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ORIGINAL ARTICLE

The role of catheter ablation in the management of patients with implantable cardioverter defibrillators presenting with electrical storm

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Abstract *Objective:* Electrical storm (ES) is not uncommon among patients with an implantable cardioverter defibrillator (ICD) in situ. Catheter ablation (CA) may suppress the arrhythmia in the acute setting and prevent ES recurrence.
Methods: Nineteen consecutive patients with an ICD in situ presenting with ES underwent electrophysiologic studies followed by CA. CA outcome was classified as a complete success if both clinical and non-clinical tachycardia were successfully ablated, partial success if ≥1 non-clinical tachycardia episodes were still inducible post—CA, and failure if clinical tachycardia could not be abolished. Patients were followed for a median period (IQR) of 5.6 (1.8-13.7) months. The primary endpoint was event-free survival from ES recurrence. The secondary endpoint was event-free survival from a composite of ES and/or sustained ventricular tachycardia (VT) recurrence.
Results: Clinical arrhythmia was successfully ablated in 14 out of 19 (73.7%) cases after a single CA procedure. A completely successful CA outcome was associated with significantly increased ES-free survival compared with a partially successful or failed procedure (Log rank P=0.039). Nevertheless, patients with acute suppression of all tachycardia episodes (n=11), relative to those with a partially successful or a failed CA procedure (n=8), did not differ in incidence of the composite endpoint of sustained VT or ES (Log rank P=0.278).

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Conclusion: A single CA procedure can acutely suppress clinical arrhythmia in three-quarters of cases. A completely successful CA outcome can prolong ES-free survival; however, sporadic ICD therapies cannot be abrogated.

1. Introduction

The introduction of implantable cardioverter defibrillators (ICDs) to the clinical armamentarium has resulted in a paradigm shift in the management of patients with structural heart disease, both in primary[1] and secondary[2] sudden death prevention. The use of ICDs has enabled patients to survive multiple sustained ventricular tachycardia/fibrillation (VT/VF) episodes that otherwise might have proved fatal. However, the use of ICDs has also paved the way for the emergence of another clinical entity: electrical storm (ES), defined as three or more distinct VT/VF episodes within 24 hours.

ES is not uncommon among ICD recipients[3] and has been reported at 23% over a one year follow-up,[4] ranging from 10%[5] to 40%.[6] ES events have been associated with increased hospitalization rates[4] and increased cardiac and all-cause mortality.[7] ES events adversely impact survival in ICD patients irrespective of the causative arrhythmia.[5] The same applies to Cardiac Resynchronization Therapy-Defibrillator (CRT-D) patients with ES who experience increased heart failure-related hospitalization and mortality rates relative to those with no ES.[8] In most cases, there is no clear precipitant, and medical therapy alone may be inadequate to control the arrhythmia. Electrophysiologic studies followed by catheter ablation (CA) may acutely suppress the arrhythmia[9] and modify the arrhythmogenic substrate or eliminate potential triggers, such as ventricular ectopics, and thereby prevent future episodes.[10,11]

In the present study, we aimed to assess the short-term efficacy of CA in suppressing clinical arrhythmia underlying ES in a cohort of patients presenting with a cluster of multiple appropriate ICD therapies. Furthermore, we sought to investigate which patient characteristics and/or procedural aspects define event-free survival from recurrent ES and/or sustained VT episodes.

2. Methods

2.1. Study population

All patients (n = 19) with complete follow-up data who presented at our center between April 2008 and May 2015 with ES and had previously undergone defibrillator placement (ICD or CTR-D) were included in the study. ES was defined as three or more distinct episodes of VT or VF within 24 hours leading to appropriate defibrillator interventions. Consecutive ICD therapies following previously failed attempts to restore sinus rhythm were considered to be a single arrhythmic episode. Inappropriate ICD interventions for supraventricular tachycardia or due to device malfunction were not considered. Patients presenting with polymorphic VT or VF in the context of electrolyte abnormalities or an acute coronary syndrome were not included in the analysis. The study protocol was approved by our institution's ethics committee.

2.2. Electrophysiologic study and CA

On admission, all participants were transferred to the coronary care unit and were treated as per guidelines with intravenous beta-blockers, amiodarone, sedatives and device reprogramming. All patients underwent electrophysiologic studies during the index hospitalization as soon as hemodynamic stability was achieved. As per our institution's ventricular stimulation protocol, we aimed to reproduce the clinical arrhythmia by pacing the right ventricle at three different cycle lengths adding up to three extra stimuli at various coupling intervals. All inducible VTs were mapped using the Ensite-Navx® electro-anatomical mapping system.

All inducible VTs (clinical and non-clinical) were targeted for ablation using irrigated tip ablation catheters. In well-tolerated VTs, the exact location of the critical tachycardia isthmus was identified via activation mapping and further confirmed with entrainment maneuvers. In cases where the clinical VT was not inducible or not tolerated, CA was attempted during sinus rhythm. Substrate mapping was undertaken, and radio-frequency energy was delivered at areas exhibiting fragmented and late potentials as well as high pace-map scores (Figure 1).

Complete success was defined as complete suppression of all clinical and non-clinical VTs that were reproduced in the lab. In cases in which one or more non-clinical VTs remained inducible at the end of the study, the CA outcome was considered to be a partial success. The CA outcome was characterized as a failure if the clinical VT remained reproducible by the end of the study.

2.3. Follow-up and study endpoints

After hospital discharge, patients were reviewed after one month, three months and then twice a year (or sooner if clinically indicated) at our center's dedicated pacing clinic. Clinic visits involved history taking focused on arrhythmic episodes, a brief physical examination, an ECG and device interrogation using a programmer. The follow-up period ranged from the CA date to ES recurrence. For patients with an uneventful course, the follow-up period was terminated on the date of their last visit at the pacing clinic before

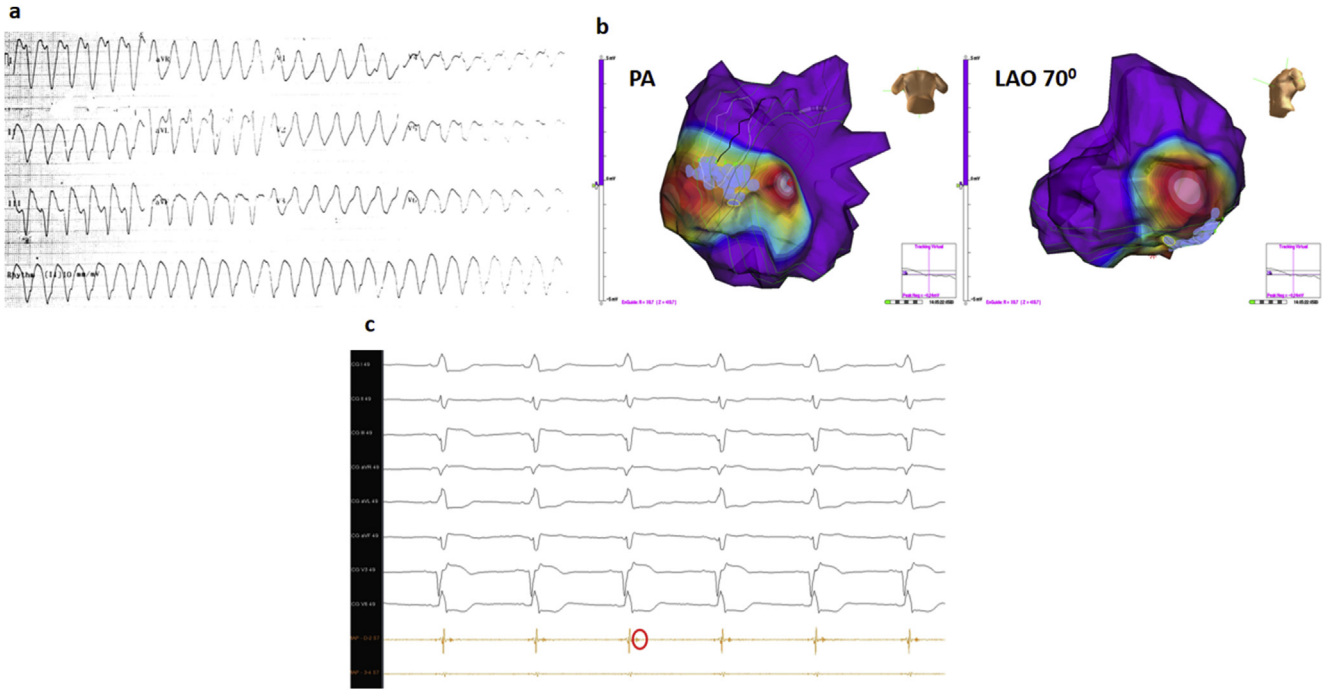

Figure 1 **a**. Clinical tachycardia exhibiting a RBBB morphology, superior axis and deep S waves along the lateral leads. b. Propagation map during ventricular tachycardia (PA/LAO70^0 views) of the same patient as in **Figure 1.a.**, displaying the earliest activation area (denoted with red color) corresponding to the apico-lateral left ventricular wall and RF lesions (white circles) at the tachycardia critical isthmus. **c.** Catheter ablation during sinus rhythm guided by late potentials (red circle).

June 2015. The primary endpoint was event-free survival from ES recurrence. The secondary endpoint was event-free survival from the composite of appropriate ICD therapy due to sustained VT/VF or ES recurrence.

2.4. Statistical analysis

Continuous variables were tested for normality using the Kolmogorov-Smirnov test and are presented as the means ±SD or medians (IQR) accordingly. Qualitative data are presented as absolute figures and percentages. The means and medians were compared between groups using the independent sample Student's t-test or Mann-Whitney U test, respectively. The distribution of proportions between the groups was tested using the chi-square test. The annualized event rates were calculated according to the equation: $\text{annual event rate} = \left(\frac{number\ of\ events}{patient \times years}\right) \times 100$. The incidence of the primary and secondary endpoints was assessed by Kaplan-Meier event-free survival estimates, while between-groups event-free survival curves were compared using the Log Rank test. A test result with a P value of 0.05 or less was considered statistically significant.

3. Results

A total of 19 consecutive patients who presented with ES and had an ICD in situ were included in the study. In all cases, the culprit arrhythmia was sustained monomorphic VT. The median time (IQR) elapsed since ICD implantation to ES occurrence was 13.6 (4.4-41.3) months. All patients underwent an electrophysiologic study, and CA of all inducible VTs was attempted. After a single CA procedure, in 11 (57.9%) patients, complete suppression of all inducible VTs was achieved (complete success). In three (15.8%) patients, one or more non-clinical VTs remained inducible post-ablation (partial success), whereas in five (26.3%) patients, the culprit arrhythmia could not be abolished (failure).

The baseline demographic and clinical characteristics of the patients are presented in Table 1. Background medical therapy, cardiovascular implantable electronic device type/indication and CA procedural aspects are also included. No statistically significant difference in any of the above parameters was observed between patients with complete procedural success compared to those with partial success or failure. Of note, the number of different VT morphologies that were induced during the electrophysiologic study did not differ between the two patient groups.

All patients were observed for a median period (IQR) of 5.6 (1.8-13.7) months. During follow-up, seven sustained VT episodes and three ES episodes were documented. The annualized event rates for ES and combined endpoint of sustained VT or ES were 13.2% and 45.2%, respectively (Figure 2a and 2b). Patients who underwent CA with complete success, relative to those with partial success or failure, experienced significantly increased ES-free survival during follow-up (Figure 3a). However, the two groups experienced similar rates of sustained VT or ES (Figure 3b).

Table 1 Baseline characteristics of the study population (n=19). Data are absolute figures (%) or mean values ± SD [or median values (IQR) for non-normally distributed variables].

	Overall (n=19)	Complete success (n=11)	Partial success/ failure (n=8)	P value
Demographics & clinical characteristics				
Age (years)	63.5 ± 10.4	67.1 ± 9.8	58.6 ± 9.6	0.079
Gender (Male/Female)	16/3 (84.2/15.8)	10/1 (90.9/9.1)	6/2 (75.0/25.0)	0.348
HF etiology (IHD/DCM/ARVC)	14/3/2 (73.7/15.8/10.5)	9/1/1 (81.8/9.1/9.1)	5/2/1 (62.5/25.0/12.5)	0.598
NYHA (I/II/III)	1/8/10 (5.3/42.1/52.6)	1/5/5 (9.1/45.5/45.5)	0/3/5 0/37.5/62.5)	0.591
EF (%)	30.0 (22.5-35.0)	30.0 (22.5-30.0)	33.8 (23.1-36.9)	0.545
Rhythm (sinus/atrial fibrillation)	18/1 (94.7/5.3)	10/1 (90.9/9.1)	8/0 (100.0/0)	0.381
Pharmacotherapy				
Beta-blocker	18 (94.7)	11 (100.0)	7 (87.5)	0.228
Amiodarone	18 (94.7)	11 (100.0)	7 (87.5)	0.228
Sotalol	1 (5.3)	0 (0.0)	1 (12.5)	0.228
Class I AAD	3 (15.8)	1 (9.1)	2 (25.0)	0.348
ACEi/ARBs	9 (47.4)	5 (45.5)	4 (50.0)	0.845
MRAs	14 (73.7)	7 (63.6)	7 (87.5)	0.243
Digoxin	1 (5.3)	1 (9.1)	0 (0.0)	0.381
Loop diuretics	15 (78.9)	9 (81.8)	6 (75.0)	0.719
Cardiovascular implantable electronic device therapy				
Device type (ICD/CRT-D)	14/5 (73.7/26.3)	8/3 (72.7/27.3)	6/2 (75.0/25.0)	0.912
Primary/secondary prevention	4/15 (21.1/78.9)	1/10 (9.1/90.9)	3/5 (37.5/62.5)	0.134
Procedural aspects				
Inducible VT morphologies (n)	2.0 (1.0-3.0)	2.0 (1.0-3.0)	1.5 (1.0-3.0)	0.717
RF applications (n)	33.7 ± 12.9	31.3 ± 9.3	36.9 ± 16.9	0.374
Fluoroscopy time (min)	50.0 (38.0-55.0)	40.0 (38.0-50.0)	50.0 (41.0-58.8)	0.351
Total procedure time (min)	237.9 ± 61.2	249.1 ± 47.4	222.5 ± 77.0	0.364

HF=Heart Failure; IHD=Ischemic Heart Disease; DCM=Dilated Cardiomyopathy; ARVC=Arrhythmogenic Right Ventricular Cardiomyopathy; NYHA= New York Heart Association; EF=Ejection Fraction; AAD=Anti-arrhythmic Drugs; ACEi/ARBs=Angiotensin Converting Enzyme inhibitors/Angiotensin Receptor Blockers; MRAs=Mineralocorticosteroid Antagonists; ICD/CRT-D=Implantable Cardioverter Defibrillator/Cardiac Resynchronization Therapy-Defibrillator; VT=Ventricular Tachycardia; RF=Radiofrequency.

4. Discussion

In the present study, we assessed the efficacy of a single CA procedure in the acute suppression of clinical arrhythmias in a cohort of ICD patients presenting with ES. Further, we explored patient- and procedure-related factors that exhibit prognostic value regarding ES and/or sustained VT recurrence.

In our study, the rate of complete success after a single CA procedure was 57.9%, whereas in 73.7% of cases, clinical arrhythmia was acutely suppressed. In a cohort with characteristics similar to our own, the rates of complete and partial success were 44% and 84%, respectively.[11] In another study, including exclusively dilated cardiomyopathy patients, acute complete success was achieved in 63% of cases.[12] Of note, the reported outcome followed a median of 1.5 procedures per patient, and 33% of them were additionally subjected to epicardial ablation.[12] In the largest single-center study that included patients with various cardiomyopathies, the acute complete success rate was 89% after 1−3 procedures, 10.5% of which involved an epicardial approach.[10] The relatively lower acute success rates in our cohort, relative to those reported in the literature, may be attributed to the differing patient populations; 26.3% of our patients exhibited non-ischemic cardiomyopathy. Furthermore, the reported outcomes in our study were after a single CA procedure, and no epicardial approach was undertaken in any of the cases.

In our study, 84.2% of patients were free from ES after a single CA procedure, but only 63.2% were free from any VT recurrence. Our results are consistent with those of another group of investigators, who reported that CA prevented any VT recurrence in approximately half of all cases.[11] Others have reported even lower ES and VT recurrence rates post−CA, ranging from 6 to 8% and 31 to 34%, respectively.[10,13] The relatively high arrhythmia burden observed in our study may be explained, at least in part, by the fact that nearly 80% of our patients had an ICD in situ for secondary prevention. It is well documented that patients with a history of aborted sudden death or hemodynamically unstable VT are at substantially greater risk for incident ES.[8,14] Moreover, only 26.3% of our patients had a CRT in situ; there is evidence that patients treated with CRT-D are less likely to develop ES compared with standard ICD recipients, which may be attributed to the beneficial effect of CRT in cardiac electrical and structural remodeling.[14] Among CRT-D patients, the ES prevalence has been reported to be as low as 7% and appears to be confined to the subgroup of patients deemed to be non-responders.[8]

In our study, none of the patients with acute complete success experienced any ES recurrence during follow-up; on the contrary, ES recurrence was documented in 37.5% of patients in whom CA was partially successful or failed. This finding is consistent with previous reports in which a failed CA was associated with an 80% ES recurrence rate, whereas no ES episodes were documented among those patients in

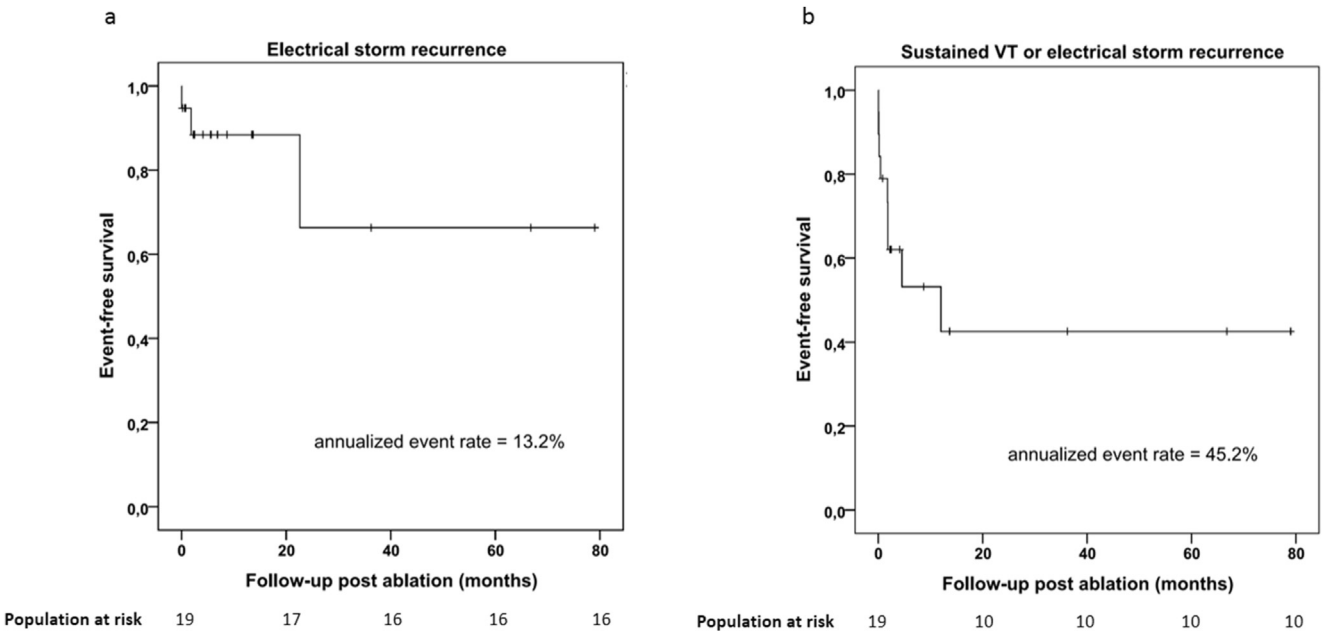

Figure 2 Event-free survival in the total patient cohort (n = 19) **a.** from electrical storm recurrence and **b.** from the composite of sustained ventricular tachycardia or electrical storm recurrence.

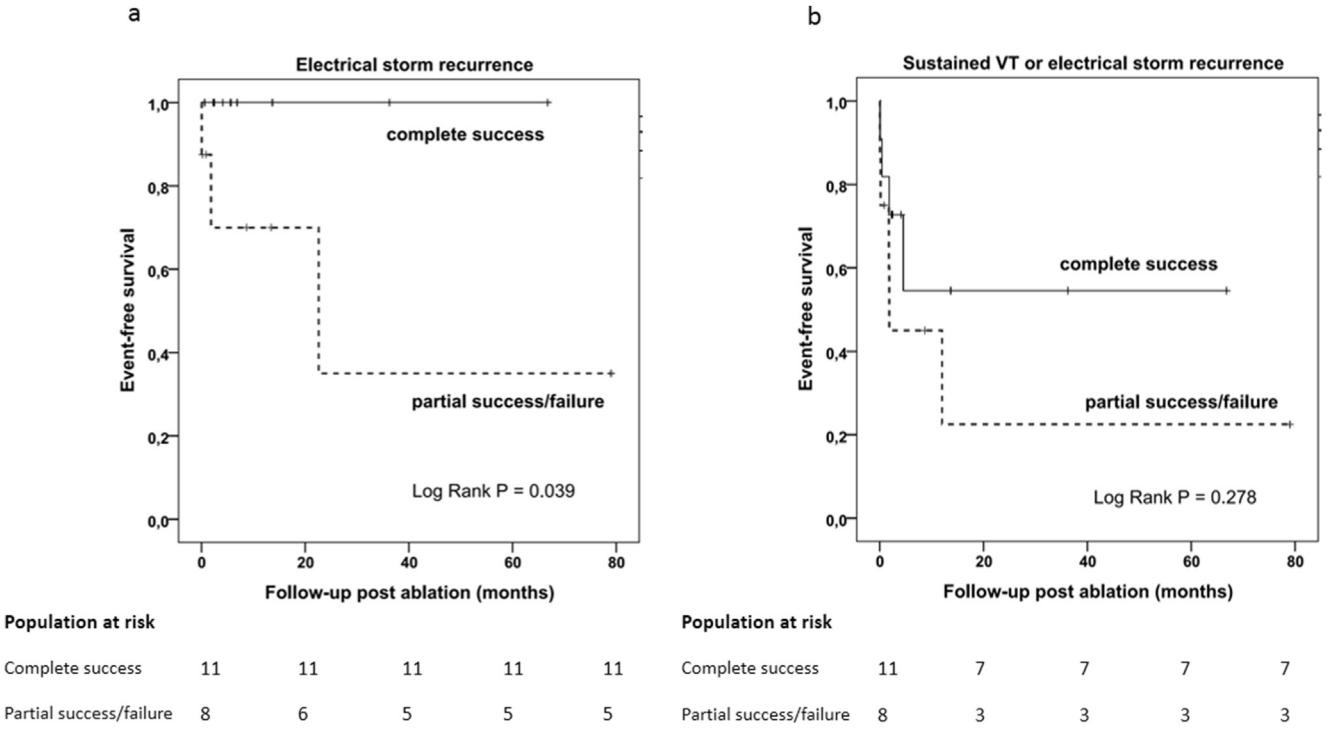

Figure 3 Event-free survival stratified by the catheter ablation outcome **a.** from electrical storm recurrence and **b.** from the composite of sustained ventricular tachycardia or electrical storm recurrence.

whom all inducible VTs were acutely abolished.[10] In our study, 63.6% of patients with complete success were free from any VT recurrence compared with only 37.5% among those with partial success or failure. However, event-free survival from the composite endpoint of sustained VT or ES did not differ significantly between the two groups.

There is some discrepancy in the literature as to whether CA acute outcomes are predictive of event-free survival from arrhythmic events. In two studies, a completely successful CA procedure was associated with longer event-free survival from VT recurrence or appropriate ICD therapies.[12,15] Interestingly, another group

reported that non-inducibility of VT post-CA was not predictive of future arrhythmic events.[11] In our study, CA outcomes were the sole predictor of event-free survival from ES recurrence.

4.1. Limitations

This is a single-center study that included a relatively small population of ICD recipients presenting with ES. Patients were identified retrospectively; however, patient data were prospectively collected. The length of follow-up was relatively short, precluding analysis of hard endpoints, including mortality. The small sample size was also prohibitive for any subgroup analysis.

5. Conclusions

Our results indicate that a single CA procedure can effectively suppress clinical arrhythmias in approximately three-quarters of patients presenting with ES. Ideally, all inducible tachycardias should be targeted for ablation as following this approach appears to diminish the likelihood of ES recurrence. However, even a completely successful CA outcome is insufficient to prevent incident sporadic VT episodes triggering appropriate ICD therapies.

Conflict of interests

There is no conflict of interest between any of the authors and any institutional or commercial establishment. No funding was received for the present study.

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