without spontaneous VT, programmed stimulation was performed from the RV apex, RV outflow tract, and right atrium at drive trains of 2 different cycle lengths (500 or 400 ms and 330 ms), with ≤3 extra stimuli, with and without the use of isoproterenol (1–3 μg/min). If necessary, incremental burst pacing up to cycle lengths of 280 and 200 ms in the RV and atrium, respectively, was performed for VT induction. The filter setting for the bipolar intracardiac electrograms was 30 to 500 Hz. Differential diagnoses, such as a typical atrioventricular reentrant tachycardia and bundle branch reentry, were excluded by established deductive criteria during EPS in combination with diagnostic maneuvers, activation mapping, and entrainment.

Activation Mapping

A 7-French deflectable, nonirrigated, quadripolar catheter with a 4-mm distal electrode, an embedded thermistor, and 2-5-2 mm

interelectrode spacing (Cordis Webster Inc, Diamond Bar, CA, or EP Technologies Inc, San Jose, CA) was introduced retrogradely for mapping and ablation. If a 3-dimensional (3D) mapping system (Ensite NavX System; St Jude Medical Inc, St Paul, MN) was used, endocardial LV geometry was first created. Activation mapping during VT was performed, and specifically, sites with His or Purkinje potentials associated with local ventricular electrograms, extending from left basal septal sites with bundle of His recordings to most apical sites with presystolic Purkinje potentials (apical PP), were marked on the LV geometry (Figure 1). During cases where only conventional mapping was performed, sites with the earliest PP during VT were identified (Figure 2). Whenever possible, entrainment was performed to confirm participation of the targeted site in VT. If VT was not inducible, catheter ablation was not performed.

Radiofrequency Ablation

Temperature-controlled radiofrequency energy was delivered at the site with the earliest PP during VT. The power output was titrated to as high as 35 W to achieve a target temperature of 40°C to 60°C for ≤120 s. The ablation procedure was considered successful if FVT terminated during ablation or if any VT was not inducible 30 minutes after ablation despite repeat programmed stimulation and isoproterenol infusion.

Follow-Up

After the procedure, continuous ECG monitoring was performed for 24 hours. All antiarrhythmic agents were not restarted in the absence of postoperative arrhythmia recurrence. All patients were reviewed in clinic monthly after the procedure for the first 3 months and then followed up every 6 months. A 12-lead ECG and 24-hour Holter monitoring were performed at every clinic visit. Arrhythmia recurrence was defined as symptomatic recurrence with ECG documentation of recurrent VT either on the 12-lead ECG or Holter monitoring.

Statistical Analysis

Continuous variables and categorical variables were described by mean±SD and percentages, respectively. An independent samples *t* test and paired samples *t* test were performed for comparisons of the corresponding parameters and paired data. χ^2 test was used for comparison of categorical data. To determine the association between procedural parameters and VT recurrence, univariable and multivariable Cox proportional regression analyses were performed, and results were expressed as hazard ratios with 95% confidence intervals. *P* value of <0.05 was considered as statistically significant.

Results

Patient Characteristics

From January 2008 to December 2012, 120 consecutive patients underwent EPS and ablation for FVT, refractory to a mean of 1.3±0.9 antiarrhythmic medications (Figure 3). Fifty-six patients received intravenous verapamil during episodes of VT, before EPS that terminated VT in all patients. Two patients had previously undergone unsuccessful ablation attempts at their referring hospitals. The mean age was 29.3±12.7 (range, 7–69) years, and they were predominantly men (81.7%). The median duration of symptoms before EPS was 14 (25th to 75th percentile, 3–63 months) months. All but 3 patients reported palpitations, whereas the remaining 3 experienced presyncope or syncope. Echocardiography confirmed structurally normal hearts in all cases with a mean LV ejection fraction of 65.3±4.5%.

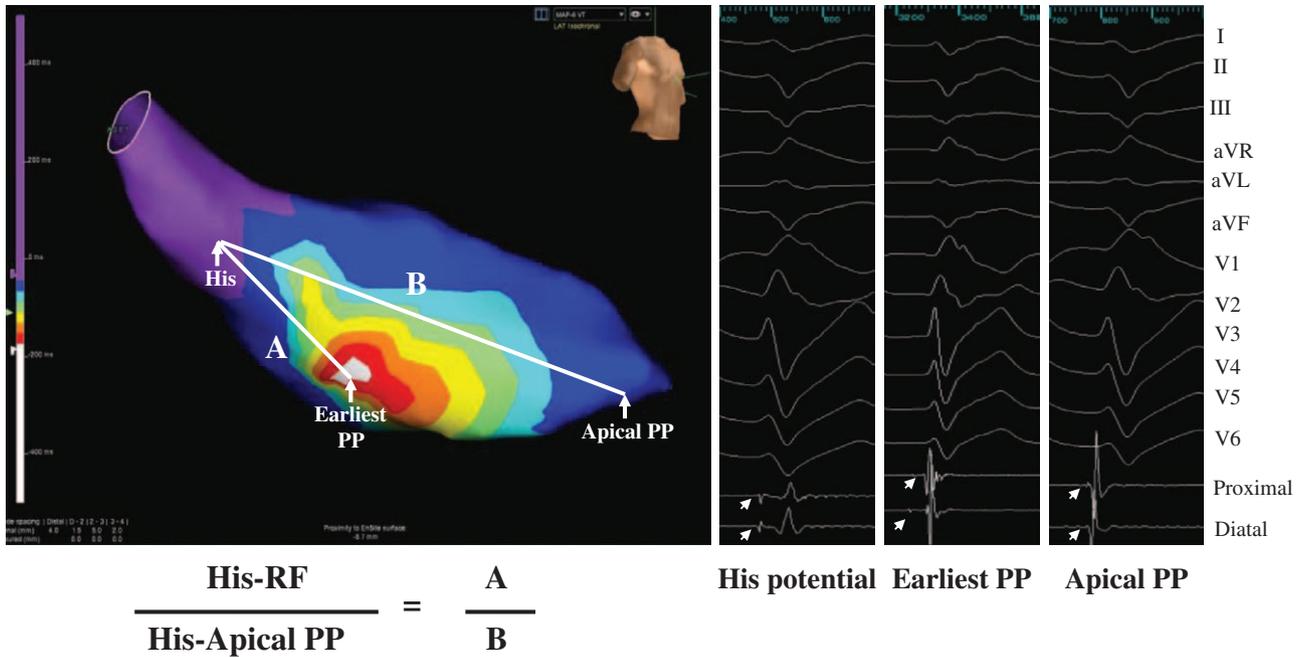


Figure 1. Activation map using the NavX system was created during fascicular ventricular tachycardia (FVT). Septal sites with His or Purkinje potentials, extending from most basal septal sites with bundle of His recordings to most apical sites with presystolic Purkinje potentials (apical PP), were marked on the left ventricular geometry. The site with the earliest presystolic Purkinje potential (earliest PP) during FVT was targeted by catheter ablation. The distance between the most basal His recording to the earliest PP was expressed as a ratio of the distance between the His bundle and apical PP, as an objective measure to indicate the position of ablation sites along the course of the left fascicles.

Electrophysiological Studies

In all patients, preprocedural ECGs demonstrated sinus rhythm with normal axes and QRS durations. AH (80.4±15.6 ms) and HV (44.4±8.2 ms) intervals were within normal limits before ablation. VT was not inducible in 3 patients whom therefore did not proceed to catheter ablation. In the remaining 117 patients, monomorphic VT involved the LPF

(LPFVT; right bundle branch block–like morphology with superior axis; mean VT cycle length, 362.1±79.4 ms; mean QRS duration, 123.9±14.0 ms; HV intervals during VT, -11.9±13.0 ms), and the left anterior fascicle (LAFVT; right bundle branch block–like morphology with right inferior axis; mean VT cycle length, 364.0±26.9 ms; mean QRS duration, 124.6±12.0 ms; HV intervals during VT, -7.5±2.1 ms) in 115



Figure 2. Intracardiac electrograms during electrophysiological studies of left posterior fascicular ventricular tachycardia (LPFVT). Note the more rounded diastolic potential (DP) of the anterograde limb and sharper presystolic Purkinje potential (PP) of the retrograde limb of LPFVT recorded on the ablation catheter (ABL). Radiofrequency ablation delivered at this site with the earliest PP-terminated LPFVT. CS indicates coronary sinus; and His, His bundle.

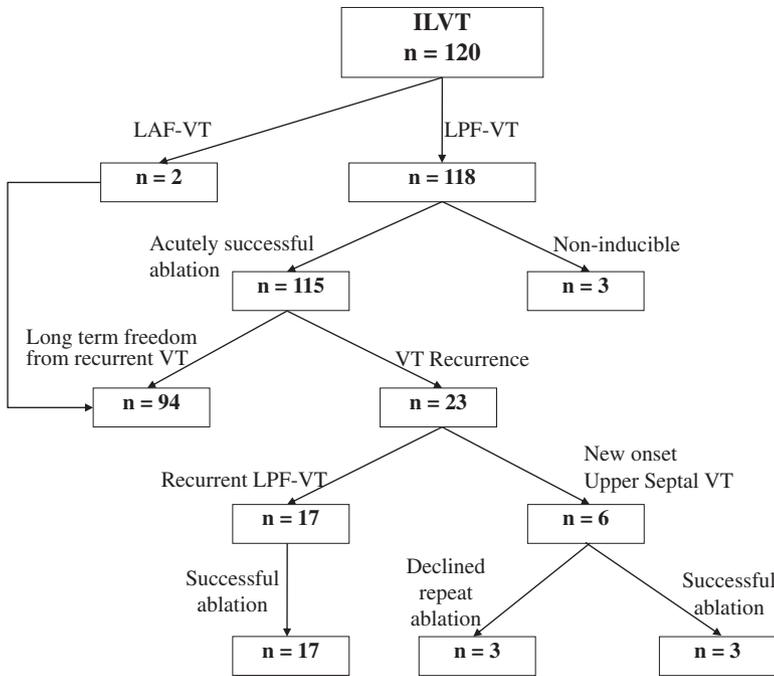


Figure 3. Flowchart of consecutive patients with fascicular ventricular tachycardia enrolled in this study. LAF indicates left anterior fascicle; LPF, left posterior fascicle; ILVT, idiopathic left ventricular tachycardia; and VT, ventricular tachycardia.

and 2 patients, respectively. In all patients, bundle of His was activated retrogradely during VT (often with VA dissociation), ruling out alternative diagnosis, such as bundle branch re-entry and supra-VT with aberrancy.

Mapping and Ablation

The mean earliest PP preceded the onset of QRS during VT by 30.1±9.3 ms (Figure 2). A 3D mapping system was used in

71.6% of cases. In LPFVT subjects, the earliest PP was located 61.3±23.7 (range, 40–116) mm from the most basal septal LV site where a His potential could be measured or 69.0±10.8% of the course that extended along the septum from the bundle of His to the end of the LPF (His-RF/His-apical PP; Figure 1). Similarly for patients with LAFVT, the earliest PP was located 61.0±8.5 (55–67) mm from the most basal LV site where a His potential could be measured and 68.5±5.4% of the course that

Table 1. Procedural Details According to Changes in ECG Frontal Axis After Successful Left Posterior Fascicular Ventricular Tachycardia Ablation

| | New Onset LPFB (n=23) | Rightward Shift in Frontal Axis (n=67) | Axis Unchanged (n=25) | P Value |
|---|--------------------------|---|--------------------------|---------|
| Procedural time, min | 138.4±54.8 | 138.4±54.8 | 122.4±57.3 | 0.66 |
| Fluoroscopy time, min | 12.9±5.5 | 15.9±8.3 | 11.0±4.5 | 0.83 |
| Fluoroscopy dose, cym ² | 63.5±62.9 | 90.0±24.5 | 53.4±21.8 | 0.37 |
| Axis before ablation, ° | 59.4±21.8 | 53.8±20.7 | 47.3±24.5 | 0.33 |
| Axis after ablation, ° | 101.8±13.5 | 64.1±16.1 | 44.9±26.8 | <0.01 |
| AH during SR, ms | 75.0±32.5 | 77.0±15.0 | 83.6±12.2 | 0.75 |
| HV during SR, ms | 46.0±14.1 | 44.8±7.9 | 45±9.8 | 0.98 |
| VT cycle length, ms | 382.0±70.7 | 347.3±84.3 | 379.2±77.1 | 0.72 |
| VH interval during VT, ms | -10.7±9.3 | -13.5±9.4 | -14.6±3.9 | 0.31 |
| His-RF site/His-apical PP, % | 0.57±0.13 | 0.61±0.16 | 0.77±0.10 | 0.03 |
| Earliest PP-QRS interval during VT, ms | 31.4±5.4 | 30.5±8.3 | 30.7±9.2 | 0.87 |
| RF energy, W | 30.0±4.4 | 31.1±5.3 | 29.7±6.0 | 0.65 |
| Temperature achieved, °C | 52.2±3.5 | 51.5±6.1 | 49.0±4.5 | 0.26 |
| VT recurrence during follow-up, % | 9 (39.1) | 10 (14.9) | 4 (16.0) | 0.04 |
| VT recurrence during follow-up (per 100 person-years) | 0.62 | 0.06 | 0.19 | <0.01 |

His-RF/His-apical PP is the linear distance between the most basal left-sided His potential to the site of successful RF ablation expressed as a percentage of the distance between the most basal left-sided His potential and the most apically recorded PP during left posterior fascicular VT. LPFB indicates left posterior fascicular block; PP, presystolic Purkinje potential; RF, radiofrequency; SR, sinus rhythm; and VT, ventricular tachycardia.

Table 2. Characteristics of Recurrent VT

| | Recurrence With LPFVT (n=17) | | | Recurrence With Upper Septal VT (n=6) | | |
|---|------------------------------|-----------------|---------|---------------------------------------|-----------------|---------|
| | Index Ablation | Repeat Ablation | P Value | Index Ablation | Repeat Ablation | P Value |
| Left posterior fascicular block during sinus rhythm preablation | 0 | 4 | 0.03 | 0 | 5 | <0.01 |
| VT cycle length, ms | 337.7±98.9 | 369.8±104.4 | 0.04 | 288±42.0 | 331.7±38.7 | 0.30 |
| VT Frontal axis, ° | -98.3±17.2 | -76.2±73.3 | 0.31 | -96.7±12.6 | 78.7±20.3 | <0.01 |
| VT QRS duration, ms | 121.8±7.6 | 121.8±13.2 | 0.56 | 122.3±2.5 | 106.7±4.9 | 0.01 |
| HV interval, ms | -10.5±10.7 | -6.2±10.2 | 0.04 | -7.3±6.7 | 25.0±2.0 | 0.02 |
| Earliest PP-QRS/DP-QRS interval, ms* | 34.0±8.4 | 34.7±10.2 | 0.88 | 32.3±2.5 | 46.7±12.7* | 0.15 |
| His-RF site/His-apical PP, % | 62.3±6.4 | 61.1±1.7 | 0.57 | 63.1±4.4 | 14.0±1.7 | <0.01 |

His-RF/His-apical PP is the linear distance between the most basal left-sided His potential to the site of successful RF ablation expressed as a percentage of the distance between the most basal left-sided His potential and the most apically recorded PP during LPFVT. DP indicates diastolic potential; LPFVT, left posterior fascicular VT; PP, presystolic Purkinje potential; RF, radiofrequency; and VT, ventricular tachycardia.

* indicates the number is DP-QRS interval.

extended along the septum from the bundle of His to the end of the LAF. Entrainment was performed successfully in 20% of cases, demonstrating concealed fusion and participation of the ablation site in FVT.

Ablation was acutely successful by targeting the earliest PP in all 117 patients with inducible FVT, with noninducibility of any VT despite programmed stimulation and isoproterenol infusion achieved as the electrophysiological end point.

At the end of the procedure, HV intervals during sinus rhythm remained unchanged in all patients.

ECG changes during sinus rhythm were seen in the majority of patients who underwent ablation of LPFVT. Twenty-three (20%) subjects developed new onset LPF block, whereas 67 patients (58.3%) exhibited rightward shift in their frontal axis compared with baseline (frontal axis, 31°–84°). The axis remained unchanged in the remaining 25 patients (21.7%).

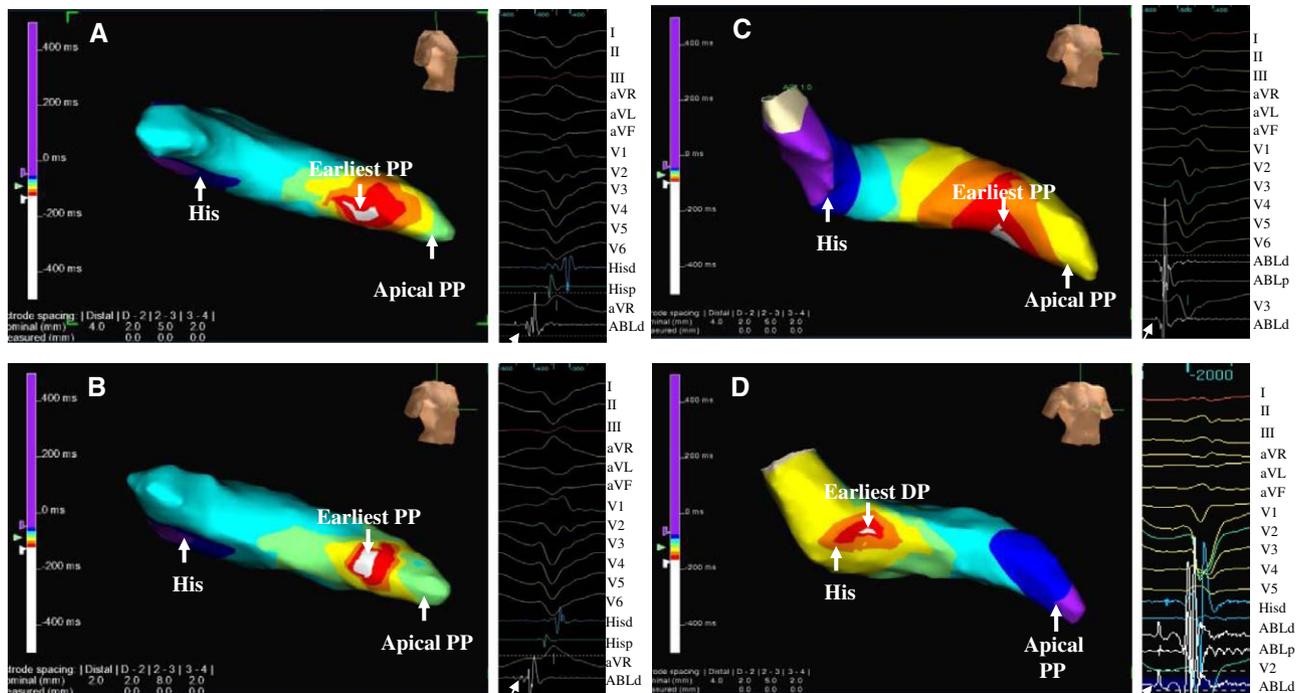


Figure 4. **A**, Activation map in patient 1 recorded during the first ablation procedure for left posterior fascicular ventricular tachycardia (LPFVT). **B**, Activation map in patient 1 recorded during the second ablation procedure after presenting with recurrent LPFVT. **C**, Activation map in patient 2 recorded during the first ablation procedure with LPFVT. **D**, Activation map in patient 2 recorded during the second ablation procedure after presenting with upper septal VT. Note in patient 1 the earliest presystolic Purkinje potential (PP) during the first and second procedure was similar in location, strongly suggestive that the index LPFVT had recurred. In comparison, the site of successful ablation during upper septal VT in patient 2 is much more basal compared with the original site of ablation during LPFVT. **A–C**, Ablation catheter was recording the site with the earliest PP (white arrow), whereas during mapping of upper septal VT (**D**), the earliest diastolic potential (DP) is targeted (white arrow). The local activation at each site was measured by annotating the local His/PP, rather than the ventricular electrogram.

Table 3. Predictors for Successful Left Posterior Fascicular Ventricular Tachycardia Recurrence

| | Univariable HR (95% CI) | P Value | Multivariable HR (95% CI) | P Value |
|-------------------------------------|-------------------------|---------|---------------------------|---------|
| Age | 0.99 (0.92–1.01) | 0.72 | ... | ... |
| Sex | 0.99 (0.99–1.01) | 0.99 | ... | ... |
| Earliest PP-QRS interval | 0.99 (0.94–1.05) | 0.82 | ... | ... |
| New onset LPFB after first ablation | 2.57 (0.58–11.38) | 0.21 | ... | ... |
| His-RF site/His-apical PP | 0.10 (0.01–17.98) | 0.39 | ... | ... |
| VH interval during VT | 1.04 (0.98–1.12) | 0.21 | ... | ... |
| VT cycle length | 0.98 (0.97–0.99) | 0.02 | 0.98 (0.97–0.99) | 0.03 |
| VT QRS duration | 0.91 (0.84–0.99) | 0.04 | ... | ... |

His-RF/His-apical PP is the linear distance between the most basal left-sided His potential to the site of successful RF ablation expressed as a percentage of the distance between the most basal left-sided His potential and the most apically recorded PP during left posterior fascicular VT. HR indicates hazard ratio; LPFB, left posterior fascicular block; PP, presystolic Purkinje potential; SR, sinus rhythm; and VT, ventricular tachycardia.

Development of LPF block was associated with more proximal ablations (His-RF/His-apical PP ratio of 0.57 ± 0.13 versus 0.77 ± 0.10 in patients whose frontal axis remained unchanged; $P=0.03$; Table 1). ECG remained unchanged in the 2 patients with LAFVT after ablation. No complications occurred during the index procedure.

Arrhythmia Recurrences During Follow-Up and Repeat Ablation

With a median follow-up of 55.7 months (25th to 75th percentile, 38.9 to 71.7 months), VT recurred in 23 patients with LPFVT. There was no recurrence of LAFVT. The median time to recurrence was 2.5 months (25th to 75th percentile, 1.5 to 17 months) after the index ablation. In 17 patients, the recurrent VT had ECG morphology similar to the clinical

LPFVT targeted at the index ablation, although with longer tachycardia cycle lengths and shorter VH intervals (Table 2). All consented to repeat ablation. The VT induced during the repeat procedure had similar electrophysiological parameters, including cycle length, HV intervals, and prematurity of the earliest PP in relation to QRS onset. The earliest PP during FVT was again mapped to the vicinity of the LPF, to a location in close proximity, and to the ablation site of the index procedure (Figure 4A and 4B). Ablation was acutely successful again in all 17 patients, and FVT has not recurred during a median follow-up of 40.3 months (25th to 75th percentile, 25.9 to 55.4 months). The development of LPF block did not confer any protection from recurrent FVT (Tables 1 and 3).

Interestingly, in the remaining 6 patients, recurrent VT exhibited a different ECG morphology, with narrower QRS

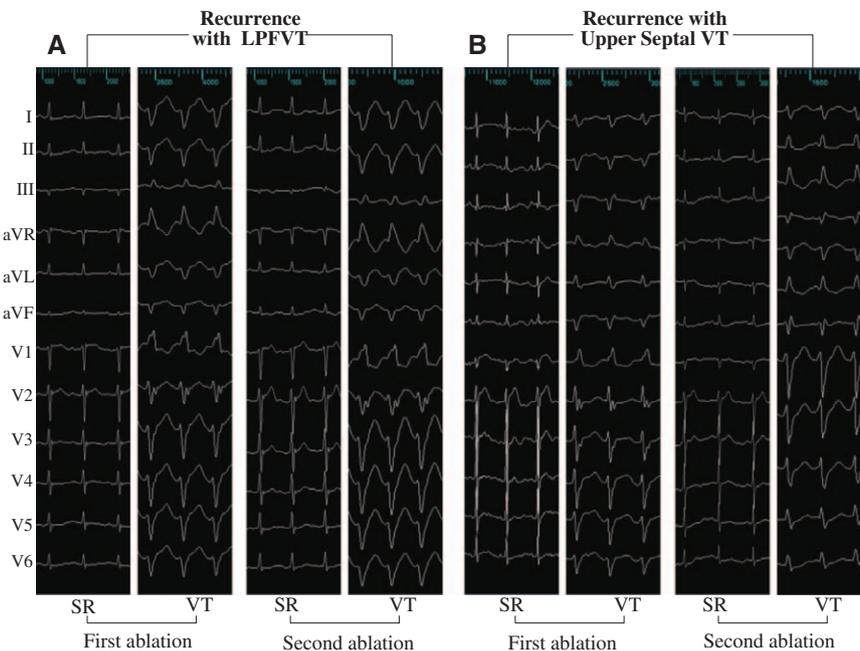


Figure 5. Twelve-lead ECG of index and recurrent fascicular ventricular tachycardia (FVT). Both patients labeled A and B, presented with left posterior fascicular VT (LPFVT; left) that was successfully ablated during their index ablation. ECG axis was unchanged after the index ablation in patient A, whereas there was onset of LPF block after the first ablation in patient B. LPFVT of near-identical morphology recurred in patient A and was successfully reablated. In patient B, VT recurrence was because of upper septal VT that was ablated during the second procedure. SR indicates sinus rhythm.

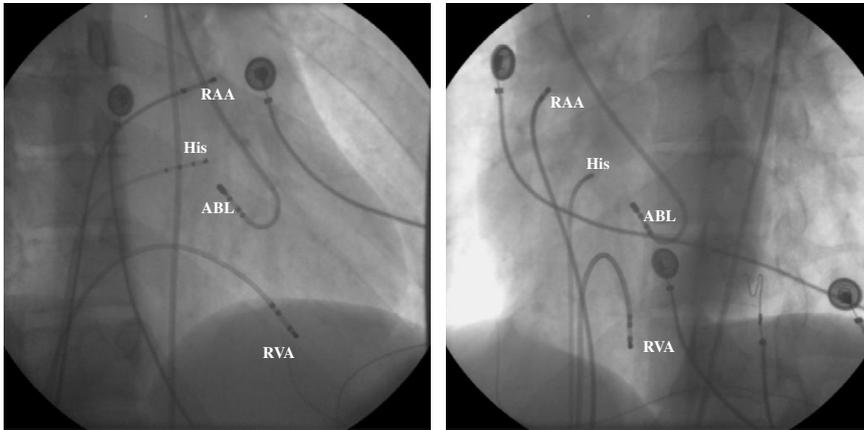


Figure 6. Right anterior oblique (**left**) and left anterior oblique (**right**) of the ablation catheter (ABL) position during upper septal ventricular tachycardia ablation. Note the proximity to the right-sided His catheter. RAA indicates right atrial appendage; and RVA, right ventricular apex.

and variable inferior axis (Figure 5; Figure II in the Data Supplement; Table 2). Five of these 6 patients had developed new-onset LPF block after the first ablation. Only 3 patients agreed to undergo a repeat EPS. During the second ablation procedure, the LPF was activated in an anterograde direction with a resultant positive HV interval that was shorter during VT compared with sinus rhythm. EPS and activation mapping confirmed the diagnosis of upper septal VT. Concealed entrainment was only successful in 1 patient with a post-pace interval (320 ms) minus tachycardia cycle length (315 ms) of 5 ms (Figure III in the Data Supplement). The lower turnaround of the upper septal VT circuit, as marked by the site with the most premature diastolic potential, was targeted. The ablation site was significantly more basal compared with the index ablation (Table 2; Figures 4C, 4D, and 6). Radiofrequency ablation was initiated cautiously at 10 W, gradually increased to a maximum of 20 W, and was acutely successful in all 3 patients without any atrioventricular nodal injury or ECG changes. All 3 patients remain free from recurrent arrhythmias after a median follow-up of 46.1 months.

Three patients in whom VT was not inducible at the first procedure did not return for repeat EPS. Therefore, the single procedural success rate of FVT ablation without the need for antiarrhythmic agents in an unselected cohort of patients is 80.3% (94/117). Allowing for repeat procedures, 97.4% (114/117) of patients were free from recurrent VT during a median follow-up of 55.7 months.

Predictors of Idiopathic LV Tachycardia Recurrence

Multivariable analysis was performed to identify risk factors of LPFVT recurrence after an acutely successful ablation procedure (Table 3). Only faster VT cycle lengths predicted LPFVT recurrence (VT cycle length in patients with and without LPFVT recurrence, 307.7 ± 49.6 versus 361.7 ± 62.7 ms; $P=0.03$). Development of LPF block did not protect against LPFVT recurrence.

Discussion

Major Findings

Our strategy of targeting the most premature PP with limited ablation during ongoing FVT is associated with high acute

procedural success (100%) although $\approx 20\%$ of patients subsequently developed arrhythmia recurrence. Two thirds of FVT recurrence were caused by the reappearance of the same FVT that was treated during the index ablation, whereas the rest was caused by new-onset upper septal VT. Shorter tachycardia cycle length was the sole predictor of LPFVT recurrence. The development of new LPF block was associated with more basal ablations and did not protect against LPFVT recurrence.

Identifying Targets for FVT Ablation

The reentrant pathway of LPFVT is understood to consist of a decrementally conducting, abnormal Purkinje fiber located in the vicinity of the distal third of the LPF Purkinje network that gives rise to a diastolic potential (often termed P1 potential) serving as the anterograde limb and a faster conducting, normal fiber that accounts for the PP (also known as P2) serving as the retrograde limb. It is highly probable that ventricular myocardium serves as the bridge between the anterograde and retrograde limbs.^{3,10} When activation mapping can be performed during ongoing VT, LPFVT can be successfully ablated by targeting either diastolic (P1) or the earliest PP (P2 potentials), the latter representing the lower turnaround of the LPFVT circuit.^{8,10} The advantages of targeting the earliest PP include their more apical locations, reducing the risk of atrioventricular nodal or bundle branch injury and need for fewer radiofrequency energy applications.¹⁸ Furthermore, diastolic (P1) potentials may not be recorded in all patients.⁸ Although different smaller series have selected varying ablation targets namely P1, earliest PP, or even the exit site (site with the earliest ventricular activation), acute success rates are consistently high, suggesting that the reentrant FVT can be interrupted at multiple points along the reentrant circuit.^{8,9,11,18} Consistent with these previous reports, our predefined strategy of targeting the earliest PP during LAFVT or LPFVT was acutely successful in all patients.

Electrophysiological End Points of FVT Ablation

Locating the optimal site for ablation becomes more difficult when FVT is difficult to induce or is nonsustained. Numerous ablation strategies performed during sinus rhythm to overcome this hurdle have been reported. Purkinje potentials visible after the QRS complex, which may be characteristic of delayed retrograde activation of abnormal Purkinje fibers

that act as the anterograde limb of LPFVT, have been targeted during sinus rhythm. Although these potentials seem unique to patients with FVT compared with a small group of control patients without FVT, such electrograms are recordable over a sizeable area of the septum and can be detected remotely in the LAF Purkinje network in patients presenting with LPFVT.^{4,10} Thus, undertaking such a strategy would result in a substantial septal area being ablated with the risk of injury to the conducting system. A more anatomically guided approach of placing 7 to 15 ablation lesions in a linear pattern, perpendicular to the long axis of the ventricle approximately midway from the base to the apex in the region of the mid to midinferior septum, guided by the presence of Purkinje potentials and pace mapping was reported to be effective in 6 patients with nonsustained LPFVT.⁶ Consistent with our results that the successful ablation site is located on average 69% of the septal course extending from the bundle of His to the end of the left fascicle, it is highly plausible that such lesion sets could transect the lower turnaround of the LPFVT circuit, preventing arrhythmia recurrence. Finally, a few groups have suggested the creation of partial or complete LPF block as a reproducible, easily demonstrable electrophysiological end point for LPFVT ablation.^{7,14,19} In our study, the development of complete LPF block was associated with more basally located ablations. Furthermore, the formation of LPF block did not reduce the risk of LPFVT recurrence. These findings, in conjunction with other observations that selective capture of the LPF during LPFVT did not affect tachycardia cycle length, LPFVT can still develop in patients with preexisting LPF block, and the vast majority of patients remained arrhythmia free after LPFVT ablation without developing new-onset LPF block, would suggest that the LPF does not participate in LPFVT circuit.^{5,13,20} Hence, rightward shift in the ECG axis is most likely because of inadvertent collateral damage to the LPF, particularly when ablation is delivered more basally. Therefore, our results would imply that creation of LPF block is unlikely to be an effective electrophysiological end point for FVT ablation, although this hypothesis was not tested directly in the experimental design. It is also noteworthy that 5 of 6 patients who developed arrhythmia recurrence with upper septal VT developed LPF block after their first index. It is speculative but plausible that the inadvertent creation of sites of slow conduction within the Purkinje network could be proarrhythmic, promoting reentry amongst different septal circuits.

Predictors of FVT Recurrence

In a previous study of 79 patients whom underwent ablation of idiopathic VT, which included 40 FVT patients, 9 patients (5 FVT subjects) developed VT recurrence.¹² The only significant predictor of arrhythmia recurrence was the endocardial activation time at the successful ablation. In our study with a larger sample size, only faster tachycardia cycle length but not prematurity of the local PP potential predicted FVT recurrence. More rapid ventricular contractions may lead to reduced catheter stability and tissue contact, impairing ablation lesion size and quality. Subsequent recovery of conduction between the anterograde and retrograde limbs of the LPFVT circuit allowed for VT

recurrence. Hence, during the repeat procedure, the successful ablation site was once again mapped to a similar location and additional ablation rendered once again FVT noninducible.

Potential for Multifascicular VT

Upper septal VT is the most uncommon variant of fascicular VT, characterized by a tachycardia circuit that uses parts of the LPF as the anterograde limb (with simultaneous bystander activation of the right bundle and LAF to produce a narrow QRS) and septal Purkinje fiber or auxiliary fascicle as the retrograde limb.^{15,16} Such VT has also been described as fast-slow fascicular VT, whereby the slower conducting septal fascicle serves as the retrograde limb as opposed to the fast-slow fascicular VT seen in LAFVT and LPFVT, whereby anterograde limb is the slower conducting abnormal Purkinje fiber.²¹ It has been reported by Nishiuchi et al¹⁵ recently that upper septal VT was responsible for arrhythmia recurrence in a patient who had previously undergone successful ablation of LPFVT, similar to 6 patients in our cohort. However, upper septal VT can also present as the de novo arrhythmia.¹⁶ Unlike LPFVT, it is important to target the earliest diastolic potential originating from the septal fascicle, which marks the lower turnaround of the upper septal VT circuit. Ablating the earliest PPs around the anterograde limb, where concealed entrainment can be achieved, could result in fascicular or bundle branch block. Moreover, VT can remain inducible with the tachycardia switching to revolve around the LAF as upper septal VT with a different ECG morphology or around the right bundle branch to form bundle branch reentrant VT.¹⁶

Limitations

Only patients with inducible FVT underwent ablation, and therefore, our findings during activation mapping would not be applicable for patients with noninducible VT. Intravenous verapamil was not administered during EPS to avoid rendering FVT noninducible. Therefore, the possibility of focal Purkinje VT being the diagnosis in a few cases cannot be excluded.

Conclusions

Ablation of FVT guided by activation mapping is associated with a single procedural success rate without the use of antiarrhythmic drugs of 80.3% that increases to 97.4% with repeated ablations. Only faster tachycardia cycle length but not the development of new LPF block predicted LPFVT recurrence. Arrhythmia recurrences after an initially successful ablation were caused by recurrent FVT involving the same fascicle in two thirds of patients and new onset of upper septal VT in the remainder.

Sources of Funding

This work was supported by grants from the National Natural Science Foundation of China (grant no. 81470456 and 81170160), by National Twelfth Five-Year Plan for Science and Technology Support (grant no. 2011BAI11B13), by a project funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions, by the Six Peak Talents Foundation of Jiangsu Province (grant no. 2011-WS-071), and by the Program for Development of Innovative Research Team in the First Affiliated Hospital of Nanjing Medical University (grant no. IRT-004).

Disclosures

None.

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