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ORIGINAL ARTICLE

Ventricular Duration Map Area as a Valuable and Effective Target for VT Ablation End Point in Ischemic Cardiomyopathy: The VEDUM FREEDOM Study

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BACKGROUND: Ventricular electrogram duration map (VEDUM) is a new approach for the identification of the arrhythmogenic substrate critical for ventricular tachycardia (VT), and it is based on the evaluation of the prolonged bipolar electrograms. Our aim is to evaluate the prognostic role of the VEDUM area in patients with VT and ischemic cardiomyopathy.

METHODS: We enrolled all patients with ischemic cardiomyopathy who underwent VT ablation in 2 different centers. After isthmus transection for VT inducible, the procedure was aimed at noninducibility of any VT plus substrate modification. For each patient, we retrospectively analyzed the amount of the VEDUM area covered during catheter ablation. The primary outcome included any recurrence of sustained VT.

RESULTS: Seventy-one patients (mean age: 69.9±8.9 years; males 93%) were enrolled. The mean size of the VEDUM area was 14.6±10.3 cm^2, and it was visualized in a low voltage area in 65 (91.6%) patients. A deceleration zone and late potentials were recorded inside the VEDUM area in 71.8% and 73.2%, respectively. During a mean follow-up of 24.4±13.9 months, the primary outcome occurred in 18 (25.4%) cases; the arrhythmia free-survival was significantly lower in patients with ablation of at least 75% of the VEDUM area (VEDUM <50%: 57.5%; 50% <VEDUM <75%: 76%; VEDUM >75%: 89.5%; log-rank *P* value: 0.047). The ablation of at least 50% of the VEDUM area (hazard ratio, 0.374 [0.147–0.947]; *P* value, 0.038) and the VT inducibility (hazard ratio, 4.087 [1.341–12.450]; *P* value, 0.013) represented the only predictors of VT recurrence.

CONCLUSIONS: VEDUM area ablation represented a new target for catheter ablation of VT in patients with ischemic cardiomyopathy.

GRAPHIC ABSTRACT: A graphic abstract is available for this article.

Key Words: cardiomyopathies ■ catheter ablation ■ defibrillator ■ heart failure ■ ventricular tachycardia

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WHAT IS KNOWN?

- The substrate leading to ventricular tachycardia (VT) circuits is characterized by heterogeneous and slow conduction zones.
- The ventricular electrograms duration map area represents a discrete region critical for VT circuit, also in patients with multiple VT morphologies.

WHAT THE STUDY ADDS

- A complete abolition of the ventricular electrograms duration map area is correlated with better outcome; patients ablated >75% of the ventricular electrograms duration map area had consistently less VT recurrences if compared with the other 2 groups (50< X <75% and <50%).
- Ventricular electrograms duration map area abolition plus VT non inducibility could represent an effective end point during VT ablation procedures.

Nonstandard Abbreviations and Acronyms

DZ	deceleration zone
ICD	implantable cardioverter defibrillator
ICM	ischemic cardiomyopathy
LP	late potential
LVA	low voltage area
VEDUM	ventricular electrograms duration map
VT	ventricular tachycardia

Patients with ventricular tachycardia (VT) and ischemic cardiomyopathy (ICM) are at high risk for adverse outcomes.[1,2] The implantable cardioverter defibrillator (ICD) is the cornerstone of therapy for the prevention of sudden cardiac death but unfortunately, ICDs do not prevent VT recurrence.[3] Indeed, about one-third of persons with an ICD will have episodes of VT and receive an ICD shock within 3 years after implantation.[4] ICD therapies are associated with impaired quality of life, worsening of heart failure, and higher mortality.[1,5] In this scenario, catheter ablation has become the mainstay strategy for the treatment of scar-related VT to reduce arrhythmia recurrence and the number of ICD shocks.[2,6] Due to the risk of hemodynamic deterioration related to repeated attempts of VT induction and the risk for electrical shock cardioversion, the identification of subtle target site during sinus rhythm is currently an important research field. Functional mapping approaches have emerged as a pivotal tool for the identification of slow conduction areas and vulnerable zones which represent an effective target for ablation procedures.[7–9] Among them, the ventricular electrogram duration map (VEDUM) is based on the identification of longest bipolar electrogram registered during sinus rhythm and allows to select a discrete area of inhomogeneous conduction (VEDUM area) critical for VT circuit, also in patients with multiple VT morphologies.[10] Nowadays, no data are available about the long-term prognostic role of the VEDUM method. For this reason, our study aims to evaluate the clinical outcome related to ablation of the VEDUM area during catheter ablation in patients with ICM.

METHODS

Study Design and Patient Population

We have included in this retrospective study all consecutive patients with ICM who underwent VT ablation in 2 institutions (San Raffaele Hospital, Milan and Isola Tiberina—Gemelli Isola Hospital, Rome) from January 2021 to December 2023. The study protocol was approved by the institutional review committee of each center, and written informed consent was obtained from each patient before every interventional procedure. The data supporting this study's findings are available from the corresponding author on reasonable request.

Procedural Workflow

All procedures were performed under general anesthesia. The antiarrhythmic therapy was discontinued at least 5 half-lives before the procedure, when clinically appropriate. An epicardial approach was performed following the failure of a prior endocardial procedure, or when a detailed endocardial mapping during VT failed to reveal the complete diastolic pathway. In cases of simultaneous epicardial mapping, the pericardium was accessed percutaneously using the method described by Sosa et al[11] before systemic heparinization. Epicardial mapping was performed immediately after pericardial access.

Electroanatomical maps were achieved with the Advisor HD Grid Mapping Catheter Sensor Enabled (Abbott, Minneapolis) in omnipolar configuration. All maps were performed during sinus rhythm or atrial fibrillation with (1) intrinsic QRS activation when possible or (2) right ventricular pacing in cases of pacemaker dependence; biventricular stimulation was avoided. The voltage and the local activation time maps were created by using the EnSite X AutoMap Mapping Tool (Abbott, Minneapolis). Ventricular maps created with other catheters or navigation systems were excluded from the present study to avoid off-line retrospective analysis biases for electrogram duration maps.

Substrate Identification

Bipolar voltage mapping was performed using established voltage settings of <0.5 mV for dense scar and <1.5 mV for border zone.[12] Late potentials (LP) were defined as any low voltage electrogram (<1.5 mV) with a single component or multiple continuous delayed electrical components, separated from the higher amplitude component of the local ventricular electrogram recorded after the surface QRS end.[13] The extension of LPs (LPs area) was measured offline by drawing a continuous line around the areas of interest to be quantified.

Isochronal crowding (isochronal late activation mapping) was depicted to display the entire ventricular activation during sinus or paced rhythm, noting the electrograms at the last

deflection. Isochronal late activation mapping was displayed with 8 equally distributed isochrones of activation (12.5% of ventricular activation comprised each isochrone). The mapping catheter was returned to remap regions if density was insufficient or if abnormal electrograms from the first pass could not be adequately distinguished from noise. Deceleration zones (DZ) were defined as regions with isochronal crowding with >3 isochrones within a 1 cm radius.[7]

Ablation Protocol

Ablation strategies were conducted at VT interruption when feasible, isthmus transection, and subsequent substrate modification (DZ, LPs, local abnormal ventricular activity areas ablation) as per center/operator preference. Radiofrequency ablation was performed at a power setting of 50 W (temperature limit of 43 °C) using an irrigated ablation catheter (Flexability or Tactiflex ablation catheter—Abbott). A pure substrate modification strategy was applied in cases of hemodynamically untolerated VTs and in those that remained noninducible throughout the procedure. At the end of the procedure, programmed ventricular stimulation was repeated up to the fourth extra stimulus to confirm the noninducibility of any VT. If the VT was still inducible and hemodynamically tolerated, activation mapping and ablation were performed to terminate the ongoing VT.

VEDUM Retrospective Analysis

A VEDUM map blinded to the electrophysiologist in charge of the procedure was created. As described in the previous article, the difference between local activation time T2 (last electrogram deflection) and local activation time T1 (first electrogram deflection) is computed by TurboMap for each bipole combination and used to populate a color-coded VEDUM map. VEDUM electrograms are annotated only with continuous electrical activity (isoelectric components inside the signal were excluded from the analysis).[10] After calculating the electrograms length, the autocolor mapping tool was applied to realize an 8-color-coded map of all electrograms. The VEDUM area was defined as the ventricle zone confined by the isochronal crowding consequently in an abrupt electrogram duration change.[10] Electroanatomical maps with inconsistent high-density definitions in the area of interest were excluded from the present analysis. The extension of the VEDUM area was measured offline by drawing a continuous line around the areas of interest to be quantified. The spatial location of the VEDUM area registered during sinus/paced rhythm was projected on the bipolar voltage map and then correlated with other functional maps (DZs, LPs) to establish the presence of overlapping between them.

For all patients was assessed the localization and time of each RF application and we included in the lesion set all RF applications delivered in the same part of the ventricle for at least 10 seconds at 50 W (temperature limit of 43 °C). Finally, the lesion set was superimposed on the VEDUM map and experienced engineers (F.C., G.D., A.D.G., and B.B.) calculated the overlap/mismatch area, as depicted in the Figure 1. Thus, population was divided into 3 groups based on the VEDUM area covered during the ablation:

- VEDUM <50%: patients with VEDUM area ablated <50%.
- VEDUM 50< X <75%: patients with VEDUM area covered from 50% to 75%.
- VEDUM >75%: patients with VEDUM area ablated >75%.

Clinical Follow-Up

All patients were followed up clinically. The first visit occurred routinely after 1 month and thereafter every 6 months. If clinically required, additional clinical visits were added in the follow-up. ICD logs were carefully analyzed for evaluating all arrhythmias recurrences. ICD programming was set as per the final programmed ventricular stimulation results as our standard routine.[14] Sustained VT is defined as a continuous VT lasting at least 30 seconds and requiring an intervention for termination.[3] Every sustained VT, ventricular fibrillation episode, or ICD intervention was considered as VT recurrence.

Statistical Analysis

The normal distribution of all continuous variables was checked by visual methods (Q-Q plot and histogram) and the significance test (Kolmogorov-Smirnov normality test and Shapiro-Wilk test). For continuous variables, descriptive statistics were provided (number of available observations, mean, SD), whereas median (interquartile range) was used for non-normal data. Categorical data were described as simple frequency and percentage (%). Comparisons among groups were performed using Pearson bivariate test and χ^2 tests for categorical covariates; nonparametric test of Kruskal-Wallis was used to compare non-normally distributed continuous variable. The Kaplan-Meier method was used to estimate cumulative event rates in the groups; differences in each group were compared using log-rank tests. Univariate and multivariate analysis was performed for identifying the predictors of VT recurrence, and all the variables with significant association (P<0.10) in univariate analysis were included in multivariate analysis. All statistical analyses were performed using STATA statistical analysis software (version 16).

RESULTS

Patients' Characteristics

Between January 2021 and December 2023, we enrolled 71 patients with ICM who underwent VT ablation. The study population's demographic, clinical, and instrumental characteristics are reported in Table 1. Overall, the mean age was 70±9 years, and 93% (n=66) of the patients were male. Percutaneous coronary intervention was the most common revascularization strategy (63.4%; n=45) followed by coronary artery bypass graft (26.8%; n=19); the remaining 9.8% (n=7) cases had chronic coronary occlusion. Heart failure was the most frequent cardiovascular comorbidity, and the mean left ventricular ejection function was 37±9%.

Structural and Functional Substrate Characteristics of the VEDUM Area

VT characteristics are summarized in Table 2. We induced 129 VT morphologies (1.82 VTs/pts), and

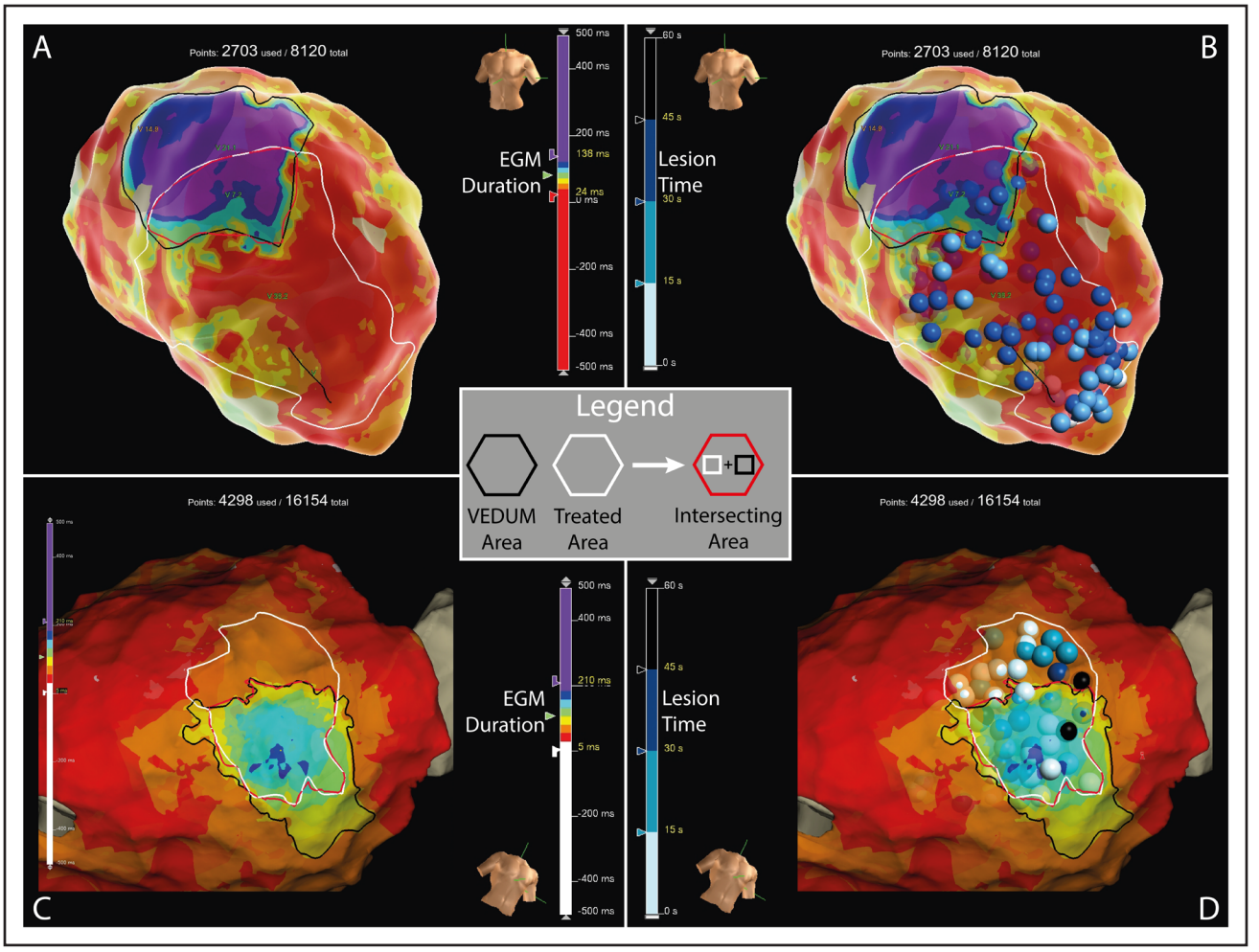

Figure 1. For example, of different percentage of ventricular electrograms (EGM) duration map (VEDUM) area covered during catheter ablation.

107 (78.1%) of them were hemodynamically tolerated (14 [13.1%] through extracorporeal membrane oxygenation). A complete VT activation map (≥90% of the tachycardia cycle length) was obtained in 76% (n=98; 91.6% of total induced VTs) of morphologies and the overall mean cycle length was 326±76 ms. VT was not inducible by programmed electrical stimulation at the end of the procedure in 90.1% of patients. Procedural complications were observed in 7% (n=5) of patients and the rate of major complications was 2.8% (n=2); Table S1. Structural and functional substrate characteristics of the VEDUM area are summarized in Table 2. The VEDUM area was wider than LPs area (VEDUM area: 14.6±10.3 cm^2 versus LPs area: 9.4±8.9 cm^2; *P* value: 0.003) but narrower than low voltage area (LVA; VEDUM area: 14.6±10.3 cm^2 versus LVA area: 30.7±23.3 cm^2; *P* value: 0.001). The VEDUM area was detected inside a LVA (<1.5 mV) in 91.6% (n=65); LPs were identified in 60 (84.5%) patients and the VEDUM area was recorded inside a LPs area in 51 (71.8%) cases. A discrete DZ area was observed in 55 (77.5%) cases, and it was in a VEDUM area in 73.2% of patients.

Clinical Follow-Up

During a mean follow-up of 24.4±14 months, 18 (25.4%) patients had VT recurrences. As depicted in the Figure 2, freedom from VT arrhythmia at 24 months was 73.3% (interquartile range, 60.9%–82.4%). Twelve (66.7%) of them with sustained VT received an appropriate shock while in the other patients (33.3%) the VT episodes were interrupted by anti-tachycardia pacing. The ablation of at least 50% of the VEDUM area (hazard ratio, 0.374 [0.147–0.947]; *P* value, 0.038) and the VT inducibility (hazard ratio, 4.087 [1.341–12.450]; *P* value, 0.013] represented the only predictors of VT recurrence (Table 3).

Prognostic Implication of VEDUM Area Ablation

As specified in the methods section, patients were divided into 3 groups based on the VEDUM area covered during the catheter ablation (Figure S1). Demographics and instrumental characteristics are summarized in the Table 4. No difference in terms of structural and functional characteristics of the VEDUM area was observed. The extension of the LPs area

Table 1. Baseline Characteristics

Quantitative variables			Qualitative variables	
	Mean±SD	Median (IQR)		Value (%)
Age, y	69.9±8.9	70 (64–77)	Male Sex	66 (93)
CHA_2DS_2VA	4.2±1.1	4 (3–5)	Hypertension	60 (84.5)
HAS-BLED	2.7±0.9	3 (2–3)	Diabetes	21 (29.6)
LVEDV, mL	169.4±44.6	160 (136–199)	CAD	71 (100)
LVESV, mm	63.2±19	61 (55.8–62.5)	CABG	19 (26.8)
LVEF, %	37.2±9.1	35 (30.3–44.3)	PCI	45 (63.4)
			Chronic occlusion	7 (9.8)
			Heart failure	62 (87.3)
			Stroke/TIA	5 (7)
			Renal disease	16 (22.5)
			COPD	8 (11.3)
			AF/AFL history	20 (28.2)

Baseline characteristics and risk factors of the study population. AF indicates atrial fibrillation; AFL, atrial flutter; CABG, coronary artery bypass graft; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; IQR, interquartile range; LVEDV, left ventricular end diastolic volume; LVEF, left ventricular ejection fraction; LVESV, left ventricular end systolic volume; PCI, percutaneous coronary intervention; and TIA, transient ischemic attack.

Table 2. Structural and Functional Substrate Characteristics of the VEDUM Area

VT characteristics		
VT morphologies/patients		1.82
Patients with multiple VTs		29 (40.8)
VT hemodynamically tolerated		107 (78.1)
In ECMO		14 (13.1)
VT Map available		98 (76)
VT inducibility at the end of procedure		7 (9.9)
Area extension		
	Mean±SD	Median (IQR)
VEDUM, cm^2	14.6±10.3	12.2 (6.8–19.7)
LPs, cm^2	9.4±8.9	6.4 (3.2–13.0)
Scar, cm^2	30.7±23.3	24.7 (14.5–38.7)
Structural and functional substrate at the VEDUM area		
LVAs		65 (91.6)
LPs		51 (71.8)
DZs		52 (73.2)

DZ indicates deceleration zone; ECMO, extracorporeal membrane oxygenation; IQR, interquartile range; LP, late potential; LVA, low voltage area; VEDUM, ventricular electrograms duration map; and VT, ventricular tachycardia.

(VEDUM <50%: 14.4±13.2 cm^2 versus VEDUM 50< X <75%: 8.5±5.3 cm^2 versus VEDUM >75%: 6.7±5 cm^2; *P* value, 0.23) and LVA (VEDUM <50%: 33.9±27.2 cm^2 versus VEDUM 50< X <75%: 32±22.5 cm^2 versus VEDUM >75%: 25.3±19.3 cm^2; *P* value, 0.46) was comparable between groups. Otherwise, the VEDUM area was significantly different among groups (VEDUM <50%: 20±12.9 cm^2 versus VEDUM 50< X <75%: 14.2±7.2 cm^2 versus VEDUM >75%: 8.9±5.4 cm^2; *P* value, 0.001). The VT inducibility at the end of procedure was more frequent in the group VEDUM <50% (VEDUM <50%: 6 [25%] versus VEDUM 50< X <75%: 1 [3.8%] versus VEDUM >75%: 0 [0]; *P* value, 0.01).

During the follow-up, the number of VT recurrence was significantly higher in the group VEDUM <50% (VEDUM <50%: 10 [41.7%] versus VEDUM 50< X <75%: 6 [23.1%] versus VEDUM >75%: 2 [9.5%]; *P* value, 0.04). As depicted in the Figure 3, freedom from VT arrhythmia at 24 months after catheter ablation was considerably higher in the group VEDUM >75% (VEDUM <50%: 57.5% versus VEDUM 50< X <75%: 76% versus VEDUM >75%: 89.5%; log-rank *P* value, 0.047). No difference in the overall radiofrequency time (VEDUM <50%: 1674±873s versus VEDUM 50< X <75%: 1739±647s versus VEDUM >75%: 1647±1043s; *P* value, 0.93) and in the VEDUM area (VEDUM <50%: 888±637s versus VEDUM 50< X <75%: 964±456s versus VEDUM >75%: 853±992s; *P* value, 0.86) was observed between groups.

In Figure S2, we reported the arrhythmia-free survival of catheter ablation of patients in which the VEDUM area was covered for at least 50% (VEDUM <50%: 57.5% versus VEDUM >50%: 81.9%; log-rank *P* value, 0.029; Panel A) and 75% (VEDUM <75%: 66.6% versus VEDUM >75%: 89.5%; log-rank *P* value, 0.051; Panel B).

Based on the univariate analysis, we divided our population into 4 groups and performed a comparison among them (Figure 4); patients in which VEDUM area was ablated for at least 50% and VT was not inducible at the end of the procedure, experienced the lower number of VT recurrence.

DISCUSSION

This study provides the first analysis of the prognostic role of the VEDUM area in patients with VT and ICM. The main findings are the following:

- A complete abolition of the VEDUM area is correlated with better outcomes; patients ablated more than 75% of the VEDUM area had consistently fewer recurrences if compared with the other 2 groups (50< X <75% and <50%).
- VEDUM area abolition >50% and VT non inducibility were both significant predictors of VT recurrence.

The duration of the bipolar electrograms was already identified as an effective method to detect endocardial and epicardial slow conduction zones in patients with scar-related VT.[10] In our past experience, all prolonged bipolar electrograms were confined in a discrete zone called the VEDUM area, and in patients with multiple VTs, all isthmuses were included in the same VEDUM area, supporting the hypothesis that this

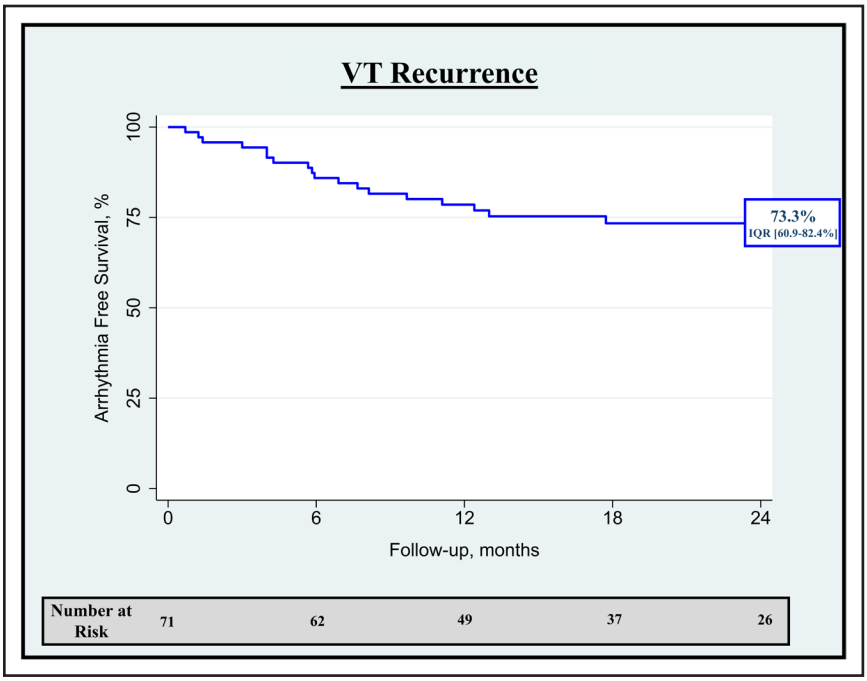

Figure 2. Overall arrhythmia-free survival after catheter ablation.
IQR indicates interquartile range; and VT, ventricular tachycardia.

area was critical for the reentry.[10] Moreover, the recognition of the longest electrogram registered inside the VT isthmus was correlated with a prompt VT termination, highlighting the concept of vulnerable areas inside the isthmus itself.[15,16] The VEDUM area has a higher probability of containing VT isthmus if compared with the LPs area.[10]

VEDUM Area and Its Correlation With LVA, LPs, and DZs

The extension of the VEDUM area results in about half of the LVA (VEDUM area: 14.6±10.3 cm^2 versus LVA area: 30.7±23.3 cm^2; *P* value, 0.001); therefore, the VEDUM area may represent a possible target for the

Table 3. Predictors of VT Recurrence

	Univariate		Multivariate	
	HR (95% CI)	*P* value	HR (95% CI)	*P* value
Age, y	1.008 (0.957–1.061)	0.771		
Hypertension	0.549 (0.180–1.675)	0.292		
Diabetes	1.345 (0.504–3.586)	0.554		
Heart failure	1.269 (0.291–5.523)	0.751		
EF >35%	0.782 (0.293–2.086)	0.624		
CABG vs PCI	1.132 (0.586–2.187)	0.713		
VT map available	0.711 (0.273–1.844)	0.484		
VEDUM area, cm^{2}*	1.052 (0.975–1.139)	0.183		
LP area, cm^{2}*	1.014 (0.897–1.12)	0.973		
LV area, cm^{2}*	1.012 (0.967–1.043)	0.827		
Presence of DZ	0.920 (0.567–1.493)	0.737		
LP abolition	0.532 (0.189–1.496)	0.232		
RF time, s†	1.005 (0.995–1.006)	0.893		
Ablation of VEDUM >50%	0.374 (0.147–0.947)	0.038	0.491 (0.172–1.398)	0.183
VT hemodynamically tolerated	1.080 (0.347–3.358)	0.896		
VT inducibility	4.087 (1.341–12.450)	0.013	2.618 (0.748–9.167)	0.132

CABG indicates coronary artery bypass graft; DZ, deceleration zone; EF, ejection fraction; HR, hazard ratio; LP, late potentials; LV, low voltage; PCI, percutaneous coronary intervention; RF, radiofrequency; VEDUM, ventricular electrograms duration map; and VT, ventricular tachycardia.

*For an increase of 2 cm^2.

†For an increase of 30 s.

Table 4. Baseline Characteristics Based on the VEDUM Covered During Catheter Ablation

	VEDUM <50% (n=24)	VEDUM 50%< X <75% (n=26)	VEDUM >75% (n=2)	*P* value
Baseline characteristics				
Age, y	70.1±7.3	70.4±8.9	69.1±10.6	0.89
Male sex	22 (91.7)	25 (96.2)	19 (90.5)	0.73
Hypertension	19 (79.2)	25 (96.2)	16 (76.2)	0.10
Diabetes	8 (33.3)	7 (26.9)	6 (28.6)	0.90
Heart failure	22 (91.7)	24 (92.3)	16 (76.2)	0.24
LVEF, %	36.3±9.1	35.8±7.8	40.1±10.4	0.23
Stroke/TIA	3 (12.5)	2 (7.7)	0	0.31
CHA_2DS_2VA	4.2±1.2	4.5±1	3.7±0.9	0.06
Renal disease	5 (20.8)	5 (19.2)	6 (28.6)	0.77
Failed AADs				
Amiodarone	13 (54.2)	16 (61.5)	12 (57.1)	0.87
β-blocker	19 (79.2)	22 (84.6)	15 (71.4)	0.55
Mexiletine	3 (12.5)	4 (15.4)	2 (9.5)	0.91
Sotalol	4 (16.7)	3 (11.5)	5 (23.8)	0.53
VT characteristics				
VT morphologies/pts	2±1.6	1.6±1	1.9±1.6	0.62
Pts with multiple VTs	10 (41.7)	10 (38.5)	9 (42.9)	0.95
VT inducibility at the end of the procedure	6 (25)	1 (3.8)	0	0.01
Area extension				
VEDUM, cm^2	20±12.9	14.2±7.2	8.9±5.4	0.001
LPs, cm^2	14.4±13.2	8.5±5.3	6.7±5	0.23
Scar, cm^2	33.9±27.2	32±22.5	25.3±19.3	0.46
Structural and functional substrate in the VEDUM area				
LVAs	22 (91.7)	24 (92.3)	19 (90.5)	1
LPs	15 (62.5)	22 (84.6)	14 (66.7)	0.17
DZs	17 (70.8)	22 (84.6)	13 (61.9)	0.19
Radiofrequency time				
Total time, s	1674±873	1739±647	1647±1043	0.93
In the VEDUM area, s	888±637	964±456	853±992	0.86
VEDUM area covered, cm^2	6.5±4.9	8.5±4.1	7.3±4.5	0.31

AAD indicates antiarrhythmic drugs; DZ, deceleration zones; LP, late potential; LVA, low voltage area; LVEF, left ventricular ejection fraction; TIA, transient ischemic attack; VEDUM, ventricular electrograms duration map; and VT, ventricular tachycardia.

homogenization of the arrhythmogenic tissue, reducing procedural time, and complications.[17] In our experience, in about 10% of the cases the VEDUM area was extended outside the LVA; these data are coherent with previous findings reporting a minority of cases with VT interruption in a site with normal voltage.[18] Otherwise, the mean area of LPs results significantly smaller than the VEDUM area (VEDUM area: 14.6±10.3 cm^2 versus LPs area: 9.4±8.9 cm^2; *P* value, 0.003). As previously reported, we have observed a slight mismatch in the localization of VEDUM and LPs area; in the 15% of the patients, LPs were outside the VEDUM area.[10] Besides the physiological reason, the electrogram annotation underlies the rationale for this mismatch: during the acquisition of the VEDUM map, electrograms with isoelectric line are excluded. Indeed, the electrograms with these characteristics highlight points of local conduction block and it is debated if their ablation is necessary and effective in VT prevention.[19]

Finally, specific comments are deserved about the relationship between DZs and the VEDUM area. A discrete DZ was observed in the majority of the cases (73.2%), thus confirming that the VEDUM area is a ventricular zone with conduction abnormalities. The application of only 8 colors to display the activation map from the earliest to the latest signal, including also very LPs, generates a wide interindividual variability of the isochronal time, thus influencing the detection of DZs.[20] The results obtained in our study and the recent improvement in electrogram quality acquisition could overcome the oversimplification of the

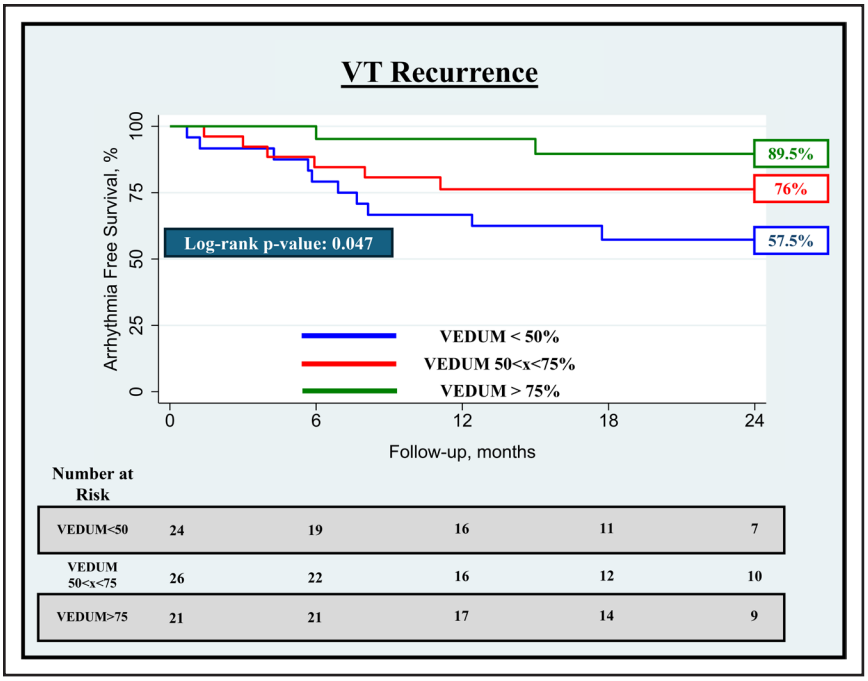

Figure 3. Arrhythmia-free survival after catheter ablation based on the ventricular electrograms duration map (VEDUM) area covered.
VT indicates ventricular tachycardia.

color-coded ventricular maps that are obtained by single annotation of the local electrograms.[21]

Clinical Implication of the VEDUM Area as Target for VT Ablation

The VEDUM approach is a functional mapping method that involves the analysis of the whole electrogram's duration and components. It is well-known that the electrogram duration could be considered a valuable portrayal of the conduction properties of the tissue[22] and that a substrate leading to VT circuits is characterized by heterogeneous and slow conduction, also in ICM.[23] The VEDUM can highlight a comprehensive evaluation of the arrhythmogenic substrate, including the information received from both local abnormal ventricular activities and LP mapping, as previously discussed. This hypothesis could justify our findings that patients in the group VEDUM <50% have experienced more frequently VTs inducibility at the end of the procedure and a higher recurrence rate during follow-up compared with other groups.

Although the elimination of local abnormal ventricular activities is a fascinating approach for substrate VT

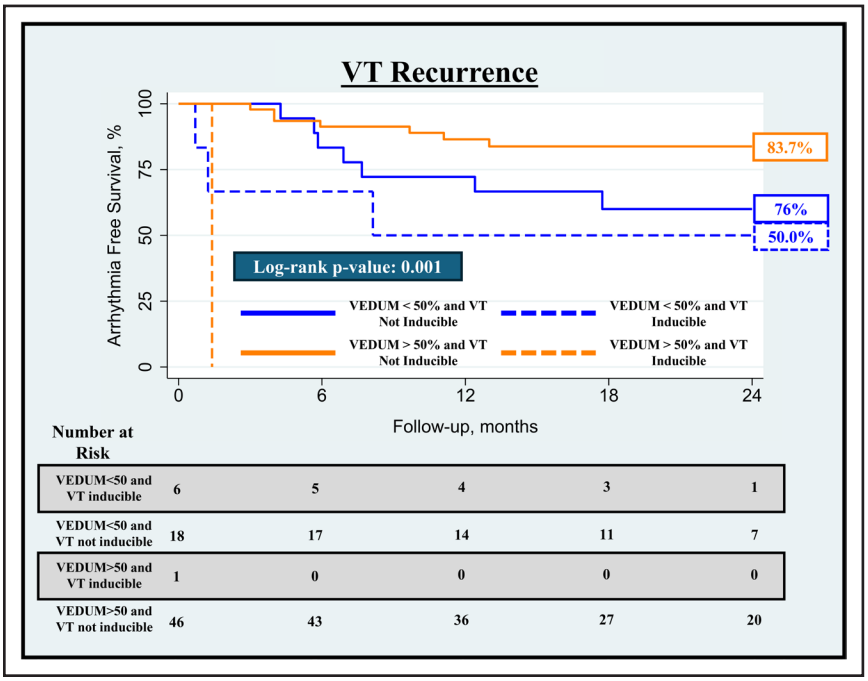

Figure 4. Arrhythmia-free survival after catheter ablation based on the ventricular electrograms duration map (VEDUM) area covered and ventricular tachycardia (VT) inducibility at the end of the procedure.

homogenization, the local abnormal ventricular activities require a high expertise in electrical signals' evaluation and multiple pacing maneuvers increasing procedural time. Otherwise, VEDUM does not require pacing maneuvers and can be performed offline after the standard acquisition of the preferred functional mapping algorithm for the substrate evaluation.

Moreover, the VEDUM area is a simple empirical target to use, especially in the case of noninducible patients with no other clear end point.[24] It has been documented that the VEDUM area contains, in the majority of the cases, all isthmuses of mappable VTs[10] confirming the complex and inhomogeneous conduction peculiarity of this area. This observation could be very useful in the operative clinical setting, especially in the case of not-tolerated VT. VT ablation procedures are constantly increasing, also due to technological improvements, involving low-volume centers with less experienced operators and sometimes without anesthesia team support. Improving in bipolar electrograms acquisition may facilitate either signal automatic annotations or to enhance understanding of the local activation pattern. The possibility of implementing new functional mapping methods to decrease the need for activation mapping could be the cornerstone of the spread of these procedures worldwide.

Limitations

Our study has several limitations that need to be acknowledged. (1) It was a retrospective study and enrolled only patients with ICM. (2) Although the initial omnipolar acquisition of the electrograms, the VEDUM analysis is based on bipolar electrograms. This limitation was reduced with multiple acquisitions during high-density mapping and the possibility to use multiple bipoles due to the shape of the HD Grid catheter. (3) VEDUM map can be performed offline with the turbo mapping tool, which is time-consuming and cannot be easily applied in live cases automatically. (4) VEDUM electrograms may contain part of far field activation that influence the maximum length of the electrogram itself; for this reason, the first deflection and last deflection annotations were reviewed manually. (5) The effects of pacing maneuvers and the different site of stimulation on the functional properties (modification of the electrogram length) were not tested. (6) The lesion set was superimposed on the VEDUM map, and the degree of overlap was qualitative calculated due to the lack of a dedicated software.

Conclusions

VEDUM area ablation could represent a new target for catheter ablation of VT in patients with ICM. Patients in whom the VEDUM area was ablated for at least 50% and VT was not inducible at the end of the procedure experienced a lower number of VT recurrences during follow-up.

ARTICLE INFORMATION

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Supplemental Material

Table S1
Figures S1 and S2

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