Clinical Medicine Insights: Cardiology

ORIGINAL RESEARCH

Predictors of Success in Ablation of Scar-Related Ventricular Tachycardia

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Abstract: During ablation of re-entrant ventricular tachycardia (VT) 3-dimensional mapping systems are now used to properly delineate the scar tissue and aid ablation of scar-related VT. The aim of our study was to outline how the mode of ablation predicts success and recurrence in large scar-related VT. When comparing patients with recurrence and patients with no recurrence, univariate analysis showed that number of ablation lesions (28 ± 8 vs. 12 ± 8, $P = 0.01$) and more linear ablation lesions rather than focal lesions ($P = 0.03$) were associated with long-term success. We demonstrated that more extensive ablation lesions and creation of linear lesions is associated with better success rate and lower recurrence rate during ablation of large scar-related ventricular tachycardia.

Keywords: ventricular tachycardia, myocardial scar, RF-ablation

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Introduction

Reentry is the major mechanism of ventricular tachycardia (VT) associated with myocardial scarring. The reentry circuits can be large, extending over several centimeters. The circuits often contain critical isthmuses or channels that can be identified using entrainment mapping, where focal ablation lesions can interrupt the circuit. However, radiofrequency (RF) ablation for VT is often difficult, in part because of the frequent presence of multiple reentry circuits, giving rise to multiple VT morphologies and to unstable VTs that do not allow extensive mapping.[1,2]

The borders of reentry circuit isthmuses are defined by conduction block. In animal models studied several days after infarction, this block is often functional in nature.[3,4] In human hearts explanted many years after the infarction, extensive fibrosis creating areas of fixed conduction blockage is often present.[5,6] These observations suggest that reentry circuit isthmuses can potentially be defined during sinus rhythm by delineating the areas of dense fibrous scar. This work was done to study the predictors of success of scar-related VT ablation using a 3-dimensional (3D) electro-anatomical CARTO mapping system.

Methods

Study population

This study included 34 patients with scar-related sustained monomorphic VT who were referred for RF catheter ablation at EP lab at Ain-Shams University hospitals between January 2008 and June 2010. IRB approval and the written, informed consent of the 34 patients were obtained.

Careful history and clinical examination was performed on all patients with a special emphasis regarding risk factors, history of sudden cardiac death, prior myocardial infarction or cardiac surgery, ICD implantation with careful reviewing of VT episodes and number of shocks, analysis of the presenting arrhythmia (type, frequency, hemodynamic stability, morphology) and concomitant medical therapy.

Findings of the different cardiac imaging modalities (echocardiography, myocardial perfusion, cardiac CT and MRI) were documented, especially those related to LV ejection fraction, segmental wall motion abnormalities, and the presence or absence of myocardial scar or valvular affection.

Indications for ablation included frequent ICD shocks in spite anti-arrhythmic drugs, and frequent VT recurrence in spite anti-arrhythmic drugs in patients without ICDs.

Electrophysiological procedure

All patients gave a written consent and the study was approved by the local ethics committee.

Systemic anticoagulation was maintained with intravenous administration of unfractionated heparin (initial bolus of 50 IU/kg IV followed by 1000 to 2000 IU per hour) throughout the procedure guided by serial measurement of ACT.

Mapping and ablation was carried out using the CARTO-XP (Biosense Webster, Inc., Diamond Bar, CA, USA) with the 8 Fr Navistar catheter (Biosense Webster, Inc.). Intracardiac electrograms (EGMs) were filtered at 30 to 400 Hz and displayed at 100 mm/s on a real-time recording system (Prucka Inc., USA); peak-to-peak amplitude was measured automatically.

Mapping techniques

Mapping during VT (Activation map)

If tachycardia was hemodynamically well tolerated, the initial mapping modality was activation mapping; the ventricle was mapped during the induced clinical VT by dragging the mapping catheter over the endocardium. Mapping began in the LV if the tachycardia had right bundle branch block (RBBB) morphology. Otherwise, mapping was initiated in the right ventricle (RV).

Localization of the critical isthmuses of the reentrant circuits was the target. Infarct regions were sought first, and more detailed mapping was achieved around these areas with proper identification of the whole scar. Regions of early activation were identified and further mapping was performed in these regions with the recording of low-amplitude potentials, diastolic potentials, or double potentials to localize potential critical isthmuses.

Sites with local signals near the onset or preceding the QRS complex were mapped in higher density. Entrainment mapping from these sites was carried out to determine their proximity to the reentrant circuit and their location within the critical isthmus. Voltage maps were created automatically with activation map in CARTO system (Fig. 1).

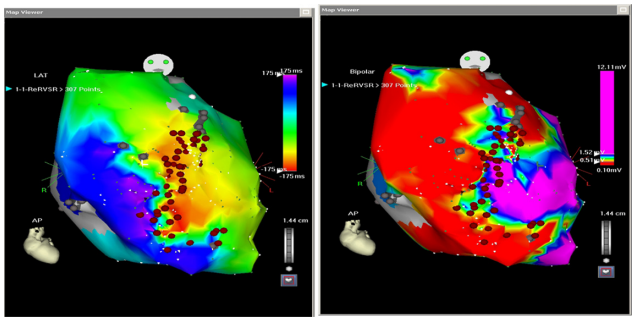

Figure 1. Activation map in AP view (left panel) and voltage map in the same view (right panel) in a patient who had scar-related RV-VT.
Notes: The voltage map shows a large scar involving the anterolateral wall of RV. Ablation involved the isthmus of the re-entry circuit as seen on the activation map closer to the exit site area and as seen on the voltage map it was located near the medial edge of the scar.

Sites targeted for ablation were the sites at which entrainment resulted in:

1. Concealed fusion
2. Post-pacing interval (PPI) within 30 ms of the tachycardia cycle length (TCL)
3. Stimulus to QRS interval (S-QRS) = Diastolic potential to QRS interval or within 20 msec[7] (Fig. 2).

Mapping during sinus rhythm (voltage map)

If the VT was non-mappable either due to being hemodynamically unstable (signs of low perfusion status which necessities cardioversion to sinus rhythm for adequate peripheral perfusion), or due to non-inducible, changing morphology during the same VT or more than 2 different VT morphologies, then voltage maps were constructed during sinus or paced rhythm. In voltage maps, normal myocardium was defined as bipolar voltage $>$ 1.5 mV, Dense scar was defined as bipolar voltage $<$ 0.5 mV, while abnormal myocardium was defined as bipolar voltage between 0.5 and 1.5 mV, which is most commonly found surrounding the scar identified as scar border zone in which most isthmuses are located.[8]

12-lead ECG of spontaneous and induced VT was analyzed to regionalize the site of origin of the VT using standard criteria. Pace mapping was performed to produce QRS morphology similar to that of clinical/inducible VT (Fig. 3). Sites of perfect pace-match with delay between pacing stimulus and the onset of QRS (S-QRS)

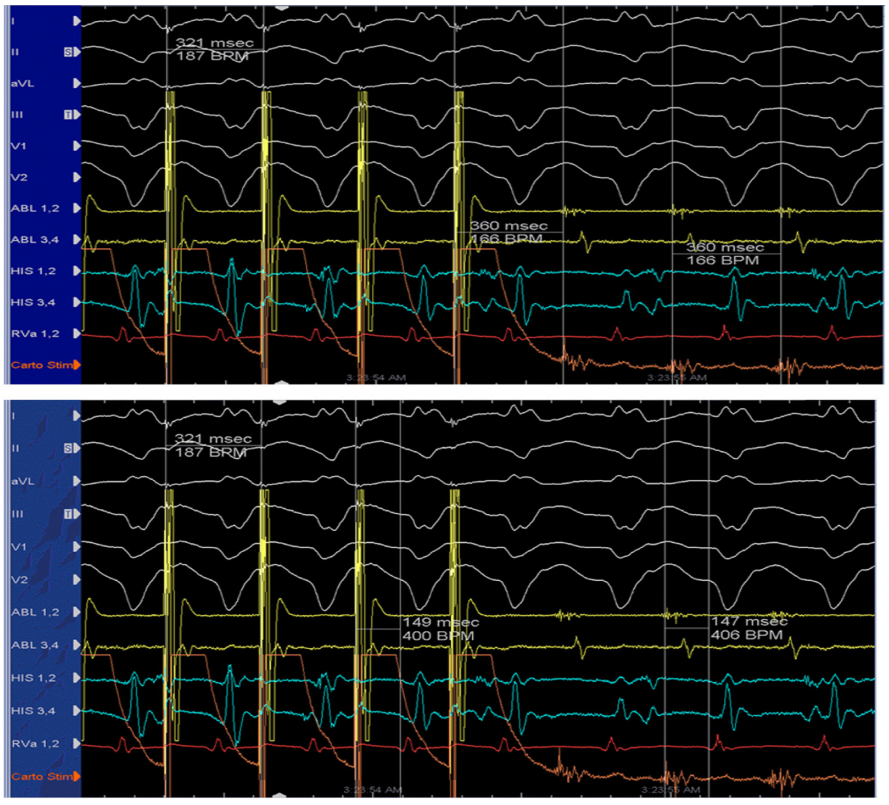

Figure 2. Surface ECG and EGMs obtained from ablation catheter (ABL), His catheter (His) and RV apical catheter (RVa) during VT.
Notes: Entrainment mapping in a patient who had scar related VT, (upper panel) shows low voltage mid diastolic potentials that is captured demonstrating entrainment with concealed fusion and the PPI = TCL, (lower panel) shows stimulus to QRS interval = diastolic potential to QRS interval.

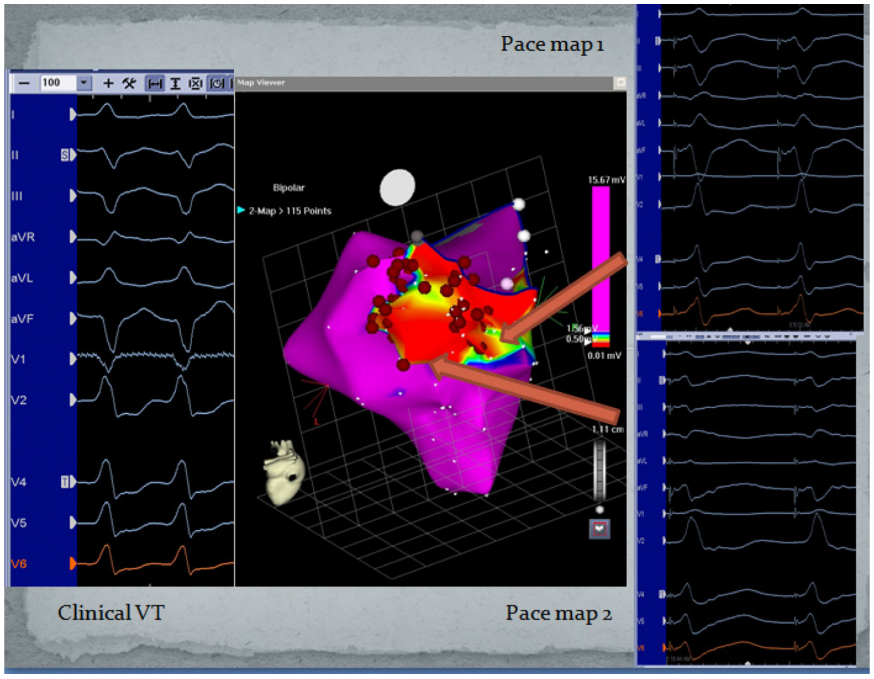

Figure 3. A Voltage map of the LV in a patient with inferoposterior wall LV scar presented with clinical VT (left panel), which was induced at the beginning of the study.
Notes: A perfectly matching pace mapping to the clinical VT was achieved at the septal border zone of the scar (pace map 1) while pacing from the inferior border zone (pace map 2) showed mismatch to clinical VT.

at the scar margin identify sites for critical isthmuses and were targeted by ablation. A linear ablation set was used until the VT was rendered non-inducible.

RF ablation strategies

RF current was delivered from a mapping/ablation catheter (Navistar thermo-cool irrigated tip catheter, Biosense Webster Inc.) with a 3.5-mm tip. RF current was delivered with power of 35 Watt (maximum was 40 W) was applied in a temperature-controlled mode. The target temperature was 40 °C, with a cooling rate of 18 mL/min. The continuous flow during mapping was 2 mL/min.

Sequential point lesions creating linear lesion across the critical isthmus

In both the VT-mapping group and the substrate-mapping group, patients were treated with focal ablation lesions (treatment with focal unconnected RF-applications in an attempt to ablate a critical channel) and/or linear ablation lesions (connected RF-applications forming lines placed inside the scar or at its border zone, connecting electrical barriers, or areas of block, or arranged in a cross-like fashion through the scar area; Fig. 4).

Strategy of placing linear lesions

Linear lesions were placed using 3 guiding principles:

1. Lesions would extend across the borders of the endocardium that demonstrated abnormal bipolar electrogram voltage.
2. Lesions would typically extend from the areas demonstrating the lowest amplitude signals (0.5 mV) to areas demonstrating a distinctly normal signal (>1.5 mV) or to a valve continuity.

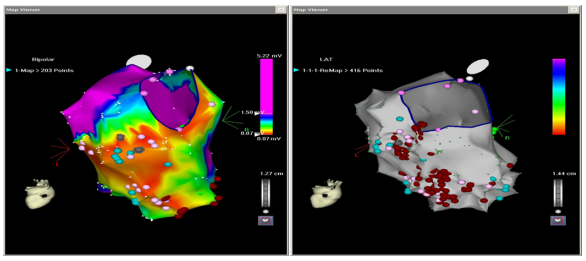

Figure 4. (Left panel) shows voltage map in modified PA view with large scar involving inferior, posterior and lateral wall of LV with detected areas of double potentials representing areas of block (blue tag points). (right panel) shows sites of ablation lesions (red point tags), linear ablation lesions at an isthmus on the lateral edge of the scar connecting areas of double potentials and mitral annulus and on the other side of the scar another linear ablation lesions were placed along an isthmus situated between to areas of block (blue point tags).

3. Lesions would cross through the border zones at sites where mapping approximated the QRS morphology of VT.

Endpoints and success of ablation

The endpoint of focal applications in the VT-mapping group was VT termination by RF-ablation, while in the substrate-mapping group, the endpoint was elimination of isolated potentials and proposed critical isthmuses. When doing linear lesions, the completion of the designed lines was the target.

Acute success of the procedure was defined as non-inducibility of the clinical VT as well as other inducible VTs during the procedure using PES protocol with up to 3 extra stimuli.

Follow up

Patients continued to use the same oral antiarrhythmic medications after ablation as they had before ablation. Patients were routinely followed up in the outpatient clinic at 3, 6, and 12 months and then every 6 months thereafter. Patients with an ICD underwent device interrogation at each clinic visit to assess arrhythmia recurrence. Holter monitor recording was routinely obtained at 3 and 6 months after the procedure and whenever the patient had symptoms. Long-term success was defined as a lack of recurrence of sustained (clinical and non-clinical) VT and/or appropriate ICD therapy.

Data analysis

Data were analyzed on an IBM personal computer, using Statistical Product and Service Solutions (SPSS) software computer program version 15. Data were described as mean ± standard deviation (SD) for quantitative (Numerical) variables and as frequency and percentage for qualitative (Categorical) variables. Comparison was performed with an unpaired *T* test and Chi square test. A *P* value of <0.05 was considered significant.

Results

This study included 34 patients (32 males, 2 females) who sustained monomorphic scar related VT with a mean age of 53.3 ± 11 years. Twelve patients (35.2%) had previous ICD implantation for ventricular arrhythmias. All patients had structural heart disease; 22 patients (64.7%) had previous myocardial infarction, 6 patients (17.6%) had dilated cardiomyopathy, 4 patients (11.7%) had RV scar related VT (mostly due to early ARVD), and 2 patients (5.8%) with previous heart surgery for congenital heart disease. (Table 1).

Mapping and ablation data

At the beginning of the study, attempts of VT induction were carried out in all patients using PES protocol. All 34 patients had inducible 64 VTs (51 clinical VTs and 13 non-clinical inducible VTs) with an average of 1.9 ± 1.25 total VTs/patient (1.5 ± 0.7 clinical VTs/Patient) and a mean cycle length of 322 ± 71 msec.

Seventeen (26.5%) of induced VTs were hemodynamically unstable, so they were terminated. Activation mapping was the chief mapping protocol in 20 patients (58.8%) who had sustained, hemodynamically stable VTs while substrate mapping was the chief protocol in 14 patients (41.1%). Activation mapping could identify the critical isthmuses of mapped VTs in all 20 patients. The mean scar area was 67 ± 26 cm^2 as calculated from voltage maps of CARTO XP system. The distribution of ventricular scar areas is detailed in Table 2.

Linear RF-lesions were created in 32 (94.1%) patients (Figs. 1 and 4), while focally placed RF-lesions were created in 2 patients (5.8%). Acute success of RF-ablation was achieved in 24 patients (70%); the remaining 10 patients (30%) had re-induction of some or all of the targeted VTs.

Table 1. Baseline patients' characteristics.

Characteristics	N = 34
Male sex, n (%)	32 (94.1)
Age (years)	53.3 ± 11
EF (%)	48 ± 10
Patients with ICDs, n (%)	12 (35.2)
Indication for VT ablation, n (%)	
Frequent ICD therapies	12 (35.2)
Recurrent VT and failure of AADs	22 (64.7)
Structural heart disease, n (%)	
IHD (post infarction)	22 (64.7)
DCM	6 (17.6)
ARVD	4 (11.7)
CHD	2 (5.8)
AADs, n (%)	
Amiodarone	31 (91.1)
Sotalol	9 (26.4)
Mexiletine	9 (26.4)

Abbreviations: AADs, antiarrhythmic drugs; IHD, ischemic heart disease; DCM, dilated cardiomyopathy; ARVD, arrhythmogenic right ventricular dysplasia; CHD, congenital heart disease.

Table 2. Distribution of ventricular scar areas.

Regional distribution	n = 34
RV septum, n (%)	2 (5.8)
RV apex, n (%)	2 (5.8)
RVOT, n (%)	2 (5.8)
LV anteroseptal, n (%)	16 (47)
LV inferolateral, n (%)	10 (29.4)
LV apex, n (%)	2 (5.8)

Abbreviations: RV, right ventricular; RVOT, right ventricular outflow tract; LV, left ventricular.

Follow up data

All patients were followed up for a mean period of 12 ± 6 months; Patients remained on their antiarrhythmic medication regimen for the duration of follow-up. VT recurrence occurred in 16 patients having a recurrence rate of 47%.

The 16 patients who experienced recurrence included 8 of the patients with failure to obtain acute success during the procedure in addition to 8 patients who had acute success during the procedure. Patients with recurrence were compared to patients who did not experience recurrence to estimate the predictors of recurrence (Table 3).

When comparing patients with recurrence and patients with no recurrence, there was no significant difference between both groups with regards age, sex, etiology of VT, LV ejection fraction, number of VT (clinical or induced)/ patient, scar size, procedure time, and use of activation, entrainment or pace mapping for localization of ablation targets (Table 3).

Univariate analysis showed an increased number of ablation lesions (28 ± 8 in non-recurrent group versus 12 ± 8 in recurrent group, $P = 0.01$) and more linear ablation lesions (3 ± 2 in non-recurrent group versus 1 ± 1 in recurrent group, $P = 0.03$) as predictors of long-term success and low recurrence.

In non-recurrent group, acute success of clinical targeted VTs was 94.4% (in 17 patients out of 18 patients) compared to 43.7% (7 patients) in recurrence group ($P < 0.05$). Also, acute success rate of all induced VTs was 88.8% in non-recurrent group compared to only 37.5% in recurrent group ($P < 0.05$).

Discussion

Different electroanatomically-guided mapping and ablation strategies for ablation of stable or unstable

Table 3. Comparison between recurrence and non-recurrence patients.

Characteristics	Non recurrence (N = 18)	Recurrence (N = 16)	*P* value
Age (years)	56 ± 8	51 ± 12	NS
Male sex; n (%)	17 (94.4)	15 (93.7)	NS
Hypertension; n (%)	11 (61.1)	8 (50)	NS
DM; n (%)	8 (44.4)	9 (56.3)	NS
CAD; n (%)	12 (66.6)	10 (62.5)	NS
Prior cardiac surgery; n (%)	4 (22.2)	4 (25)	NS
EF %	47 ± 12	50 ± 10	NS
Number of clinical VT/patient	1.3 ± 0.7 (25 VT)	1.6 ± 1 (26 VT)	NS
Procedural data			
Induced VTs number/patient	1.8 ± 1.2 (32 VT)	2 ± 1.3 (32 VT)	NS
Mapping protocol; n (%)			
Activation map	11 (61.1)	9 (56.3)	NS
Substrate mapping	7 (39)	7 (43.7)	
Unstable VT, %	32 (8 VT)	34.6 (9 VT)	NS
Scar size (cm^2)	64 ± 30	73 ± 28	NS
Ablation lesions no.	28 ± 8	12 ± 8	0.01
Number of linear ablation	3 ± 2	1 ± 1	0.03
Procedure time (min.)	263 ± 46	245 ± 50	NS
Fluoroscopy time (min.)	72 ± 24	61 ± 39	NS
Acute success for clinical VTs, %	94.4	43.7	<0.05
Acute success for all VTs, %	88.8	37.5	<0.05
Follow up period (months)	14 ± 5	11 ± 8	NS

Abbreviations: DM, diabetes mellitus; CAD, coronary artery disease; VT, ventricular tachycardia.

scar related VTs have been previously described.[8–10] These studies used long linear lesions along the infarct border[8] or ablated critical isthmuses within the infarct area identified during sinus rhythm, pacing, or VT.[10,11] The outcome of those patients, in whom a critical isthmus of the VT could be identified, was significantly better compared with patients in whom an isthmus could not be characterized. Most of the studies concentrated mainly on improving mapping and ablation strategies aiming at increasing acute success rates.

The current work was designed to assess the predictors of long-term success of RF-ablation of scar related VTs where VT ablation was planned to be performed by a complete CARTO map either during VT or sinus rhythm in all patients, who were followed up for a mean period of 12 ± 6 months.

The main findings of this study were that linear ablation strategy with more ablation lesions led to a decreased rate of recurrence. Also, acute success of ablation procedure rendering all-inducible VTs non-inducible at the end of the procedure was associated with long-term success and a decreased rate of recurrence.

In our series, acute procedural success defined as abolition of all inducible VTs and was achieved in 70% of the cases, which is comparable to acute success rates reported by other studies.[12–16] Acute procedural success was achieved in 81% of patients in the Euro-VT study.[23]

Our studied population was a mixed group of patients with scar related VTs and different structural heart diseases (most commonly ischemic heart disease), in contrast to the majority of studies,[12–16] which usually had a uniform patient population except for a few reports.[8]

Our recurrence rate was 47%, which compared well with data obtained from other reports stating recurrences in 19 to up to 50% of patients.[17] Kottkamp et al[13] reported a 36% recurrence rate in a series of 28 patients with pleomorphic, unstable and/or incessant post-infarction scar-related VT, while O'Donnell et al[18] reported only 22% recurrence rate in their series of 112 post-infarction VT patients. The Euro-VT study reported recurrence rate of 49% in post infarction scar related VT.[23]

Using univariate analysis, our data outlined 3 major predictors of long-term success and no recurrence in patients with large scars; the initial 2 predictors were a greater number of ablation lesions and ablation lines with the use of a linear ablation strategy. This issue was not specifically addressed in other studies; however, several studies reported high procedural success and low recurrence rates with linear ablation lesions, especially those extending from dense scar to the normal myocardium or anatomic boundary.[8,9]

The number of clinical or induced VTs did not show significant between-group differences in our work and this is in contrast with the SMASH-VT study, which highlighted that the number of VTs induced during the procedure was predictive of 2-year outcomes.[24] This difference is probably because we tried to abolish as many as possible of all clinical and induced VTs inside the EP lab, in contrast to some EP centers that try to abolish only the clinical VTs.

The final major predictor based on our findings was acute procedural success defined as abolishment of all inducible VTs (clinical and non-clinical); this finding was similar to other authors' findings. Some authors reported that when the targeted VTs remain inducible after ablation, the recurrence risk exceeds 60%,[18,19] while others found that inducible, nonclinical VTs are associated with an increased risk of recurrence.[20,21] Della Bella et al[22] reported in their series of post-infarction VT patients that acute success was the only independent predictor of long-term outcome in multivariate analysis.

Furthermore, our work revealed that arrhythmia burden (multiple VT morphologies) or unstable VTs are not related to long time outcome, which is contradictory to other reports that found a relation to high recurrence.[9,22] That particular point might require further investigation.

Study limitations

This study was conducted in a single center with relatively new experience in using a 3D electro-anatomical mapping system (CARTO XP).

Conclusions

In this limited study population, scar related VT ablation using a 3D electro-anatomical CARTO mapping system appeared to be an effective and safe procedure, with an overall success rate of 70% and a

overall recurrence rate of 47%. We demonstrated that more extensive ablation lesions and creation of linear lesions are associated with better success rates and lower recurrence rates during ablation of large scar-related ventricular tachycardia.

In addition, we found that rendering VTs non-inducible at the end of the procedure is a vital predictor of long-term outcomes.

Author Contributions

Conceived and designed the experiments: MTG, RSA, AMA, JKZ. Analyzed the data: MTG, RSA, AMA, JKZ. Wrote the first draft of themanuscript: MTG, RSA. Contributed to the writing of the manuscript: MTG, RSA, AMA, JKZ. Agree with manuscript results and conclusions: MTG, RSA. Jointly developed the structure and arguments for the paper: AMA, JKZ. Made critical revisions and approved final version: AMA, JKZ. All authors reviewed and approved of the final manuscript.

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Competing Interests

Author(s) disclose no potential conflicts of interest.

Disclosures and Ethics

As a requirement of publication the authors have provided signed confirmation of their compliance with ethical and legal obligations including but not limited to compliance with ICMJE authorship and competing interests guidelines, that the article is neither under consideration for publication nor published elsewhere, of their compliance with legal and ethical guidelines concerning human and animal research participants (if applicable), and that permission has been obtained for reproduction of any copyrighted material. This article was subject to blind, independent, expert peer review. The reviewers reported no competing interests.

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