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CLINICAL RESEARCH
Ventricular arrhythmias

Arrhythmia exacerbation after post-infarction ventricular tachycardia ablation: prevalence and prognostic significance

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Aims Catheter ablation is an effective treatment for post-infarction ventricular tachycardia (VT). However, some patients may experience a worsened arrhythmia phenotype after ablation. We aimed to determine the prevalence and prognostic impact of arrhythmia exacerbation (AE) after post-infarction VT ablation.

Methods and results A total of 1187 consecutive patients (93% men, median age 68 years, median ejection fraction 30%) who underwent post-infarction VT ablation at six centres were included. Arrhythmia exacerbation was defined as post-ablation VT storm or incessant VT in patients without prior similar events. During follow-up (median 717 days), 426 (36%) patients experienced VT recurrence. Events qualifying as AE occurred in 67 patients (6%). Median times to VT recurrence with and without AE were 238 [interquartile range (IQR) 35–640] days and 135 (IQR 22–521) days, respectively ($P = 0.25$). Almost half of the patients (46%) who experienced AE experienced it within 6 months of the index procedure. Patients with AE had had longer ablation times during the ablation procedures compared to the rest of the patients (median 42 vs. 34 min, $P = 0.02$). Among patients with VT recurrence, the risk of death or heart transplantation was significantly higher in patients with than without AE (hazard ratio 1.99, 95% CI 1.28–3.10; $P = 0.002$) after adjusting for age, gender, ejection fraction, cardiac resynchronization therapy, post-ablation non-inducibility, and post-ablation amiodarone use.

Conclusion Arrhythmia exacerbation after ablation of infarct-related VT is infrequent but is independently associated with an adverse long-term outcome among patients who experience a VT recurrence. The mechanisms and mitigation strategies of AE after catheter ablation require further investigation.

Keywords Ventricular tachycardia • Catheter ablation • Recurrence • Arrhythmia exacerbation • Proarrhythmia

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What's new?

- A small percentage of patients undergoing catheter ablation for infarct-related ventricular tachycardia (VT) may experience worsening of the arrhythmia phenotype post-ablation manifesting with new VT storm or incessant VT.
- Such arrhythmia exacerbation (AE) is independently associated with an increased risk of death or need for heart transplantation over long-term follow-up.
- Patients with AE had on average longer ablation times indicating either a worse initial arrhythmogenic substrate or the possibility of a proarrhythmic effect of ablation as a contributor to AE in some cases.
- The specific mechanisms of AE and strategies for mitigation of any possible ablation-related proarrhythmic effects require further investigation.

Introduction

Catheter ablation of ventricular tachycardia (VT) in patients with structural heart disease can reduce implantable cardioverter-defibrillator (ICD) shocks and can improve quality of life in some patients.[1] However, not all patients experience elimination or reduction of VT events. In the pre-approval Thermocool VT Ablation trial of post-infarction VT, 20% of patients experienced an increase in the number of VT episodes after ablation.[2] Furthermore, we previously demonstrated that most of the VTs recurring after VT ablation are new VTs, based on analysis of stored ICD electrograms.[3] Whether an increase in VT events and new VTs emerging after ablation are attributable to the natural progression of the VT substrate or to a proarrhythmic effect of ablation is unclear.

The possibility of arrhythmia exacerbation (AE) after VT ablation procedures and its impact on outcomes have not been systematically assessed. The purpose of this multicentre study was to determine the prevalence and significance of a worsening arrhythmia phenotype in patients with post-infarction VT undergoing catheter ablation.

Methods

Patient population

We included adult patients who underwent catheter ablation procedures for post-infarction VT from six centres in the USA and Europe (University of Michigan, Ann Arbor, MI; Brigham and Women's Hospital, Boston, MA; University of California, Los Angeles, CA; San Raffaele University Hospital, Milan, Italy; University of Leiden Hospital, the Netherlands; and University of Bordeaux Hospital, France). All patients had evidence of prior myocardial infarction by history and/or objective testing.

Electrophysiology procedure and ablation

The study was approved by the institutional review board of the University of Michigan. The index ablation procedures have been previously detailed.[4,5] In brief, after informed consent was obtained, the patients were prepped and draped in a sterile manner. Multielectrode catheters were placed in the right ventricle and the His position. Programmed ventricular stimulation was performed with up to four extrastimuli from two sites. For mapping and ablation, 3.5-mm irrigated-tip catheters were used in conjunction with an electroanatomic mapping system. Ablation strategies were also detailed previously.[4] Tolerated VTs were targeted by entrainment mapping and non-tolerated VTs were mapped by pace-mapping or other substrate-based techniques targeting abnormal electrograms or late potentials. Programmed stimulation was repeated post-ablation unless there was concern about the haemodynamic status of the patient in which case programmed stimulation was deferred. Procedural success was classified as complete when no sustained monomorphic VT was inducible, partial when only nonclinical VT was inducible and failed when the clinical VT was inducible at the end of the procedure. Post-ablation use of antiarrhythmic medications was individualized on a case-by-case basis. In general, antiarrhythmic medications were discontinued or the dose was reduced if the procedure was deemed successful unless there was another indication for antiarrhythmic therapy. In the event of partially successful or failed procedures, antiarrhythmic drug therapy was resumed.

Data collection and definitions

Patient data from each participating centre were documented on standardized forms. Baseline data were collected on patient characteristics, previous ablation procedures at other institutions, and use of antiarrhythmic medications. We documented whether patients had a history of VT storm or incessant VT in the 3 months preceding the ablation procedure. Ventricular tachycardia storm was defined as at least three distinct episodes of sustained VT or ventricular fibrillation with or without ICD therapies within a 24-h period. Continuous sustained VT recurring promptly despite repeated intervention for termination over several hours was defined as incessant VT.[6] We also collected data on procedural characteristics, post-ablation antiarrhythmic medication use and the dates of VT recurrences, defined as sustained VT documented electrocardiographically or by stored ICD electrograms. Arrhythmia exacerbation was defined as VT storm or incessant VT during follow-up regardless of when they occurred post-ablation in patients without a prior history of such events.

The main outcome of the study was a composite of death or heart transplantation (HTx). In patients who did not experience these outcomes, the last date known to be alive was documented. Follow-up data were obtained from clinic and emergency room visits, hospital admissions, and device interrogations, or by contacting the referring physicians.

Data analysis

The first procedure at each participating centre was considered the index procedure. Categorical variables are reported as frequencies and percentages, whereas continuous variables are reported as medians and interquartile ranges (IQRs). Categorical variables were compared with chi-square testing. Because all continuous variables were skewed to the right upon graphical visualization, the continuous variables were compared with Wilcoxon rank-sum testing.

A Cox regression model was used to assess whether recurrence with worsened arrhythmia phenotype was predictive of subsequent death or HTx in the full study population, with the index ablation date being the fiducial point for the analysis. Recurrence with worsening arrhythmia occurred at varying time points during follow-up and therefore was treated as a time-dependent covariate equal to 0 before recurrence and 1 afterwards. Baseline variables (all variables listed in *Table 1*) were considered for inclusion in the model and were selected using a forward stepwise selection approach. Association estimates are expressed as hazard ratios (HRs) with 95% confidence intervals (CIs).

We also assessed the association between AE and death/HTx separately in the subgroup of patients who had any VT recurrence. The

Table 1 Baseline demographic, comorbidity and procedural characteristics by arrhythmia exacerbation status

	Total ($n = 1187$)	No AE ($n = 1120$)	AE ($n = 67$)	*P*-value
Age (years), median (IQR)	68 (61–74)	68 (61–74)	67 (61–73)	0.57
Male gender, *n* (%)	1106 (93)	1042 (93)	64 (96)	0.43
Prior ablation, *n* (%)	302 (25)	288 (26)	14 (21)	0.38
Hypertension, *n* (%)	751 (63)	709 (63)	42 (63)	0.92
Dyslipidaemia, *n* (%)	795 (67)	757 (68)	38 (57)	0.07
Diabetes, *n* (%)	296 (25)	286 (26)	10 (15)	0.05
CKD, *n* (%)	448 (38)	418 (37)	30 (45)	0.22
Atrial fibrillation, *n* (%)	352 (30)	329 (29)	23 (34)	0.39
LVEF (%), median (IQR)	30 (24–40)	30 (24–40)	28 (25–35)	0.05
NYHA class, *n* (%)				0.92
I	234 (20)	222 (20)	12 (18)	
II	630 (53)	594 (53)	36 (54)	
III	274 (23)	257 (23)	17 (25)	
IV	49 (4)	47 (4)	2 (3)	
CRT, *n* (%)	338 (28)	319 (28)	19 (28)	0.98
VT storm/incessant VT, *n* (%)	582 (49)	582 (52)	0 (0)	NA
Prior amiodarone, *n* (%)	749 (63)	703 (63)	46 (69)	0.33
Non-inducible at beginning, *n* (%)	141 (12)	132 (12)	9 (13)	0.69
Procedure time (min), median (IQR)	255 (199–345)	255 (200–345)	240 (192–308)	0.54
RF time (min), median (IQR)	34 (19–54)	33 (19–54)	42 (27–78)	0.02
Ablation type, *n* (%)				0.65
Endocardial	1050 (88)	991 (88)	59 (88)	
Epicardial	12 (1)	12 (1)	0 (0)	
Both	125 (11)	117 (10)	8 (12)	
N clinical VTs, median (IQR)	1 (1–2)	1 (1–2)	1 (1–3)	0.34
N induced VTs, median (IQR)	2 (1–4)	2 (1–4)	3 (2–5)	0.07
Procedural success status, *n* (%)				
Complete	767 (65)	726 (65)	41 (61)	0.80
Partial	256 (22)	242 (22)	14 (21)	
Failure	55 (5)	51 (5)	4 (6)	
Not tested	109 (9)	101 (9)	8 (12)	
Discharge amiodarone, *n* (%)	443 (37)	415 (37)	28 (42)	0.44
Discharge class 1 AAD, *n* (%)	58 (5)	56 (5)	2 (3)	0.46
Discharge sotalol, *n* (%)	142 (12)	134 (12)	8 (12)	0.99

AAD, antiarrhythmic drug; AE, arrhythmia exacerbation; CKD, chronic kidney disease; CRT, cardiac resynchronization therapy; ICD, implantable cardioverter-defibrillator; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; RF, radiofrequency energy; VT, ventricular tachycardia.

time of the VT recurrence with worsened arrhythmia phenotype was the fiducial point for this analysis. Survival free of death/HTx in the subgroups of patients with and without AE was compared with Kaplan–Meier curves and tested with the log-rank test. We also used a multivariable Cox regression model for the endpoint of death or HTx including AE as one of the covariates and other covariates that were again selected using a forward stepwise selection approach. Analyses were performed in Stata 14.0 (College Station, TX), and statistical significance was set at $P \leq 0.05$.

Results

Patient and procedural characteristics

One thousand, one hundred, and eighty-seven patients who underwent catheter ablation of post-infarction VT were included in this analysis [93% men, median age 68 years, median left ventricular ejection fraction (LVEF) 30%]. *Table 1* details their demographic and clinical characteristics. One-quarter of the patients had had a prior ablation elsewhere and 749 (63%) patients were taking amiodarone at the time of the ablation procedure. A total of 582 patients (49%) had experienced VT storm or incessant VT within the 3 months before ablation (189 patients had both). The patients had a median of 1 (IQR 1–2) documented clinical VT pre-ablation.

The majority of the procedures (88%) were limited to endocardial ablation. In 125 procedures (11%), both endocardial and epicardial mapping and/or ablation was performed. A median of 2 (IQR 1–4) VTs were induced during the procedures. The median total procedure and radiofrequency (RF) times were 255 and 34 min, respectively. The ablation resulted in complete non-inducibility of VT in 767 patients (65%). In 109 patients (9%), post-ablation programmed

stimulation was deferred for haemodynamic reasons. In 55 patients (5%), the procedure failed to eliminate clinical VTs and in 256 patients (22%), only non-clinical VTs remained inducible post-ablation.

One hundred and thirty patients (11%) were newly started on at least one antiarrhythmic drug post-ablation. Of them, 57 (5%) patients were newly started on amiodarone as a standalone or combination antiarrhythmic. In 363 patients (31%), amiodarone was discontinued post-ablation, and in 357 patients (30%), all antiarrhythmics were discontinued post-ablation. A total of 443 patients (37%) were discharged on amiodarone post-ablation, including patients on pre-existing amiodarone therapy ($n = 386$) and those newly initiated on amiodarone ($n = 57$).

VT recurrence and arrhythmia exacerbation

During a median follow-up of 717 days (IQR 326–1186), 426 (36%) patients experienced VT recurrence. One hundred and forty-one of these recurrences consisted of VT storm or incessant VT. In 67 of these 141 patients (6% of the total population), there was no prior history of VT storm or incessant VT, therefore, AE was considered to have occurred in these patients. Survival until VT recurrence meeting the definition of AE occurred at a median of 238 (IQR 35–640) days post-ablation, whereas VT recurrence not meeting AE definition occurred 401 (IQR 51–747) days post-ablation (log-rank $P < 0.001$; *Figure 1*). Among the 67 cases of AE, 16 (24%) occurred within 1 month post-ablation, 15 (22%) occurred 1–6 months post-ablation, 9 (14%) occurred 6–12 months post-ablation, and 27 (40%) occurred more than 1 year post-ablation.

Clinical characteristics and arrhythmia exacerbation

Table 1 shows the characteristics of patients and procedures according to AE status. There was a borderline lower median LVEF in patients who experienced AE (median 28%, IQR 25–35%) vs. those who did not (median 30%, IQR 25–35%). Also, patients with AE had longer RF times during the ablation procedures than the other patients (median 42 vs. 34 min, $P = 0.02$). When the analysis was limited to patients with VT recurrence (*Table 2*), there was not a significant difference in the LVEF or the RF times between the patients with and without AE. Compared to those with late AE (≥6 months post-ablation), those with earlier AE had had on average longer procedure durations (*Table 3*). There were no associations between amiodarone or other antiarrhythmic drug discontinuation post-ablation with incident AE.

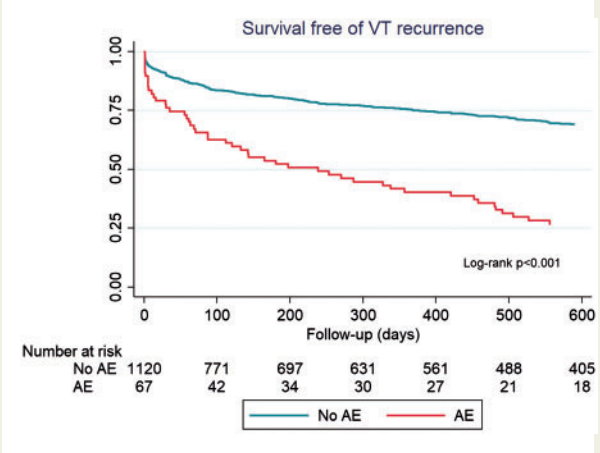

Figure 1 Survival free of VT recurrence in patients with and without arrhythmia exacerbation. AE, arrhythmia exacerbation; VT, ventricular tachycardia.

Long-term follow-up

During the follow-up period, 20 patients (2%) underwent HTx and 275 patients (23%) died. The composite of death/HTx occurred in 282 patients (24%) at a median 413 days (IQR 111–804) after ablation. This composite outcome occurred in 113/426 patients (27%) with VT recurrence and 26/67 patients (39%) with AE. Among patients with VT recurrence, death/HTx occurred at a median of 414 days after recurrence. Among patients with VT recurrence and AE, death/HTx occurred at a median of 203 days after recurrence.

In multivariable Cox regression analysis treating AE as a time-varying covariate, there was a trend for an association between AE and an increased death/HTx risk, although it was not statistically significant (HR 1.99, 95% CI 0.95–4.17; $P = 0.067$).

In the subgroup of patients with VT recurrence, the risk of death/HTx after the VT recurrence was significantly higher in patients with than without AE (log-rank $P = 0.005$; *Figure 2*). In multivariate analysis adjusted for age, gender, LVEF, cardiac resynchronization therapy (CRT), post-ablation non-inducibility, and post-ablation amiodarone use the effect estimate for the association between AE and death/HTx was HR = 1.99 (95% CI 1.28–3.10, $P = 0.002$). Results were similar when the population was limited to patients who did not have a prior history of VT storm or incessant VT ($n = 605$) with the HR for the association of AE with death/HTx being equal to 3.13 (95% CI 1.75–5.62, $P = 0.003$). Further, in order to explore whether the association between AE and long-term outcome may be mediated by the recurrence with VT storm/incessant VT (as opposed to recurrence with new VT storm/incessant VT as defined by AE), we performed another sensitivity analysis adding the type of VT recurrence (with vs. without VT storm/incessant VT) as a covariate in the multivariate Cox model focusing on the patients with VT recurrence. The association between AE and death/HTx remained unchanged. In the same analysis, recurrence with VT storm/incessant VT by itself was not associated with adverse outcome independently of AE (HR 1.20, 95% CI 0.81–1.76, $P = 0.37$).

In a post-hoc analysis, we examined the association between repeat ablations and long-term outcome. Among the patients with VT recurrence, a total of 220 (52%) underwent a repeat ablation. Patients with AE were significantly more likely to undergo repeat ablation compared to patients without AE (84% vs. 46%, $P < 0.001$). Survival free of death/HTx after index ablation was no different between AE patients with and without repeat ablation [median 728 days (IQR 455–1214) and 720 days (IQR 287–1195), respectively; log-rank $P = 0.08$]. In a multivariable Cox regression model of the time from VT recurrence to death/HTx, after adjusting for age, gender, LVEF, and CRT, the HR (95% CI) associated with repeat ablation was 0.37 (0.12–1.16), $P = 0.088$.

Table 2 Baseline demographic, comorbidity and procedural characteristics by arrhythmia exacerbation status among patients with VT recurrence

	Total ($n = 426$)	Recurrence without AE ($n = 359$)	Recurrence with AE ($n = 67$)	*P*-value
Age (years), median (IQR)	67 (61–73)	68 (61–74)	67 (61–73)	0.96
Male gender, *n* (%)	395 (93)	331 (92)	64 (96)	0.34
Prior ablation, *n* (%)	108 (25)	94 (26)	14 (21)	0.36
Hypertension, *n* (%)	249 (58)	207 (58)	42 (63)	0.44
Dyslipidaemia, *n* (%)	290 (68)	252 (70)	38 (57)	0.03
Diabetes, *n* (%)	106 (25)	96 (27)	10 (15)	0.04
CKD, *n* (%)	162 (38)	132 (37)	30 (45)	0.22
Atrial fibrillation, *n* (%)	124 (29)	101 (28)	23 (34)	0.31
LVEF (%), median (IQR)	29 (23–35)	30 (23–35)	28 (25–35)	0.69
NYHA class, *n* (%)				0.95
I	74 (17)	62 (17)	12 (18)	
II	232 (54)	196 (55)	36 (54)	
III	102 (24)	85 (24)	17 (25)	
IV	18 (4)	16 (4)	2 (3)	
CRT, *n* (%)	129 (30)	110 (31)	19 (28)	0.71
VT storm/incessant VT, *n* (%)	222 (52)	222 (62)	0 (0)	NA
Prior amiodarone, *n* (%)	277 (56)	231 (64)	46 (69)	0.50
Non-inducible at beginning, *n* (%)	44 (10)	35 (10)	9 (13)	0.36
Procedure time (min), median (IQR)	252 (200–336)	259 (202–341)	240 (192–308)	0.54
RF time (min), median (IQR)	36 (23–57)	36 (23–55)	42 (27–78)	0.09
Ablation type, *n* (%)				0.45
Endocardial	372 (87)	313 (87)	59 (88)	
Epicardial	8 (2)	8 (2)	0 (0)	
Both	46 (11)	0 (0)	8 (12)	
N clinical VTs, median (IQR)	1 (1–2)	1 (1–2)	1 (1–3)	0.33
N induced VTs, median (IQR)	2 (1–4)	2 (1–4)	3 (2–5)	0.33
Procedural success status, *n* (%)				
Complete	249 (58)	208 (58)	41 (61)	0.90
Partial	105 (25)	91 (25)	14 (21)	
Failure	24 (6)	20 (6)	4 (6)	
Not tested	48 (11)	40 (11)	8 (12)	
Discharge amiodarone, *n* (%)	183 (43)	155 (43)	28 (42)	0.83
Discharge class 1 AAD, *n* (%)	20 (5)	18 (5)	2 (3)	0.47
Discharge sotalol, *n* (%)	61 (14)	53 (15)	8 (12)	0.55

AAD, antiarrhythmic drug; AE, arrhythmia exacerbation; CKD, chronic kidney disease; CRT, cardiac resynchronization therapy; ICD, implantable cardioverter-defibrillator; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; RF, radiofrequency energy; VT, ventricular tachycardia.

Discussion

Main findings

In this multicentre study of patients with post-infarction VT, AE defined as newly occurring VT storm or incessant VT after a catheter ablation was infrequent, occurring in ~6% of patients. The patients who experienced AE had a lower survival free of death/HTx compared with those with recurrent VT not attributable to AE. Among the patients who experienced a recurrence of VT and after adjustment for several potential confounding variables, AE was an independent risk factor for a worse long-term outcome.

Criteria for arrhythmia exacerbation

In this multicentre study, the criterion for AE was one that could be easily applied based on the clinical manifestation of recurrent VT. A new VT storm and/or new incessant VT are indisputable events that can easily be tracked during follow-up. Another possible indicator of AE is an increase in the incidence of VT events.[2] Quantification of the incidence of recurrent VT events is feasible prospectively by serial ICD interrogations but is difficult in retrospective studies because recurrences are not usually quantified in a standardized fashion. Furthermore, VTs with a rate below the programmed monitor zone will not be detected by the device. Another possible manifestation of

Table 3 Baseline demographic, comorbidity, and procedural characteristics by arrhythmia exacerbation status among patients with early (<6 months) vs. Late (≥6 months) arrhythmia exacerbation

	Early AE (*n* = 31)	Late AE (*n* = 36)	*P*-value
Age (years), median (IQR)	68 (59–73)	66 (62–75)	0.90
Male gender, *n* (%)	29 (94)	35 (97)	0.47
Prior ablation, *n* (%)	7 (23)	7 (19)	0.55
Hypertension, *n* (%)	16 (52)	26 (72)	0.08
Dyslipidaemia, *n* (%)	16 (52)	22 (61)	0.43
Diabetes, *n* (%)	5 (16)	5 (14)	0.80
CKD, *n* (%)	13 (42)	17 (47)	0.66
Atrial fibrillation, *n* (%)	10 (32)	13 (36)	0.74
LVEF (%), median (IQR)	26 (20–35)	30 (25–34)	0.56
NYHA class, *n* (%)			0.58
I	6 (19)	6 (17)	
II	14 (45)	22 (61)	
III	10 (33)	7 (19)	
IV	1 (3)	1 (3)	
CRT, *n* (%)	10 (32)	9 (25)	0.51
Prior amiodarone, *n* (%)	18 (58)	28 (78)	0.08
Non-inducible at beginning, *n* (%)	3 (10)	6 (17)	0.40
Procedure time (min), median (IQR)	298 (240–374)	210 (180–285)	0.007
RF time (min), median (IQR)	54 (35–78)	34.5 (21–56)	0.29
Ablation type, *n* (%)			0.60
Endocardial	28 (90)	31 (86)	
Epicardial	0 (0)	0 (0)	
Both	3 (10)	5 (14)	
N clinical VTs, median (IQR)	1 (0–6)	1 (1–2.5)	0.87
N induced VTs, median (IQR)	3 (2–5)	2 (1–4)	0.14
Procedural success status, *n* (%)			
Complete	18 (59)	23 (64)	0.32
Partial	6 (19)	8 (22)	
Failure	1 (3)	3 (8)	
Not tested	6 (19)	2 (6)	
Discharge amiodarone, *n* (%)	16 (52)	12 (33)	0.13
Discharge class 1 AAD, *n* (%)	2 (6)	0 (0)	0.12
Discharge sotalol, *n* (%)	4 (13)	4 (11)	0.82

AAD, antiarrhythmic drug; AE, arrhythmia exacerbation; CKD, chronic kidney disease; CRT, cardiac resynchronization therapy; ICD, implantable cardioverter-defibrillator; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; RF, radiofrequency energy; VT, ventricular tachycardia.

AE is the emergence of new VT morphologies. However, this could also simply reflect the natural progression of the arrhythmia substrate rather than proarrhythmia. Ventricular remodelling resulting in collagen fibre deposition[7] is a time-dependent process that eventually generates the milieu necessary for post-infarction re-entry.[8,9] This is an ongoing process that continues after an ablation procedure and may generate a new arrhythmogenic substrate over time independent of the ablation. The impact of ablation on collagen turnover within the scar is not known and it is likely that the dynamics of scar remodelling interact with the fibrosis from ablation lesions.

Arrhythmia exacerbation and outcomes

To the best of our knowledge, the appearance of new VT storm or incessant VT after catheter ablation and their prognostic value has not been reported previously. This occurred in 6% of the patient population and was associated with adverse outcomes among patients with VT recurrence. The clustering of VT events after an ablation may impact on outcomes as shown in a recent study by Santoro *et al.*[10] In their analysis of 96 patients who underwent catheter ablation for VT associated with non-ischaemic dilated cardiomyopathy, VT clustering (defined as the occurrence of three or more appropriate ICD interventions within 2 weeks) occurred in more than half of the patients with a VT recurrence. Patients experiencing VT clustering had a higher mortality rate during a mean follow-up of 56 months post-ablation compared to patients with recurrence but without clustering of VT events. Importantly, in multivariate analysis, VT clustering and NHYA class were the only independent predictors of death.

Recurrence after VT ablation is a well-established predictor of adverse long-term outcome,[5,11] but herein we demonstrate that

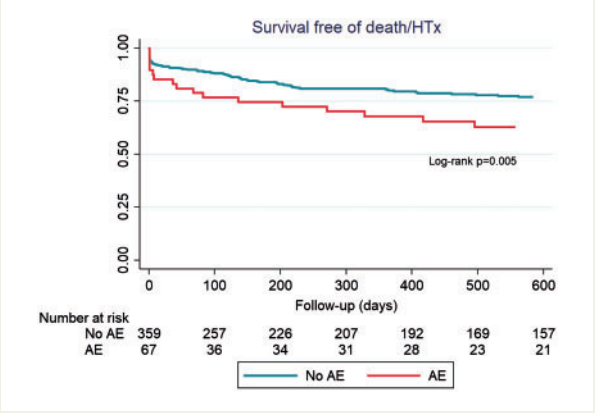

Figure 2 Survival free of death/HTx in patients with vs. those without arrhythmia exacerbation (among patients with VT recurrence). AE, arrhythmia exacerbation; HTx, heart transplantation; VT, ventricular tachycardia.

recurrence with an exacerbated arrhythmic phenotype is prognostically even more powerful as it was associated with worse outcomes compared to those patients who had a recurrence but without AE. In addition, the association of AE with adverse outcome was independent of the recurrence with VT storm or incessant VT. This indicates that recurrence with VT storm or incessant VT alone is not sufficient and that a worsening from the pre-ablation arrhythmia phenotype is necessary to confer the adverse prognostication. In our study, repeat ablation was common among patients with AE and we noted a statistical trend towards an association of repeat ablation with an improved long-term outcome ($P = 0.088$). A statistically significant difference may not have been detected due to limited power of this subgroup analysis.

When evaluating possible predictors of AE, only the duration of RF energy delivered was significantly associated with AE. There was also a trend for lower ejection fraction among patients who experienced AE compared to those who did not. Awareness that ablation procedures have the potential to exacerbate VT is important for the operator and the treated patients. Strategies to minimize the occurrence of AE need to be evaluated and further research into AE mechanisms is of key importance in this regard.

Possible mechanisms of arrhythmia exacerbation

While our data do not directly prove that ablation lesions can worsen ventricular arrhythmias, they support the possibility that such proarrhythmia is a real phenomenon after VT ablation procedures. Intact myocytes have been described interspersed with necrotic myocytes within ablation lesions in animal models when RF ablation was performed within scar tissue.[12] It is conceivable that further isolation of myofibre bundles by RF lesions within scar contributes to the extent of complex anisotropy required for VT. Creation of new obstacles that can serve as anatomic barriers might further facilitate re-entry. Furthermore, ablation lesions might modify the pre-existing arrhythmia substrate such that a circuit more readily sustains re-entry. Tissue injury resulting in abnormal automaticity is another possible mechanism that may be operational among early recurrences with AE.

Patients with AE had longer ablation times compared to patients without AE. Longer ablation times have also been noted in patients with adverse outcomes in other ablation studies.[2,11] It is unclear whether the association of longer ablation times and adverse outcomes reflects a worse arrhythmogenic substrate, a causal effect from ablation lesions, or a combination of the two. Delivery of more ablative lesions might increase the odds of creating lesions that have the potential to promote proarrhythmia. Prior observations of new VTs occurring in proximity to incomplete ablation lesions[3] support the notion that ablation lesions may at least in part account for AE. However, longitudinal data with respect to the cardiomyopathic substrate over time were not available and therefore progressive adverse remodelling of the underlying cardiomyopathy cannot be excluded as a potential mechanism for AE.

Limitations

Firstly, this is a retrospective observational analysis with an inherent risk of confounding variables that were not accounted for in the analysis. Secondly, in this study, we did not have detailed mapping information from redo procedures that would allow analysis of prior ablation lesions resulting in potential proarrhythmia. Sequential data on ejection fraction, left ventricular end-diastolic dimensions, or brain natriuretic peptide that may indicate adverse ventricular remodelling were not collected at initial presentation and during follow-up. In the absence of longitudinal data on the evolution of the severity of cardiomyopathy, we cannot rule out that AE might have occurred due to disease and substrate progression, rather than due to the ablation lesions. Although there was no association between amiodarone discontinuation post-ablation and incident AE, we cannot comment on the possible impact of dose reduction and arrhythmic events, since we have no information about antiarrhythmic drug adjustments after discharge.

Conclusions

Arrhythmia exacerbation, defined as a new post-ablation VT storm or incessant VT, is infrequent but has a negative impact on outcomes when it occurs after ablation of post-infarction VT. Future studies should focus on clarifying the mechanisms of AE, enabling an ablation strategy that might prevent or minimize any ablation-related proarrhythmic effects.

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Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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Ventricular tachycardia catheter ablation after repaired tetralogy of Fallot: how to overcome an electrical short circuit

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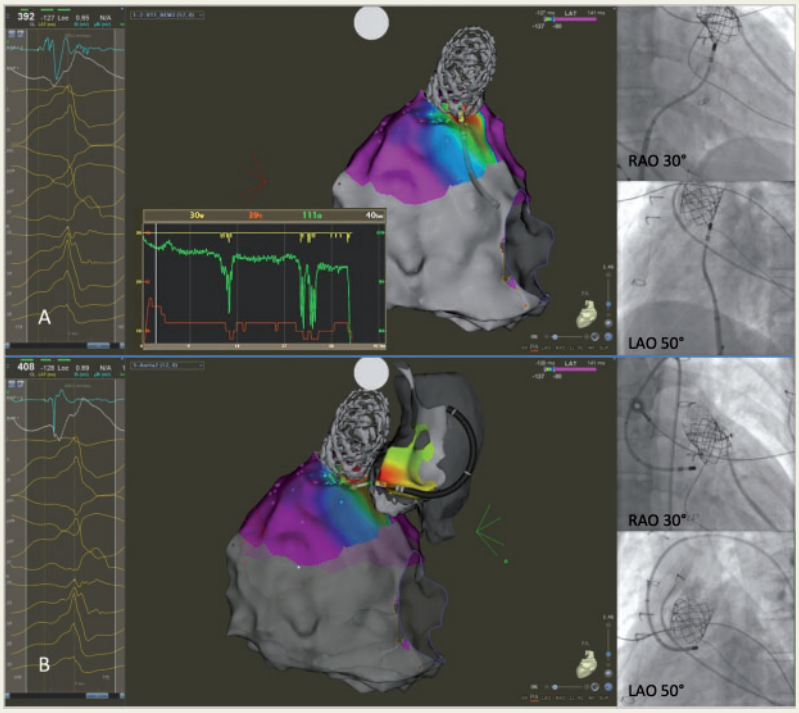

A 30-year-old man with a history of surgical repair of tetralogy of Fallot and percutaneous pulmonary valve replacement (Melody, Medtronic, Minneapolis, MN, USA) was admitted for sustained ventricular tachycardia (VT) with a rate of 160 b.p.m., inferior axis and right bundle branch block morphology. The patient was scheduled for radiofrequency catheter ablation (RFCA) and pre-procedural multislice computed tomography was performed. At the electrophysiological study, an activation map during ongoing VT did show an "early-meets-late" pattern between the right ventricular outflow tract ant the tricuspid valve. No mid-diastolic potentials and only half of the VT cycle length were recorded, thus suggesting a focal mechanism and a line of block, due to a prior RFCA (Supplementary material online, *Video*). The site of origin (SOO) was localized at the septal aspect of the prosthetic pulmonary valve (local activation −17 ms to QRS begin, QS unipolar). Radiofrequency energy delivery at this site was not possible because of repetitive abrupt impedance drop due to intermittent contact with the valve struts (*Panel A*). Radiofrequency catheter ablation close underneath the SOO only resulted in temporary VT termination. Hence, the aortic root was mapped. A local presystolic signal (−18 ms to QRS begin, QS unipolar) could be recorded in the right coronary cusp (*Panel B*). Radiofrequency here promptly terminated VT and rendered the arrhythmia non-inducible. In our case, an intramural substrate was initially inaccessible because of an electrical short circuit with a prosthetic valve. Pre-procedural imaging and the use of a 3D-electroanatomical mapping system provided a good understanding of cardiac anatomy and allowed successful ablation from an alternative adjacent structure.

The full-length version of this report can be viewed at: https://www.escardio.org/Education/E-Learning/Clinical-cases/Electrophysiology.