Acute Hemodynamic Decompensation During Catheter Ablation of Scar-Related Ventricular Tachycardia

Incidence, Predictors, and Impact on Mortality

Pasquale Santangeli, MD; Daniele Muser, MD; Erica S. Zado, PA-C; Silvia Magnani, MD; Sumun Khetpal, MS; Mathew D. Hutchinson, MD; Gregory Supple, MD; David S. Frankel, MD; Fermin C. Garcia, MD; Rupa Bala, MD; Michael P. Riley, MD, PhD; David Lin, MD; J. Eduardo Rame, MD; Robert Schaller, DO; Sanjay Dixit, MD; Francis E. Marchlinski, MD; David J. Callans, MD

Background—The occurrence of periprocedural acute hemodynamic decompensation (AHD) in patients undergoing radiofrequency catheter ablation of scar-related ventricular tachycardia (VT) has not been previously investigated.

Methods and Results—We identified univariate predictors of periprocedural AHD in 193 consecutive patients undergoing radiofrequency catheter ablation of scar-related VT. AHD was defined as persistent hypotension despite vasopressors and requiring mechanical support or procedure discontinuation. AHD occurred in 22 (11%) patients. Compared with the rest of the population, patients with AHD were older (68.5±10.7 versus 61.6±15.0 years; P=0.037); had a higher prevalence of diabetes mellitus (36% versus 18%; P=0.045), ischemic cardiomyopathy (86% versus 52%; P=0.002), chronic obstructive pulmonary disease (41% versus 13%; P=0.001), and VT storm (77% versus 43%; P=0.002); had more severe heart failure (New York Heart Association class III/IV: 55% versus 15%, P<0.001; left ventricular ejection fraction: 26±10% versus 36±16%, P=0.003); and more often received periprocedural general anesthesia (59% versus 29%; P=0.004). At 21±7 months follow-up, the mortality rate was higher in the AHD group compared with the rest of the population (50% versus 11%, log-rank P<0.001).

Conclusions—AHD occurs in 11% of patients undergoing radiofrequency catheter ablation of scar-related VT and is associated with increased risk of mortality over follow-up. AHD may be predicted by clinical factors, including advanced age, ischemic cardiomyopathy, more severe heart failure status (New York Heart Association class III/IV, lower ejection fraction), associated comorbidities (diabetes mellitus and chronic obstructive pulmonary disease), presentation with VT storm, and use of general anesthesia. **(*Circ Arrhythm Electrophysiol*. 2015;8:68-75. DOI: 10.1161/CIRCEP.114.002155.)**

Key Words: catheter ablation ■ mortality ■ ventricular tachycardia

Radiofrequency catheter ablation (RFCA) has an established therapeutic role in managing recurrent drug-refractory scar-related ventricular tachycardia (VT).[1] Owing to the complex substrate, concomitant heart failure, and associated comorbidities, patients undergoing catheter ablation of scar-related VT experience significant morbidity and mortality rates.[2,3] In these patients, use of anesthesia, sustained hypotension as a result of spontaneous or induced VT, and fluid overload might contribute to periprocedural acute hemodynamic decompensation (AHD) requiring advanced hemodynamic support or procedure discontinuation.[4,5] Thus far, no data are available on the prevalence, predictors, and clinical significance of periprocedural AHD during catheter ablation of scar-related VT. The proper identification of patients at high risk of periprocedural AHD would also have important implications for procedural planning because it would allow anticipation of the need for mechanical hemodynamic support. In this study, we evaluated the incidence and clinical predictors of periprocedural AHD during RFCA of scar-related VT and assessed its effect on mortality.

Methods

The study cohort consisted of consecutive patients who underwent RFCA of scar-related VT in the setting of ischemic or nonischemic cardiomyopathy at the Hospital of the University of Pennsylvania between January 2010 and December 2011. Patients with idiopathic VT and those with congenital heart disease were excluded. Whenever possible, antiarrhythmic drugs were discontinued for ≥4 half-lives before the procedure. Patients who were on chronic therapy with β-blockers or inhibitors of the renin–angiotensin–aldosterone system routinely held the medications the morning of the procedure (last dose administered the night before). Before the procedure, all patients

Received June 2, 2014; accepted October 30, 2014.

From the Cardiovascular Division, Department of Medicine, Hospital of the University of Pennsylvania, Philadelphia, PA.

The Data Supplement is available at http://circep.ahajournals.org/lookup/suppl/doi:10.1161/CIRCEP.114.002155/-/DC1.

Correspondence to David J. Callans, MD, Hospital of the University of Pennsylvania, 9 Founders Pavilion – Cardiology, 3400 Spruce St, Philadelphia, PA 19104. E-mail david.callans@uphs.upenn.edu

WHAT IS KNOWN

- Patients with scar-related ventricular tachycardia (VT) can be effectively treated with radiofrequency catheter ablation. Owing to the complex substrate, concomitant heart failure, and associated comorbidities, periprocedural hemodynamic decompensation may occur in these patients.
- The prevalence and predictors of periprocedural acute hemodynamic decompensation during catheter ablation of scar-related VT have not been previously investigated.

WHAT THE STUDY ADDS

- Periprocedural hemodynamic decompensation occurred in 11% of consecutive cases undergoing catheter ablation of scar-related VT and was associated with increased mortality over follow-up.
- Clinical factors associated with decompensation included advanced age, ischemic cardiomyopathy, more severe heart failure status, comorbidities (diabetes mellitus and chronic obstructive pulmonary disease), presentation with VT storm, and use of general anesthesia.
- Identification of patients at risk of hemodynamic decompensation might be used to guide prophylactic interventions, such as mechanical hemodynamic support or adoption of substrate-based ablation approaches without inducing VT to attempt to avoid hemodynamic decompensation.

with history of ischemic cardiomyopathy or symptoms suggestive for underlying coronary artery disease underwent a left heart catheterization study or noninvasive stress test to rule out active cardiac ischemia. The study conformed to the institutional guidelines of the University of Pennsylvania Health System, and all patients gave written informed consent.

Electrophysiology Study and Catheter Ablation

Patients presented to the cardiac electrophysiology laboratory in the fasting state. Conscious sedation was used whenever possible. General anesthesia with an inhaled anesthetic (typically sevoflurane) was used when necessary at the discretion of the operator or anesthesiologist involved in the procedure for ventilation, oxygenation, or patient comfort. Catheters were placed into position in the heart using fluoroscopic guidance. A 6-Fr quadripolar catheter with 5-mm interelectrode distance (Bard Inc., Delran, New Jersey) was placed at the right ventricular (RV) apex. A deflectable 8-Fr mapping/ablation catheter that had a 3.5-mm irrigated tip and a 2-mm ring electrode separated by 1 mm (Thermocool, Biosense Webster, Diamond Bar, California) was advanced to the RV (transvenous approach), left ventricle (LV; retrograde aortic or transseptal approach), or epicardial space according to the presumed site of origin of the VT or the underlying substrate. In particular, the decision for an epicardial approach was made when (1) the 12-lead ECG of the VT suggested an epicardial origin; (2) there was evidence of epicardial substrate on imaging studies (eg, magnetic resonance, intracardiac echocardiography); and (3) failure of endocardial ablation procedure.[6] Access to the pericardial space and epicardium was obtained using the percutaneous subxiphoid approach described by Sosa et al.[7] A 64-element phased-array intracardiac echocardiography catheter (AcuNav, Acuson, Mountain View, California) was used to assist catheter manipulation, radiofrequency energy delivery, and tissue-catheter contact and monitor for complications. A detailed 3-dimensional electroanatomic voltage map (CARTO™; Biosense Webster, Inc., Diamond Bar, California) was created during sinus or paced rhythm to identify the areas of low voltage and abnormal electrograms consistent with scar, as previously reported.[8–10] Programmed ventricular stimulation was performed and induced VT(s) were compared with those occurring spontaneously. Induced VT(s) were identified as a clinical rhythm when matched the cycle length and morphology of stored implantable cardioverter defibrillator electrograms (near-field and far-field) and the 12-lead ECG when available. Prioritization was made to eliminate the clinical VT(s) and all mappable nonclinical VT(s). All induced VT(s) with a cycle length within >250 ms were also considered potentially relevant and routinely targeted for ablation. For hemodynamically tolerated VT(s), entrainment mapping was performed within the low-voltage area at sites showing diastolic activity to identify critical sites of the VT re-entrant circuit. A critical site that was appropriate target for ablation was defined as a site showing entrainment with concealed QRS fusion and return cycle within 30 ms of the VT cycle length with matching stimulus-QRS and electrogram-QRS intervals[11] or where VT terminated during pacing without global capture.[12] Radiofrequency energy was delivered at these sites using powers ≤50 W with a goal 12- to 15-Ohm impedance drop. If delivery of radiofrequency energy failed to terminate VT within 30 to 60 seconds, the ablation catheter was moved to an alternative site meeting the same criteria. For hemodynamically unstable VTs, substrate modification was performed with linear or cluster lesions targeting sites identified by pace mapping and late potentials, as previously described.[9] After ablation, repeat programmed stimulation with ≤3 ventricular extrastimuli delivered from 2 different sites at 2 pacing cycle lengths was performed to determine the procedural success, defined as lack of inducibility of the clinical VT(s) and of all the mappable and unmappable nonclinical induced VT(s) with cycle length >250 ms.

Study End Points

The primary study end point was occurrence of periprocedural AHD, defined as sustained hypotension (ie, systolic blood pressure <80–90 mm Hg), despite increasing doses of vasopressors and requiring mechanical hemodynamic support (ie, intra-aortic balloon pump or left ventricular assist devices) and procedure discontinuation. The secondary end point was all-cause mortality during follow-up.

Clinical Follow-Up

Patients were routinely evaluated at 4 to 8 weeks after ablation and then at 3- to 6-month intervals. For patients not followed at our Institution, the referring cardiologists were contacted and implantable cardioverter defibrillator interrogations reviewed to determine arrhythmia recurrence. Telephone interviews were performed at 6- and 12-month intervals with patients or family members to confirm the absence of arrhythmias symptoms. The Social Security Death Index database was also queried to determine vital status.

Statistical Analysis

Continuous data are reported as mean±standard deviation (SD) or median and interquartile range for skewed distributions. Categorical data are reported as number and percentages. The unpaired Student *t* test, 1-way analysis of variance, and the χ^2 test were used to compare differences across groups. Univariate logistic regression analysis was applied for assessment of the association of baseline clinical and procedural variables with occurrence of AHD. Mortality at follow-up was reported with a time-to-event analysis, and survival curves were created using the Kaplan–Meier method with differences between groups compared with the log-rank test. Univariate Cox proportional hazard regression was used to identify baseline clinical variables predictive of mortality over follow-up. Relative risk estimates for mortality from univariate Cox regression analyses were reported as hazard ratio (HR) and 95% confidence interval (CI). The mortality at 6 months was studied in a logistic regression analysis (no censoring

within 6 months). A level of $P<0.05$ was considered to indicate statistical significance. Statistical analyses were done by STATA 12.1 statistical package (Stata Corporation, College Station, TX).

Results

Clinical Characteristics and Procedural Data

The baseline clinical characteristics and procedural data of the patient population are presented in Tables 1 and 2. A total of 193 patients (age 62.4±14.7 years, 170 [88%] males) were included in the analysis; 108 (56%) patients had ischemic cardiomyopathy. The mean left ventricular ejection fraction was 35±15%, with 38 (20%) patients presenting with severe heart failure symptoms (New York Heart Association—NYHA functional class III/IV). Right ventricular dysfunction evaluated at preprocedural transthoracic echocardiogram was present in 73 (38%) patients and was judged moderate/severe in 37 (19%) cases. The majority of patients (178/193 [92%]) had an implantable cardioverter defibrillator before the ablation procedure and experienced recurrent VT, despite treatment with 1.7±0.9 antiarrhythmic drugs. A total of 90 (47%) patients presented with VT storm, defined as ≥3 separate sustained episodes of VT in the 24 hour before ablation.[13] Other medications included a β-blocker in 169 (88%) patients, an inhibitor of the renin–angiotensin system in 138 (72%), a diuretic in 106 (55%), and spironolactone in 50 (26%) patients. During the ablation procedure, a median of 2 VTs per patient (interquartile range 1–4 per patient) were induced; specifically, clinical VT was induced in 163 (84%) patients. At the end of the procedure, VT noninducibility at programmed electric stimulation was achieved in 116/165 (70%) patients.

Table 1. Baseline Clinical Data of the Overall Study Population and According to the Occurrence of Periprocedural Acute Hemodynamic Decompensation (AHD)

Variable	Overall (N=193)	AHD (N=22)	No AHD (N=171)	*P* Value*
Clinical data				
Age, y	62.4±14.7	68.5±10.7	61.6±15.0	0.037
Male sex, n (%)	170 (88)	21 (95)	149 (87)	0.257
Diabetes mellitus, n (%)	39 (20)	8 (36)	31 (18)	0.045
COPD†, n (%)	31 (16)	9 (41)	22 (13)	0.001
OSAS, n (%)	13 (7)	1 (5)	12 (7)	0.663
PAD, n (%)	12 (6)	1 (5)	11 (6)	0.730
Creatinine ≥1.5 mg/dL	45 (23)	6 (27)	39 (23)	0.641
BUN, mmol/L	22±13	25±11	21±13	0.197
Systolic blood pressure, mm Hg	124±15	122±16	124±15	0.377
Ischemic cardiomyopathy, n (%)	108 (56)	19 (86)	89 (52)	0.002
NYHA class III/IV, n (%)	38 (20)	12 (55)	26 (15)	<0.001
VT storm, n (%)	90 (47)	17 (77)	73 (43)	0.002
Echocardiographic data				
LVEF, %	35±15	26±10	36±16	0.003
LVEF <25%, n (%)	53 (27)	12 (55)	41 (24)	0.002
LVEDD, mm	59±11	61±9	58±11	0.288
RV dysfunction (moderate/severe), n (%)	37 (19)	6 (27)	31 (18)	0.305
Therapy				
Beta-blockers, n (%)	169 (88)	21 (95)	148 (87)	0.233
ACE-I/ARB, n (%)	138 (72)	18 (82)	120 (70)	0.255
Diuretics, n (%)	106 (55)	16 (73)	90 (53)	0.075
Spironolactone, n (%)	50 (26)	5 (23)	45 (27)	0.707
Failed antiarrhythmics, n	1.7±0.9	1.9±0.8	1.7±0.9	0.469
ICD, n (%)	105 (54)	13 (59)	92 (54)	0.639
CRT-D, n (%)	70 (36)	9 (41)	61 (36)	0.631

ACE-I/ARB indicates angiotensin-converting enzyme inhibitor/angiotensin II receptor blocker; BUN, blood urea nitrogen; COPD, chronic obstructive pulmonary disease; CRT-D, cardiac resynchronization therapy with ICD; ICD, implantable cardioverter defibrillator; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; OSAS, obstructive sleep apnea syndrome; PAD, peripheral artery disease; RV, right ventricle; and VT, ventricular tachycardia.

*Comparison between AHD and no AHD group. Values are reported as mean±SD or number (%).

†Includes a primary or secondary diagnosis of COPD (ICD-9 codes 490–492, 494, 496) associated with an inpatient or outpatient encounter.

Table 2. Procedural Data of the Overall Study Population and According to the Occurrence of Periprocedural Acute Hemodynamic Decompensation (AHD)

Variable	Overall (N=193)	AHD (N=22)	No AHD (N=171)	*P* Value*
General anesthesia, n (%)	62 (32)	13 (59)	49 (29)	0.004
No. of VT induced	2 (1–4)	2 (1–4)	2 (1–4)	0.862
Clinical VT induced, n (%)	163 (84)	22 (100)	141 (82)	0.033
VT cycle length, ms†	370 (300–440)	390 (330–450)	360 (300–430)	0.017
Endo-epicardial approach, n (%)	44 (23)	2 (9)	42 (25)	0.104
External DC shocks, n	1 (0–2)	1 (0–2)	0 (0–2)	0.063
Radiofrequency time, min	62 (36–62)	67 (49–67)	62 (34–62)	0.414
Procedural time, hours	8 (6–8)	8 (7–8)	8 (6–8)	0.717

Values are reported as mean (range), median (IQR) or number (%). DC indicates direct current; IQR, interquartile range; and VT, ventricular tachycardia.

*Comparison between AHD and no AHD group.

†Includes all the induced VTs.

Incidence and Predictors of Periprocedural AHD

Periprocedural AHD occurred in 22 (11%) patients during 24 ablation procedures (Tables 1 and 2). In the majority of patients (63%), AHD did not occur during sustained VT activation mapping and was observed during substrate ablation. A mechanical hemodynamic support device was placed in 9/22 (41%) patients, and the procedure was discontinued prematurely in 17/22 (77%) cases. Data from periprocedural invasive hemodynamic monitoring with a pulmonary artery catheter were available in 8/22 (36%) cases; the filling pressures did not uniformly increase before the AHD event, with a median pulmonary capillary wedge pressure of 26 mm Hg (interquartile range 17–33 mm Hg). A definite increase in

Table 3. Predictors of Periprocedural Acute Hemodynamic Decompensation (AHD) at Univariate Logistic Regression Analysis

Variable	OR	95% CI	*P* Value
Clinical data			
Age >60 y	3.24	1.07–9.82	0.037
Male sex	3.71	0.48–28.50	0.208
Diabetes mellitus	2.81	1.15–6.90	0.024
COPD*	5.46	2.24–13.33	<0.001
OSAS	0.51	0.07–4.00	0.521
PAD	0.58	0.07–4.62	0.609
Creatinine ≥1.5 mg/dL	0.98	0.37–2.58	0.961
BUN, mmol/L	1.01	0.97–1.05	0.705
Systolic blood pressure, mm Hg	0.99	0.96–1.03	0.737
Ischemic cardiomyopathy	6.26	1.81–21.62	0.004
NYHA class III/IV	6.11	2.53–14.75	<0.001
VT storm	5.12	1.84–14.22	0.002
Echocardiographic data			
LVEF <25%	3.00	1.27–7.07	0.012
LVEDD, mm	1.02	0.98–1.07	0.311
RV dysfunction (moderate/severe)	1.34	0.50–3.58	0.558
Therapy			
Beta-blockers	2.87	0.37–22.26	0.312
ACE-I/ARB	2.10	0.69–6.40	0.190
Diuretics	2.05	0.82–5.16	0.125
Spironolactone	0.68	0.24–1.91	0.470
CRT-D	1.12	0.48–2.64	0.791
Procedural data			
General anesthesia	3.56	1.50–8.44	0.004
No. of VT induced	0.99	0.79–1.25	0.929
VT cycle length, ms†	1.00	0.99–1.01	0.228
Radiofrequency time, min	1.00	0.99–1.02	0.735
Procedural time, hours	0.97	0.78–1.22	0.803

ACE-I/ARB indicates angiotensin-converting enzyme inhibitor/angiotensin II receptor blocker; BUN, blood urea nitrogen; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CRT-D, cardiac resynchronization therapy with ICD; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; OR, odds ratio; OSAS, obstructive sleep apnea syndrome; PAD, peripheral artery disease; RV, right ventricle; and VT, ventricular tachycardia.

*Includes a primary or secondary diagnosis of COPD (ICD-9 codes 490–492, 494, 496) associated with an inpatient or outpatient encounter.

†Includes all the induced VTs.

pulmonary capillary wedge pressure preceding AHD was recorded in only 1 patient. Compared with the rest of the population, patients who experienced periprocedural AHD were older (68.5±10.7 versus 61.6±15.0 years; *P*=0.037); had a higher prevalence of diabetes mellitus (36% versus 18%; *P*=0.045), ischemic cardiomyopathy (86% versus 52%; *P*=0.002), and chronic obstructive pulmonary disease (COPD: 41% versus 13%; *P*=0.001); had more severe heart failure symptoms (NYHA class III/IV: 55% versus 15%; *P*<0.001); presented more often with VT storm (77% versus 43%; *P*=0.002), and had lower left ventricular ejection fraction (26±10% versus 36±16%; *P*=0.003). Of note, there was no significant difference in the overall prevalence of significant RV dysfunction between AHD patients and the rest of the population (27% versus 18%; *P*=0.305; Table 1); RV dysfunction (moderate to severe) was also not significantly associated with increased AHD risk at univariate logistic regression analysis (Table 3).

Among procedural data, only use of general anesthesia was significantly associated with AHD (59% versus 29%; *P*=0.004). In addition, patients who had AHD had a trend toward higher number of external DC shocks during the procedure (median 1 [0–2] versus 0 [0–2]; *P*=0.063). No other clinical or procedural data showed a significant association with AHD.

Effect of AHD on Mortality

After a mean follow-up of 21±7 months, 30 (16%) patients died. The mortality rate over follow-up was significantly higher in the AHD group compared with the rest of the population (50% versus 11%; log-rank *P*<0.001; Figure 1). Patients with AHD had higher rates of 30-days (8% versus 3%; *P*=0.150), 6-month (29% versus 6%; *P*<0.001), and 1-year mortality (38% versus 7%; *P*<0.001; Figure 1). Univariate predictors of mortality included older age (HR=1.07 per 1 year increase; 95% CI, 1.04–1.11; *P*<0.001), COPD (HR=2.67; 95% CI, 1.22–5.84; *P*=0.014), serum creatinine ≥1.5 mg/dL (HR=2.97; 95% CI, 1.44–6.11; *P*=0.003), NYHA class III/IV (HR=3.40; 95% CI, 1.65–7.00; *P*=0.001), left ventricular ejection fraction <25% (HR=4.69; 95% CI, 2.26–9.75; *P*<0.006), moderate to severe RV dysfunction (HR=2.35; 95% CI, 1.10–5.03; *P*=0.027), VT storm (HR=2.46; 95% CI, 1.15–5.25; *P*=0.010), and periprocedural AHD (HR=5.54; 95% CI, 2.63–11.67; *P*<0.001).

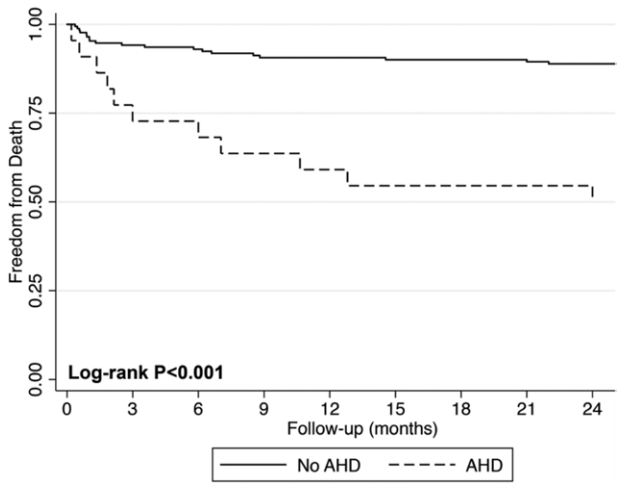

Figure 1. Kaplan–Meier survival curve showing freedom from death in patients experiencing periprocedural acute hemodynamic decompensation (AHD) compared with the rest of the population.

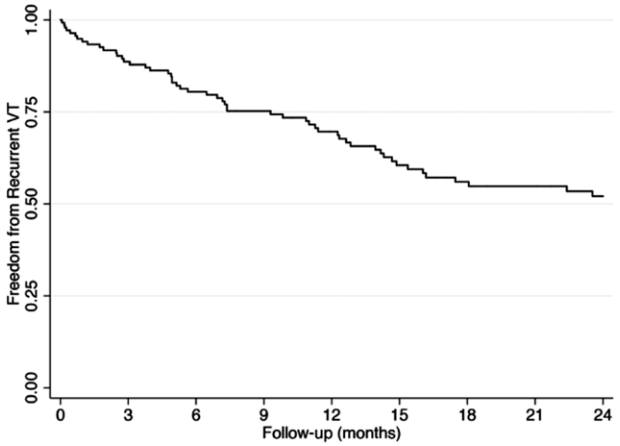

Figure 2. Kaplan–Meier survival curve showing freedom from any sustained ventricular tachycardia (VT) recurrence.

Arrhythmia-Free Survival

Complete follow-up data with printouts of ECG and implantable cardioverter defibrillator interrogations were available in 142/193 (74%) patients. After a mean follow-up of 12.5±8.9 months (median 12.1 months, interquartile range 4.3–24 months), cumulative VT-free survival was 63% (Figure 2). In particular, VT recurred over follow-up in 33% of patients who subsequently died versus 38% of patients who remained alive throughout the study follow-up (P=0.657 for comparison). At Cox regression analysis, VT recurrence was also not associated with increased risk of death (HR=0.81; 95% CI, 0.35–1.90; P=0.632; Table 4).

Discussion

To the best of our knowledge, this is the first study to assess the incidence, predictors, and clinical significance of periprocedural AHD in patients undergoing RFCA of scar-related VT. Periprocedural AHD occurred in 11% of patients and could be predicted by 8 clinical factors: COPD, advanced age, ischemic cardiomyopathy, worse heart failure status (NYHA class III or IV and lower EF), clinical presentation with VT storm, use of general anesthesia, and diabetes mellitus. Periprocedural AHD was also found to be a strong predictor of mortality over follow-up.

Significant Findings and Clinical Implications

Over the last decade, significant improvements in the techniques and technologies available for RFCA have been paralleled by an increasing number of procedures performed in high-risk and complex patient subsets.[1–3] Patients with scar-related VT represent a unique challenge, owing to the complexity of the underlying substrates, the presence of concomitant heart failure worsened by recurrent episodes of VT, and the high prevalence of associated comorbidities. In these patients, the occurrence of periprocedural AHD is a major concern because it typically leads to emergent need for advanced cardiac support or unplanned procedure discontinuation.

No previous study has investigated the incidence of periprocedural AHD and the clinical profile of patients experiencing this complication. The latter would have important clinical implications with respect to patient selection and preprocedural planning because it would prompt a more aggressive treatment of the underlying heart failure status, including consideration for prophylactic mechanical cardiac support devices. In our study, the occurrence of periprocedural AHD could be predicted by clinical variables that indicate a worse heart failure status (poor left ventricular function and severe heart failure symptoms), ischemic cardiomyopathy, a more critical clinical presentation (VT storm), associated comorbidities (COPD and diabetes mellitus), and use of general anesthesia. Such variables might be combined into a score that warrants future

Table 4. Univariate Analysis of Clinical and Procedural Variables Affecting All-Cause Mortality During Follow-Up

	Univariate Analysis		
	HR	95% CI	*P* Value
Clinical data			
Age, y	1.07	1.04–1.11	<0.001
Male sex	0.86	0.30–2.46	0.779
Diabetes mellitus	1.20	0.52–2.80	0.672
COPD*	2.67	1.22–5.84	0.014
PAD	1.82	0.55–6.01	0.324
Creatinine ≥1.5 mg/dL	2.97	1.44–6.11	0.003
Systolic blood pressure, mm Hg	0.97	0.94–1.01	0.101
Ischemic cardiomyopathy	1.64	0.77–3.51	0.199
NYHA class III/IV	3.40	1.65–7.00	0.001
VT storm	2.46	1.15–5.25	0.020
Echocardiographic data			
LVEF <25%	4.69	2.26–9.75	<0.001
LVEDD, mm	1.03	0.99–1.07	0.072
RV dysfunction (moderate/severe)	2.35	1.10–5.03	0.027
Therapy			
Beta-blockers	0.91	0.32–2.59	0.854
ACE-I/ARB	0.95	0.43–2.07	0.892
Diuretics	2.11	0.96–4.60	0.062
Spironolactone	0.78	0.35–1.69	0.522
CRT-D	1.67	0.81–3.41	0.163
Noninducibility at PES	0.75	0.30–1.89	0.549
Periprocedural AHD	5.54	2.63–11.67	<0.001
General anesthesia	1.40	0.67–2.91	0.367
Recurrent VT	0.81	0.35–1.90	0.632

ACE-I/ARB indicates angiotensin-converting enzyme inhibitor/angiotensin II receptor blocker; BUN, blood urea nitrogen; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CRT-D, cardiac resynchronization therapy with ICD; HR, hazard ratio; LVEF, left ventricular ejection fraction; LVEDD, left ventricular end-diastolic diameter; NYHA, New York Heart Association; PAD, peripheral artery disease; PES, programmed electric stimulation; RV, right ventricle; and VT, ventricular tachycardia.

*Includes a primary or secondary diagnosis of COPD (ICD-9 codes 490–492, 494, 496) associated with an inpatient or outpatient encounter.

testing in independent and larger cohorts of patients (see Data Supplement). If confirmed in independent and larger patient cohorts, a combination of the clinical variables above might help to select patients who might benefit the most from substrate-based ablation approaches to minimize the risk of hemodynamic impairment caused by multiple VT inductions for activation and entrainment mapping[4,14] or to identify upfront patients requiring prophylactic mechanical hemodynamic support; in this regard, a careful and refined patient selection is of utmost importance to optimize the implementation and cost-effectiveness of these new technologies.[15,16]

The adverse effect of comorbidities, such as COPD and diabetes mellitus, in the setting of scar-related VT ablation is a novel finding and is consistent with what has been reported for other invasive cardiac procedures.[17–19] Among procedural variables, use of general anesthesia was found to be another predictor of AHD. In this regard, the induction and recovery phase of general anesthesia represent significant hemodynamic stressors, with occurrence of hypotension and significant changes in autonomic tone that can predispose to cardiac ischemia, systemic hypoperfusion, and AHD.[20,21] On the other hand, other unmeasured confounders may play a role in the association between use of general anesthesia and periprocedural AHD found in our study. As mentioned, conscious sedation was the preferred anesthesia protocol, with general anesthesia used at the discretion of the operator or anesthesiologist. This might introduce an element of bias because we could not fully evaluate the individual reasons underlying the choice of general anesthesia in our patient population. However, it is important to emphasize that a direct comparison of baseline clinical characteristics of patients who underwent RFCA under general anesthesia and those who received conscious sedation did not show significant baseline imbalances between the 2 groups (Table 5). In fact, patients who received general anesthesia appeared at lower risk compared with those who received conscious sedation, being significantly younger, less likely to have ischemic cardiomyopathy, and with smaller LV end-diastolic diameters (Table 5).

Table 5. Comparison of Clinical Characteristics Between Patients Who Underwent Ablation Under General Anesthesia and Those Who Received Conscious Sedation

Variable	General Anesthesia (N=62)	Conscious Sedation (N=131)	*P* Value*
Clinical data			
Age, y	58±16	65±14	0.003
Male sex, n (%)	52 (84)	118 (90)	0.214
Diabetes mellitus, n (%)	16 (26)	23 (18)	0.183
COPD*, n (%)	10 (16)	21 (16)	0.986
OSAS, n (%)	3 (5)	10 (8)	0.469
PAD, n (%)	3 (5)	9 (7)	0.585
Creatinine ≥ 1.5 mg/dL	14 (23)	31 (24)	0.868
BUN, mmol/L	21±12	22±13	0.827
Systolic blood pressure, mm Hg	125±14	123±15	0.531
Ischemic cardiomyopathy, n (%)	25 (40)	83 (63)	0.003
NYHA class III/IV, n (%)	17 (27)	21 (16)	0.063
VT storm, n (%)	26 (42)	64 (49)	0.368
Echocardiographic data			
LVEF, %	37±16	34±15	0.240
LVEF <25%, n (%)	14 (23)	39 (30)	0.296
LVEDD, mm	56±11	60±10	0.043
RV dysfunction (moderate/severe), n (%)	15 (24)	22 (17)	0.223
Therapy			
Beta-blockers, n (%)	55 (89)	114 (87)	0.740
ACE-I/ARB, n (%)	40 (64)	98 (75)	0.139
Diuretics, n (%)	30 (48)	76 (58)	0.209
Spironolactone, n (%)	18 (29)	32 (24)	0.495
Failed antiarrhythmics, n	1.9±0.8	1.6±0.9	0.092
ICD, n (%)	39 (63)	66 (50)	0.103
CRT-D, n (%)	17 (27)	53 (40)	0.079

Values are reported as mean±SD or number (%). ACE-I/ARB indicates angiotensin-converting enzyme inhibitor/angiotensin II receptor blocker; BUN, blood urea nitrogen; COPD, chronic obstructive pulmonary disease; CRT-D, cardiac resynchronization therapy with ICD; ICD, implantable cardioverter defibrillator; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; OSAS, obstructive sleep apnea syndrome; PAD, peripheral artery disease; RV, right ventricle; and VT, ventricular tachycardia.

*Includes a primary or secondary diagnosis of COPD (ICD-9 codes 490–492, 494, 496) associated with an inpatient or outpatient encounter.

Effect of Periprocedural AHD on Mortality

The mortality rate over long-term follow-up in the present study appeared substantially lower than that reported in an earlier study by our group, including patients from a decade ago.[22] Indeed, the overall 2-year mortality rate was 16%, which is comparable with that reported in major heart failure trials, in which patients with recurrent VT have generally been excluded.[23] This finding is encouraging, and it might reflect improved outcomes with RFCA procedures, which is in line with recent observational data.[24] Periprocedural AHD was also found to predict mortality over follow-up. This did not seem to be related to less aggressive treatment of VT in these patients because the radiofrequency time in the AHD group was not significantly different from that in the rest of the population. In addition, there appeared not to be a relation between procedural outcomes, recurring arrhythmia, and survival in our patient cohort. If the results of our study will be confirmed in a prospective cohort, it would be important to design randomized trial with prophylactic hemodynamic support systems in patients at higher risk of AHD to assess whether AHD can be prevented and subsequent mortality reduced.

Limitations

The main limitation of this study was inherent to its observational nature. The number of AHD and mortality events was relatively small, which limits a precise assessment of independent predictors.[25] Conscious sedation was the preferred anesthesia protocol, and general anesthesia was used in select cases. It could be argued that use of general anesthesia might have been reserved to patients judged at higher risk by the operator or anesthesiologist involved in the procedure, although a direct comparison of baseline clinical characteristics between patients who received general anesthesia and

those who received only conscious sedation actually suggested a lower risk in the general anesthesia group. Our institution is a tertiary referral center for catheter ablation of VT; as such, the study cohort is affected by an unavoidable degree of referral bias, and the results might not be generalized to other institutions. Clinical information about further comorbidities, more complete echocardiographic data, recent hemodynamic assessment, and specific characteristics of the electrophysiological substrate and other procedural details, such as number of VT inductions or time spent during activation/entrainment mapping versus substrate mapping and ablation in sinus rhythm, could have improved the risk stratification of patients for periprocedural AHD. In this regard, it is important to emphasize that none of the patients included in this study underwent a pure substrate-based ablation approach, and VT induction was attempted at least once in every patient. Therefore, our results may not be generalized to other institutions adopting different ablation approaches. Similarly, we cannot exclude a role for other unmeasured clinical, laboratory, and procedural variables in predicting survival during follow-up. Nonetheless, periprocedural AHD appeared a strong predictor of mortality over follow-up.

Conclusions

Periprocedural AHD occurs in 11% of patients undergoing RFCA of scar-related VT and is associated with increased risk of mortality over follow-up. Periprocedural AHD could be predicted by 8 clinical factors, namely, advanced age, COPD, use of general anesthesia, ischemic cardiomyopathy, NYHA class III/IV, lower left ventricular ejection fraction, VT storm, and diabetes mellitus.

Sources of Funding

Supported in part by the Susan and Murray Bloom Research Fund.

Disclosures

None.

References

1. Aliot EM, Stevenson WG, Almendral-Garrote JM, Bogun F, Calkins CH, Delacretaz E, Della Bella P, Hindricks G, Jaïs P, Josephson ME, Kautzner J, Kay GN, Kuck KH, Lerman BB, Marchlinski F, Reddy V, Schalij MJ, Schilling R, Soejima K, Wilber D; European Heart Rhythm Association (EHRA); Registered Branch of the European Society of Cardiology (ESC); Heart Rhythm Society (HRS); American College of Cardiology (ACC); American Heart Association (AHA). EHRA/HRS Expert Consensus on Catheter Ablation of Ventricular Arrhythmias: developed in a partnership with the European Heart Rhythm Association (EHRA), a Registered Branch of the European Society of Cardiology (ESC), and the Heart Rhythm Society (HRS); in collaboration with the American College of Cardiology (ACC) and the American Heart Association (AHA). *Heart Rhythm*. 2009;6:886–933. doi: 10.1016/j.hrthm.2009.04.030.
2. Stevenson WG, Wilber DJ, Natale A, Jackman WM, Marchlinski FE, Talbert T, Gonzalez MD, Worley SJ, Daoud EG, Hwang C, Schuger C, Bump TE, Jazayeri M, Tomassoni GF, Kopelman HA, Soejima K, Nakagawa H; Multicenter Thermocool VT Ablation Trial Investigators. Irrigated radiofrequency catheter ablation guided by electroanatomic mapping for recurrent ventricular tachycardia after myocardial infarction: the multicenter thermocool ventricular tachycardia ablation trial. *Circulation*. 2008;118:2773–2782. doi: 10.1161/CIRCULATIONAHA.108.788604.
3. Tung R, Josephson ME, Reddy V, Reynolds MR; SMASH-VT Investigators. Influence of clinical and procedural predictors on ventricular tachycardia ablation outcomes: an analysis from the substrate mapping and ablation in Sinus Rhythm to Halt Ventricular Tachycardia Trial (SMASH-VT). *J Cardiovasc Electrophysiol*. 2010;21:799–803. doi: 10.1111/j.1540-8167.2009.01705.x.
4. Miller MA, Dukkipati SR, Mittnacht AJ, Chinitz JS, Belliveau L, Koruth JS, Gomes JA, d'Avila A, Reddy VY. Activation and entrainment mapping of hemodynamically unstable ventricular tachycardia using a percutaneous left ventricular assist device. *J Am Coll Cardiol*. 2011;58:1363–1371. doi: 10.1016/j.jacc.2011.06.022.
5. Bunch TJ, Mahapatra S, Madhu Reddy Y, Lakkireddy D. The role of percutaneous left ventricular assist devices during ventricular tachycardia ablation. *Europace*. 2012;14 Suppl 2:ii26–ii32.
6. Vallès E, Bazan V, Marchlinski FE. ECG criteria to identify epicardial ventricular tachycardia in nonischemic cardiomyopathy. *Circ Arrhythm Electrophysiol*. 2010;3:63–71. doi: 10.1161/CIRCEP.109.859942.
7. Sosa E, Scanavacca M, d'Avila A, Pilleggi F. A new technique to perform epicardial mapping in the electrophysiology laboratory. *J Cardiovasc Electrophysiol*. 1996;7:531–536.
8. Callans DJ, Ren JF, Michele J, Marchlinski FE, Dillon SM. Electroanatomic left ventricular mapping in the porcine model of healed anterior myocardial infarction. Correlation with intracardiac echocardiography and pathological analysis. *Circulation*. 1999;100:1744–1750.
9. Marchlinski FE, Callans DJ, Gottlieb CD, Zado E. Linear ablation lesions for control of unmappable ventricular tachycardia in patients with ischemic and nonischemic cardiomyopathy. *Circulation*. 2000;101:1288–1296.
10. Cano O, Hutchinson M, Lin D, Garcia F, Zado E, Bala R, Riley M, Cooper J, Dixit S, Gerstenfeld E, Callans D, Marchlinski FE. Electroanatomic substrate and ablation outcome for suspected epicardial ventricular tachycardia in left ventricular nonischemic cardiomyopathy. *J Am Coll Cardiol*. 2009;54:799–808. doi: 10.1016/j.jacc.2009.05.032.
11. Hsia HH, Lin D, Sauer WH, Callans DJ, Marchlinski FE. Relationship of late potentials to the ventricular tachycardia circuit defined by entrainment. *J Interv Card Electrophysiol*. 2009;26:21–29. doi: 10.1007/s10840-009-9421-8.
12. Bogun F, Krishnan SC, Marine JE, Hohnloser SH, Schuger C, Oral H, Pelosi F, Chugh A, Morady F. Catheter ablation guided by termination of postinfarction ventricular tachycardia by pacing with nonglobal capture. *Heart Rhythm*. 2004;1:422–426. doi: 10.1016/j.hrthm.2004.06.009.
13. Credner SC, Klingenheben T, Mauss O, Sticherling C, Hohnloser SH. Electrical storm in patients with transvenous implantable cardioverter-defibrillators: incidence, management and prognostic implications. *J Am Coll Cardiol*. 1998;32:1909–1915.
14. Santangeli P, Di Biase L, Burkhardt DJ, Bai R, Mohanty P, Carbucicchio C, Dello Russo A, Casella M, Mohanty S, Pump A, Hongo R, Beheiry S, Yan R, Pelargonio G, Santarelli P, Zucchetti M, Horton R, Sanchez JE, Lakkireddy D, Elayi CS, Tondo C, Natale A. Endo-epicardial homogeneization of the scar abolishes the periprocedural need for mechanical cardiac support and improves long-term outcomes of hemodynamically unstable ventricular tachycardia ablation. *Heart Rhythm*. 2012;9:S354–S355.
15. Miller MA, Reddy VY. Percutaneous hemodynamic support during scar-ventricular tachycardia ablation: is the juice worth the squeeze? *Circ Arrhythm Electrophysiol*. 2014;7:192–194. doi: 10.1161/CIRCEP.114.001590.
16. Reddy YM, Chinitz L, Mansour M, Bunch TJ, Mahapatra S, Swarup V, Di Biase L, Bommana S, Atkins D, Tung R, Shivkumar K, Burkhardt JD, Ruskin J, Natale A, Lakkireddy D. Percutaneous left ventricular assist devices in ventricular tachycardia ablation: multicenter experience. *Circ Arrhythm Electrophysiol*. 2014;7:244–250. doi: 10.1161/CIRCEP.113.000548.
17. Adabag AS, Wassif HS, Rice K, Mithani S, Johnson D, Bonawitz-Conlin J, Ward HB, McFalls EO, Kuskowski MA, Kelly RF. Preoperative pulmonary function and mortality after cardiac surgery. *Am Heart J*. 2010;159:691–697. doi: 10.1016/j.ahj.2009.12.039.
18. Konecny T, Somers K, Orban M, Koshino Y, Lennon RJ, Scanlon PD, Rihal CS. Interactions between COPD and outcomes after percutaneous coronary intervention. *Chest*. 2010;138:621–627. doi: 10.1378/chest.10-0300.
19. Banning AP, Westaby S, Morice MC, Kappetein AP, Mohr FW, Berti S, Glauber M, Kellett MA, Kramer RS, Leadley K, Dawkins KD, Serruys PW. Diabetic and nondiabetic patients with left main and/or 3-vessel coronary artery disease: comparison of outcomes with cardiac surgery and paclitaxel-eluting stents. *J Am Coll Cardiol*. 2010;55:1067–1075. doi: 10.1016/j.jacc.2009.09.057.

20. Reich DL, Hossain S, Krol M, Baez B, Patel P, Bernstein A, Bodian CA. Predictors of hypotension after induction of general anesthesia. *Anesth Analg*. 2005;101:622–628, table of contents. doi: 10.1213/01.ANE.0000175214.38450.91.
21. Fukusaki M, Kanaide M, Inadomi C, Takada M, Terao Y, Sumikawa K. The effect of sevoflurane-induced hypotension in combination with acute hypervolaemic haemodilution on middle cerebral artery flow velocity in surgical patients. *Eur J Anaesthesiol*. 2008;25:657–661. doi: 10.1017/S0265021508003955.
22. Sauer WH, Zado E, Gerstenfeld EP, Marchlinski FE, Callans DJ. Incidence and predictors of mortality following ablation of ventricular tachycardia in patients with an implantable cardioverter-defibrillator. *Heart Rhythm*. 2010;7:9–14. doi: 10.1016/j.hrthm.2009.09.014.
23. Pfeffer MA, Swedberg K, Granger CB, Held P, McMurray JJ, Michelson EL, Olofsson B, Ostergren J, Yusuf S, Pocock S; CHARM Investigators and Committees. Effects of candesartan on mortality and morbidity in patients with chronic heart failure: the CHARM-Overall programme. *Lancet*. 2003;362:759–766.
24. Bunch TJ, Weiss JP, Crandall BG, Day JD, May HT, Bair TL, Osborn JS, Mallender C, Fischer A, Brunner KJ, Mahapatra S. Patients treated with catheter ablation for ventricular tachycardia after an ICD shock have lower long-term rates of death and heart failure hospitalization than do patients treated with medical management only. *Heart Rhythm*. 2014;11:533–540. doi: 10.1016/j.hrthm.2013.12.014.
25. King G, Zeng L. Logistic regression in rare events data. *Political Anal*. 2001;9:137–163.