KARDIOLOGIA POLSKA

Polish Heart Journal
The Official Peer-reviewed Journal of the Polish Cardiac Society since 1957

Online first
This is a provisional PDF only. Copyedited and fully formatted version will be made available soon

ISSN 0022–9032 e-ISSN 1897–4279

Radiofrequency catheter ablation of ventricular tachycardia using combined endocardial techniques in patients with structural heart disease improves procedural effectiveness and reduces arrhythmia episodes

Authors: Grzegorz Karkowski, Andrzej Ząbek, Michał Szotek, Łukasz Drużbicki, Jacek Lelakowski, Jacek Legutko, Marc Gosnell, Marcin Kuniewicz

Article type: Original article

Received: July 14, 2022

Accepted: December 1, 2022

Early publication date: December 5, 2022

Radiofrequency catheter ablation of ventricular tachycardia using combined endocardial techniques in patients with structural heart disease improves procedural effectiveness and reduces arrhythmia episodes

Short title: Combined ablation techniques in treatment of ventricular tachycardia.

Grzegorz Karkowski[1], Andrzej Ząbek[1], Michał Szotek[1], Łukasz Drużbicki[2], Jacek Lelakowski[1], Jacek Legutko[3, 4], Marc Gosnell[5, 6], Marcin Kuniewicz[1, 6]

[1]Department of Electrocardiology, John Paul II Hospital, Kraków, Poland
[2]Department of Pediatric Cardiac Surgery, Institute of Pediatrics, Jagiellonian University Medical College, Kraków, Poland
[3]Department of Interventional Cardiology, Institute of Cardiology, Jagiellonian University Medical College, Kraków, Poland
[4]Clinical Department of Interventional Cardiology, John Paul II Hospital, Kraków, Poland
[5]Department of Anatomy, Jagiellonian University Medical College, Kraków, Poland
[6]Department of Cardiology, Loyola University Medical Center

Correspondence to:
Marcin Kuniewicz, MD, PhD,
Department of Electrocardiology,
John Paul II Hospital,
Prądnicka 80, 31–202 Kraków, Poland,
phone: +48 12 614 22 77,
e-mail: kuniewiczm@gmail.com

WHAT'S NEW?

Combination of multiple mapping techniques, two or three, improves procedural efficacy and reduces cardioverter-defibrillator interventions. Systematized procedure in step-by-step sequence to ventricular tachycardia ablation is comparable to efficacy of endo — epi approach.

ABSTRACT

Background: Radiofrequency catheter ablation (RFCA) of ventricular tachycardia (VT) in patients with structural heart disease (SHD) is by evidence, safe and effective. However, arrhythmia recurrence is still relatively high and the optimal procedural strategy is unclear. In clinical practice, several combinations of mapping and ablation techniques are used to improve VT ablation efficacy.

Aim: The study aimed to evaluate and provide evidence of the efficiency and safety of a systematized combination of VT ablation (mapping) techniques in patients with SHD.

Methods: From 2016 to 2019, 47 patients (54 procedures) with SHD (89% heart failure, 94% ischemic heart disease, 37% VT storm) who underwent RFCA of VT were retrospectively analyzed from a group of 58 consecutive patients. During RFCA of VT, different combinations of three techniques, (activation mapping (AM), pace-mapping (PM), and substrate-based mapping (SbM), were used. The procedures were performed using the CARTO® 3 (Biosense Webster Inc., Diamond Bar, CA, US) electro-anatomical mapping system.

Results: During a median (interquartile range [IQR]) follow-up of 25.5 months (11.75–52.25), VT-free survival after ablation was 68.5% (n = 37/54 procedures). Acute procedural success was achieved in 85% (n = 46/54 procedures). The number of induced VT morphologies, induction of non-clinical or unsustained VT after ablation and less VT mapping techniques used during procedure were related to decreasing VT free-survival.

Conclusions: VT ablation strategy based on combined systematized techniques is effective and safe in long-term follow-up patients with SHD.

Key words: catheter ablation, heart failure, pace-mapping, ventricular tachycardia

INTRODUCTION

Modern treatment of ischemic heart disease and heart failure has significantly improved patient mortality, while patients who required treatment for ventricular tachycardia (VT) has increased. Monomorphic VT is mainly associated with a co-existing arrhythmia substrate, such as scarring (post-infarction) or fibrosis. Episodes of ventricular tachycardia can significantly worsen a patient's quality of life (QoL) and increase mortality [1, 2]. Treatment of VT is based on pharmacotherapy and radiofrequency catheter ablation (RFCA). RFCA is the most effective method of VT treatment, which reduces the number of implantable cardioverter-defibrillator (ICD) high-energy shocks and improves QoL and patient outcomes after a VT storm [3–6].

Fundamentally, three techniques of VT mapping are used in clinical practice. The first is activation and entrainment mapping, the second is substrate-based mapping (SbM), and the third is pace-mapping (PM). Activation/entrainment mapping (AM) defines the VT mechanism and localization of the arrhythmia circuit with critical isthmus. Although AM is a very desirable mapping technique, it requires sustained VT with hemodynamic tolerance.

A second technique, SbM, is an effective complement to AM and aimed to eliminate VT substrate represented by abnormal ECG's in the low-voltage areas. Three-dimensional (3D) electro-anatomical mapping systems define low-voltage areas (scar and the fibrotic regions) and facilitate the identification and ablation of the arrythmia substrate. Effective SbM compared to AM, decreases the recurrence rate of VT and is optimal for use in unmappable VT.

The third commonly used method in VT ablations is ventricular pace-mapping (PM). This method is beneficial in focal VT and has the potential to assist in identifying critical areas of VT re-entry [7].

Among patients with structural heart disease (SHD), all RF ablation methods can be provided separately or may be combined in various configurations to eliminate VT. The selected technique depends on the patient's condition and arrhythmia complexity.

Aim

This retrospective analysis concentrates on the safety and efficiency of the VT mapping technique combination in patients with structural heart disease (SHD) in the long-term follow-up.

METHODS

Fifty-eight consecutive patients with SHD undergoing a VT ablation procedure between January 2016 and November 2019 were used for analysis. Forty-seven patients with 54 RFCA (7 repeat procedures) were retrospectively evaluated. Eleven of the patients who did not fulfil eligibility criteria (loss of follow-up, lacking record of final arrythmia inducibility, lack of sufficient electrophysiological data from the procedure) were excluded from the study.

According to the ESC guidelines, patients were referred for RFCA immediately after VT occurred or was noted in ICD recordings [8, 9]. The procedures were performed using an electrophysiological system (Bard Labsystem Pro 2.4) and the CARTO® 3 (Biosense Webster Inc., Diamond Bar, CA, US) electro-anatomical mapping system.

Transthoracic echocardiography was used to assess the size and location of previous myocardial damage. Coronary angiography was performed on all patients before RF ablation to exclude an ischemic cause of sustained ventricular arrhythmia (exception of 1 patient). All RFCA procedures were performed under conscious sedation achieved with midazolam and fentanyl, as necessary. Ablations were performed by skilled operators (>150 ablations/year) experienced with VT ablations techniques.

Left ventricular access was either transaortic, transseptal or both. Intravenous heparin was administered to maintain an activated clotting time of 250–350 sec. The 3D geometry of the ascending aorta (in transaortic access) and the left ventricle was reconstructed with a fast anatomical map with voltage map (bipolar map setting: from 0.5 to 1.5mV) performed by ablation catheter with automatic annotation by CARTO® Confidence module. The workflow sequence starts from substrate base mapping, then pace mapping, and if possible, activation mapping. Bellow, all consequent phases are described.

The substrate-based mapping was performed during sinus rhythm in patients with rhythm over 50 bpm or RV pacing in stimulation dependant patients. The map collection contained at least 500 points.

During mapping of the left ventricle, local abnormal ventricular activities (LAVA) and late potentials (LP) were identified and marked. The area of dense scar (<0.5 mv) was confirmed and depicted by the lack of stimulation (20 mA/1 ms). Subsequently, programmed ventricular stimulation (PVS) from the right ventricle (RV) was performed in drive train 500 ms with up to 3 extra stimuli decremented to ventricular refractoriness (>200 ms) or VT induction. If no VT was induced from the RV, the stimulation program was repeated from the left ventricle. After VT

induction, the QRS pattern in the VT was collected, and arrhythmia interrupted. Next, the VT exit site was predefined by pace-mapping (defined as QRS morphology compliance with clinical VT of more than 85%), after which the entrance site was determined (defined as an abrupt shift in QRS morphology to ≤ 30% of the clinical VT). During PM, a delay of post-pacing stimulation interval stimulus-QRS (S-QRS) was marked and measured (Figure 1, Figure 2). If two methods were used (PM + SbM), this approach was named as "dual-technique". For hemodynamically tolerable VT's, activation mapping was also performed and this technique was named "triple". Finally, consequent to all presented techniques, the area of interest was determined. Entrainment mapping was performed at pre-defined points of interest, in the case of VT hemodynamical tolerance, followed by RF application (VT maintenance as short as possible). The RFCA was performed in the area of interest predefined by all applied techniques. During mappable VT (triple mapping technique), activation and entrainment mapping of the critical isthmus was an initial target, followed by LAVA's elimination in a predefined area. The dual mapping technique procedures aimed to target and eliminate LAVAs from the predefined area, proven by no pacing capture from the ablated region.

Finally, the PVS from right and left ventricle was performed for RFCA efficacy assessment in all cases. When non-inducibility of any sustained VT occurred, the procedure was considered as effective (acute success).

Follow-up

During the follow-up period, the patients were monitored in the outpatient clinic with device interrogation (minimum twice per year) or remained under tele-monitoring control (CareLink™, Medtronic; Home Monitoring, Biotronik). Any VT recurrence with an adequate ICD intervention (anti-tachycardia pacing or delivery of a high energy shock) was evaluated and considered as an ablation failure during the follow-up period. Repeat ablation, if necessary, was considered with an endo- or epicardial approach. The endocardial procedures were performed in the same electrophysiology lab, while the epicardial approach was transferred to the reference electrophysiology centre and excluded from analysis. The minimum follow-up was a period of 12 months.

Ethical statement

The Study was approved by an appropriate institutional review board (L.dz.OIL/KBL/7/2021). The approval of the bioethics committee was not obligatory due to the retrospective nature of the study.

Statistical analyses

Data is presented as numbers and percentages for categorical variables with means and standard deviations (SDs) for normally distributed continuous variables or medians and interquartile ranges for continuous variables with a nonnormal distribution. The normality of data distribution was verified by the Kolmogorov–Smirnov test. Categorical variables were analyzed using the chi-squared test or Fisher's exact test.

The graphic presentation of the long-term VT-free survival is shown using Kaplan–Meier curves. The Andersen-Gill model for recurrent event times (simple extension of the Cox model) was used to test the effects of clinically significant predictors of VT recurrence. Survival curves were compared with the log-rank test. All pooled estimates were displayed with a 95% CI. The non-parametric Mann-Whitney U test for independent samples was used to compare period between the single (first-time) and repeat procedure.

All statistical tests were 2-tailed, and a P <0.05 was considered statistically significant. All the analyses were performed in IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, US) and the R statistical package, Version 4.2.1 (http://r-project.org).

RESULTS

Study group characteristics

We retrospectively analyzed 54 RF ablation procedures (7 repeat ablations) of VT. Almost all the included patients (n = 47) with SHD had systolic heart failure (89%; n = 43) and ischemic heart disease with previous myocardial infarction (94%; n = 44). Three patients from the selected group had dilated cardiomyopathy. All the patients underwent ICD implantation for primary or secondary prevention before ablation.

From the 54 included ablation cases, 87% (n=47) were single (first-time) ablations and 13 % (n = 7) were repeat ablations. VT storm as an indication for the ablation procedure was observed in 37% (n = 20) of all cases, while 63% (n = 34) were due to detection of repeated sustained VT (terminated with ICD shocks or anti-tachycardia pacing [ATP]) in the implanted device's memory.

In the single (first-time) ablation group (n = 47), VT storm was noticed in 24% (n = 13), while in a repeat ablation group, VT storm was the only indication (100%; n = 7) (Table 1).

Procedural characteristics and acute success

Left ventricle access was obtained mainly via the transaortic route 80% (n = 43), while transseptal approach in 20% (n = 11). Median (interquartile range [IQR]) procedural and fluoroscopy times reached 182.0 min (140.0–211.0) and 7.6 min (3.0–10.7), respectively. During the ablation procedure, 1 to 5 different VT morphologies were induced. Single VT morphology was induced in 48.1% (n = 26), two VT morphologies in 18.5% (n = 10), three morphologies in 22.2% (n = 12), and four or more in 11.2% (n = 6). A dual mapping/ablation strategy (SbM + PM) was used in 64.8% (n = 35) and implementation of a triple mapping technique (AM + SbM + PM) was possible in 35% (n = 19) of cases.

The acute procedural success rate was 85% (n = 46). All induced and sustained VT were non-clinical (15%, n = 8). Additionally, in 16.6% (n = 9) of procedures, non-sustained VT with spontaneous termination was induced. None of the patients had VF during the final PVS. Detailed characteristics are listed in Table 2.

Long-term ablation success

After three months of blanking period after the ablation procedure, a median (IQR) follow-up of 25.5 (11.75–52.25) months with an overall VT-free survival rate reached 68.5% (n = 37). After a repeat procedure, VT-free survival was not significantly higher than after single (first-time) ablation (71% vs. 68.5 %; $P = 0.37$) (Figure 3). The median (IQR) time of observation after the repeat procedure was 18.0 (3.0–26.0) months. The median (IQR) time for VT recurrence after the first-time procedure was 6.4 (2.2–11.6) months, so this period was considered sufficient, even though the observational period between the single (first-time) and repeat procedure was significantly different ($P = 0.024$).

A recurrence of VT was considered as an unsuccessful procedure. Seventeen patients during the observation time experienced ICD intervention (ATP or/and shock) due to VT. Fifteen of them (88%) had VT recurrence after the primary procedure, two (12%) after the repeat procedure.

From a group of patients with a VT recurrence after a single procedure n = 15, a repeat procedure was recommended due to VT storm in ten cases (67%). Seven of them were qualified for

endocardial RFCA in our EP center (repeat ablation group n = 7), and three others were referred for epicardial ablation in a different EP lab. The remaining patients (n = 5) were under clinical observation and did not accept repeat ablation due to asymptomatic, rare arrhythmia episodes terminated by ATP.

Importantly, after both single and repeat ablations in our study group, the VT storm burden was dramatically reduced (none of the patients after repeat ablation). One patient with VT during follow-up had successful heart transplantation due to heart failure progression. Comparing the patient's clinical characteristics, we have found that diabetes mellites type 2 was related to an increased VT recurrence rate. Similar impacts were exerted by numbers of induced VT during ablation or lack of the triple mapping technique combination (AM + SbM + PM) (Table 3, Figure 4).

In final ablation PVS, independent from procedural technique combination, induction of non-sustained VT (n = 9; 16.7%) or non-clinical VT (n = 8; 14.8%) was not related to a higher recurrence rate in long-term follow-up ($P = 0.5$).

Among patients with DCM (three patients) — the acute procedural success rate was 100%. The number of VT inducted during the ablation procedure was two different morphologies in one patient and one morphology in two patients. None of inducted VT were bundle branch block reentry. A dual mapping/ablation strategy (SbM + PM) was used in two DCM patients and while a triple mapping technique (AM + SbM + PM) was done in one case. The long-term success rate reached 66% (2 of 3).

Amiodarone was continued after ablation in 41% (n = 22) cases throughout the three months during the blanking period. Detailed univariate analysis with hazard ratios in long-term follow-up is presented in Table 3.

Complications

During the periprocedural period, there were 4 (7.4%) complications. Two groin hematomas not requiring intervention, one stroke (transaortic approach), one episode of pulmonary edema deteriorating to cardiac arrest (pulseless electrical activity) and patient death. In postprocedural observation, two patients died in the first year of follow-up due to progression of heart failure.

DISCUSSION

Radiofrequency catheter ablation (RFCA) of ventricular tachycardia (VT) in patients with structural heart disease (SHD) is by evidence, safe and effective [10]. However, arrhythmia recurrence is still relatively high, and the optimal procedural strategy is unclear [11]. The aim of our study was to evaluate and provide evidence of the efficiency and safety of a systematized combination of VT ablation (mapping) techniques in patients with SHD. Starting from substrate-based mapping followed by pace mapping, and activation mapping (if possible), may be a useful strategy to enhance VT ablation procedures.

Substrate-based ablation concerns more widely fibrotic areas (scar) and conduction channels represented by fragmented/late potentials (Figure 4). Total elimination of LAVAs/LPs seems to be an optimal endpoint of substrate-based ablation but is difficult to achieve [12–15]. In the Wolf study, total substrate elimination was successful in only 64 %, with a VT-free survival rate of 73% after one year [13]. In a recent prospective and randomized multicentre study (Berlin VT), RF ablation was performed within the entire area of late potentials. Total LP elimination was achieved more frequently than non-inducible VT. During the 24-month follow-up, the recurrence of ventricular tachyarrhythmia reached 39.7% in preventive and 48.2% in deferred ablation strategy [16]. In the present study, total substrate elimination (LAVAs/LP) was not the main, but an optional target of ablation. Mainly substrate-based ablation was limited to the myocardium area related to induced clinical or non-clinical VT.

Pace mapping has also been featured as a technique to identify the critical VT isthmus [7, 17]. Demonstrating high compliance of a paced QRS complex in clinical VT with a short S-QRS interval is typical for VT exit (Figure 3). Pacing with prolonged S-QRS interval and high compliance to VT demonstrates a potential critical isthmus. Once pacing shows an abrupt transition to unmatched QRS morphology, this indicates the entrance of clinical VT [7]. This technique helps to identify the critical VT isthmus without performing activation mapping but may not recognize the multiple circuit branches with other VT morphology [17]. Our study identified the primary ablation target by pace-mapping related to abnormal regional electrograms elucidated by initial substrate mapping. This specified “area of interest” was the perfect zone for activation and entrainment mapping (if possible).

Unfortunately, the long-term effectiveness of VT pace-mapping as a single mapping strategy in publications is not known. Combinations of PM and SbM were the most common RFCA strategy in our study (64.8%).

The final step of the workflow was activation mapping and especially entrainment mapping. This technique is performed to confirm the VT critical isthmus site and completes VT mapping [18]. However, activation mapping and entrainment is not possible in every procedure. Prolonged, sustained VT during the mapping process may increase the risk of periprocedural hemodynamic collapse and may not be applicable [19]. Otherwise, VT inducibility and stability are difficult to sustain. Additionally, it has been shown that this single technique is not always sufficient in defining the optimal site for RFCA [20]. According to the literature, RFCA based only on activation/entrainment mapping has a relatively high (48%) risk of arrhythmia recurrence in a 12-month follow-up. Compared to substrate-based ablation, it had an inferior outcome [21]. Our strategy did not force the third step — AM (35.2% of cases) and was reserved for insistent or slow VT's with relatively low periprocedural hemodynamic decompensation. Once the three steps were achieved, the VT mapping was optimal. The results prove this strategy. The long-term follow-up — 24 months without VT reoccurrence reached 85% after three mapping methods were used and 64% without activation mapping (P = 0.041). However, as it is emphasized in the limitation section, due to the small number of patients, the results should be considered with caution.

Repetitive, non-inducibility of VT after ablation was an acceptable endpoint in our study. We showed that the induction of non-clinical VT or non-sustained VT at the end of the procedure increases the risk of arrhythmia recurrence in long-term observation, which has also been demonstrated in previous publication [22].

Apart from the ablation strategy, a primary VT burden significantly impacted the results. Although VT storm was not related to an increased VT recurrence rate, the number of induced VT's during procedure had the highest impact in long-term success (p=0.012). Our results overlap with other publications [23]. Nevertheless, during the observation period after repeat ablations, the VT storm burden was reduced considerably compared to the single VT RFCA which seems to be important for patient's QoL [24].

Our results of long-term VT-free survival (overall 68.5%) complies with available results also with epicardial techniques used [13,14,21,25]. The balance between optimal procedural outcome with procedural complexity and aggression (total LP abolition, epicardial approach) remains further studied. Also, for further investigation, the role of diabetes should be deeply analyzed. In the urinative model, DM2 had the highest risk value of VT recurrence (p=0.20 HR 7.69). The recent

colossal impact of SGLT2 inhibitors in HF treatment and reduction of arrhythmic burden may reflect this outcome [26, 27].

Our study shows that VT ablation based on combined and systematized techniques (step by step), with all their benefits and limitations, are safe and effective in in patients with SHD after long-term follow up.

Study limitations

The study has a relatively small sample size and was provided in a single-centre set-up. Retrospective and non-randomized characters also have a decreased final impact. A small number of patients requires consideration with caution. Despite these limitations, we believe that portraying limitations did not meaningfully disturb results.

CONCLUSIONS

Our study shows that the VT mapping and ablation procedure based on combined and systematized techniques — step by step, with all their benefits and limitations, is safe and effective in patients with SHD after long-term follow-up.

Article information

Conflict of interest: None declared.

Funding: None.

REFERENCES

1. Sweeney MO, Sherfesee L, DeGroot PJ, et al. Differences in effects of electrical therapy type for ventricular arrhythmias on mortality in implantable cardioverter-defibrillator patients. Heart Rhythm. 2010; 7(3): 353–360, doi: 10.1016/j.hrthm.2009.11.027, indexed in Pubmed: 20185109.

2. Kamphuis HCM, de Leeuw JRJ, Derksen R, et al. Implantable cardioverter defibrillator recipients: quality of life in recipients with and without ICD shock delivery: a prospective study. Europace. 2003; 5(4): 381–389, doi: 10.1016/s1099-5129(03)00078-3, indexed in Pubmed: 14753636.
3. Kumar S, Romero J, Mehta NK, et al. Long-term outcomes after catheter ablation of ventricular tachycardia in patients with and without structural heart disease. Heart Rhythm. 2016; 13(10): 1957–1963, doi: 10.1016/j.hrthm.2016.07.001, indexed in Pubmed: 27392945.
4. Kuck KH, Schaumann A, Eckardt L, et al. Catheter ablation of stable ventricular tachycardia before defibrillator implantation in patients with coronary heart disease (VTACH): a multicentre randomised controlled trial. Lancet. 2010; 375(9708): 31–40, doi: 10.1016/S0140-6736(09)61755-4, indexed in Pubmed: 20109864.
5. Carbucicchio C, Santamaria M, Trevisi N, et al. Catheter ablation for the treatment of electrical storm in patients with implantable cardioverter-defibrillators: short- and long-term outcomes in a prospective single-center study. Circulation. 2008; 117(4): 462–469, doi: 10.1161/CIRCULATIONAHA.106.686534, indexed in Pubmed: 18172038.
6. Jagosz M, Jędrzejczyk-Patej E, Kowalska W, et al. Quality of life in patients with a subcutaneous vs. transvenous implantable cardioverter-defibrillator. Kardiol Pol. 2022; 80(6): 679–684, doi: 10.33963/KP.a2022.0110, indexed in Pubmed: 35475461.
7. de Chillou C, Sellal JM, Magnin-Poull I. Pace mapping to localize the critical isthmus of ventricular tachycardia. Card Electrophysiol Clin. 2017; 9(1): 71–80, doi: 10.1016/j.ccep.2016.10.005, indexed in Pubmed: 28167087.
8. Priori SG, Blomström-Lundqvist C, Mazzanti A, et al. 2015 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death: The Task Force for the Management of Patients with Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death of the European Society of Cardiology (ESC). Endorsed by: Association for European Paediatric and Congenital Cardiology (AEPC). Eur Heart J. 2015; 36(41): 2793–2867, doi: 10.1093/eurheartj/ehv316, indexed in Pubmed: 26320108.

9. Masarone D. Last before-death alert remote monitoring transmission in patients with heart failure with reduced ejection fraction. Kardiol Pol. 2022; 80(3): 254–255, doi: 10.33963/KP.a2022.0060, indexed in Pubmed: 35195272.
10. Kucharz A, Kułakowski P. Fragmented QRS and arrhythmic events in patients with implantable cardioverter-defibrillators. Kardiol Pol. 2020; 78(11): 1107–1114, doi: 10.33963/KP.15471, indexed in Pubmed: 32631025.
11. Sapp J. Streamlining Ventricular Tachycardia Ablation Workflow. JACC Clin Electrophysiol. 2020; 6(11): 1449–1451, doi: 10.1016/j.jacep.2020.09.004, indexed in Pubmed: 33121674.
12. Jaïs P, Maury P, Khairy P, et al. Elimination of local abnormal ventricular activities: a new end point for substrate modification in patients with scar-related ventricular tachycardia. Circulation. 2012; 125(18): 2184–2196, doi: 10.1161/CIRCULATIONAHA.111.043216, indexed in Pubmed: 22492578.
13. Wolf M, Sacher F, Cochet H, et al. Long-Term outcome of substrate modification in ablation of post-myocardial infarction ventricular tachycardia. Circ Arrhythm Electrophysiol. 2018; 11(2): e005635, doi: 10.1161/CIRCEP.117.005635, indexed in Pubmed: 29440186.
14. Silberbauer J, Oloriz T, Maccabelli G, et al. Noninducibility and late potential abolition: a novel combined prognostic procedural end point for catheter ablation of postinfarction ventricular tachycardia. Circ Arrhythm Electrophysiol. 2014; 7(3): 424–435, doi: 10.1161/CIRCEP.113.001239, indexed in Pubmed: 24833642.
15. Berruezo A, Fernández-Armenta J, Andreu D, et al. Scar dechanneling: new method for scar-related left ventricular tachycardia substrate ablation. Circ Arrhythm Electrophysiol. 2015; 8(2): 326–336, doi: 10.1161/CIRCEP.114.002386, indexed in Pubmed: 25583983.
16. Willems S, Tilz RR, Steven D, et al. Preventive or Deferred Ablation of Ventricular Tachycardia in Patients With Ischemic Cardiomyopathy and Implantable Defibrillator (BERLIN VT): A Multicenter Randomized Trial. Circulation. 2020; 141(13): 1057–1067, doi: 10.1161/CIRCULATIONAHA.119.043400, indexed in Pubmed: 32000514.
17. de Chillou C, Groben L, Magnin-Poull I, et al. Localizing the critical isthmus of postinfarct ventricular tachycardia: the value of pace-mapping during sinus rhythm. Heart Rhythm. 2014; 11(2): 175–181, doi: 10.1016/j.hrthm.2013.10.042, indexed in Pubmed: 24513915.

18. Kumar S, Tedrow U, Stevenson W. Entrainment mapping. Card Electrophysiol Clin. 2017; 9(1): 55–69, doi: 10.1016/j.ccep.2016.10.004, indexed in Pubmed: 28167086.
19. Yadav A, Ramasamy S, Theodore J, et al. Catheter ablation of scar based ventricular tachycardia - Procedural characteristics and outcomes. Indian Heart J. 2020; 72(6): 563–569, doi: 10.1016/j.ihj.2020.09.009, indexed in Pubmed: 33357646.
20. Stevenson WG, Wilber DJ, Natale A, et al. Irrigated radiofrequency catheter ablation guided by electroanatomic mapping for recurrent ventricular tachycardia after myocardial infarction: the multicenter thermocool ventricular tachycardia ablation trial. Circulation. 2008; 118(25): 2773–2782, doi: 10.1161/CIRCULATIONAHA.108.788604, indexed in Pubmed: 19064682.
21. Di Biase L, Burkhardt JD, Lakkireddy D, et al. Ablation of stable VTs versus substrate ablation in ischemic cardiomyopathy: the VISTA randomized multicenter trial. J Am Coll Cardiol. 2015; 66(25): 2872–2882, doi: 10.1016/j.jacc.2015.10.026, indexed in Pubmed: 26718674.
22. Ghanbari H, Baser K, Yokokawa M, et al. Noninducibility in postinfarction ventricular tachycardia as an end point for ventricular tachycardia ablation and its effects on outcomes: a meta-analysis. Circ Arrhythm Electrophysiol. 2014; 7(4): 677–683, doi: 10.1161/CIRCEP.113.001404, indexed in Pubmed: 24879789.
23. Aldhoon B, Wichterle D, Peichl P, et al. Outcomes of ventricular tachycardia ablation in patients with structural heart disease: The impact of electrical storm. PLoS One. 2017; 12(2): e0171830, doi: 10.1371/journal.pone.0171830, indexed in Pubmed: 28187168.
24. Lelakowski J, Kuniewicz M, Rydlewska A, et al. Quality of life after RF ablation of reentrant supraventricular tachycardias and ventricular ectopic beats in own observation [article in Polish]. Pol Merkur Lekarski. 2010; 28(168): 438–443, indexed in Pubmed: 20642100.
25. Kuck KH, Tilz RR, Deneke T, et al. Impact of Substrate Modification by Catheter Ablation on Implantable Cardioverter-Defibrillator Interventions in Patients With Unstable Ventricular Arrhythmias and Coronary Artery Disease: Results From the Multicenter Randomized Controlled SMS (Substrate Modification Study). Circ Arrhythm Electrophysiol. 2017; 10(3), doi: 10.1161/CIRCEP.116.004422, indexed in Pubmed: 28292751.

26. von Lewinski D, Tripolt NJ, Sourij H, et al. Ertugliflozin to reduce arrhythmic burden in ICD/CRT patients (ERASe-trial) - A phase III study. Am Heart J. 2022; 246: 152–160, doi: 10.1016/j.ahj.2022.01.008, indexed in Pubmed: 35045327.

27. Lelonek M, Grabowski M, Kasprzak JD, et al. An expert opinion of the Heart Failure Association of the Polish Cardiac Society on the 2021 European Society of Cardiology guidelines for the diagnosis and treatment of acute and chronic heart failure: Heart failure guidelines from a national perspective. Kardiol Pol. 2022; 80(2): 239–246, doi: 10.33963/KP.a2022.0021, indexed in Pubmed: 35076082.

Table 1. Baseline patient's characteristics (n = 47)

Baseline characteristic	**Value**
Age, years, median (IQR)	64.5 (60.7–69.5)
Male, n (%)	45 (95.7)
Hypertension, n (%)	35 (74.5)
Diabetes mellitus/IFG, n (%)	16 (34.0)
Obesity with BMI >30, n (%)	20 (42.5)
Nicotinism, n (%) Former smokers Active smokers	 36 (76.6) 6 (12.8)
Heart failure, n (%)	42 (89.4)
Significant renal failure, n (%) eGFR <40 ml/min/1.73m^2	4 (8.5)
NYHA class, n (%) I II III IV	 5 (10.6) 25 (53.2) 11 (23.4) 1 (2.1)
Ischemic heart disease, n (%)	44 (93.6)
Dilated cardiomyopathy, n (%)	3 (6.4)
Left ventricle ejection fraction, %, median (IQR)	30.0 (20.0–40.0)
Dyslipidemia, n (%)	31 (66.0)
Atrial fibrillation, n (%)	17 (36.2)
Thyroid insufficiency and hyperthyroidism in medical history, n (%) Under treatment hyperthyroidism Under treatment hypothyroidism	9 (19.1) 4 (8.5) 5 (10.6)

Abbreviations: IFG, impaired fasting glucose; NYHA, New York Heart Association; VT, ventricular tachycardia

Table 2. Procedural characteristics

	Overall 54 (100)
LV access, n (%)	Transaortic: 43 (79.6) Transseptal: 11 (20.4)
No. of VT morphologies induced during ablation, n (%) for all patients One Two Three Four or more	 26 (48.1) 10 (18.5) 12 (22.2) 6 (11.2)
No. of VT morphologies induced during ablation, n (%) DCM subgroup One Two	 2 (Non-BBBR VT) 1 (Non-BBBR VT)
Procedural time, min, median (IQR)	182 (140.0–211.0)
Fluoroscopy time, min, median (IQR)	7.6 (3.0–10.7)
PVS after ablation, n (%) Clinical VT NsVT Nonclinical VT	 0 (0.0) 9 (16.7) 8 (14.8)
Dual mapping/ablation technique (PM+SbM), n (%)	35 (64.8)
Triple mapping/ablation technique (PM+SbM+AM), n (%)	19 (35.2)
Redo ablation, n (%)	7 (13.0)
VT Storm, n (%)	20 (37.0)

Abbreviations: AM, activation mapping; LV, left ventricular; PM, pace-mapping; Non-BBBR VT, non-bundle branch block reentry ventricular tachycardia; nsVT, non-sustained ventricular tachycardia; PVS, programmed ventricular stimulation; SbM, substrate based mapping; TA, transaortic; TS, transseptal

Table 3. Predictors of time to VT recurrence in univariate Cox regression analysis in the matched groups (n = 54)

	Univariate analysis	
	HR (NA) (95% Cl)	***P*-value**
Age	0.89 (0.76–1.04)	0.144
HT	3.80 (0.64–22.72)	0.142
Dyslipidemia	1.54 (0.42–5.69)	0.518
NYHA class	1.71 (0.57–5.19)	0.340
HF >II	2.17 (0.62–8.23)	0.426
DM	7.69 (1.39–43.48)	0.020
AF	1.09 (0.26–4.50)	0.905
LV EF	1.04 (0.95–1.14)	0.340
VT storm	1.24 (0.36–4.32)	0.731
Ablation technique[a]	5.11 (1.07–24.43)	0.041
Number of VTs morphologies induced	2.36 (1.20–4.61)	0.012
Induction of any-VT in final PVS	1.17 (0.73–1.89)	0.532
Amiodaron	0.33 (0.09–1.16)	0.084

[a]Triple technique vs dual technique (triple references)

Abbreviations: AF, atrial fibrillation; CI, confidence interval; DM, diabetes mellitus; HF, heart failure; HR (NA), non-adjusted hazard ratio; HT, hypertension; LVEF, left ventricle ejection fraction; PVS, programmed ventricular stimulation; VT, ventricular tachycardia

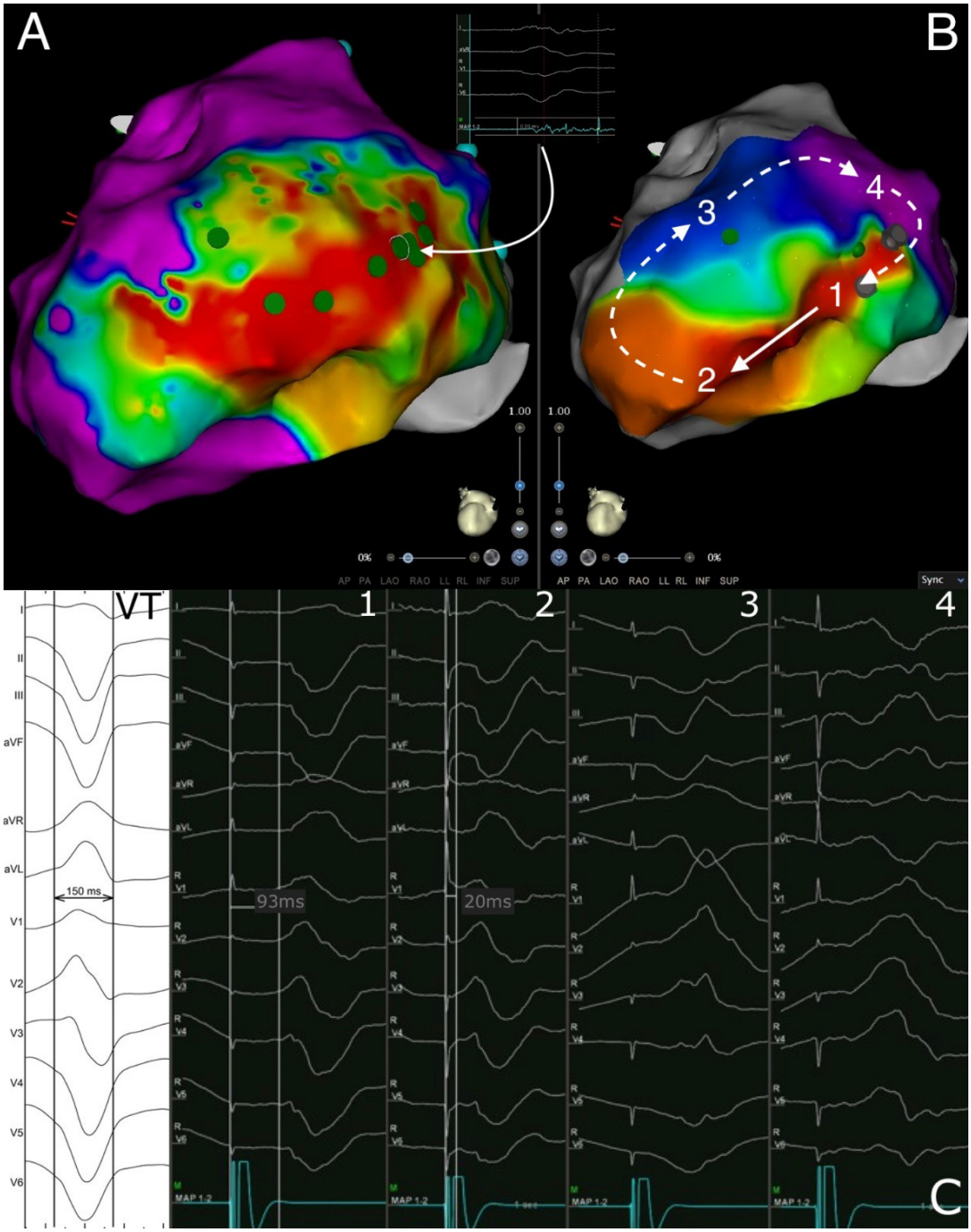

Figure 1. A–C. Substrate based mapping and pace mapping combination. **A.** Voltage map (0.2–1.5 mV) of the left ventricle shows low voltage area extending from MV (blue dots) to apex with LPs (green dots) marked in central part of the scar (<0.2 mV). Panel **B.** shows reconstruction of the VT circuit performed by pace mapping (color coded, same as activation mapping). In panel **C.** pacing from a different position is shown. Pacing side no 1 is located inside condition channel — paced QRS morphology compliance with clinical VT more than 85% with long S-QRS (93 ms).

Pacing side no 2 is of VT exit side with good QRS compliance and short Stimulus-QRS (20ms). No 3 area with border QRS compliance (85%–30%) to clinical VT shows outer loop and no 4 with low QRS compliance (<30%) is entrance sight of VT circuit

Abbreviations: LPs, late potentials; MV, mitral valve; VT, ventricle tachycardia

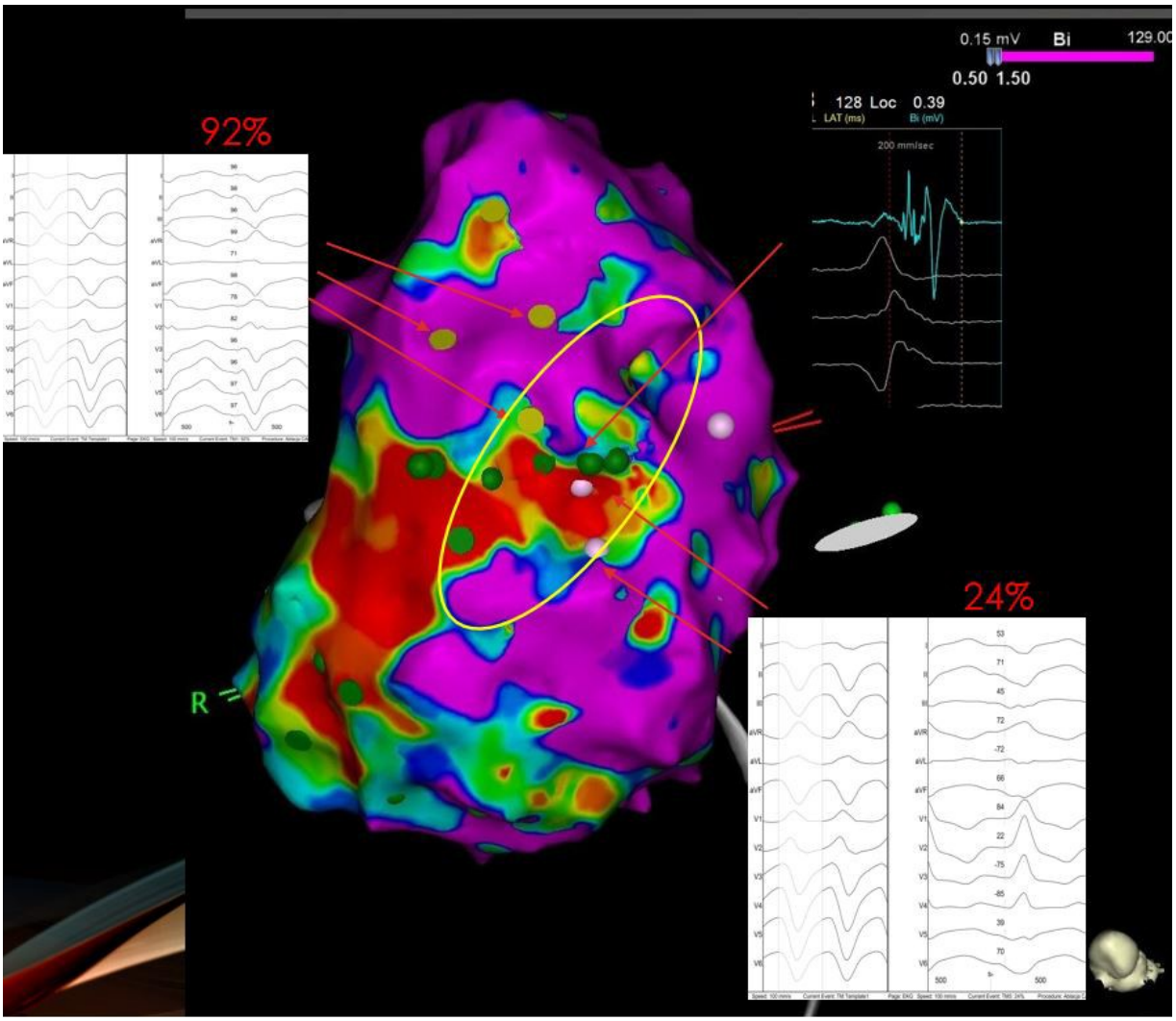

Figure 2. Substrate based mapping and pace mapping technique. Voltage map (0.5–1.5 mV) of left ventricle during sinus rhythm with marked LPs (green dots) (CARTO, Biosense Webster Inc., Diamond Bar, CA, US). VT pace-mapping limited to locate VT exit side (yellow dots) (PM, 92% compatibility to clinical VT) and VT entrance side (white dots) (abrupt transition in clinical VT compatibility, 24%). Primary targeted area for ablation based on PM + mapping of regional LPs, marked by yellow circuit

Abbreviations: see Figure 1

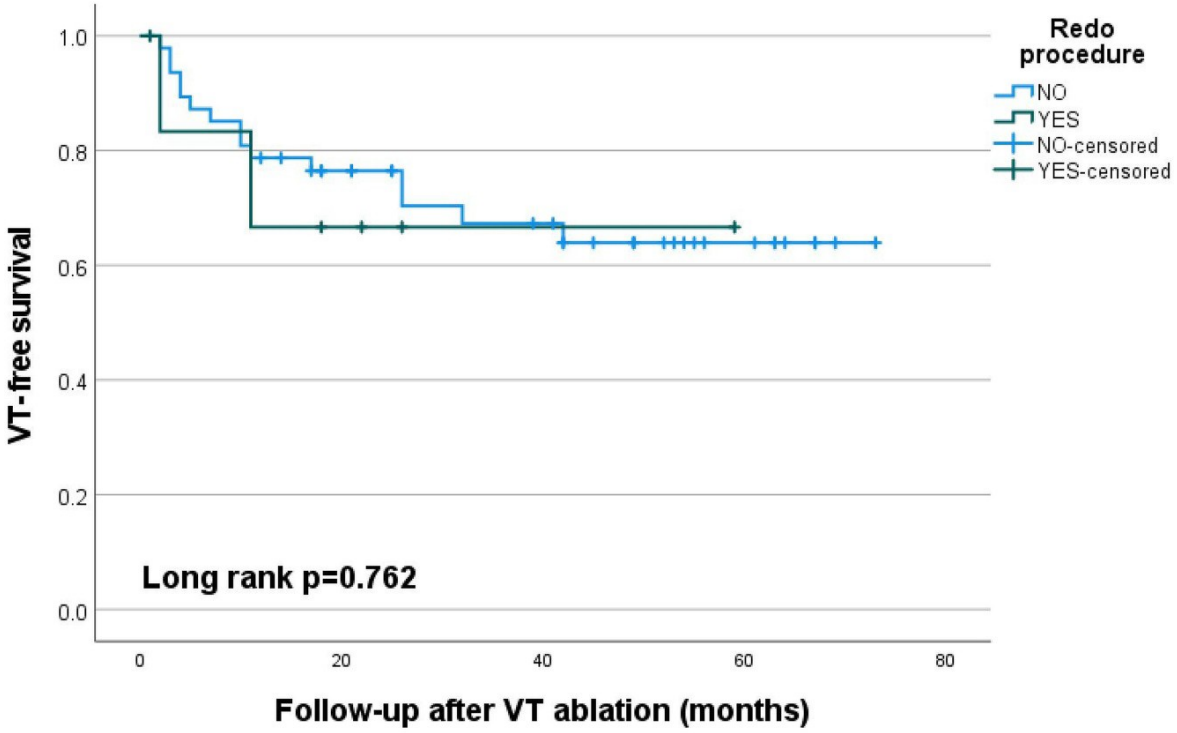

Figure 3. Kaplan–Meier curves of the long-term ablation success (VT-free) according to ablation procedure (single vs. repeat ablation)

Abbreviations: see Figure 1

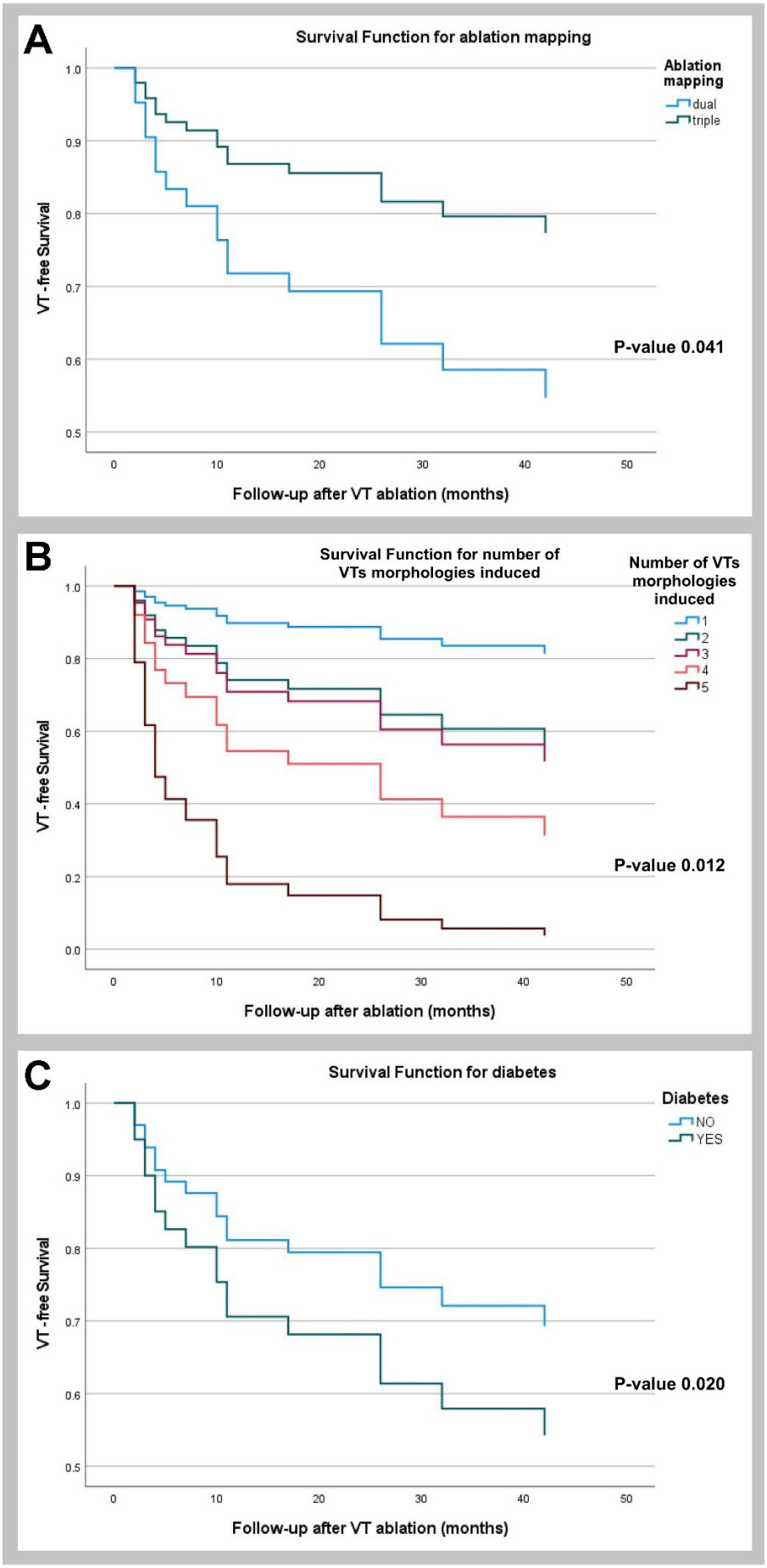
A
Survival Function for ablation mapping
Ablation mapping
dual
triple
VT -free Survival
1.0
0.9
0.8
0.7
0.6
0.5
P-value 0.041
0
10
20
30
40
50
Follow-up after VT ablation (months)
B
Survival Function for number of VTs morphologies induced
Number of VTs morphologies induced
1
2
3
4
5
VT -free Survival
1.0
0.8
0.6
0.4
0.2
0.0
P-value 0.012
0
10
20
30
40
50
Follow-up after ablation (months)
C
Survival Function for diabetes
Diabetes
NO
YES
VT -free Survival
1.0
0.9
0.8
0.7
0.6
0.5
P-value 0.020
0
10
20
30
40
50
Follow-up after VT ablation (months)

Figure 4. A. VT-free survival curves depending on ablation mapping technique (dual vs. triple). **B.** Number of VT morphologies during ablation. **C.** Diabetes

Abbreviations: see Figure 1