Successful ventricular tachycardia ablation in patients with electrical storm reduces recurrences and improves survival

Pasquale Vergara, MD, PhD,* Roderick Tung, MD,† Marmar Vaseghi, MD, PhD, FHRS,‡ Chiara Brombin, PhD,§ David Frankel, MD,‖ Luigi Di Biase, MD, PhD,¶ Koichi Nagashima, MD,# Usha Tedrow, MD, MS,# Wendy S. Tzou, MD,** William H. Sauer, MD,** Nilesh Mathuria, MD,†† Shiro Nakahara, MD, PhD,‡‡ Kairav Vakil, MD,§§ Venkat Tholakanahalli, MD,§§ T. Jared Bunch, MD,‖‖ J. Peter Weiss, MD,‖‖ Timm Dickfeld, MD,¶¶ Rama Vunnam, MD,¶¶ Dhanunjaya Lakireddy, MD,## J. David Burkhardt, MD,*** Anna Correra, MD,* Pasquale Santangeli, MD,‖ David Callans, MD,‖ Andrea Natale, MD,*** Francis Marchlinski, MD,‖ William G. Stevenson, MD,# Kalyanam Shivkumar, MD, PhD,‡ Paolo Della Bella, MD*

*From the *San Raffaele Hospital, Milan, Italy, †University of Chicago Medical Center, Chicago, Illinois, ‡UCLA Cardiac Arrhythmia Center, UCLA Health System, Los Angeles, California, §University Centre for Statistics in the Biomedical Sciences, Vita-Salute San Raffaele University, Milan, Italy, ‖Perelman School of Medicine at the University of Pennsylvania, Philadelphia, Pennsylvania, ¶Albert Einstein College of Medicine/Montefiore Medical Center, New York, New York, #Brigham and Women's Hospital, Boston, Massachusetts, **University of Colorado, Aurora, Colorado, ††Baylor St. Luke's Medical Center/Texas Heart Institute, Houston, Texas, ‡‡Dokkyo Medical University Koshigaya Hospital, Saitama, Japan, §§University of Minnesota Medical Center, Minneapolis VA Medical Center, Minneapolis, Minnesota, ‖‖Intermountain Heart Institute, Intermountain Medical Center, Murray, Utah, ¶¶University of Maryland Medical Center, Baltimore, Maryland, ##University of Kansas Medical Center, Kansas City, Kansas, and ***Texas Cardiac Arrhythmia Institute, St. David's Medical Center, Austin, Texas.*

OBJECTIVE The purpose of this study was to evaluate the characteristics and outcome of patients undergoing ablation after electrical storm (ES).

METHODS Clinical and procedural characteristics, ventricular tachycardia (VT) recurrence, and mortality rates from 1940 patients undergoing VT ablation were compared between patients with and without ES.

RESULTS The group of 677 patients with ES (34.9%) were older, were more frequently men, and had a lower ejection fraction, more advanced heart failure, and a higher prevalence of cardiovascular comorbidities as compared with those without ES (86.1% patients with ES had ≥2 comorbidities vs 71.4%; $P < .001$). Patients with ES had more inducible VTs (2.5 ± 1.8 vs 1.9 ± 1.9; $P < .001$), required longer procedures (296.1 ± 119.1 minutes vs 265.7 ± 110.3 minutes; $P < .001$), and had a higher in-hospital mortality (42 deaths [6.2%] vs 18 deaths [1.4%]; $P < .001$). At 1-year follow-up, patients with ES experienced a higher risk of VT recurrence and mortality (32.1% vs 22.6% and 20.1% vs 8.5%; long-rank, $P < .001$ for both). Among patients with ES, those without any inducible VT after ablation had a higher survival rate (86.3%) than did those with nonclinical VTs only (72.9%), those with clinical VTs inducible at programmed electrical stimulation (51.2%), and not-tested patients (65.0%) (long-rank, $P < .001$ for all). In multivariate analysis, ES remained an independent predictor of in-hospital mortality, VT recurrence, and 1-year mortality ($P < .001$).

CONCLUSION Patients with ES have a high risk of VT recurrence and mortality. Patient and procedure characteristics are consistent

Dr Di Biase is a consultant to Biosense Webster, St. Jude Medical, and Stereotaxis. Dr Nagashima is the recipient of a Medtronic Japan Fellowship. Dr Tedrow has received honoraria from Medtronic, Boston Scientific, and St. Jude Medical and research grants from Biosense Webster and St. Jude Medical. Dr Bunch is a consultant to Boston Scientific. Dr Burkhardt is a consultant to Biosense Webster. Dr Stevenson is the recipient of a patent for needle ablation consigned to Brigham and Women's Hospital. Dr Shivkumar was supported by the National Heart, Lung, and Blood Institute (grant no. R01HL084261). Dr Della Bella is a consultant to St. Jude Medical and has received honoraria for lectures from Biosense Webster, St. Jude Medical, and Biotronik. **Address reprint requests and correspondence:** Dr Pasquale Vergara, Arrhythmia Unit and Electrophysiology Laboratory, Ospedale S. Raffaele, Milan 20132, Italy. E-mail address: pasqualevergara@hotmail.com.

http://dx.doi.org/10.1016/j.hrthm.2017.08.022

with advanced cardiac disease and longer and more complex procedures. In patients with ES, acute procedural success is associated with a significant reduction in VT recurrence and improved 1-year survival.

KEYWORDS Ventricular tachycardia; Catheter ablation; Electrical storm; Ischemic cardiomyopathy; Nonischemic cardiomyopathy

(Heart Rhythm 2018;15:48–55)

Introduction

The use of implantable cardioverter-defibrillators (ICDs) and improvements in pharmacological therapies have improved survival in patients with impaired systolic function. ICD therapies can successfully terminate acute ventricular arrhythmias, but do not modify the arrhythmic substrate nor prevent subsequent ventricular tachycardia (VT) episodes. Electrical storm (ES) is a life-threatening arrhythmic emergency characterized by ≥3 VT or ventricular fibrillation (VF) episodes treated by the ICD within 24 hours.[1–3] Catheter ablation has been shown to reduce VT burden and appropriate ICD therapies in patients with structural heart disease.

The aims of this study were to characterize the population of patients who required catheter ablation for the treatment of ES and to evaluate the impact of acute procedural success on VT recurrence and survival of those patients from the largest available up-to-date multicenter database.

Methods

Study design

The International VT Ablation Center Collaborative Group (IVTCC) consists of 12 international sites that specialized in VT management with a developed protocol for data sharing.[4] For 1940 patients, physicians reported whether they had already experienced ES; those patients were included in the present analysis. *ES* was defined as ≥3 VT/VF episodes within 24 hours. The study was approved by the institutional review boards of the respective participating centers.

Ablation procedure

Ablation procedure methodology of the IVTCC has already been described.[4] Ablation was performed targeting VTs induced by programmed electrical stimulation (PES) and modifying the electrical substrate.[5,6] After ablation, PES was repeated unless hemodynamic instability or prohibitive procedural duration.

Clinical follow-up

Patients were followed up by ICD interrogation at 3, 6, and 12 months. For patients not followed up at an IVTCC center, referring cardiologists were contacted and ICD interrogations reviewed. Remote control follow-ups were carefully checked for VT recurrence. Telephone interviews were also routinely performed with patients or family members. *Recurrent VT/VF* was defined as documented VT/VF lasting >30 seconds or any appropriate ICD therapy including antitachycardia pacing. Study end points were VT recurrence after the last ablation procedure, death, and heart transplant. Antiarrhythmic therapy after ablation was at the discretion of the treating physician.

Statistical analysis

Continuous variables are expressed as mean ± SD; the independent samples *t* test and Mann-Whitney *U* test was used to compare normally and nonnormally distributed continuous variables, respectively. Categorical variables are summarized as frequency and percentage and compared using the Pearson χ^2 exact test.

Univariate analysis was performed to evaluate the association of clinical and procedural variables in terms of VT recurrence and mortality. Kaplan-Meier survival curves were used to estimate freedom from recurrent VT, transplant, and death. The log-rank test was used to compare VT-free survival times of patients with and without ES, also stratified by the result of PES after ablation (no inducible VT [no-VT], only nonclinical VT [nc-VT], at least 1 VT inducible, clinical VT still inducible [c-VT], and PES not repeated [no-PES]); the same analysis was repeated within the group with ES.

Cox regression analysis was performed to identify risk/protective factors for VT recurrence or death on the entire sample and also by considering patients with ES separately (see Supplemental Methods). Analyses were performed using R statistical software (R Development Core Team, 2016); the significance level was set at .05.

Results

A total of 1940 patients with structural heart disease who underwent VT ablation in 12 centers from the IVTCC were included in the present analysis; of those, 677 patients (34.9%) had an ES episode before the index ablation procedure. Patients with ES were older (64.4 ± 12.5 years vs 61.3 ± 13.6 years; $P < .001$), were more frequently men, and had a lower left ventricular ejection fraction (LVEF) and New York Heart Association (NYHA) class II or greater as compared with patients without ES. Patients with ES were also more frequently affected by cardiovascular comorbidities such as hypertension, hyperlipidemia, atrial fibrillation, diabetes, and chronic kidney disease and more frequently had an already implanted cardiac resynchronization therapy device; they more frequently had prior ablation, with a higher number of procedures than did patients with VT who presented without ES. The arrhythmia more frequently manifested with syncope in patients with ES. Patients undergoing VT ablation after ES were more likely to have been previously treated with antiarrhythmic drugs, in particular with class 1A and class 1B antiarrhythmic drugs, β-blockers, and amiodarone; they were also more frequently treated by a combination of ≥2 drugs. Detailed baseline patient characteristics are summarized in Table 1.

Ventricular ablation procedure

The group of 677 patients treated after ES had more VTs inducible by PES (2.5 ± 1.8 vs 1.9 ± 1.9; $P < .001$), requiring the delivery of more radiofrequency ablation (46.0 ± 32.4 minutes vs 35.2 ± 28.0 minutes; $P < .001$) and longer procedures (296.1 ± 119.1 minutes vs 265.7 ± 110.3 minutes; $P < .001$) than did patients without ES (Table 2). Patients with ES required mechanical hemodynamic support more frequently than did the others (61 patients [9.0%] vs 58 patients [4.6%]; $P = .001$). No significant differences in the rate of epicardial and combined endo-epicardial mapping were shown between the 2 groups of patients; at least 1 not mappable VT was induced in 296 patients with prior ES (56.8%) and in 466 patients without prior ES (55.5%) ($P = .63$).

PES was not repeated in more patients with ES (40 [6.5%] vs 38 [3.2%]; $P = .001$). Information about the result of PES after ablation was available for 1712 patients. Among patients in whom the acute outcome of the procedure was tested by PES, 395 patients with ES (63.9%) and 834 without ES (71.2%) ($P = .0017$) had no-VT; only nc-VT was more frequently inducible in patients with ES (140 [22.7%] vs 214 [18.3%]; $P = .026$); c-VT was observed in 43 patients with ES (7.0%) and in 86 patients without ES (7.3%) ($P = .91$).

While the number of procedure-related complications was similar for patients with and without prior ES, patients with ES had a higher in-hospital mortality (35 deaths [5.2%] vs 17 deaths [1.3%]; $P < .001$). Among patients with ES, 9 (25.7%) died of recurrent VT after ablation, 13 (37.1%) had a cardiac death not related to VTs (heart failure in 12 patients [34.3%] and myocardial infarction in 1 patient [2.8%]), and 6 patients (17.15%) died of noncardiac causes; in 7 patients the cause of death was not reported; in-hospital death occurred in 8 patients with c-VT (20.5%) as compared with 21 (5.0%) of no-VT patients with ES ($P < .001$).

In Cox proportional hazard modeling, after adjusting for covariates, ES was independently associated with higher acute hospital mortality (hazard ratio [HR] 2.89; 95% confidence interval [CI] 1.44–5.80).

Table 1 Baseline characteristics of patients with and without ES

Characteristic	No storm	ES	*P*
Patients (%)	1263 (65.1)	677 (34.9)	
Age (y)	61.3 ± 13.6	64.4 ± 12.5	<.001
Sex: male	1084 (85.9)	603 (89.1)	.048
Ischemic cardiomyopathy	641 (50.8)	370 (54.7)	.1
LVEF (%)	35.2 ± 13.2	30.4 ± 13.4	<.001
NYHA class			<.001
I	405 (33.0)	144 (21.8)	
II	473 (38.6)	226 (34.2)	
III	313 (25.5)	216 (32.7)	
IV	35 (2.9)	74 (11.2)	
CRT	294 (23.7)	211 (32.2)	<.001
≥1 previous ablation procedures	488 (38.6)	300 (40.6)	.015
No. of previous VT ablation procedures	0.5 ± 0.8	0.6 ± 0.9	.022
Syncope	102 (16.0)	74 (23.6)	.004
Prior heart surgery	358 (29.5)	209 (32.0)	.3
Hypertension	617 (45.4)	353 (40.2)	.038
Hyperlipidemia	634 (55.7)	368 (62.7)	.005
Atrial fibrillation	285 (25.3)	204 (33.2)	.001
Diabetes	227 (18.5)	177 (26.8)	<.001
Chronic kidney disease	328 (26.1)	252 (37.5)	<.001
Creatinine level (mg/dL)	1.2 ± 0.6	1.4 ± 0.9	<.001
Previous drug therapy			
Class 1A AAD	17 (1.4)	26 (4.1)	<.001
Class 1B AAD	166 (14.0)	155 (24.7)	<.001
Class 1C AAD	57 (4.8)	24 (3.8)	.3
β-Blockers	947 (76.2)	563 (84.3)	<.001
Amiodarone	605 (51.0)	404 (64.3)	<.001
Sotalol	161 (13.6)	75 (11.9)	.3
≥2 AADs	183 (15.4)	154 (24.5)	<.001

Values are presented as mean ± SD or as n (%).

AAD = antiarrhythmic drug; CRT = cardiac resynchronization therapy; ES = electrical storm; LVEF = left ventricular ejection fraction; NYHA = New York Heart Association; VT = ventricular tachycardia.

VT recurrences in patients with ES

During the year after ablation, patients with ES experienced a higher risk of VT recurrence than did those without prior ES (32.1% vs 22.6%; long-rank, $P < .001$) (Figure 1). Among patients with no-VT, patients with ES had a worse VT-free survival as compared with those without ES (73.2% vs 80.1%; long-rank, $P = .003$); findings were similar for those with at least 1 VT inducible (61.2% vs 71.0%; long-rank, $P = .028$) or c-VT inducible (27.9% vs 62.8%; long-rank, $P < .001$) (Supplemental Figure 1). Among patients with ES, patients with nc-VT had a VT-free survival not significantly different from that of patients with no-VT (71.4% vs 73.2%; long-rank, $P = .235$); both classes had a better VT-free survival than did those with c-VT (27.9%; long-rank, $P < .001$ and $P < .001$, respectively) and no-PES patients (47.5%; long-rank, $P = .011$ and $P < .001$, respectively) (Figure 2).

In Cox proportional hazard modeling, after adjusting for covariates, ES was independently associated with a greater likelihood of VT recurrences (HR 1.23; 95% CI 0.98–1.535). In patients with ES, Cox proportional hazard modeling identified the result of PES after ablation, nonischemic cardiomyopathy (HR 1.534; 95% CI 1.081–2.178), LVEF (HR 0.977; 95% CI 0.964–0.991), and hypertension (HR 0.723; 95% CI 0.503–1.037) as associated with VT recurrences (Figure 3). The risk of VT recurrence decreased by 2.3% for each unit increase in LVEF. In patients with no-VT and patients with nc-VT, the risk of VT recurrence at 1 year decreased, respectively, by 76.9% (HR 0.231; 95% CI 0.138–0.386) and 74.8% (HR 0.252; 95% CI 0.140–0.453) relative to patients with c-VT.

Mortality after ablation in patients with ES

During the year after ablation, the rate of death in patients with ES was higher than in those without ES (20.1% vs

Table 2 Procedural characteristics

Characteristic	No storm	ES	*P*
Patients (%)	1263 (60.8)	677 (32.8)	
Induced VTs per patient	1.9 ± 1.9	2.5 ± 1.8	<.001
0	175 (13.9)	40 (5.9)	
1	419 (33.2)	188 (27.8)	
2	283 (22.4)	158 (23.3)	
3	153 (12.1)	106 (15.7)	
≥4	150 (32.2)	156 (52.7)	
Total radiofrequency delivery time (min)	35.2 ± 28.0	46.0 ± 32.4	<.001
Total procedure time (min)	265.7 ± 110.3	296.1 ± 119.1	<.001
Hemodynamic support	50 (4.6)	44 (9.0)	.001
Endocardial + epicardial mapping	329 (27.5)	169 (27.1)	.6
Only mappable VTs	374 (44.5)	225 (43.2)	.5
Any mappable VT	508 (60.5)	320 (61.4)	.7
Any unmappable VT	466 (55.5)	296 (56.8)	.6
Acute ablation result			
Absence of any inducible VTs	834 (71.2)	395 (63.9)	.002
Only nonclinical VT still inducible	214 (18.3)	140 (22.7)	.03
Clinical VT still inducible	86 (7.3)	43 (7.0)	.915
PES not repeated after ablation	38 (3.2)	40 (6.5)	.002
Procedural complications	77 (6.5)	45 (7.3)	.5
Death before hospital discharge	18 (1.4)	42 (6.2)	<.001

Values are presented as mean ± SD or as n (%).
ES = electrical storm; NS = not significant; PES = programmed electrical stimulation; VT = ventricular tachycardia.

8.5%; long-rank, $P < .001$) (Figure 4). Patients with ES had a lower survival than did those without ES whenever no VT (86.3% vs 94.4%; long-rank, $P < .001$), at least 1 VT (67.8% vs 85.0%; long-rank, $P < .001$), nc-VT (72.9% vs 85.5%; long-rank, $P = .007$), or c-VT was still inducible (51.2% vs 83.7%; long-rank, $P < .001$) or no PES was performed after ablation (65.0% vs 84.2%; long-rank $P = .046$) (Supplemental Figure 2).

Among patients with ES, those with no-VT had a better survival than did patients with nc-VT, c-VT, and no-PES (86.3% vs 72.9%, 51.2%, and 65.0%; long-rank, $P < .001$ for all comparisons); patients with nc-VT had a better survival that did those with c-VT (long-rank, $P < .001$) (Figure 5).

In Cox proportional hazard modeling, after adjusting for covariates, ES was associated with an HR of 1.5 (95% CI 1.09–2.07) for mortality. Among the subgroup of patients with ES, in Cox proportional hazard modeling, the result of PES after ablation, advanced NYHA class, LVEF, and previously performed VT ablation (HR 1.575; 95% CI 1.018–2.435); diabetes mellitus (HR 1.549; 95% CI 0.994–2.414); and chronic kidney disease (HR 1.515; 95% CI 0.973–2.361) were associated with death (Figure 6). In particular, in patients with ES, the mortality risk decreased by 4.9% (HR 0.951; 95% CI 0.927–0.976) as LVEF increased by 1 unit. Moreover, although the effect is not significant, the

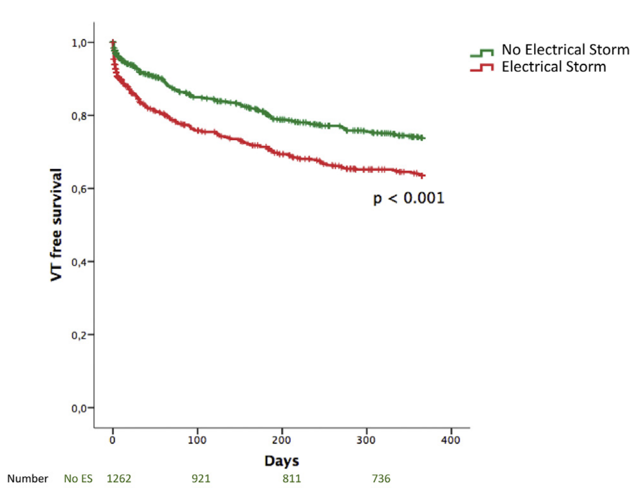

Figure 1 Kaplan-Meier curves of survival free from ventricular tachycardia (VT) recurrences in patients with and without electrical storm (ES).

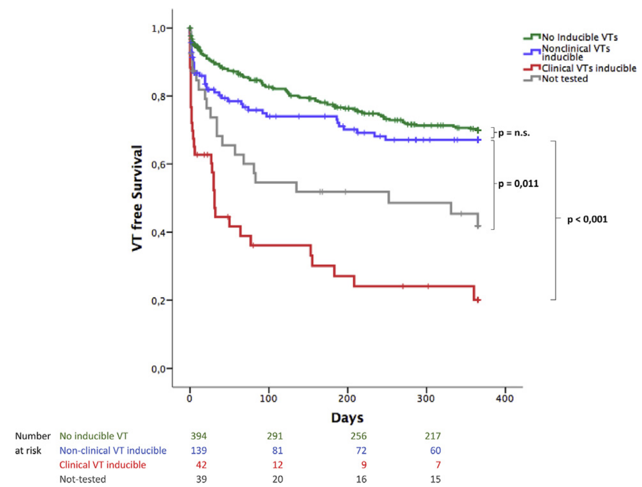

Figure 2 Kaplan-Meier curves of survival free from ventricular tachycardia (VT) recurrences in patients with electrical storm stratified by the results of acute programmed electrical stimulation after ablation. NS = not significant.

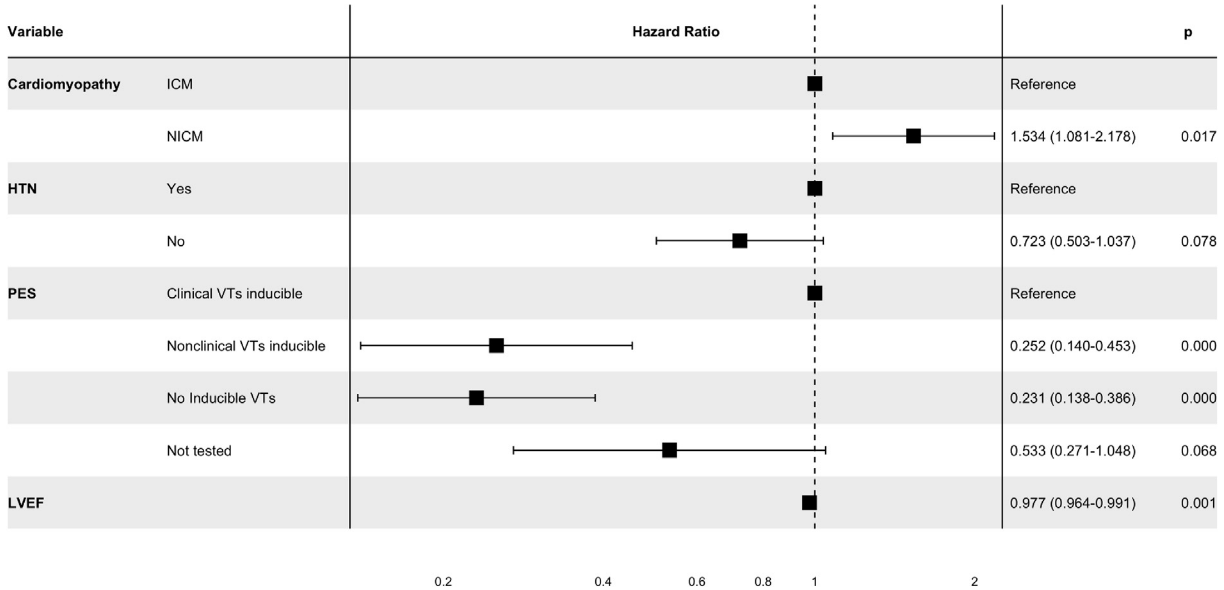

Figure 3 Hazard ratio plot of predictors of ventricular tachycardia (VT) recurrences by multivariate analysis in patients with electrical storm. Among the subgroup of patients with ES, in Cox proportional hazard modeling, the result of programmed electrical stimulation (PES) after ablation, nonischemic cardiomyopathy (NICM), left ventricular ejection fraction (LVEF), and hypertension (HTN) were predictors of ventricular tachycardia recurrences. ICM = ischemic cardiomyopathy.

mortality risk increased by 1.7% (HR 1.017; 95% CI 0.995–1.040) as age increased by 1 year. Patients with no-VT and those with nc-VT had a rate of death at 1 year of 81.4% (HR 0.186; 95% CI 0.093–0.371) and 41.9% (HR 0.581; 95% CI 0.291–1.162), respectively, relative to c-VT ones. Patients in NYHA class III and IV, respectively, had a risk of death at 1 year 2.608 (95% CI 0.994–6.844) and 2.918 (95% CI 1.028–8.284) times higher than those in NYHA class I.

Patients with ES and absence of VT recurrences after ablation had a better survival than did those with VT recurrences during follow-up (88.7% vs 61.3%; long-rank, $P < .001$); their survival, however, was lower than that of patients without both ES and VT recurrences (88.7% vs 94.6%; long-rank, $P < .001$).

Discussion

The present study describes the characteristics of the largest available series of patients with VT ablation for ES. These data showed that patients with ES are among the highest risk VT population with regard to recurrence and mortality. This is also the first study to evaluate the occurrence of comorbidities in a large cohort of patients with ES. Baseline and procedural characteristics are consistent with advanced substrates that present with ES. However, acute procedural success is associated with improved survival.

Patients with ES represent a relatively small portion of patient enrolled in large studies of VT ablation and most of the previously published data are single-center small series or case reports. ES is a challenging condition that occurs in

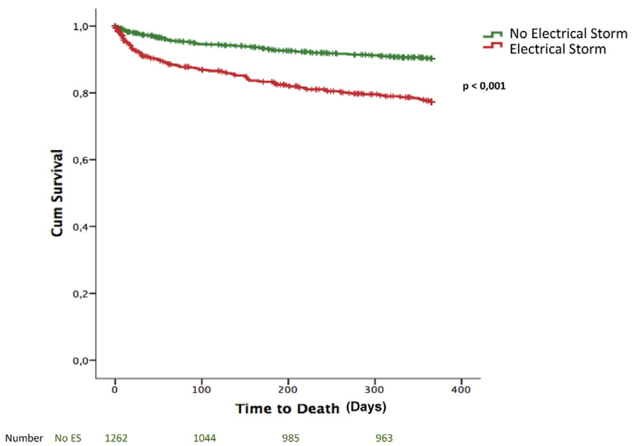

Figure 4 Kaplan-Meier curves of survival in patients with and without electrical storm (ES).

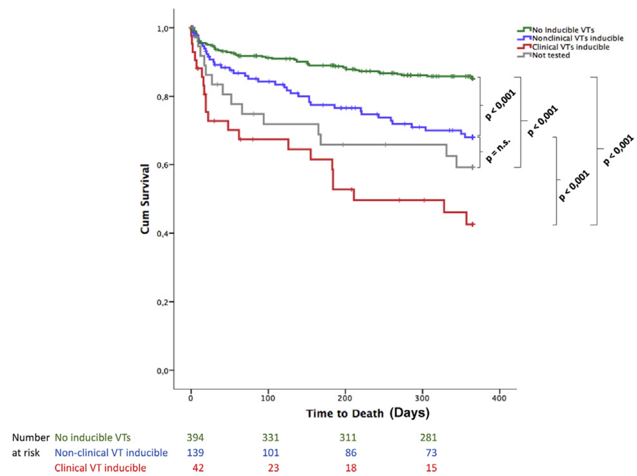

Figure 5 Kaplan-Meier curves of survival free from death in patients with electrical storm stratified by the results of acute programmed electrical stimulation after ablation. VT = ventricular tachycardia.

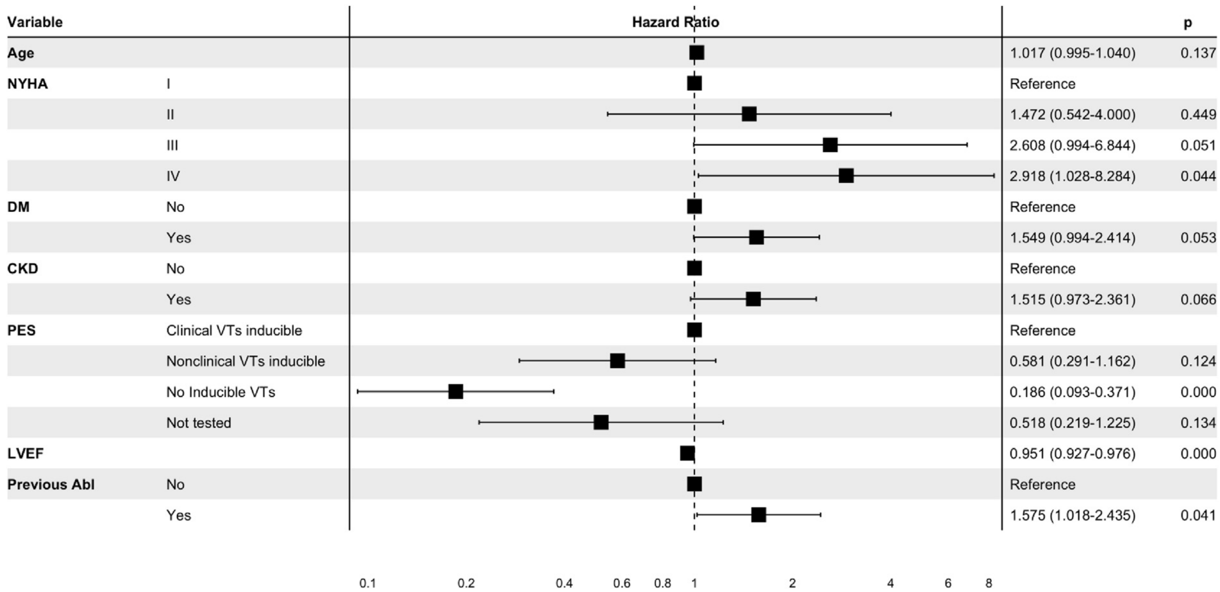

Figure 6 Hazard ratio plot of predictors of death by multivariate analysis in patients with electrical storm. Among the subgroup of patients with ES, in Cox proportional hazard modeling, the result of programmed electrical stimulation (PES) after ablation, left ventricular ejection fraction (LVEF), advanced New York Heart Association functional classification (NYHA), previously performed ventricular tachycardia (VT) ablation (Previous Abl), diabetes mellitus (DM), and chronic kidney disease (CKD) were selected by a stepwise procedure as predictors of death.

~10%–28% of patients with an ICD,[1–3] and it was associated with a 3.15-fold increase in the risk of death.[7] The high mortality may be related to the compound effects of the arrhythmia, the delivery of several ICD shock in a short time frame, and advanced heart failure; the relative contributions of these factors to mortality remains a matter of debate.[8] It is well known that sudden death is tachyarrhythmia associated in two-thirds of the patients with an ICD.[9] ICD shocks may cause myocardial damage and are associated with increased mortality[10–13]; these factors act on fragile patients, whom we identified to be older, with a lower LVEF, more advanced heart failure status, and more cardiovascular comorbidities, as compared with patients without ES. In this study, we showed that the 1-year survival of patients with ES is 61.3% if they continue to experience VT episodes after ablation and it was 88.7% when ablation was successful without VT recurrences. This might suggest that the arrhythmic episodes have a prominent detrimental effect on patient's survival and that the adverse impact can be mitigated by a successful VT ablation procedure. However, survival of patients with ES and absence of VT recurrences was lower than that of patients without either ES and VT recurrences, suggesting that nonarrhythmic factors still act on these patients and might lead to death. It is possible that a comprehensive approach including not only the arrhythmia ablation but also careful treatment of the comorbidities that are more common in patients with ES, such as advanced heart failure, hypertension, hyperlipidemia, atrial fibrillation, diabetes, and chronic kidney disease, might have a positive effect on survival.

Timing of VT ablation

ES was the condition more frequently considered as the main indication for ablation in the survey by Dagres et al.[14] Several studies suggested that the outcome of ablation is better when performed earlier: in the study by Dinov et al,[15] VT recurred less frequently in the early ablation strategy (catheter ablation within 30 days after the first documented VT episode: 37.3%) as compared with later interventions (>60%); similar results were shown by Frankel et al,[16] who classified patients as "late referrals" if they had ≥2 VT episodes, with the first and most recent episodes separated by ≥1 month. In the VTACH trial,[17] early VT ablation before defibrillator implantation prolonged time to recurrence of VT; in the SMASH VT trial,[18] an early ablation was associated with a reduction of ICD shocks afterward.

In our study, patients treated by ablation after ES were older than those without ES and more likely to have been previously treated with ≥1 antiarrhythmic drugs; the complexity of the procedure (more VTs inducible by PES before ablation, more radiofrequency delivery, more frequent hemodynamic support, and longer procedures times) and the mortality during the year after ablation were both higher in patients with ES. It appears, therefore, that ES is an event typical of the late phases in the history of patients with heart failure. It is conceivable that an ablation strategy in earlier phases of the patient's history, before the occurrence of ES, might improve the quality of life and survival with lower technical procedure complexity; however, only randomized controlled trials could provide definitive conclusions on this issue.[19,20]

End points for VT ablation in patients with ES

In the present multicenter experience, the abolition of the clinical VT, although associated with VT recurrence risk <30% during mid-term follow-up, had only a vague effect on survival; although harder to be obtained, the end point of absence of any inducible VT was associated with the highest (86.3%) survival rate. This confirms previous results in postinfarction patients by Yokokawa et al,[19] who showed that absence of any VT inducibility postablation was independently associated with lower mortality.

Patients with ES undergoing VT ablation had an in-hospital mortality 4 times higher than that of patients without prior ES. The higher acute mortality is evident in patients with advanced heart failure, those requiring periprocedural hemodynamic support, and those undergoing epicardial procedures. It cannot be excluded that repeated arrhythmia inductions might negatively affect the already impaired myocardium.[20] A strategy of substrate-based ablation can minimize the need for repetitive inductions of VT for mapping during ongoing arrhythmia.[6,21–24] In the VISTA trial,[25] substrate targeted ablation was associated with lower VT recurrence (15.5%) as compared with ablation of only the clinical VT (48.3%); the combined incidence of rehospitalization and mortality was also better with substrate targeted ablation.

Study limitations

The participating centers in the IVTCC are high-volume ablation hospitals that serve as state- or nationwide referrals for VT ablation procedures. As such, it is possible that there is a referral bias that may limit the generalizability of our results. The IVTCC database did not include detailed information about the ventricular substrate (voltage maps and magnetic resonance imaging scans) or severity of comorbidities, thus precluding further analysis on the correlation between the arrhythmic disease, stage of heart failure, severity of comorbidities, and outcomes. Because of the retrospective multicenter nature of this study, some clinical and procedural characteristics were not available for analysis. Antiarrhythmic drug therapy was left to the discretion of the treating physicians, and it could influence outcomes.

Conclusion

Patients with ES have characteristics and comorbidities consistent with advanced heart failure substrates. They are among the highest risk population with regard to arrhythmia recurrences and mortality. However, acute ablation success is associated with better 1-year survival. Further studies are warranted to determine whether early use of ablation can improve the outcomes in this patient population.

Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrthm.2017.08.022.

References

1. Exner DV, Pinski SL, Wyse DG, Renfroe EG, Follmann D, Gold M, Beckman KJ, Coromilas J, Lancaster S, Hallstrom AP. Electrical storm presages nonsudden death: The Antiarrhythmics Versus Implantable Defibrillators (AVID) Trial. Circulation 2001;103:2066–2071.
2. Bansch D, Bocker D, Brunn J, Weber M, Breithardt G, Block M. Clusters of ventricular tachycardias signify impaired survival in patients with idiopathic dilated cardiomyopathy and implantable cardioverter defibrillators. J Am Coll Cardiol 2000;36:566–573.
3. 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.
4. Tung R, Vaseghi M, Frankel DS, et al. Freedom from recurrent ventricular tachycardia after catheter ablation is associated with improved survival in patients with structural heart disease: an International VT Ablation Center Collaborative Group Study. Heart Rhythm 2015;12:1997–2007.
5. Arenal A, Glez-Torrecilla E, Ortiz M, Villacastin J, Fdez-Portales J, Sousa E, del Castillo S, Perez de Isla L, Jimenez J, Almendral J. Ablation of electrograms with an isolated, delayed component as treatment of unmappable monomorphic ventricular tachycardias in patients with structural heart disease. J Am Coll Cardiol 2003;41:81–92.
6. Vergara P, Trevisi N, Ricco A, Petracca F, Baratto F, Cireddu M, Bisceglia C, Maccabelli G, Della Bella P. Late potentials abolition as an additional technique for reduction of arrhythmia recurrence in scar related ventricular tachycardia ablation. J Cardiovasc Electrophysiol 2012;23:621–627.
7. Guerra F, Shkoza M, Scappini L, Flori M, Capucci A. Role of electrical storm as a mortality and morbidity risk factor and its clinical predictors: a meta-analysis. Europace 2014;16:347–353.
8. Nayyar S, Ganesan AN, Brooks AG, Sullivan T, Roberts-Thomson KC, Sanders P. Venturing into ventricular arrhythmia storm: a systematic review and meta-analysis. Eur Heart J 2013;34:560–571.
9. Pires LA, Lehmann MH, Steinman RT, Baga JJ, Schuger CD. Sudden death in implantable cardioverter-defibrillator recipients: clinical context, arrhythmic events and device responses. J Am Coll Cardiol 1999;33:24–32.
10. Sweeney MO, Sherfesee L, DeGroot PJ, Wathen MS, Wilkoff BL. Differences in effects of electrical therapy type for ventricular arrhythmias on mortality in implantable cardioverter-defibrillator patients. Heart Rhythm 2010;7:353–360.
11. Larsen GK, Evans J, Lambert WE, Chen Y, Raitt MH. Shocks burden and increased mortality in implantable cardioverter-defibrillator patients. Heart Rhythm 2011;8:1881–1886.
12. Poole JE, Johnson GW, Hellkamp AS, et al. Prognostic importance of defibrillator shocks in patients with heart failure. N Engl J Med 2008;359:1009–1017.
13. Mitchell LB, Pineda EA, Titus JL, Bartosch PM, Benditt DG. Sudden death in patients with implantable cardioverter defibrillators: the importance of post-shock electromechanical dissociation. J Am Coll Cardiol 2002; 39:1323–1328.
14. Dagres N, Varounis C, Flevari P, Piorkowski C, Bode K, Rallidis LS, Tsougos E, Leftheriotis D, Sommer P, Hindricks G, Kremastinos DT. Mortality after catheter ablation for atrial fibrillation compared with antiarrhythmic drug therapy: a meta-analysis of randomized trials. Am Heart J 2009;158:15–20.
15. Dinov B, Arya A, Bertagnolli L, Schirripa V, Schoene K, Sommer P, Bollmann A, Rolf S, Hindricks G. Early referral for ablation of scar-related ventricular tachycardia is associated with improved acute and long-term outcomes: results from the Heart Center of Leipzig ventricular tachycardia registry. Circ Arrhythm Electrophysiol 2014;7:1144–1151.
16. Frankel DS, Mountantonakis SE, Robinson MR, Zado ES, Callans DJ, Marchlinski FE. Ventricular tachycardia ablation remains treatment of last resort in structural heart disease: argument for earlier intervention. J Cardiovasc Electrophysiol 2011;22:1123–1128.
17. Kuck KH, Schaumann A, Eckardt L, Willems S, Ventura R, Delacretaz E, Pitschner HF, Kautzner J, Schumacher B, Hansen PS. Catheter ablation of stable ventricular tachycardia before defibrillator implantation in patients with coronary heart disease (VTACH): a multicentre randomised controlled trial. Lancet 2010; 375:31–40.
18. Reddy VY, Reynolds MR, Neuzil P, Richardson AW, Taborsky M, Jongnarangsin K, Kralovec S, Sediva L, Ruskin JN, Josephson ME. Prophylactic catheter ablation for the prevention of defibrillator therapy. N Engl J Med 2007; 357:2657–2665.
19. Yokokawa M, Kim HM, Baser K, et al. Predictive value of programmed ventricular stimulation after catheter ablation of post-infarction ventricular tachycardia. J Am Coll Cardiol 2015;65:1954–1959.
20. Kanjwal K, Imran N, Grubb B, Kanjwal Y. Troponin elevation in patients with various tachycardias and normal epicardial coronaries. Indian Pacing Electrophysiol J 2008;8:172–174.
21. Di Biase L, Santangeli P, Burkhardt DJ, et al. Endo-epicardial homogenization of the scar versus limited substrate ablation for the treatment of electrical storms in patients with ischemic cardiomyopathy. J Am Coll Cardiol 2012;60:132–141.

22. Jais P, Maury P, Khairy P, et al. Elimination of local abnormal ventricular activities: a new end point for substrate modification in patients with scar-related ventricular tachycardia. Circulation 2012;125:2184–2196.
23. Tzou WS, Frankel DS, Hegeman T, Supple GE, Garcia FC, Santangeli P, Katz DF, Sauer WH, Marchlinski FE. Core isolation of critical arrhythmia elements for treatment of multiple scar-based ventricular tachycardias. Circ Arrhythm Electrophysiol 2015;8:353–361.
24. Tung R, Mathuria NS, Nagel R, Mandapati R, Buch EF, Bradfield JS, Vaseghi M, Boyle NG, Shivkumar K. Impact of local ablation on interconnected channels within ventricular scar: mechanistic implications for substrate modification. Circ Arrhythm Electrophysiol 2013;6:1131–1138.
25. Di Biase L, Burkhardt JD, Lakkireddy D, et al. Ablation of stable VTs versus substrate ablation in ischemic cardiomyopathy: the VISTA randomized multicenter trial. J Am Coll Cardiol 2015;66:2872–2882.

Update

Heart Rhythm
Volume 15, Issue 3, March 2018, Page 472

DOI: https://doi.org/10.1016/j.hrthm.2018.02.002

mapping time 25 minutes; Figure 1A and Supplemental Video 1A) with a very small gap (0.123 mV on the mini-basket catheter) with fragmented potentials within a dense scar (measuring 5 mm in diameter; Figure 1A). Entrainment from the anterior part of the scar demonstrated a postpacing interval – tachycardia cycle length of 0 ms, although it was not possible to capture the isthmus and the posterior/inferior part of the dense scar despite high-output pacing. The ultra–high-resolution mapping–guided ablation procedure with an open-irrigated 3.5-mm-tip ablation catheter (Celsius ThermoCool SF; Biosense Webster, Inc, Diamond Bar, CA) was performed at the isthmus site where a very low amplitude (0.04 mV) was recorded (Figure 1B, ABL indicates ablation; AP, anteroposterior; CSd, coronary sinus distal; CSp, coronary sinus proximal; MV, mitral valve; RA, right atrium; TV, tricuspid valve). The AT terminated within 5 seconds of ablation.

This case demonstrates the utility of the ultra–high-resolution mapping system Rhythmia for detailed characterization of the mechanism of a microreentrant AT. The Rhythmia mapping system has recently been reported to be effective for the mapping of complex scar-related reentrant ATs with identification of distinct critical isthmuses with ultra–high-resolution mapping.[1] Importantly, mapping of this tachycardia with conventional lower resolution mapping techniques may have inaccurately identified this as a focal AT, which in turn could potentially lead to unsuccessful ablation (confidence mask 0.2 mV; Supplemental Video 1B).

Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrthm.2017.10.032.

Reference

1. Anter E, McElderry TH, Contreras-Valdes FM, Li J, Tung P, Leshem E, Haffajee CI, Nakagawa H, Josephson ME. Evaluation of a novel high-resolution mapping technology for ablation of recurrent scar-related atrial tachycardias. Heart Rhythm 2016;13:2048–2055.

ERRATUM

In the article titled “Successful ventricular tachycardia ablation in patients with electrical storm reduces recurrences and improves survival” by Pasquale Vergara, Roderick Tung, Marmar Vaseghi, et al that published in the January issue of Heart Rhythm (2018; 15: 48-55), Dr Frankel’s name should have been written as David S. Frankel, MD. The error is regretted.