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Original Article

Impact of New Technologies and Approaches for Post–Myocardial Infarction Ventricular Tachycardia Ablation During Long-Term Follow-Up

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Background—During the past years, many innovations have been introduced to facilitate catheter ablation of post–myocardial infarction ventricular tachycardia. However, the predictors of outcome after ablation were not thoroughly studied.

Methods and Results—From 2009 to 2013, consecutive patients referred for post–myocardial infarction ventricular tachycardia ablation were included. The end point of the procedure was complete elimination of local abnormal ventricular activities (LAVA) and ventricular tachycardia (VT) noninducibility. The predictors of outcome with primary end point of VT recurrence were assessed. A total of 125 patients were included (age: 64±11 years; 7 women) for 142 procedures. The left ventricle was accessed via transseptal, retrograde aortic, and epicardial approaches in 87%, 33%, and 37% of patients, respectively. Three-dimensional electroanatomical mapping system was used in 70%, multipolar catheter in 51%, and real-time image integration in 38% (from magnetic resonance imaging in 39% and multidetector computed tomography in 93%) of patients. Before ablation, VT was inducible in 75%, and endocardial/epicardial LAVA were present in 88%/75%. After ablation, complete LAVA elimination was achieved in 60%, and VT noninducibility in 83%. During a median follow-up of 850 days (interquartile range, 439–1707), VT recurrence was observed in 36%. Multivariable analysis identified 3 independent outcome predictors: the ability to achieve complete LAVA elimination (R^2=0.29; P<0.0001; risk ratio=0.52 [0.38–0.70]), the use of real-time image integration (R^2=0.21; P=0.0006; risk ratio=0.49 [0.33–0.74]), and the use of multipolar catheters (R^2=0.08; P=0.05; risk ratio=0.75 [0.56–1.00]).

Conclusions—Achievement of complete LAVA elimination and use of scar integration from imaging and multipolar catheters to focus high-density mapping are independent predictors of VT-free survival after catheter ablation for post–myocardial infarction ventricular tachycardia. **(*Circ Arrhythm Electrophysiol*. 2016;9:e003901. DOI: 10.1161/CIRCEP.116.003901.)**

Key Words: catheter ablation ■ heart failure ■ infarction ■ myocardial infarction ■ ventricular tachycardia

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Catheter ablation is an effective technique for the management of post–myocardial infarction ventricular tachycardia (post-MI VT).[1–3] The role of substrate-based VT ablation techniques is expanding.[4–7] In this context, elimination of local abnormal ventricular activities (LAVA) has emerged as an important end point for VT ablation.[7] During the past decade, the emergence of innovations, such as three-dimensional electroanatomic mapping (3D-EAM),[8] multipolar catheters for high-density mapping,[7] and real-time integration of structural VT substrate from imaging, have enhanced our ability to identify ablation targets.[9] However, the impact of these technological innovations on ablation outcome has not been systematically studied.[1,10–14] The purpose of this study is to identify the impact of these innovations on ablation outcome for post-MI VT.

Methods

Study Population

From January 2008 to November 2013, consecutive patients undergoing catheter ablation for post-MI VT were enrolled. Inclusion criteria were history of MI and drug-resistant sustained VT. Exclusion

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WHAT IS KNOWN

- Elimination of LAVA has emerged as an important end point for VT ablation.
- Many technical innovations for VT ablation were introduced over the past years, including 3D-mapping system, image integration, and multipolar mapping catheter. However, the impact of these novel techniques on the clinical outcome of post-MI VT ablation has not been thoroughly investigated.

WHAT THE STUDY ADDS

- The ability to achieve complete LAVA elimination, the use of image integration, and high-density mapping with multipolar catheters are independent predictors of VT-free survival after catheter ablation for post-MI VT.
- Aiming for complete LAVA elimination using real-time image integration and multipolar catheter is a feasible and useful approach in patients with post-MI VT.

criteria were presence of intracardiac thrombus, New York Heart Association class IV heart failure, and cardiac surgery within the past 2 months (unless VT was incessant). VT storm was defined as ≥3 VT episodes in 24 hours.

All patients underwent catheter ablation with the same end point, that is, complete LAVA elimination during sinus rhythm (SR)[7] and noninducibility of any VT, but with various methods according to the evolution of EP technology during the course of the study. The use of 3D-EAM, multipolar catheters, and real-time image integration was solely based on the availability of the technology and was independent of patient characteristics (except for contraindications to contrast-enhanced multidetector computed tomography [MDCT] and magnetic resonance imaging [MRI]). This study was approved by the Institutional Review Board, and all patients gave informed consent.

Electrophysiological Mapping Study

Procedures were performed under conscious sedation. A 5F, steerable, quadripolar/decapolar catheter (Xtrem; Sorin, France, or Dynamic; BostonScientific, Inc, Cambridge, MA) was placed in the right ventricular apex or coronary sinus. The left ventricle was accessed by a transseptal (BRK Needle, Agilis Sheath; St Jude Medical, St Paul, MN) or retrograde aortic approach. Epicardial mapping (Tuohy Needle, Agilis Sheath; St Jude Medical) was performed[15] in cases with suspected epicardial VT origin (from 12-lead ECG and/or absence of endocardial LAVA and/or failure of endocardial ablation). Contraindications to epicardial access included previous cardiac surgery and pericardial adhesions. After left ventricle access, a 50 U/kg heparin bolus was administered (activated clotting time maintained at >250 seconds). Twelve-lead ECG and intracardiac electrograms were recorded continuously (LabSystem Pro; Bard Electrophysiology, MA, or Siemens Axiom Sensis XP; Siemens, Munich, Germany).

Mapping was performed using either a 3.5-mm open-irrigated catheter (NaviStar ThermoCool; Biosense Webster, Diamond Bar, CA) and/or a multipolar high-density mapping catheter (PentaRay; 2-6-2 mm interelectrode spacing, 1 mm electrodes; Biosense Webster). Peak-to-peak amplitudes of 0.5 to 1.5 mV and <0.5 mV were used to define the low-voltage zone and the dense scar zone,

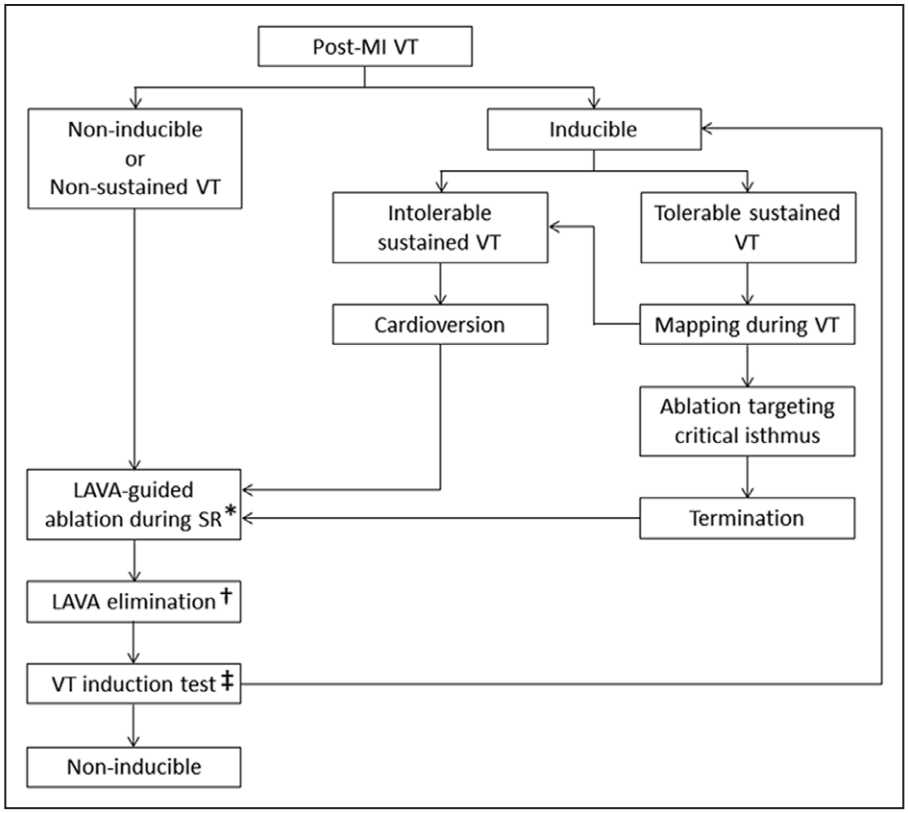

Figure 1. Flow chart for ventricular tachycardia (VT) ablation in post–myocardial infarction (post-MI) patients. *In case with no local abnormal ventricular activity (LAVA) during sinus rhythm (SR), ablation was guided by pace mapping. †LAVA-guided ablation was limited in case LAVA located near coronary arteries and phrenic nerve on the epicardium or persisted after extensive ablation. ‡In case of intolerable VTs with cardioversion >2 times during the procedure, VT inducibility was not tested.

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Table 1. Patient Characteristics

Baseline clinical characteristics	
Age, y	64±11
Male sex	135 (95)
Hypertension	91 (64)
Diabetes mellitus	25 (18)
Dyslipidemia	121 (85)
Smoking	76 (53)
Multivessel disease	61 (43)
Previous CABG	31 (22)
Previous PCI	75 (53)
ICD	116 (82)
Left ventricular ejection fraction, %	33±10
Amiodarone	94 (66)
β-Blocker	134 (94)
Ventricular arrhythmia storm	69 (49)
Redo procedure	31 (22)
Procedural techniques	
Transseptal approach	124 (87)
Retrograde aortic approach	48 (34)
Epicardial access	52 (37)
Multipolar catheter	73 (51)
3D-EAM	99 (70)
Real-time image integration	54 (38)
Integration of MDCT data*	50 (93)
Integration of MRI data*	21 (39)
Baseline VT inducibility	
Inducible VT	106 (75)
Clinical VT induced	86 (61)
Nonclinical VT induced	67 (47)
Mean VT cycle length, ms	406±103
Shortest VT cycle length, ms	370±107
DCC for intolerable VT/VF	29 (20)
Mapping characteristics	
Number of endocardial mapping points†	370 (228–747)
Low-voltage endocardial area, cm^2†	68 (32–97)
Dense scar endocardial area, cm^2†	26 (12–54)
Presence of LAVA on endocardium	125 (88)
Number of epicardial mapping points†	432 (328–758)
Low-voltage epicardial area, cm^2†	71 (41–85)
Dense scar epicardial area, cm^2†	33 (16–45)
Presence of LAVA on epicardium‡	39 (75)
Ablation and procedural end points	
Total RF time	32 (20–50)

(*Continued*)

Table 1. Continued

Epicardial ablation	29 (20)
Epicardial RF time§	5 (2–13)
Procedure time	250±82
Inducibility tested after ablation	112 (79)
Noninducibility of VT‖	93 (83)
Complete LAVA elimination¶	79 (60)
Procedural complications	9 (6)
Follow-up	
Follow-up duration, d	850 (439–1707)
VT recurrence	53 (37)
All-cause death	23 (16)
Cardiovascular death	15 (11)
Sudden death attributed to arrhythmia recurrence	5 (4)
Follow-up duration until VT recurrence, d	119 (55–327)
Follow-up duration until death, d	869 (78–1594)

3D-EAM indicates 3-dimensional electroanatomical mapping; CABG, coronary artery bypass graft; DCC, direct current cardioversion; ICD, implantable cardioverter-defibrillator; LAVA, local abnormal ventricular activity; MDCT, multidetector computed tomography; MRI, magnetic resonance imaging; PCI, percutaneous coronary intervention; RF, radiofrequency; VF, ventricular fibrillation; and VT, ventricular tachycardia.

*Among patients with image integration.

†Applies to patients with 3D-EAM.

‡Among patients with epicardial access.

§Among patients with epicardial ablation

‖Among patients with inducibility testing.

¶Among patients with LAVA.

respectively. When a 3D-EAM system was used (CARTO3; Biosense Webster, or NavX; St Jude Medical), mapping was performed during SR to create a voltage map and annotate LAVA. For hemodynamically tolerated VT, activation mapping was performed during VT.

For image integration, structural substrate was derived from MDCT or MRI. Images were processed using dedicated software (MUSIC; Liryc-Université de Bordeaux/Inria-Sophia Antipolis, France) to render patient-specific meshes of the cardiac chambers, epicardium, coronary sinus, and coronary arteries and left phrenic nerve in case of epicardial approach.[16] The structural substrate was segmented on imaging as areas of late gadolinium enhancement on MRI and/or areas of wall thinning <5 mm on MDCT.[9] The imaging model was registered to the mapping geometry using landmark-based registration and field scaling when using NavX system or landmark-based registration and automatic surface registration when using CARTO system.

VT Inducibility and Ablation

A flow chart illustrating procedural management is provided in Figure 1. VT inducibility was assessed at the beginning of the procedure (600 and 400 ms drive trains, ≤3 extrastimuli decremented to 200 ms from the right ventricular apex). If hemodynamically stable VT was induced, conventional activation and entrainment was performed.[17] For noninducible or poorly tolerated VT, mapping was undertaken to identify LAVA during SR. LAVA was defined as sharp high-frequency ventricular potentials, distinct from the far-field ventricular electrogram occurring anytime during or after the far-field ventricular electrogram in SR.[7] Radiofrequency current was delivered with an irrigated catheter (25–50 W endocardial and 25–35 W

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epicardial). After VT termination, further ablation was performed in SR to eliminate LAVA. The procedural end point was complete LAVA elimination and noninducibility of any VT.

Follow-Up

Patients were followed up with sequential implantable cardioverter-defibrillator (ICD) interrogations (or Holter monitoring in patients without ICD) at 1, 3, 6, and 12 months for the first year and subsequently every 6 months. The primary end point was VT recurrence. Qualifying arrhythmias included any VT detected by ICDs, 12-lead ECGs, Holter monitors, or rhythm strips, regardless of morphology or rate. Death during follow-up was categorized as either cardiovascular or noncardiovascular. Among cardiovascular deaths, sudden deaths attributed to ventricular arrhythmia were recorded.

Statistical Analysis

Shapiro–Wilk and D'Agostino tests were used to assess whether quantitative data conformed to the normal distribution. Log transformation was applied in case of non-normal distribution. Continuous variables are expressed as mean±SD (normally distribution) and median (interquartile range; non-normal distribution). Categorical variables are expressed as fraction (%). Continuous variables were compared using parametric (unpaired Student *t* test) or nonparametric tests (Mann–Whitney) depending on data normality. Categorical variables were compared using χ^2 tests. Relationships between variables were assessed using Pearson or Spearman correlation coefficients (*R*). Factors associated with the 2 procedural end points (LAVA elimination and VT noninducibility) were analyzed using univariable logistic regression. Univariable Cox proportional hazards regression analysis was used to identify predictors of VT recurrence, with candidate variables including all patients' baseline characteristics, procedural techniques, procedural findings, and procedural end points. Bonferroni correction was applied to account for multiple testing. Proportional hazards assumptions were verified by plotting Schoenfeld residuals supplemented by testing for nonzero slopes. All candidate variables associated with a *P* value <0.05 on univariable analysis were considered in an automated hierarchical forward multivariable Cox regression model, except for mapping characteristics, because these were only available in case 3D-EAM was used. Assuming a VT recurrence rate of 40%,[7] this study was populated to include a maximum of 5 variables in multivariate analyses. For each variable showing predictive of VT recurrence on multivariable analysis, VT-free survival rate was plotted against time since ablation in patients with and without the variable, according to the Kaplan–Meier method. All statistical tests were 2 tailed. A *P* value <0.05 was considered to indicate statistical significance. Analyses were performed using NCSS 8 (NCSS Statistical Software, Kaysville, UT).

Results

Population

During the study period, 140 patients met the inclusion criteria. Fifteen patients were excluded (8 patients for intracardiac thrombus, 2 patients for insufficient delay post myocardial infarction [VT spontaneously resolved in both], and 5 patients declined consent). Therefore, the study population consisted of 125 patients (age: 64±11 years; 7 women; 100 [80%] ICD) who underwent 142 VT ablation procedures. Baseline characteristics are summarized in Table 1.

Mapping and Ablation Procedure

Transseptal, retrograde aortic, and epicardial approaches were performed in 124 (87%), 48 (34%), and 52 cases (37%), respectively. Criteria for epicardial access were met in 64 cases (45%), in whom pericardial access was not possible in 12 cases (3 cases because of pericardial adhesion; 7 cases

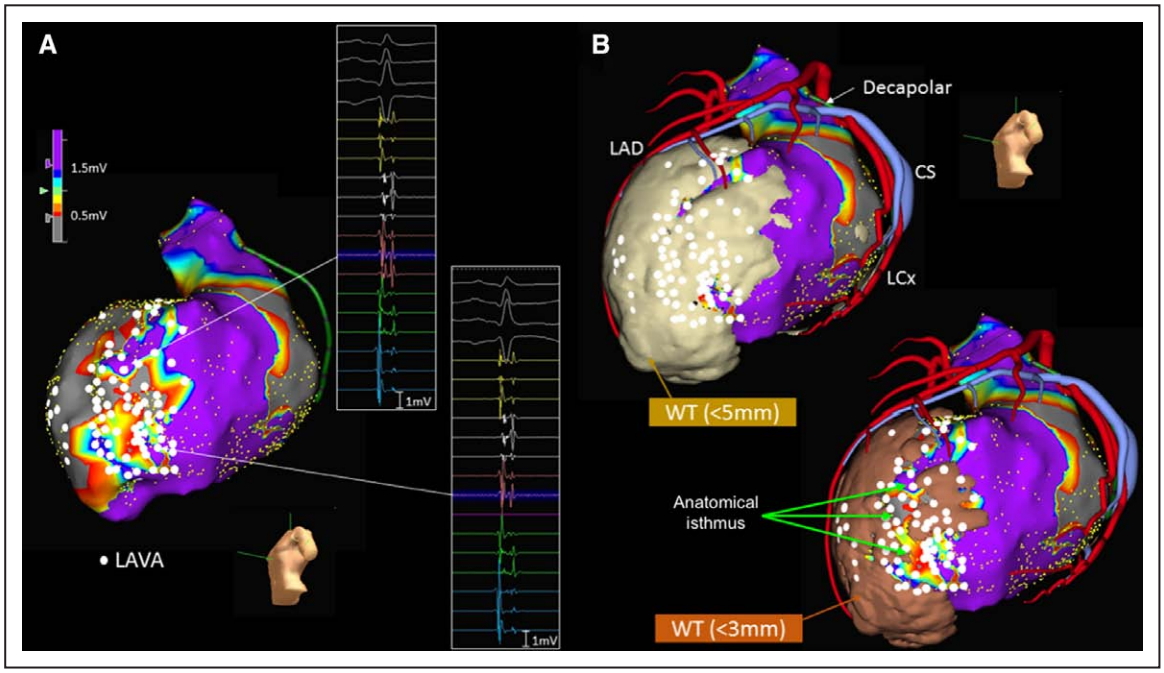

Figure 2. High-density mapping and real-time image integration. A case of post–myocardial infarction ventricular tachycardia (post-MI VT; 60 y; man) is shown. **A**, Voltage map demonstrates large scar on anterior left ventricular (LV) wall with local abnormal ventricular activity (LAVA) as recorded by a multipolar catheter. **B**, Image integration from multidetector computed tomography provides anatomic details including the course of coronary arteries (red) and coronary sinus (CS) branches (blue). A decapolar catheter (green) is placed in distal CS to monitor image registration. Anatomic substrate demonstrated as areas of moderate and severe wall thinning (WT; light and dark brown surfaces). An anatomic isthmus of moderate WT is visible (green arrows), hosting most LAVAs, many of which show normal voltage (>1.5 mV). LAD indicates left anterior descending artery; and LCx, left circumflex artery.

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Table 2. Predictors of Procedural End Points

	Complete LAVA Elimination		Noninducibility of VT	
	P Value	Odds Ratio (95% CI)	*P* Value	Odds Ratio (95% CI)
Baseline clinical characteristics				
Age, y	0.65	1.01 (0.98–1.04)	0.64	0.99 (0.94–1.04)
Male sex	0.57	0.79 (0.34–1.82)	0.85	1.11 (0.36–3.42)
Hypertension	0.37	1.18 (0.82–1.70)	0.84	1.05 (0.63–1.76)
Diabetes mellitus	0.13	1.47 (0.89–2.42)	0.72	0.89 (0.48–1.65)
Dyslipidemia	0.12	1.52 (0.90–2.59)	0.45	1.27 (0.68–2.38)
Smoking	0.21	0.77 (0.52–1.16)	0.15	1.51 (0.86–2.64)
Left ventricular ejection fraction, %	0.55	1.01 (0.98–1.05)	0.38	1.02 (0.97–1.08)
Amiodarone	0.11	1.36 (0.93–1.98)	0.91	1.03 (0.62–1.72)
β-Blocker	0.42	0.71 (0.31–1.62)	0.85	0.90 (0.30–2.67)
Ventricular arrhythmia storm	0.94	1.07 (0.66–1.34)	0.45	1.21 (0.73–2.02)
Redo procedure	0.62	0.90 (0.59–1.37)	0.20	0.70 (0.40–1.21)
Procedural techniques				
Transseptal approach	0.67	0.87 (0.47–1.63)	0.95	0.003 (0–>10 000)
Retrograde aortic approach	0.35	1.20 (0.82–1.76)	0.75	1.22 (0.77–1.98)
Epicardial access	0.46	0.87 (0.60–1.25)	0.16	1.59 (0.83–3.06)
Multipolar catheter	0.04	1.44 (1.01–2.07)	0.74	0.92 (0.56–1.51)
3D-EAM	0.46	1.15 (0.79–1.69)	0.32	0.71 (0.37–1.38)
Real-time image integration	0.82	0.96 (0.67–1.38)	0.26	0.75 (0.46–1.24)
Baseline inducibility				
Inducible VT	0.79	1.02 (0.75–1.35)	0.002	0.36 (0.19–0.69)
Mean VT cycle length, ms	0.85	1.00 (1.00–1.00)	0.45	1.00 (1.00–1.01)
Shortest VT cycle length, ms	0.93	1.00 (1.00–1.00)	0.11	1.00 (1.00–1.01)
DCC for intolerable VT/VF	0.11	0.70 (0.45–1.08)	NA*	NA*
Mapping characteristics				
Number of endocardial mapping points	0.34	1.00 (1.00–1.00)	0.17	1.00 (1.00–1.00)
Low-voltage endocardial area, cm^2	0.006	0.98 (0.97–0.99)	0.29	0.99 (0.98–1.01)
Dense scar endocardial area, cm^2	0.005	0.98 (0.96–0.99)	0.22	0.99 (0.97–1.01)
Presence of LAVA on endocardial	0.34	1.81 (0.54–6.09)	0.95	0.003 (0–>10 000)
Number of epicardial mapping points	0.61	1.00 (1.00–1.00)	0.70	1.00 (1.00–1.00)
Low-voltage epicardial area, cm^2	0.05	0.96 (0.93–1.00)	0.86	1.00 (0.95–1.05)
Dense scar epicardial area, cm^2	0.11	0.97 (0.93–1.00)	0.38	0.97 (0.89–1.04)
Presence of LAVA on epicardium	0.61	1.20 (0.60–2.41)	0.33	0.92 (0.53–1.40)
Ablation				
Total RF time, min	0.60	0.99 (0.98–1.01)	0.0003	0.95 (0.92–0.98)
Epicardial ablation	0.84	1.05 (0.68–1.62)	0.54	1.28 (0.58–2.80)
Epicardial RF time, min	0.90	1.00 (0.95–1.06)	0.50	1.07 (0.89–1.28)
Procedure time, min	0.28	1.00 (0.99–1.00)	0.002	0.99 (0.98–1.00)
Noninducibility of VT	0.16	0.70 (0.42–1.15)	…	…
Complete LAVA elimination	…	…	0.16	0.70 (0.42–1.15)

After Bonferroni correction to account for multiple testing, a *P* value <0.002 is considered to indicate statistical significance. 3D-EAM indicates 3-dimensional electroanatomical mapping; CI, confidence interval; DCC, direct current cardioversion; LAVA, local abnormal ventricular activity; RF, radiofrequency; VF, ventricular fibrillation; and VT, ventricular tachycardia.

*Not assessable because inducibility was not tested again when the arrhythmia induced at baseline was poorly tolerated.

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Table 3. Predictors of VT Recurrence

	Univariable Analysis		Multivariable Analysis		
	P Value	Risk Ratio (95% CI)	P Value	R^2	Risk Ratio (95% CI)
Baseline clinical characteristics					
Age, y	0.50	1.01 (0.98–1.04)			
Male sex	0.26	1.77 (0.66–4.76)			
Hypertension	0.57	0.92 (0.70–1.22)			
Diabetes mellitus	0.41	0.85 (0.58–1.25)			
Dyslipidemia	0.58	0.90 (0.63–1.29)			
Smoking	0.12	1.30 (0.93–1.81)			
Left ventricular ejection fraction, %	0.55	0.99 (0.96–1.02)			
Amiodarone	0.28	0.86 (0.65–1.13)			
β-Blocker	0.82	0.94 (0.56–1.57)			
Ventricular arrhythmia storm	0.19	1.20 (0.91–1.58)			
Redo procedure	0.23	1.20 (0.89–1.61)			
Procedural techniques					
Transseptal approach	0.59	1.12 (0.73–1.72)			
Retrograde aortic approach	0.71	0.95 (0.71–1.26)			
Epicardial access	0.92	1.01 (0.77–1.34)			
Multipolar catheter	0.01	0.69 (0.52–0.91)	0.05	0.08	0.75 (0.56–1.00)
3D-EAM	0.09	0.78 (0.59–1.04)			
Real-time image integration	0.001	0.54 (0.37–0.79)	0.0006	0.21	0.49 (0.33–0.74)
Baseline inducibility					
Inducible VT	0.25	1.17 (0.92–1.47)			
Mean VT cycle length	0.28	1.00 (1.00–1.00)			
Shortest VT cycle length	0.49	1.00 (1.00–1.00)			
DCC for intolerable VT/VF	0.29	1.19 (0.86–1.65)			
Mapping characteristics*					
Number of endocardial mapping points	0.05	1.00 (1.00–1.00)			
Low-voltage endocardial area	0.52	1.00 (0.99–1.01)			
Dense scar endocardial area	0.87	1.00 (0.99–1.01)			
Presence of endocardial LAVA	0.47	0.86 (0.58–1.29)			
Number of epicardial mapping points	0.50	1.00 (1.00–1.00)			
Low-voltage epicardial area	0.34	0.99 (0.97–1.01)			
Dense scar epicardial area	0.41	0.99 (0.96–1.02)			
Presence of LAVA on epicardium	0.61	0.89 (0.57–1.39)			
Ablation and procedural end points					
Total RF time	0.43	1.01 (0.99–1.02)			
Epicardial ablation	0.81	0.96 (0.69–1.33)			
Epicardial RF time	0.49	1.01 (0.97–1.06)			
Procedure time	0.98	1.00 (1.00–1.00)			
Noninducibility of VT	0.50	0.87 (0.59–1.29)			
Complete LAVA elimination	<0.0001	0.52 (0.39–0.70)	<0.0001	0.29	0.52 (0.38–0.70)

After Bonferroni correction to account for multiple testing, a *P* value <0.002 is considered to indicate statistical significance in univariable analyses. The criterion for entry in the multivariable model was *P*<0.05. 3D-EAM indicates 3-dimensional electroanatomical mapping; CI, confidence interval; DCC, direct current cardioversion; LAVA, local abnormal ventricular activity; RF, radiofrequency; VF, ventricular fibrillation; and VT, ventricular tachycardia.

*Mapping characteristics were not considered as candidates for multivariable analysis because these were only present in patients with 3D-EAM.

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because of previous cardiac surgery; 1 case because of a risk of bleeding by dual-antiplatelet therapy; and 1 case because of pericardial bleeding). A multipolar mapping catheter was used in 73 cases (51%). 3D-EAM was performed in 99 cases (70%) and associated with real-time integration of anatomy and scar from imaging in 54 cases (38%). Real-time image integration consisted of MDCT data in 50 cases (93%), MRI data in 21 cases (39%), and fused MDCT and MRI data in 17 cases (31%). A representative example of real-time integration and high-density mapping with a multipolar catheter is illustrated in Figure 2.

Procedural findings are summarized in Table 1. VT was inducible at baseline in 106 cases (75%). LAVAs were found on the endocardium in 125 cases (88%) and on the epicardium in 39 cases (75% of patients with epicardial access). A total of 216 VTs were induced, 55(25%) of which were mapped and terminated by radiofrequency application, and 161(75%) of which were unmappable because of hemodynamic intolerance, conversion to another VT during mapping, or spontaneous termination. After a total radiofrequency time of 32 minutes (interquartile range, 20–50), complete LAVA elimination was achieved in 79 cases (60% of patients with LAVA). At the end of the procedure, VT inducibility was not tested in 30 out of 142 patients (21%) because of the induction of poorly tolerated VTs requiring cardioversion >2 times during the procedure. Of the remaining 112 cases who underwent programmed stimulation, the end point of VT noninducibility was achieved in 93 out of 112 patients (83%). Eight patients had pericardial bleeding (5 related to epicardial approach). One patient required surgery, whereas the others resolved spontaneously. Permanent atrioventricular block occurred in 1 patient. There were no strokes, phrenic palsies, coronary injuries, or procedure-related deaths.

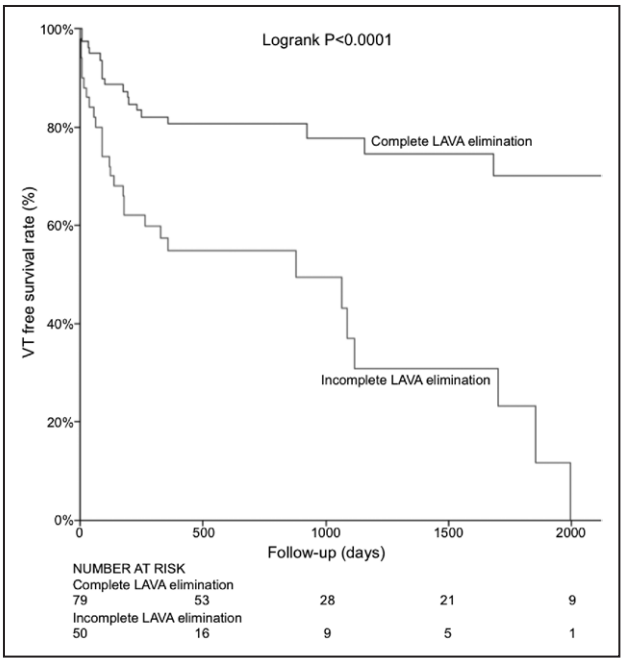

Figure 3. Ventricular tachycardia (VT)–free survival in procedures with and without complete local abnormal ventricular activity (LAVA) elimination.

Follow-Up

Follow-up characteristics are summarized in Table 1. One hundred out of 125 patients (80%) had an ICD implanted before VT ablation. A further 3 patients had an ICD implanted after VT ablation. After a median follow-up of 850 days (interquartile range, 439–1707), VT recurred in 53 out of 146 patients (36%), in which VTs were detected by the ICD (requiring antitachycardia pacing or shock) in 48 patients and recorded by the ambulance monitor or 12-lead ECG in the remaining 5 patients. Death from all causes occurred in 20 out of patients 125(16%), death from cardiac causes in 14 out 125 patients (11%), and sudden death attributed to electrical storm in 5 out of 125 patients (4%), despite ICD therapy.

Factors Associated With Procedural End Points

Results from univariable analysis for the prediction of complete LAVA elimination and noninducibility of VT are shown in Table 2. The ability to achieve complete LAVA elimination or VT noninducibility was not related to any baseline characteristics. Among procedural characteristics, low-voltage zone and dense scar zone tended to be associated with failure to achieve LAVA elimination, although the association did not reach significance after Bonferroni correction to account for multiple testing (P=0.006 and P=0.005, respectively). Baseline inducibility was associated with a lower rate of noninducibility at the end of the procedure (P=0.002). Total radiofrequency and procedure time were also associated with lower rates of noninducibility at the end of the procedure (P=0.0003 and P=0.002, respectively).

Factors Associated With Clinical Outcome

Results from univariable and multivariable analyses for the prediction of VT recurrence are summarized in Table 3. On multivariable analysis, 3 characteristics were associated with the outcome: (1) the ability to achieve complete LAVA elimination (R^2=0.29; P<0.0001; risk ratio 0.52 [0.38–0.70]), (2) the use of real-time image integration (R^2=0.21; P=0.0006; risk ratio 0.49 [0.33–0.74]), and (3) the use of multipolar catheters (R^2=0.08; P=0.05; risk ratio 0.75 [0.56–1.00]). Kaplan–Meier graphs illustrating the impact of these characteristics on VT-free survival are shown in Figures 3–5.

Procedural data in patients with versus without multipolar catheters and image integration are compared in Table 4. Patients with multipolar catheters showed higher rates of transseptal and epicardial approaches (P=0.01 and P<0.0001, respectively), higher numbers of endocardial mapping points (P<0.0001), and higher rate of endocardial LAVA (96% versus 80%; P=0.002). Patients with real-time image integration showed higher numbers of endocardial LAVA sites (43 [27–64] versus 24 [21–34]; P=0.03).

Follow-up at 1 year was available for 23 patients in whom both multielectrode mapping and image integration had been used. In this population, LAVA elimination had been achieved in 18 out of 23 patients (78%), and 20 out of 23 patients (87%) were free from recurrence at 1-year follow-up.

Discussion

This study is to our knowledge the first to analyze the incremental effect of recent technological innovations on the

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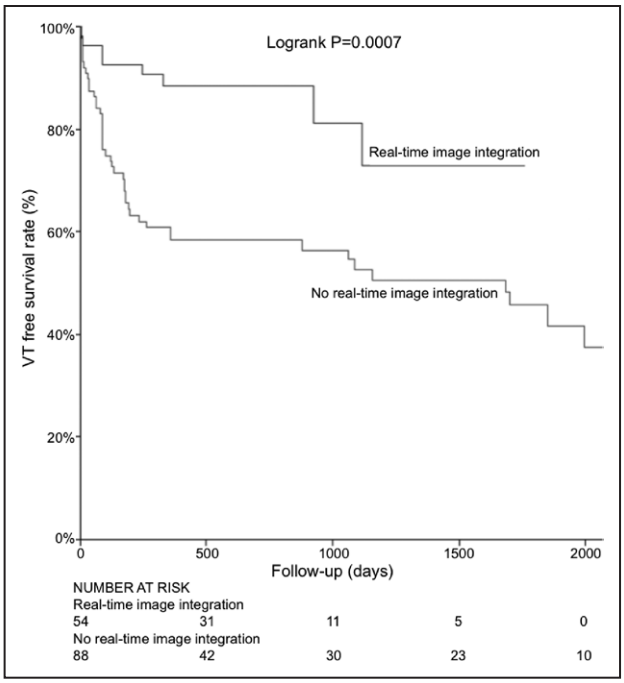

Figure 4. Ventricular tachycardia (VT)–free survival in procedures with and without real-time image integration.

efficacy of post-MI VT ablation. Using constant procedural end points in a cohort of post-MI VT patients, we demonstrate that complete LAVA elimination, scar integration from imaging, and high-density mapping with multipolar catheters are independent predictors of postablation, VT-free survival.

Impact of LAVA Elimination

Complete LAVA elimination was associated with a 2-fold reduction in risk of VT recurrence in our cohort. VT noninducibility on the contrary did not influence outcome. These findings provide further evidence that LAVA elimination of VT substrate is an efficient procedural end point.[7,18] The low predictive value of VT noninducibility is also consistent with many previous studies.[19,20]

Impact of Real-Time Image Integration

Real-time image integration was shown to be feasible with processing times compatible with routine clinical practice. Previous studies have reported good accuracy in identifying VT substrate, using MDCT, MRI,[9] or positron emission tomography.[21] Voltage mapping may fail to accurately delineate the extent of diseased myocardium because of limitations such as catheter contact issues, reduced sensitivity to far-field signal in nontransmural or midwall scar,[22] and epicardial fat interposition.[23] Additionally, the density and comprehensiveness of voltage mapping is highly dependent on operator decisions and time constraints, whereas imaging methods provide whole-heart assessment of the structural substrate with submillimetric spatial resolution in a few heartbeats. Therefore, integrating the structural substrate as defined from preprocedural imaging might improve the accuracy of mapping in identifying ablation targets.

In this study, the integration of anatomy and scar from imaging was associated with a 2-fold reduction in VT recurrence. The superior outcome in patients with image integration might be explained by the ability of imaging to comprehensively describe the structural substrate of VT, thereby enabling a more focused mapping on critical areas, at the same time ensuring that no abnormal myocardium is left unexplored. Interestingly, we identified a higher number of LAVA sites in patients with real-time image integration despite a similar number of mapping points. This observation confirms that mapping is more efficiently focused toward critical areas when guided by imaging data. Of note, however, the identification of more LAVA did not translate into higher rates of complete LAVA elimination. Therefore, the impact of image integration on outcome seems to be mediated by a more comprehensive treatment of VT substrate; however, the issue of unreachable targets remains (midwall circuits and coronary interposition).[24] In this study, VT-free survival rates in the population without image integration were comparable to those reported in the VTACH study (Ventricular Tachycardia Ablation in Coronary Heart Disease),[13] whereas the outcome in patients treated with image integration was more favorable. However, this latter outcome was similar to a previous study by Deneke et al[14] that did not use image integration (77% VT-free survival rate during a median follow-up of 16 months). This is likely because of differences in patient characteristics between studies because VTs with suspected epicardial origin, noninducible clinical VTs, and ongoing VTs during the procedure were excluded in the study by Deneke et al.[14] Moreover, in this study, poorly tolerated VTs requiring cardioversion >2 times during the procedure were observed in 21% of cases, which suggests a severe condition in the included population.

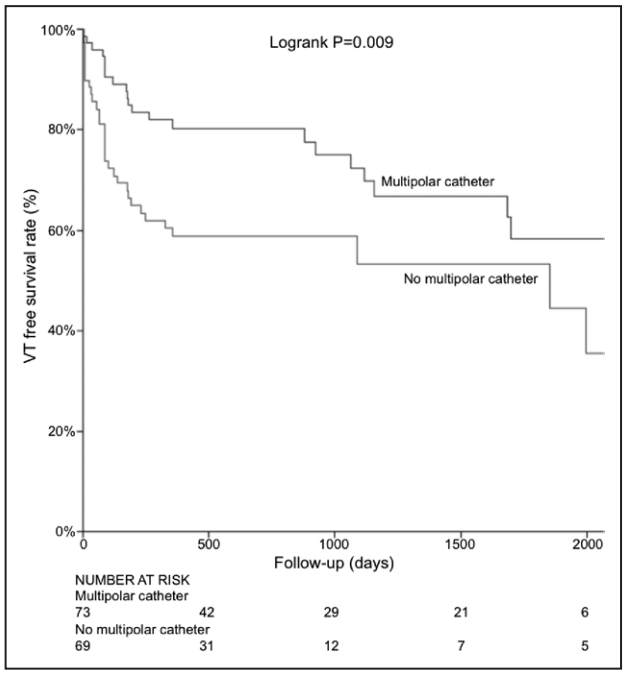

Figure 5. Ventricular tachycardia (VT)–free survival in procedures with and without multipolar catheter.

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Table 4. Procedural Characteristics in Patients With Vs Without Image Integration and Multipolar Catheters

	With RII (N=54)	Without RII (N=88)	*P* value	With Multipolar Catheters (N=73)	Without Multipolar Catheters (N=69)	*P* Value
Techniques						
Transseptal approach	49 (91)	75 (85)	0.20	69 (95)	55 (80)	0.01
Retrograde aortic approach	13 (24)	35 (40)	0.07	27 (37)	21 (30)	0.35
Epicardial access	17 (31)	35 (40)	0.32	38 (52)	14 (20)	<0.0001
Multipolar catheter	31 (57)	42 (48)	0.27	NA	NA	…
3D-EAM	54 (100)	45 (51)	<0.0001	51 (70)	48 (70)	0.97
Real-time image integration	NA	NA	…	31 (42)	23 (33)	0.27
Baseline VT inducibility						
Inducible VT	37 (69)	69 (78)	0.19	58 (79)	48 (70)	0.18
Mean VT cycle length, ms	398±113	410±96	0.57	388±103	431±97	0.03
Shortest VT cycle length, ms	368±119	372±100	0.87	360±107	385±106	0.24
DCC for untolerable VT/VF	11 (20)	18 (20)	0.45	17 (23)	12 (17)	0.17
Mapping characteristics*						
Number of endocardial mapping points	452 (284–855)	268 (198–567)	0.26	658 (378–1062)	246 (165–354)	<0.0001
Low-voltage endocardial area, cm^2	54 (25–96)	75 (45–105)	0.49	70 (39–96)	66 (17–98)	0.54
Presence of LAVA on endocardium	48 (89)	77 (88)	0.38	70 (96)	55 (80)	0.002
Number of LAVA sites on endocardium	43 (27–64)	24 (21–34)	0.03	38 (22–66)	32 (21–55)	0.16
Number of epicardial mapping points	432 (362–755)	453 (328–952)	0.83	433 (366–1092)	381 (262–576)	0.15
Low-voltage epicardial area, cm^2†	58 (39–87)	79 (53–85)	0.90	72 (41–87)	75 (63–83)	0.83
Presence of LAVA on epicardium†	15 (88)	24 (69)	0.13	30 (41)	9 (13)	0.29
Number of LAVA sites on epicardium†	19 (11–22)	36 (14–46)	0.31	19 (11–46)	20 (14–29)	0.38
Ablation and procedural end points						
Total RF time	31 (23–55)	33 (17–49)	0.20	34 (23–53)	31 (16–48)	0.21
Epicardial ablation	11 (20)	18 (20)	0.99	20 (27)	9 (13)	0.03
Procedure time	278±68	233±86	0.003	271±71	226±88	0.002
Inducibility tested after ablation	46 (85)	66 (75)	0.15	55 (75)	57 (83)	0.22
Noninducibility of VT‡	36 (78)	57 (86)	0.27	45 (82)	48 (84)	0.95
Complete LAVA elimination§	30 (59)	49 (61)	0.82	49 (68)	30 (51)	0.05
Procedural complications	3 (6)	6 (7)	0.77	6 (8)	3 (4)	0.37

3D-EAM indicates 3-dimensional electroanatomical mapping; DCC, direct current cardioversion; LAVA, local abnormal ventricular activity; RF, radiofrequency; RII, real-time image integration; and VT, ventricular tachycardia.

*Applies to patients with 3D-EAM.

†Among patients with epicardial access.

‡Among patients with inducibility testing.

§Among patients with LAVA.

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Impact of Multipolar Catheters

High-density mapping with multipolar catheters has been reported to enhance accurate depiction of slow conducting areas during SR and improves understanding of VT mechanisms.[7,25,26] However, the impact of this technology on ablation outcome has not been defined. In this study, the use of multipolar catheters was associated with a lower VT recurrence rate in patients with post-MI VT. Consistent with a recent report from our group[27], mapping with multipolar catheters was associated with a higher mapping density that translated into a higher rate of endocardial LAVA identification. The rate of complete LAVA elimination tended to be higher when using multipolar catheters. This might be explained by a more mechanistic understanding of slow conduction areas during SR and therefore by a more efficient targeting of the entry site to interconnected channels.[28] Overall, the impact of multipolar catheters on patient outcome seems to be mediated by a more comprehensive treatment of VT substrate.

Study Limitations

The objective of this study was to evaluate the impact of technological advances on efficacy of VT ablation. Therefore, a

retrospective nature was mandatory. We acknowledge that the use of different techniques during the course of the study likely led to a systematic underestimation of the impact of baseline characteristics. The impact of image integration and multipolar catheters on patient outcome after post-MI VT ablation should be confirmed in a randomized-controlled fashion. The second limitation of this study is related to its sample size, which particularly prevented us from analyzing predictors of mortality. Indeed, only 4 patients experienced sudden deaths attributed to arrhythmia recurrence in the studied population. Third, one of the inherent limitations of the nonrandomized study design is a potential confounding effect of accumulating experience for one technique influencing outcome of subsequently introduced techniques. Although this effect is negated to a degree by the fact that procedures were performed by specialists in VT ablation with >10 years of experience, it remains a potential confounding factor. Another potential bias would be an evolution in the indication to perform VT ablation during the course of the study. However, this indication remained unchanged, and particularly, the baseline characteristics (age, sex, previous percutaneous coronary intervention, previous coronary artery bypass graft, ICD, left ventricular ejection fraction, VT storm, and number of past procedures and drugs) did not differ between patients with and without image integration and between patients with and without multipolar catheters.

Conclusions

We demonstrate that the ability to achieve complete LAVA elimination, the integration of scar data from preprocedural imaging, and the use of multipolar catheters to perform high-density mapping enhances VT-free survival after post-MI VT ablation. Our results further confirm that complete LAVA elimination is a procedural end point of high predictive value.

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Disclosures

None.

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