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The impact of previous VT substrate radiofrequency catheter ablation procedures for patients presenting with electrical storm

Short title: Repeated versus single VT ablation for electrical storm patients

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WHAT'S NEW?

Patients with a history of ventricular tachycardia ablation requiring redo procedures for electrical storm episodes were more frequently affected by non-ischemic structural heart disease, required more epicardial ablation and develop more pericardial access-related complications. However, they achieved comparable rates of procedural success and all-cause mortality and ventricular arrhythmic recurrences during the first year after the procedure compared to patients undergoing first-time ablation at the time of electrical storm.

ABSTRACT

Background: Ventricular tachycardias (VT) that appear after catheter ablation (RFA) may respond poorly to conservative treatment and increase mortality. Current evidence favours

repeating RFA to reduce VT-burden and improve outcomes, if recurrences are precluded. This has not exclusively been studied in electrical storm patients.

Aims: We sought to compare patient/procedural characteristics and long-term all-cause mortality and recurrences in single-RFA versus repeat-RFA patients.

Material and methods: Retrospective single-center analysis of consecutive electrical storm patients treated by RFA monitored for 32.8 (10–68) months. Inducibility of sustained monomorphic VT was assessed by programmed ventricular stimulation. We assessed differences in patient/procedural characteristics and compared all-cause mortality and recurrences in single-RFA versus repeat-RFA during the first year post-ablation.

Results: 101 patients (mean age 59.69 [12.8] years, 32.7% non-ischemic cardiomyopathies, 34 cases of repeat-RFA) were included. Compared to single-RFA, repeat-RFA patients were more frequently non-ischemic cardiomyopathies (47.1% vs. 26.9%; P = 0.04), required more epicardial ablation (32.4% vs. 14.9%; P = 0.04) and had more frequent epicardial-access complications (14.8% vs. 1.6%; P = 0.02). All-cause mortality (repeat-RFA 10 deaths [29.4%] vs. single-RFA 21 [31.3%]; P = 0.99) and recurrences (repeat-RFA 13 recurrences [38.2%] vs. single-RFA 23 [34.3%]; P = 0.82) were comparable during follow-up. All-cause mortality (log rank P = 0.62) and recurrences (log rank P = 0.65) were similar in repeat-RFA vs. single-RFA during the first year after ablation.

Conclusions: Despite requiring more epicardial ablation and more non-ischemic myocardial substrate, repeat-RFA patients showed similar all-cause mortality and recurrences compared to single-RFA during the first year post-ablation.

Key words: all-cause mortality, electrical storm, programmed ventricular stimulation, recurrences, repeat ablation,

Introduction

Patients with a history of ventricular tachycardia (VT) catheter ablation (RFA) can develop recurrences that may respond poorly to conservative treatment and increase mortality [1, 2]. Although limited and derived from observational data, current evidence favours the role of repeat-RFA to reduce VT burden and the potential to obtain outcomes similar to single-RFA cases, provided there are no VT recurrences after ablation [3–7].

Electrical storm (ES) aggravates outcomes of VT ablation [8–10]. Repeat-RFA procedures in the setting of ES episodes have only represented 30%–60% of studied populations

in previous papers [3–7]. This study focused exclusively on ES patients and aimed to evaluate baseline patient and procedural characteristics and all-cause mortality and VT/VF recurrences in those with previous VT ablation procedures ("repeat-RFA") in comparison to those undergoing first-time VT ablation at the time of ES ("single-RFA").

MATERIALS AND METHODS

Study population

This is a retrospective longitudinal single-center analysis of consecutive implantable cardioverter defibrillator (ICD) patients treated by RFA between January 2014 and June 2023 for ES as defined in previously published papers and most recent consensus documents [11–13]: a minimum of three separate episodes of sustained ventricular monomorphic tachycardia (SMVT) treated by adequate ICD therapies in a 24-hour interval refractory to medical antiarrhythmic treatment. Patients with exclusively polymorphic VT of ventricular fibrillation episodes (not preceded by SMVT) or patients with isolated SMVT episodes (< 3 episodes/24 hours) were excluded from this analysis (Figure 1). Furthermore, RFA was not performed in ES patients demonstrating reversible causes (e.g., active ischemia, severe electrolyte abnormalities, drug toxicity) that achieved VT suppression after trigger correction. If subjects were previously naive to VT substrate ablation procedures and underwent first-time ablation at the time of study enrolment they were defined as single-RFA subjects; otherwise, if at least one VT substrate ablation procedure had been performed prior to the moment of the reference ablation and study enrolment, they were defined as repeat-RFA patients. Previous VT substrate ablation procedures were either performed in other centers or in the study centre.

Imaging, electrophysiology study and ablation strategy

Electrophysiological study and ablation were performed in fasting state under analgesia and conscious sedation. Electrogram recording and analysis was performed using Boston Scientific Labsystem PRO EP Recording System v.2.7.0.16. High density electroanatomical mapping with CARTO-3™ (Biosense Webster, Diamond Bar, CA, US) (>1800 points emphasizing the scar area and its border zone [BZ]) was performed in sinus rhythm with 16–500 Hz signal filtering. Right ventricle catheterization was obtained by transfemoral access, whereas the left ventricle was instrumented by trans-septal or retrograde aortic approach. The pericardial space was accessed by fluoroscopy-guided anterior subxiphoid puncture. Epicardial mapping and ablation was performed if the electrocardiogram SMVT morphology (either preprocedural electrocardiogram or induced by programmed ventricular stimulation [PVS] after endocardial

ablation) was considered to indicate an epicardial origin. Remote magnetic navigation (RMN) (Niobe II, Stereotaxis Inc., St. Louis, MO, US) and/or multielectrode catheter mapping (decapolar or duodecapolar) was used at the electrophysiologist's case-specific decision. Mitral regurgitation severity and biplane Simpson-based left ventricular ejection fraction (LVEF) in transthoracic echocardiography was based on previous recommendations for diagnosis [14, 15]. Ischemic cardiomyopathy (ICM) was defined by a previous myocardial infarction. Only characteristics from each patient's most recent ablation procedure were reported.

Normal myocardium was considered if local electrograms' amplitude was >1.5 mV (bipolar), >8.3 mV (unipolar LV), >5.5 mV (unipolar RV), whereas dense scar and BZ myocardium were defined by endocardial bipolar signals' amplitude <0.5 mv and 0.5–1.5 mV, respectively, in endocardial mapping. In epicardial mapping, bipolar electrograms' amplitude >1 mV defined normal myocardium. Similar to previously published analyses, a standard scar-dechannelling protocol eliminating conduction channel entrances [16] using open-irrigated ablation catheters (35–50 W, 45°C) was used. The procedural workflow protocol is summarized in Figure 2. If hemodynamically tolerated, activation/entrainment was performed for any spontaneously induced VTs during mapping. After conduction channel entry elimination, PVS was routinely performed with at least 2 drive cycle lengths (CLs) and 4 extra stimuli (ESx) (3 ESx in patients with severe heart failure symptoms at rest or extreme frailty) (at a minimum of 200 ms or until ventricular refractoriness) from two sites (medially and laterally to the scar) to test for residual inducibile arrhythmia (as previously described [12]). For inducible SMVTs with CLs ≥250 ms [17], scar reconnection was assessed using a previously validated protocol [18] to demonstrate core isolation; high-output pacing (20 mA at 2 ms pulse width) was applied at multiple (≥3) sites inside the scar that had previously demonstrated capture and had not been targeted by ablation. If scar reconnection was demonstrated, the scar-dechannelling protocol was repeated. If scar isolation was demonstrated, other potential substrate sites were emphasized by mapping, guided by the morphology of the persistently inducible VT. Clinical SMVT was interpreted by 12-lead electrocardiogram QRS morphology or by ICD-derived intracardiac electrograms with similar (± 20 ms) CLs.

A positive PVS was defined by persistently inducible sustained monomorphic VT (irrespective of clinical or non-clinical SMVT morphology) at testing, whereas the absence of any sustained monomorphic VT was considered a negative PVS. A positive PVS was further defined in relation to the type of residually inducible sustained monomorphic VT: *partial success* — elimination of clinical sustained monomorphic VT, with residually inducible

sustained monomorphic VT, *failure* — residually inducible clinical sustained monomorphic VT.

Follow-up protocol

All follow-up data was analysed in relation to the most recent ablation. All patients were scheduled for routine recurrent 6-month interval ICD interrogation visits after ablation at the study centre or at other institutions by certified electrophysiologists to detect recurrent arrhythmic episodes. Symptomatic patients (palpitations, syncopal episodes or ICD discharges) were scheduled for prompt ICD interrogation. We periodically assessed all-cause mortality by a 6 month-interval routine check-up of each patient's status using the National Health Insurance website. The exact date of the patient's death was subsequently confirmed by the patient's family or referring physician *via* telephone. For study analysis, scheduled ICD interrogation was performed in all patients that were alive in June 2023.

All-cause mortality rates were retrospectively analysed after the moment of the most recent ablation, irrespective of cardiovascular and non-cardiovascular causes of death. Recurrences were defined by SMVT or polymorphic VT/VF episodes adequately treated by ICD intervention (either antitachycardia pacing or shock). ICD detection intervals were programmed to allow detection of any ventricular arrhythmia which was previously spontaneously present induced at PVS (–20 bpm relative to the slowest known VT).

The study protocol adhered to the principles of the Declaration of Helsinki and was approved by the human research committee of the Emergency Clinical Hospital of Bucharest Ethics Committee (12521 — 01/04/2022).

Statistical analysis

Continuous data was expressed as mean (standard deviation) for normally distributed data and median (interquartile range) for non-normally distributed data. Categorical data was expressed as percentage (count). The normality of data was evaluated by Kolmogorov–Smirnov test. Categorical variables were compared using the Fisher's exact test/χ^2 analysis and continuous variables were compared using Student t-test (or one-way ANOVA test for comparison of more than two groups) if normally distributed and non-parametric tests (Mann–Whitney U Test or Kruskal–Wallis 1-way for comparison of more than two groups). Subjects without previous VT ablations were attributed to the single-RFA subgroup, whereas those with a history of at least one VT ablation were attributed to the repeat-RFA subgroup. Cox proportional hazards analyses were used to specifically assess the association between the first occurrence of time-dependent

outcome events (all-cause mortality and VT/VF recurrences, respectively) and repeat-RFA status during the first year after ablation. Furthermore, univariate Cox regression analysis was used to test the association of previously established predictors of events after ES ablation and the first occurrence of death or VT/VF recurrences during the first year after ablation; subsequently, all variables with significant effect were introduced in the multivariate model to test independent prediction of the composite end-point of death or VT/VF recurrences during the first year after ablation. Kaplan–Meier analysis was used to assess event-free survival during follow-up and log-rank pairwise comparison test was used to compare differences in survival curves of single-RFA vs. repeat-RFA patients within each of the following strata: PVS result (non-inducibility of any sustained monomorphic VT vs. residual inducibility of sustained monomorphic VT), etiology (ICM vs. NICM) and LVEF subgroup (LVEF ≤40% vs. LVEF >40%) during the first year after ablation. A 2-sided *P*-value <0.05 was considered statistically significant. Statistical analysis was performed using SPSS version 23 (IBM Corp., Armonk, NY, US) software and Prism 9 Version 9.5.0 (GraphPad Software, LLC).

RESULTS

One hundred and one patients were retrospectively included in this study. Table 1 summarizes relevant patient and procedural characteristics. There were thirty-four patients attributed to the repeat-RFA subgroup, whereas sixty-seven patients were attributed to the single-RFA subgroup. The repeat-RFA group consisted of 28 (82.5%) patients with two procedures, 5 (14.7%) with three procedures and one (2.9%) patient with four procedures in the repeat-RFA group. Twelve patients (35.2%) in the repeat-RFA group had a history of previous ablation for electrical storm, whereas the other 22 (64.7%) had a history of ablation only for VT episodes. Twelve subjects (35.2%) were previously treated and referred from other centers, whereas the rest 22 (64.7%) underwent previous VT ablation procedures in our centre. For patients with repeated ablations, the previous procedure had the following results at final PVS: negative PVS (n = 12; 35.3%), partial success (n = 13; 38.2%), failure (n = 8; 23.5%) and PVS was not performed in only one patient (2.9%). The median interval of time from the previous ablation was 3.5 (1–24) months. Seven of the eight patients with previous procedural failure underwent the repeated ablation during the same hospitalization. The median interval of time from the previous ablation was different (*P* = 0.001) in relation to the result of the previous procedure: negative PVS — 24 (7.5–51) months vs. partial success — 3 (1–4.5) months vs. failure — 0.75 (0.5–1) months. Only four out (11.8%) of the 34 repeat-RFA patients underwent epicardial ablation during the previous procedure.

There were 9 (27.2%) (single-RFA 5 [7.5%] vs. repeat-RFA 4 [11.8%]; *P* = 0.48) patients diagnosed with arrhythmogenic cardiomyopathy, 4 (12.1%) patients with non-compaction cardiomyopathy (single-RFA 1 [1.5%] vs. repeat-RFA 3 [8.8%]; *P* = 0.11), 4 (12.1%) patients with valvular cardiomyopathies (single-RFA 3 [4.5%] vs. repeat-RFA 1 [2.9%]; *P* = 0.54), 6 (5.9%) post-myocarditis cardiomyopathy (single-RFA 3 [4.5%] vs. repeat-RFA 3 [8.8%]; *P* = 0.4), 11 (10.9%) patients with idiopathic DCM (single-RFA 6 [8.9%] vs. repeat-RFA 5 [14.7%]; *P* = 0.11).

In the repeat-RFA group, epicardial ablation was more frequent in NICM vs. ICM (8 patients [53.3%] vs. 3 patients [15.8%]; *P* = 0.03). There was no difference in the rate of positive PVS in RMN procedures vs. manual procedures (n = 24 [30.4%] vs. n = 8 [36.4%]; *P* = 0.61).

There were nine patients (11.5%) that developed ablation-related non-vascular complications, predominantly in the repeat-RFA group (n = 6 [24%]; *P* = 0.027) vs. single-RFA group (n = 3 [5.7%]). These were mostly attributed to post-ablation pericardial effusions in the repeat-RFA group (n = 4 [14.8%]) vs. the single-RFA group (n = 1 [1.6%]; *P* = 0.02). None required pericardiocentesis and were treated conservatively. In the repeat-RFA group, there was one patient (3.3%) that developed transient coronary spasm that responded to intravenous nitroglycerine and one patient (3.3%) that developed periprocedural thromboembolic stroke. There were no such complications in the single-RFA group. One patient in the single-RFA group (1.9%) that developed brachial artery thromboembolism during the ablation procedure and required mechanical thrombectomy. One patient in the repeat-RFA group developed a subcutaneous hemorrhage (3.3%) during epicardial puncture attempt that was treated conservatively but mandated the deferral of the procedure. There were three local vascular complications represented by self-limited hematomas (two [6.3%] in the repeat-RFA group and one [1.5%] in the single-RFA group; *P* = 0.24) which were treated conservatively.

During a median interval of 32.8 (10–68) months there were 31 (30.7%) deaths overall. There were 10 deaths (29.4%) in the repeat-RFA group vs. 21 (31.3%) in the single-RFA group (*P* = 0.99). Overall, there were 36 (35.6%) recurrences. There were 13 recurrences (38.2%) in the repeat-RFA group vs. 23 (34.3%) in the single-RFA group; *P* = 0.82. Only 3 patients (14.3%) died from the repeat-RFA subgroup out of the 21 that did not experience recurrences during follow-up, compared to seven (53.8%) out of 13 that did experience recurrences. There were no differences regarding death during in follow-up in the single-RFA group that did not experience recurrences (8 [18.2%] out of 44; *P* = 0.69) or those who did experience recurrences (13 [56.5%] out of 23; *P* = 0.87).

During the first year after ablation, there were thirty-seven events (death or/VT/VF recurrences) observed during follow-up, as follows: 10 (9.9%) patients died during follow-up; there were 6 (9%) deaths in the single-RFA group vs. 4 (11.8%) deaths in the repeat-RFA group (P = 0.729). There were 27 (26.7%) patients with VT/VF recurrence; there were ten (29.4%) patients in the repeat-RFA group vs. 17 (25.4%) in the single-RFA group (P = 0.66). Kaplan–Meier survival log-rank analysis (Figure 3) did not demonstrate differences in all-cause mortality (P = 0.62) or recurrences (P = 0.65) between repeat-RFA vs. single-RFA subgroups during the first year after ablation (Figure 3). Positive PVS (Table 2) was the only independent factor to predict death or VT/VF recurrences during the first year after ablation (hazard ratio [HR], 8.8; 95% confidence interval [CI], 3.6–21.2; P = 0.001).

Figure 4 shows that Kaplan–Meier survival curves analysis did not demonstrate differences regarding all-cause mortality and VT/VF recurrences during follow-up stratified by PVS result (log rank pairwise comparison for all-cause mortality between single-RFA vs. repeat-RFA for negative PVS P = 0.49, positive PVS P = 0.53; log rank pairwise comparison for VT/VF recurrences between single-RFA vs. repeat-RFA for negative PVS; P = 0.84, positive PVS P = 0.75) and type of disease (log rank pairwise comparison for all-cause mortality between single-RFA vs. repeat-RFA for ICM P = 0.21; log rank pairwise comparison for VT/VF recurrences between single-RFA vs. repeat-RFA for NICM P = 0.55, ICM P = 0.49). Additionally, repeat-RFA did not influence first year all-cause mortality (HR, 1.36; 95% CI, 0.38–4.84; P = 0.628) or first year VT/VF recurrences (HR, 1.19; 95% CI, 0.54–2.601; P = 0.66) in Cox regression analysis. This was evident even after adjusting for positive PVS for both all-cause mortality (HR, 0.1.27; 95% CI, 0.36–4.52; P = 0.706) and recurrences (HR, 0.1.06; 95% CI, 0.48–2.33; P = 0.86).

We observed that, during the first year after ablation, no patients died after obtaining negative PVS, whereas 3 out of 12 (33.3%) with positive PVS died (P = 0.011). Recurrences were observed more frequent during the first year in repeat-RFA patients with positive PVS (n = 8; 66.7%) compared to negative PVS (n = 2; 9.1%; P = 0.001).

DISCUSSION

Patient and procedural characteristics

Current evidence regarding repeat-RFA VT procedures stems from five previously published sources [3–7]. Notably, our paper has exclusively analysed ES patients requiring repeat-RFA (which have only represented up to 60% of previous cohorts [3]). The rationale of a dedicated analysis was based on the previous observation that patients that require redo procedures are

more likely to present in electrical storm conditions [3, 4]. Repeat-RFA patients are more frequently affected by NICM, and require more epicardial access and ablation, which has been demonstrated [3]. The incremental value of epicardial substrate identification and ablation has also been shown in patients with previously failed endocardial ablations (even in the setting of ischemic cardiomyopathies with endo-epicardialy extending scars) [5, 7]. Although both compared subgroups have similar LVEF and heart failure severity at admission, repeat-RFA subjects had a higher severity of functional mitral regurgitation and significantly longer hospitalizations. This has been a consequence of more frequent pericardial effusions which required specific management, considering the higher need of epicardial ablation (one in three repeat-RFA patients). Interestingly, although we expected repeat-RFA procedures to encounter more extensive total scar and BZ area due to previous ablations, there was no significant difference compared to single-RFA cases.

Importantly, the rate of SMVT elimination by ablation was comparable in the single-RFA and the repeat-RFA subgroups (in approximately two thirds of cases), which is similar to reported results stemming from post-infarction repeat-RFA cases [5]. In contrast, Tzou et al. [3] have shown that repeat-RFA are less effective compared to index ablations, as almost 40% of patients are still inducible after ablation. Notably, even though pre-ablation amiodarone treatment was comparable between subgroups, it was more prevalent than in Tzou et al. [3] analysis, which may impact the observed rate of residual VT inducibility. Both subgroups had a significantly comparable high rate (>75%) of RMN use during ablations, which is particular to our centre compared to others in the vicinity. However, Akca et al. [6] have emphasized that RMN-based VT ablations appear not to improve procedural results or outcomes compared to manual ablations and only reduce fluoroscopy exposure.

In conclusion, it seems that despite higher procedural complexity in terms of epicardial ablation and more frequent non-ischemic substrate, repeat-RFA procedures may achieve similar rates of SMVT non-inducibility as single ablations.

All-cause mortality and VT/VF recurrences during follow-up

In our cohort, both single-RFA and repeat-RFA subgroups demonstrated high, yet comparable all-cause mortality (approximately one third) over 2 years of monitoring. Furthermore, survival analysis during the first year showed comparable rates of death in single vs. repeat-RFA patients, both in LVEF ≤40% vs. LVEF >40% subgroups, in ICM cases and in both positive and negative results to PVS. Similarly, one-year all-cause mortality was also in line with previous reported data by Tzou et al. [3]. One of the key factors influencing survival after VT

ablation is arrhythmic recurrence [2]. Although based on a limited number of cases, this is also evident in our data, as more than one in two patients that suffer recurrences died during follow-up, irrespective of undergoing one or multiple ablations. In contrast, mortality rates for both single and repeat-RFA patients that do not develop recurrences are approximately 15% over two years of follow-up. Notably, our data suggests the need for a redo VT ablation procedure did not influence mortality by itself, which differs from current evidence. Data published by the International VT Ablation Center Collaborative Group [3] clarify that repeat-RFA procedures have worse outcomes compared to single-RFA. However, the authors emphasize that if post-ablation VT recurrence is efficiently precluded (by adequate arrhythmogenic substrate elimination), survival does become comparable to that of single-RFA cases [3]. Notably, during the first year after ablation in the repeat-RFA subgroup, achieving end-procedural negative PVS was not followed by any deaths, whereas a positive PVS was associated with a rate of mortality of 33.3%, which emphasizes the importance of obtaining VT non-inducibility for redo procedures.

Recurrences were similar in repeat-RFA compared to single-RFA cases affecting 38.2% and 34.3% of patients, respectively, over the monitored interval. Residually inducible SMVTs at end-procedural PVS independently induced an eight-fold higher risk of events during the first year after ablation in our prediction model. In this sense, elimination of all arrhythmogenic substrate is paramount to reduce the risk of future arrhythmic episodes. However, as shown by Yokokawa et al. [19] new VTs after an index ablation may rely on either new circuits formed at the vicinity of the radiofrequency sites or on distinct substrate that was not considered to be potentially arrhythmogenic and was not the focus of ablation or end-procedural testing or on newly-formed substrate [20]. Evidently, incomplete index ablation is also commonly encountered and should mandate adequate end-procedural testing [20]. Our data showed that persistent VT inducibility at the end of the previous ablation significantly shortened the time to requiring a redo procedure. This was particularly evident for patients with previous ablation failure (i.e., persistent inducibility of clinical SMVT) which demonstrated a median interval of three weeks separating the procedures (which were performed during the same hospitalization in seven out of eight cases). This is why more aggressive PVS protocols (which has already been discussed in previous papers) or the utilization of prior-to-discharge non invasive PVS may enhance detection of residual VT circuits [12, 21–23].

One other observation is that chronic amiodarone treatment was more frequently present compared to previous reports (70.1% compared to 55% in repeat-RFA subgroup) [3]. Di Biase

et al. [24] demonstrated that “on” amiodarone ablations had a higher rate of long-term recurrences possibly due to the effect of hiding relevant substrate during PVS.

Hence, our data suggests that repeat-RFA procedures can offer a similar clinical course in terms of all-cause mortality and recurrences as single-RFA procedures. This, however, requires further validation in larger-scale samples dedicated to ES patients.

Limitations

This study included a limited number of consecutive patients (101) that developed a limited number of events during follow-up (10 deaths and 27 VT/VF recurrences during the first year after ablation and 31 deaths and 36 VT/VF recurrences overall) which were retrospectively evaluated which may create statistical bias; furthermore, repeat-RFA subjects had previous ablation procedures performed in other centres before referral to the study hospital which may impact the uniformity of procedural strategies previously applied; however, it seems there were no significant differences between outcomes in patients that had been previously treated by ablation in other hospitals; moreover; previous three-dimensional mapping information was not available in order to establish dynamic scar changes responsible for VT recurrences. Due to limited consistency in collection of data regarding causes of death, we only reported all-cause mortality, irrespective of cardiovascular (arrhythmic or non-arrhythmic) or non-cardiovascular causes.

CONCLUSION

Despite a higher need for epicardial ablation and more frequent non-ischemic myocardial substrate, repeat-RFA for individuals with electrical storm appears to be associated with similar long-term all-cause mortality and recurrences compared to single-RFA patients during the first year after ablation.

Article information

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Table 1. Demographic, clinical and procedural characteristics of patients (overall and repeat procedures vs. single procedure subgroups)

	Overall	Repeat-RFA	Single-RFA	*P*-value
Number of cases	101	34	67	

Age, years, mean (SD)	59.69 (12.8)	59.9 (14.7)	59.5 (11.8)	0.89
Males, n (%)	87 (86.1)	31 (91.2)	56 (83.6)	0.37
T2DM, n (%)	26 (33.7)	9 (26.5)	17 (25.4)	0.99
Active smoking, n (%)	20 (19.8)	8 (23.5)	12 (17.9)	0.75
Dyslipidemia, n (%)	62 (61.4)	21 (61.8)	41 (61.2)	0.99
Hypertension, n (%)	63 (62.4)	20 (58.8)	43 (64.2)	0.66
Overweight/obesity, n (%)	35 (34.7)	10 (29.4)	25 (37.3)	0.51
Beta-blocker before ablation, n (%)	83 (82.2)	27 (79.4)	56 (83.6)	0.59
Amiodarone before ablation, n (%)	68 (67.3)	22 (64.7)	46 (68.7)	0.82
CRT before ablation, n (%)	15 (14.9)	6 (17.6)	9 (13.4)	0.56
NYHA III/IV at admission, n (%)	29 (28.7)	8 (23.5)	21 (31.3)	0.49
Moderate or severe MR at admission, n (%)	**33 (32.6)**	**16 (48.5)**	**17 (25.4)**	**0.025**
AF at admission, n (%)	13 (12.9)	4 (11.8)	9 (13.4)	0.99
Type of AF — paroxysmal	24 (23.8)	9 (26.5)	15 (22.4)	0.67
Type of AF — persistent	8 (7.9)	4 (11.8)	4 (6)	
Type of AF — permanent	8 (7.9)	2 (5.9)	6 (9)	
LVEF, mean (SD)	32 (11.6)	32.9 (12)	31.5 (11.5)	0.56
Days of hospitalization, median (IQR)	**6 (4–10)**	**10 (5.2–19.5)**	**5 (4–8)**	**0.07**

NICM, n (%)	**34 (32.7)**	**16 (47.1)**	**18 (26.9)**	**0.04**
Endoepicardial ablation, n (%)	**21 (20.8)**	**11 (32.4)**	**10 (14.9)**	**0.041**
Remote magnetic navigation ablation, n (%)	79 (78.2)	27 (79.4)	52 (77.6)	0.99
Total scar/total map area, mean percentage (IQR)	20.7 (10.8–28.8)	20.3 (9.1–34.5)	20.9 (11.1–27.2)	0.86
Border-zone/total scar area, mean percentage (IQR)	60.6 (41.7–77)	60.1 (45.6–74.2)	63.4 (41.3–79.7)	0.91
Number of SMVTs induced during the procedure, median (IQR)	2 (1–3)	2 (1–3)	2 (1–3)	0.77
Substrate-based ablation strategy, n (%)	96 (95)	33 (97.1)	63 (94)	0.66
Activation mapping-based strategy, n (%)	62 (61.4)	23 (67.6)	39 (58.2)	0.39
Partial success, n (%)	32 (31.7)	12 (35.3)	20 (29.9)	0.65
Negative PVS, n (%)	55 (54.5)	19 (55.9)	36 (53.7)	0.99
Procedure duration, min, median (IQR)	185 (146–246.5)	180 (141–267.5)	185 (145–236)	0.35
Ablation-related non-vascular access-related complications, n (%)	**9 (11.5)**	**6 (24)**	**3 (5.7)**	**0.027**
Vascular access hematoma, n (%)	3 (3.1)	2 (6.3)	1 (1.5)	0.24
Beta-blocker after, n (%)	87 (86.1)	29 (85.3)	58 (86.6)	0.99

Amiodarone after, n (%)	72 (71.3)	25 (73.5)	47 (70.1)	0.81

Abbreviations: AF, atrial fibrillation; CRT, cardiac resynchronization therapy; IQR, interquartile range; LVEF, left ventricular ejection fraction; MR, mitral regurgitation; NICM, non-ischemic cardiomyopathy; NYHA, New York Heart Association; PVS, programmed ventricular stimulation; repeat-RFA, repeat procedures; SD, standard deviation; single-RFA, single-procedures; SMVT, sustained monomorphic ventricular tachycardia; T2DM, type 2 diabetes mellitus

Table 2. Univariate and multivariate Cox proportional hazards analysis for predictors of death or VT/VF recurrences during the first year of follow-up after ablation

Parameter	Univariate model		Multivariate model	
	HR (CI 95%)	*P*-value	HR (CI 95%)	*P*-value
Age	1.03 (0.9-1.06)	0.071		
Repeat-RFA	1.1 (0.5-2.4)	0.768		
NYHA III/IV at admission	**2.4 (1.1-5.1)**	**0.018**	**1.6 (0.7-3.4)**	**0.218**
Moderate or severe FMR at admission	1.7 (0.8-3.6)	0.156		
AF at admission	1.4 (0.9-2.2)	0.110		
LVEF	0.97 (0.94-1.006)	0.108		
NICM	1.9 (0.9-4.1)	0.075		
BZ/total scar area percentage	1.02 (0.9-1.05)	0.177		
Positive PVS	**9.7 (4.1-22.9)**	**< 0.001**	**8.8 (3.6-21.2)**	**< 0.001**
Ablation-related non-vascular access-related complication	2.4 (0.8-7.4)	0.115		

Abbreviations: BZ, border zone; FMR, functional mitral regurgitation; HR, hazard ratio; NICM, non-ischemic cardiomyopathy; RFA, radiofrequency catheter ablation; other — see Table 1

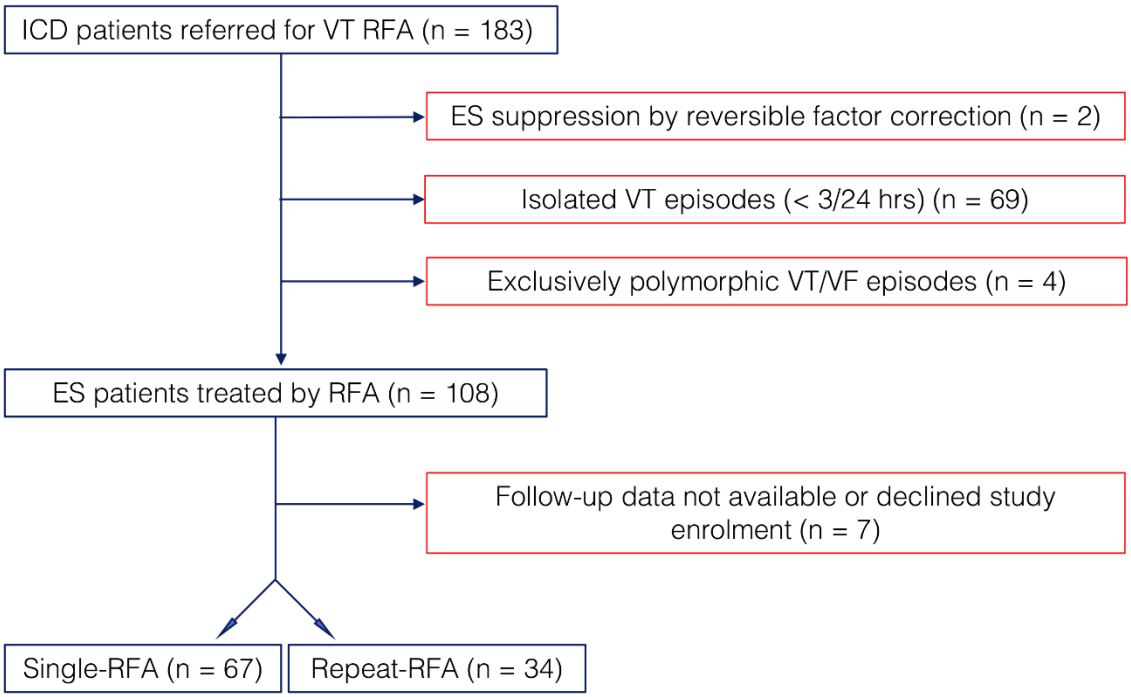

Figure 1 Flowchart detailing the selection process of the final study population

Abbreviations: ES, electrical storm; ICD, implantable cardioverter defibrillator; RFA, radiofrequency catheter ablation; VF, ventricular fibrillation; VT, ventricular tachycardia

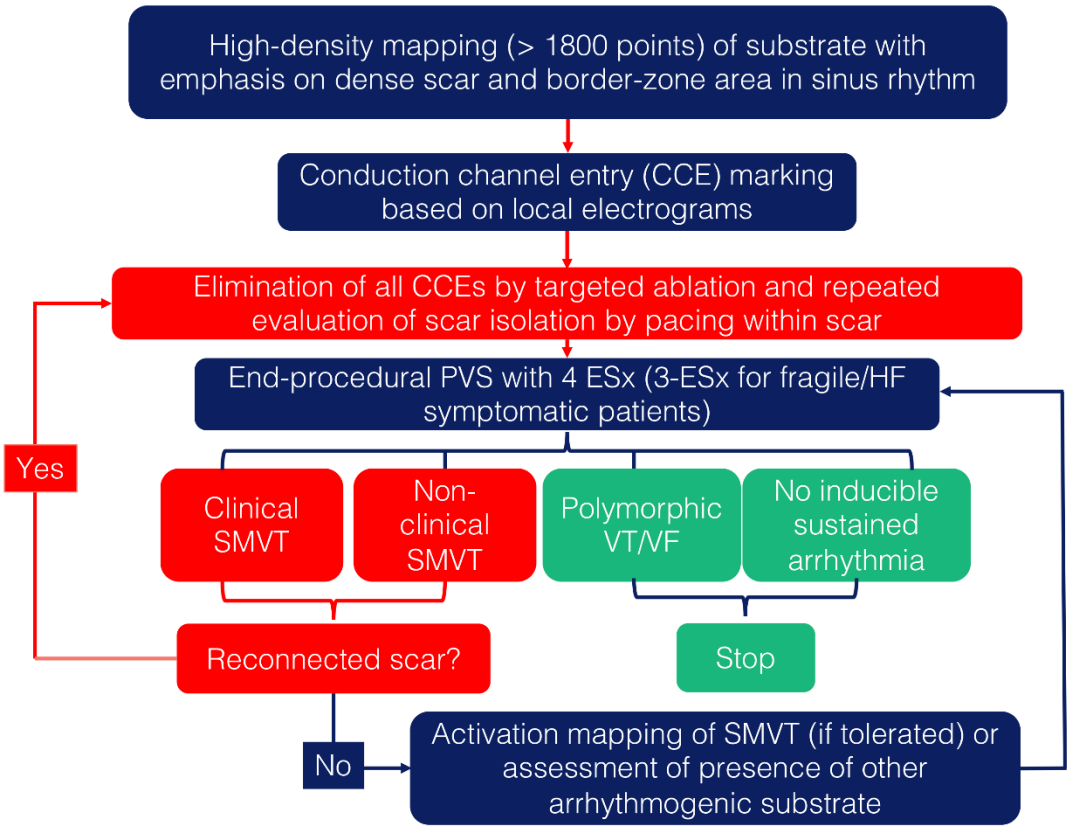

Figure 2. Flowchart detailing the ablation protocol applied for electrical storm patients

Abbreviations: CCE, conduction channel entry; ESx, extrastimuli; HF, heart failure; SMVT, sustained monomorphic ventricular tachycardia, other — see Figure 1

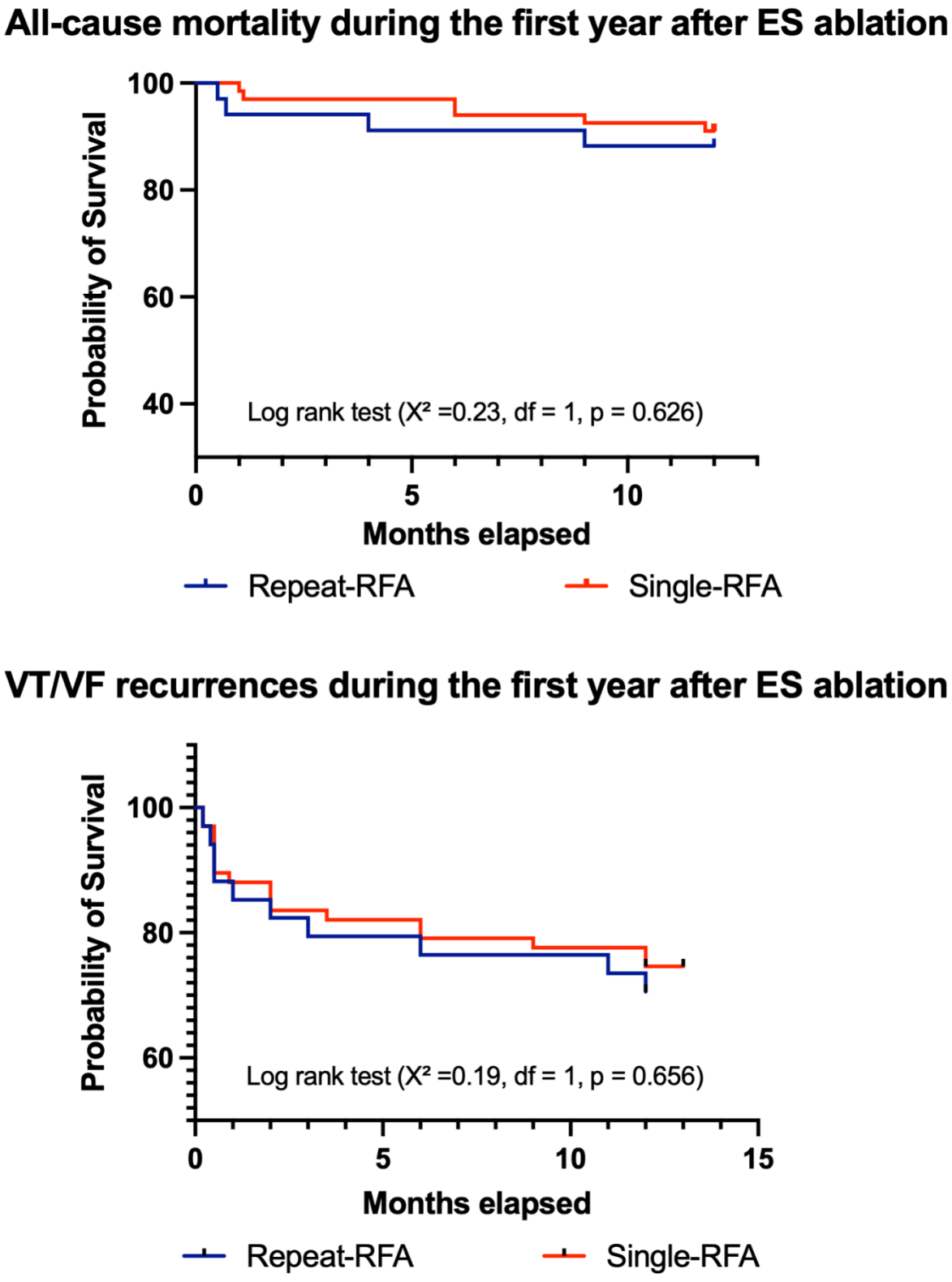

Figure 3. Kaplan–Meier survival curves showing all-cause mortality (top) and VT/VF recurrences (bottom) during the first year after ablation dichotomized by the type of RFA (single vs. repeat-RFA subgroups)

Abbreviations: LVEF, left ventricular ejection fraction; other — see Figure 1

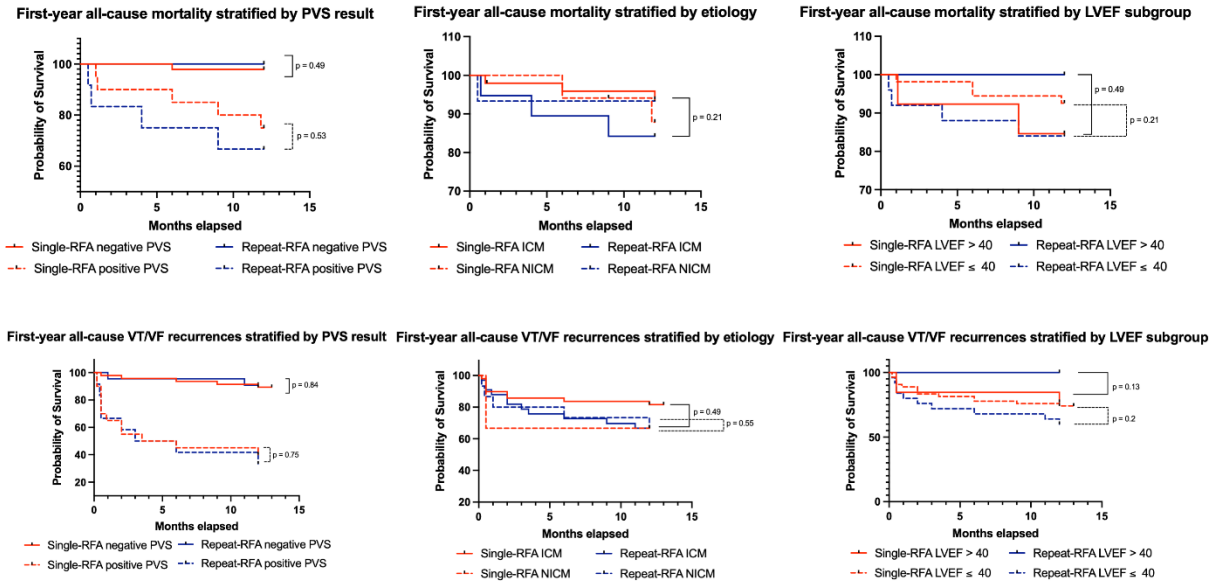

Figure 4. Kaplan–Meier survival curves showing all-cause mortality and VT/VF recurrences during follow-up dichotomized by the type of RFA (single vs. repeat-RFA subgroups) and stratified by PVS result (left column) and type of etiology (ICM vs. NICM) (central column) and LVEF subgroup (right column)

Abbreviations: ICM, ischemic cardiomyopathy; NICM, non-ischemic cardiomyopathy; PVS, programmed ventricular stimulation; other — see Figures 1 and 3