ESC European Society of Cardiology

Europace (2024) **26**, euae275
https://doi.org/10.1093/europace/euae275

CLINICAL RESEARCH

Mapping and ablation of ventricular tachycardia using dual-energy lattice-tip focal catheter: early feasibility and safety study

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Received 1 September 2024; accepted after revision 22 October 2024; online publish-ahead-of-print 31 October 2024

Aims

Catheter ablation is an effective treatment method for recurrent ventricular tachycardias (VTs). However, at least in part, procedural and clinical outcomes are limited by challenges in generating an adequate lesion size in the ventricular myocardium. We investigated procedural and clinical outcomes of VT ablation using a novel 'large-footprint' catheter that allows the creation of larger lesions either by radiofrequency (RF) or by pulsed field (PF) energy.

Methods and results

In prospectively collected case series, we describe our initial experience with VT ablation using a lattice-tip, dual-energy catheter (Sphere-9, Medtronic), and a compatible proprietary electroanatomical mapping system (Affera, Medtronic). The study population consisted of 18 patients (aged 55 ± 15 years, one woman, structural heart disease: 94%, ischaemic heart disease: 56%, left ventricular ejection fraction: 34 ± 10%, electrical storm: 22%) with recurrent sustained VTs and ≥1 previously failed endocardial RF ablation with conventional irrigated-tip catheter in 66% of patients. On average, 12 ± 7 RF and 8 ± 9 PF applications were delivered per patient. In three-fourths of patients undergoing percutaneous epicardial ablation, spasms in coronary angiography were observed after PF applications. All resolved after intracoronary administration of nitrates. No acute phrenic nerve palsy was noted. One patient suffered from a stroke that resolved without sequelae. Post-ablation non-inducibility of VT was achieved in 89% of patients. Ventricular-arrhythmia-free survival at three months was 78%.

Conclusion

VT ablation using a dual-energy lattice-tip catheter and a novel electroanatomical mapping system is feasible. It allows rapid mapping and effective substrate modification with good outcomes during short-term follow-up.

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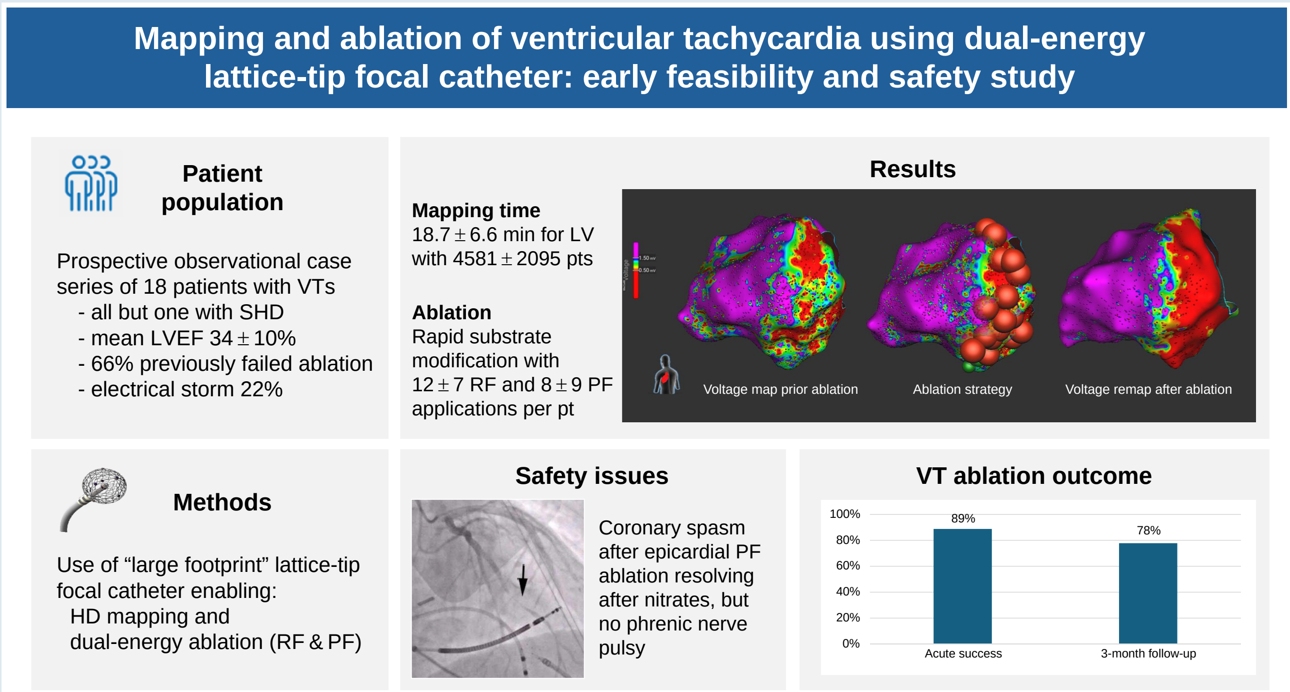
Graphical Abstract



Keywords Catheter ablation • Ventricular tachycardia • Pulsed field • Radiofrequency ablation

What's new?

- Lattice-tip catheter in combination with electroanatomical mapping system allows rapid high-density mapping of VTs and arrhythmogenic substrate.
- Ablation results in effective substrate modification without excessive troponin release with good outcomes during short-term follow-up.
- Pulsed field applications in epicardial space were commonly associated with spasms of coronary arteries but not phrenic nerve palsy.

Introduction

Catheter ablation (CA) is a well-established treatment of ventricular arrhythmias.[1,2] In patients with structural heart disease (SHD) and sustained ventricular tachycardias (VTs), CA has been shown to decrease the risk of shocks of implantable cardioverter-defibrillator (ICD), ventricular-arrhythmia-related hospitalizations[3] and possibly to improve prognosis.[4] However, the creation of deep lesions by radiofrequency (RF) ablation might be compromised in regions of fat and pre-existing scar, and risk collateral damage to coronary arteries and phrenic nerve. A lattice-tip catheter is a novel large-footprint mapping/ablation catheter (Sphere-9, Medtronic, Minneapolis, MN) that allows the application of both high-energy RF and pulsed field (PF) energy, using a compatible proprietary electroanatomical mapping system and generator (Affera, Medtronic, Minneapolis, MN).

The effectiveness and safety of the above system have been previously clinically validated for the treatment of atrial fibrillation (AF).[5] The potential application of the system for lesion creation in ventricular myocardium has been studied extensively in experiment.[6–8] However, the clinical use of a lattice-tip catheter for VT ablation has been reported only in case reports and small case series.[9,10]

We aimed to analyse the early-experience safety and efficacy of VT ablation using a lattice-tip catheter in patients with different clinical types of VT.

Methods

Study population and study design

This series included consecutive patients who underwent CA for VT between January and June 2024 using the Affera system. Patients were included when presented either with (i) SHD VTs or (ii) had a history of previously failed CA for VT. Patients with idiopathic VTs originating from typical regions like outflow tracts were not considered. All patients provided informed consent with the procedure. The institutional review board approved the study.

Catheter ablation procedure

The procedures were performed under general anaesthesia in all cases. After obtaining vascular access, procedures were navigated using a three-dimensional electroanatomic mapping system (Affera, Medtronic) and guided by intracardiac echocardiography (AcuNav, Siemens Medical Solutions). A 9 mm lattice-tip catheter (Sphere-9, Medtronic) was used for mapping and ablation. If needed, epicardial access was obtained using the Sosa technique.[11]

The Affera mapping and ablation system has been described earlier.[6] Briefly, the lattice-tip catheter contains a magnetic sensor and nine microelectrodes on the surface of the collapsible frame that collect near-field unipolar electrograms against the central indifferent electrode. The electroanatomical map is acquired rapidly by simultaneous recordings from all microelectrodes. At the same time, a dedicated algorithm automatically annotates local electrograms from each microelectrode. The mapping time was defined as the time interval between the first and last acquired point of the voltage map of the targeted chamber.

At the beginning of the procedure, unfractionated heparin was administered as an initial bolus, and further doses were adjusted to maintain the activated clotting time between 300 and 350 s. Depending on the substrate location and/or the presence of peripheral arterial disease, the left ventricle (LV) was accessed either transseptally or retrogradely.

Our mapping and ablation strategy was described previously.[12] Briefly, one quadripolar catheter was inserted into the right ventricle (RV) for pacing. At baseline, programmed ventricular stimulation from the ventricular apex was performed at two drive trains (600 and 400 ms) and up to three extrastimuli. Activation and entrainment mapping were used for well-tolerated VTs. Substrate mapping/ablation was performed primarily during spontaneous rhythm or RV pacing. Bipolar voltage maps (the lower threshold of 0.5 mV) were constructed and fragmented or late potentials were tagged. Zones of slow conduction were identified by stimulus-to-QRS onset intervals longer than 40 ms. The paced QRS morphology during sinus rhythm was used to match the exit sites of induced VTs. An increase in electrode temperature during RF/PF applications was used as a surrogate for tissue contact. The exact position and contact of the lattice-tip catheter with the tissue was confirmed by intracardiac echocardiography.

The primary strategy was high-energy RF ablation.[13] If RF ablation alone could not achieve VT suppression or adequate substrate modification, PF applications were added to consolidate the lesions further. Pulsed field was not used in close vicinity to the proximal ventricular conduction system. On the other hand, only PF energy was used in epicardial space. When RF energy was used for endocardial lesions, ablations were delivered for 30 s per lesion. For PF ablations, 5 s applications were delivered and repeated at each target site up to three times to maximize the lesion size.

The goal of CA was to abolish all abnormal signals or late potentials, often achieving electrical isolation of the scarred segment. The procedure was considered acutely successful in case of non-inducibility of any sustained VT using the same stimulation protocol as for induction.

Coronary angiography was performed before and after the epicardial PF energy delivery to identify the presence of potential coronary artery spasms. No nitrates were given prophylactically before PF applications. The phrenic nerve function after epicardial ablation was assessed by either (i) direct pacing of the phrenic nerve or (ii) observation of diaphragm motion on fluoroscopy.

Peripheral venous blood samples were obtained the next day (usually 18–24 h after the CA) to assess the serum levels of high-sensitivity troponin T (hsTnT).

Clinical follow-up

Following the CA, patients were seen in the outpatient clinic 3 months after the ablation. The recurrence of VT was assessed by clinical history and ICD interrogation. ICD programming was individualized according to the cycle lengths of clinical VTs.

Statistical analysis

Continuous variables were expressed as means with standard deviations and compared with the Student's *t*-test. Categorical variables were expressed as percentages and compared using the Wilcoxon paired test. A *P*-value of <0.05 was considered significant.

Results

The case series comprises 18 patients (aged 55 ± 15 years, one woman) with recurrent VTs. One patient had idiopathic focal VT from the crux of the heart; the others had SHD-related VT (94%). The underlying SHD was coronary artery disease (53%), non-ischaemic cardiomyopathy (35%), congenital heart disease (6%), and hypertrophic cardiomyopathy (6%). A total of 66% of patients were after ≥1 previously failed RF ablation procedure(s) (range 1–3), and 22% were in the electric storm at the time of ablation. Baseline characteristics are displayed in *Table 1*.

Table 1 Baseline characteristics

	***N* = 18**
Male sex (%)	94
Age (years)	55 ± 15
Body mass index (kg/m^2)	29 ± 4
Diabetes mellitus (%)	28
Arterial hypertension (%)	67
History of atrial fibrillation (%)	44
Structural heart disease (%)	94
Coronary artery disease (%)	56
Left ventricular ejection fraction (%)	34 ± 10
Previous unsuccessful ablation (%)	67
Electric storm at the time of ablation (%)	22
Implantable cardioverter-defibrillator (%)	94

Electroanatomic mapping

An average of 4452 ± 1724 and 4581 ± 2095 points was collected for the RV and LV voltage maps, respectively. The mean mapping time was 18.3 ± 9.6 min for RV and 18.7 ± 6.6 min for LV. The mapping was perceived as easy. However, in certain regions, such as perimitral or peritricuspid areas, navigation with intracardiac echocardiography had to be used to place the catheter correctly.

The arrhythmogenic substrate was identified on the anterior/anteroseptal LV wall (28%), inferior LV wall (28%), lateral LV wall (22%), within RV (17%), and in periaortic region (6%).

Radiofrequency or pulsed field delivery

Compared to our previous experience with a 4 mm-tip catheter, myocardial capture during pacemapping/entrainment was more difficult and sometimes impossible to achieve with the lattice-tip catheter. This could be explained by the smaller pacing electrodes on the surface of the catheter tip. Due to this limitation in pacemapping or entrainment mapping, we preferred to start ablation with high-energy RF to see changes in electrograms, which may promptly disappear when PF is used for the initial lesion. Pulsed field was delivered later to consolidate previous RF lesions.

On average, 12 ± 7 RF and 8 ± 9 PF applications were delivered per patient. In the presence of an extensive substrate, the ablation strategy most commonly comprised scar homogenization or core scar isolation (*Figure 1*). Epicardial PF ablations did not lead to transmural lesions as assessed by corresponding endocardial signals (*Figure 2*). The applications of PF energy did not induce ventricular fibrillation or sustained VT in any of the patients; however, myocardial capture was commonly observed during PF applications (*Figure 3*). This myocardial capture could result in non-specific VT termination when PF was applied during ongoing VT.

The mean procedural duration was 157 ± 31 min, with a fluoroscopy time of 5.2 ± 4.0 min (*Table 2*).

Acute ablation outcome

The ablation resulted in acute non-inducibility in 16/18 (89%) patients. In one case, the patient was after previous surgical repair of the postinfarction ventricular septal defect, and a pericardial patch covered a portion of the septum. Despite extensive RF and PF ablations close to the presumed

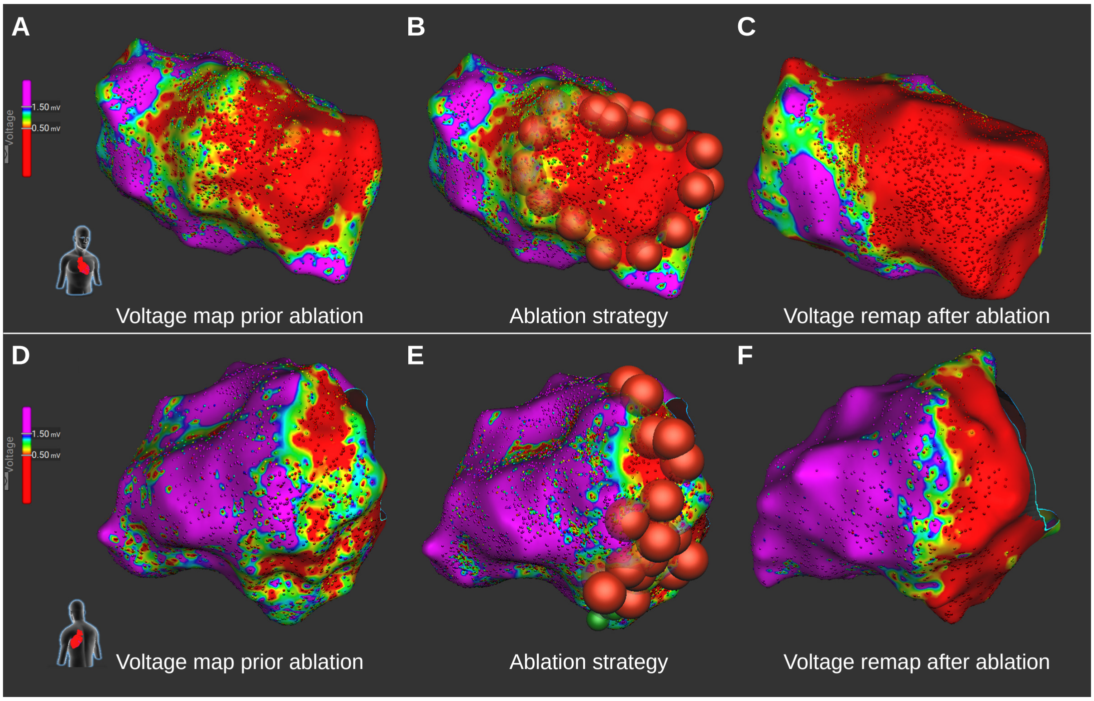


Figure 1 Examples of substrate modification in patients with VTs after previous myocardial infarction. Panels *A* to *C* show LV voltage maps in the right anterior oblique view in a patient with an extensive anteroseptal scar. Panels *D* to *F* depict LV voltage maps in posterior view in a patient after inferolateral myocardial infarction. Note the elimination of local voltage within the ablated zone after either core scar isolation (panel *B*) or substrate homogenization (panel *E*).

exit VT site, arrhythmia inducibility could not be suppressed. The patient subsequently underwent stereotactic radiotherapy. In the other patient, the ablation of the arrhythmogenic substrate on the lateral LV wall failed due to the inaccessible epicardial location of the VT circuit because of the presence of adhesions.

Complications

Coronary angiography performed after epicardial PF applications showed spasms of the adjacent coronary artery (*Figure 4*) in three out of four patients undergoing epicardial ablation. Interestingly, ECG changes attributable to ischaemia were noted only in one patient. When spasm was observed, intracoronary nitroglycerine was administered (starting at a dose of 0.5 mg and reaching up to 2–3 mg until resolution of spasm or systemic hypotension was seen). For cases with observed coronary spasm, the mean distance from the coronary artery and the centre of the lattice-tip catheter was 7 ± 3 mm. No spasm was seen in a patient, where the distance was 21 mm. In all cases, the spasm resolved after the intracoronary application of nitrates. On the other hand, no phrenic nerve palsy was observed in three patients, where PF applications were delivered in epicardial space in the vicinity of the phrenic nerve (in one case directly on site with phrenic nerve capture; in two cases within the distance of 1–2 cm). One patient suffered from a stroke, which resolved within one month without any sequelae. This was a patient with hypertrophic cardiomyopathy and a history of pre-existing thrombus in the LV aneurysm. Preprocedural imaging using transthoracic echocardiography with echocontrast revealed no thrombus, and the activated clotting time was maintained above 300 s. The source of the presumed embolism causing the stroke is, therefore, unknown.

The extent of myocardial damage

As a surrogate for myocardial damage, levels of hsTnT were assessed before and after ablation, and increased from 36 ± 26 ng/L to 995 ± 580 ng/L ($P < 0.01$).

Short-term follow-up

The VT recurred in two patients with procedural failure. In two additional patients, recurrences were seen during a short-term follow-up of 3 months. One patient had one episode of VT treated by anti-tachycardia pacing. The other case was a patient with non-ischaemic cardiomyopathy who had a recurrence of incessant slow VT from the RV inferior basal region despite previous endo-epicardial RF/PF ablation. This VT had been successfully treated with a 4 mm-tip catheter inserted underneath the inferior tricuspid leaflet. The most plausible interpretation is that with a large-tip catheter design, we failed to map/ablate the sharp angle between the myocardial wall and the posterior leaflet of the tricuspid valve (*Figure 5*).

Discussion

The main findings of this study can be summarized as follows: (i) electroanatomical mapping with the novel system was rapid and reliable; however, pacemapping or entrainment mapping was limited by frequent non-capture; (ii) ablation using a large-footprint catheter, enabling both RF and PF, is feasible and effective for rapid modification of the arrhythmogenic substrate; (iii) reachability of some narrow regions by the large tip might be limited compared to the 4 mm-tip, and intraprocedural imaging with intracardiac echocardiography might be

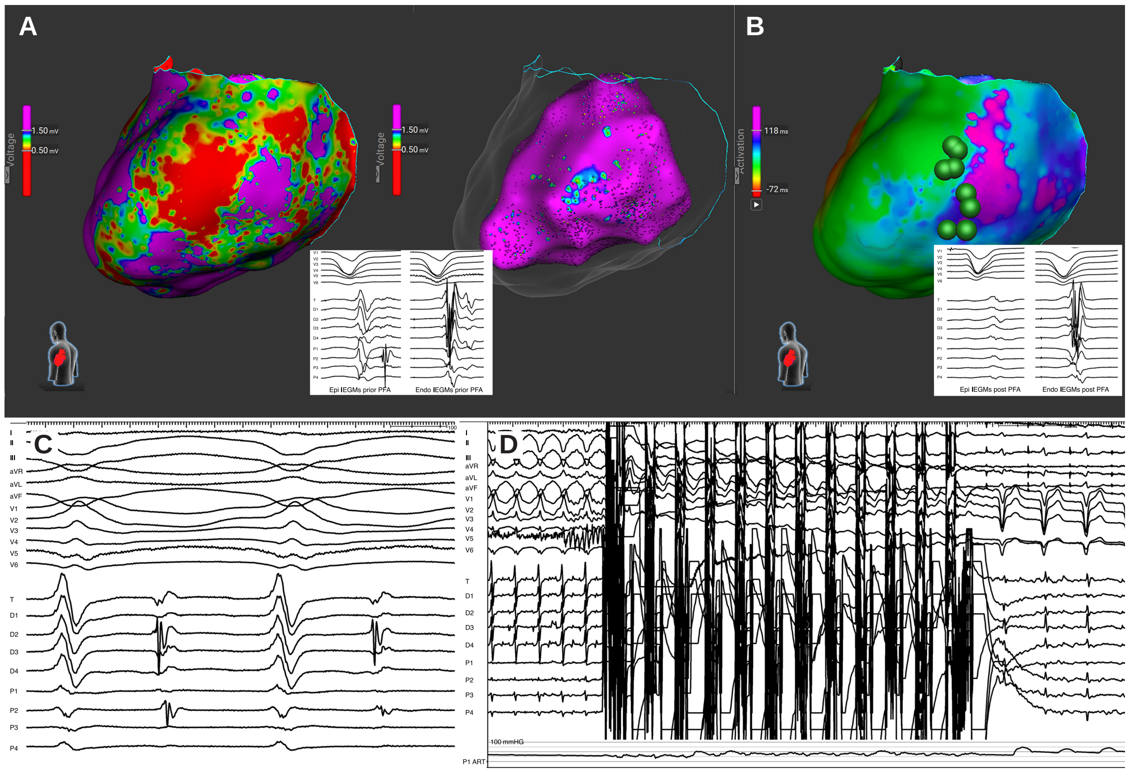


Figure 2 Panel *A* depicts epicardial (left) and endocardial (right) voltage map in the left lateral view in a patient with non-ischaemic cardiomyopathy. Panel *B* shows an epicardial activation map during sinus rhythm with delayed activation on the basal lateral wall (violet colour) with marked PF ablation tags (green). Note that the late potentials on both epicardial and endocardial local electrograms were eliminated by PF epicardial ablation. At the same time, the endocardial voltage was not affected. Panel *C* depicts mid-diastolic potentials in epicardium during inducible VT. Panel *D* shows the termination of VT during epicardial PF ablation. During PF application, note the myocardial capture (visible on ECG and arterial pressure tracing).

helpful; (iv) ablation did not result in excessive myocardial damage; (v) epicardial PF ablation adjacent to the phrenic nerve did not result in acute palsy; and (vi) PF ablation close to the coronary artery induced subclinical spasms.

Radiofrequency vs. pulsed field efficacy considerations

The current study used RF energy as the primary energy source for ablation. First, this decision was backed by historical experience with this energy source. Secondly, experimental studies have shown that RF current can create larger lesions than PF.[14] Thirdly, unlike PF, the change in local electrograms caused by ablation can be assessed after RF delivery. On the other hand, PF may provide several potential advantages over RF. Most importantly, several preclinical studies suggested that PF can penetrate better both healthy and scar/fatty tissue.[15–17] This is particularly important in patients with SHD or those undergoing repeated ablation procedures. However, acute lesions by PF compared to RF are known to have a much larger zone of reversible injury.[18] Our previous experience with PF ablation of SHD VTs using a solid-tip catheter[19] has shown that PF delivery resulted in more likely temporary suppression of VT inducibility with a higher recurrence during follow-up. Lastly, PF applications were commonly associated with local myocardial capture. Thus, when ongoing VT terminated during PF energy delivery, it was unclear whether it was due to the successful elimination of the culprit isthmus of slow conduction or due to overdrive pace termination by PF.

Radiofrequency vs. pulsed field safety considerations

Both energy sources differ concerning the risk of collateral damage. First, due to the non-thermal nature of PF, tissue overheating with a risk of steam pop is highly unlikely. Similarly, PF is known to spare ganglionic plexi and nerves.[20] In the recent analysis of 17 k patients undergoing AF ablation, the incidence of phrenic nerve injury by PF was 0.06%.[21] Our current experience with epicardial delivery of PF is in line with the above observations and suggests the relative safety of PF applications near the phrenic nerve.

In addition, Reddy *et al.*[22] have shown that using PF energy in the vicinity of the coronary arteries often resulted in their spasms, and pretreatment with nitrates could effectively prevent them. In this respect, coronary angiography in our study showed acute spasms in most of the patients with PF epicardial ablation. In some experimental studies,[23] PF application on the coronary artery led to acute spasm that was followed by chronic mild stenosis via neointimal neoplasia. On the other hand, RF application on the top of the coronary artery might lead to thrombotic occlusion. Thus, due to the non-thermal mechanism of action, it is reasonable to anticipate that the incidence of coronary artery stenosis will be lower for PF compared to the thermal alternatives. Due to this difference, PF may enable epicardial ablation of the substrate very close to the coronary artery. Nevertheless, before more data are available, it seems advisable to perform coronary angiography before and after epicardial PF delivery. Such a strategy will also allow immediate intracoronary administration of nitrates when spam is observed.

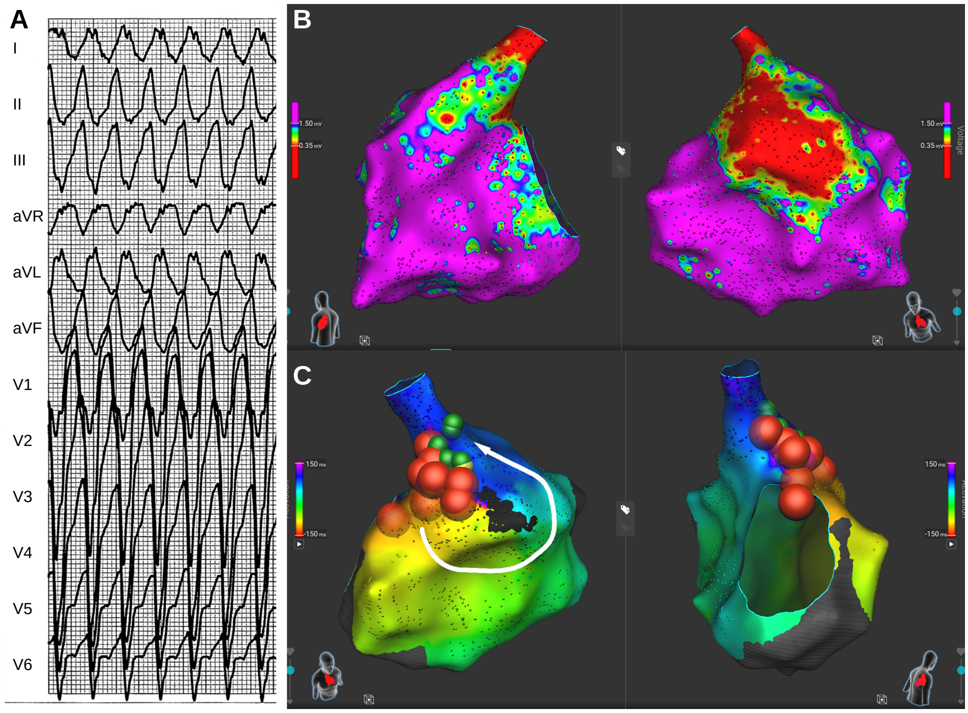


Figure 3 Panel *A* depicts a 12-lead ECG during VT in a patient with grown-up congenital heart disease after repeated surgical correction procedures and implantation of a balloon-expandable pulmonary stent valve. Panel *B* shows a voltage map of the RV with prominent scarring in the lateral RV outflow tract. Panel *C* shows the activation map during VT. The arrhythmia was successfully abolished by both radiofrequency (red tags) and pulsed field (green tags) ablation between the pulmonary valve stent and scarring on the RV lateral wall.

Table 2 Procedural characteristics and outcome

	***N* = 18**
Epicardial access (%)	22
Number of inducible ventricular tachycardia morphologies (*n*)	1.4 ± 1.3
Procedural duration (min)	157 ± 31
Fluoroscopy time (min)	5.2 ± 4.0
Fluoroscopy dose (μGy m^2)	4627 ± 9557
RF applications (*n*)	12 ± 7
PF applications (*n*)	8 ± 9
Post-ablation ventricular arrhythmia non-inducibility (%)	89
Ventricular-arrhythmia-free survival at 3 months (%)	78

Large-footprint-tip vs. 4 mm-tip focal catheter

Large-footprint lattice-tip catheter allowed rapid modification of extensive arrhythmogenic substrate either in the form of scar homogenization[24] or core scar isolation.[25] Although the concept of creating large lesions by the large-tip catheter is attractive for targeting the intramural substrate, different designs of ablation catheters might also have potential shortcomings. Some narrow areas (e.g. space between AV valves and myocardial wall, excavations within the endocardial surface, and base of the papillary muscles) might be more challenging to reach even with real-time imaging (*Figure 5*). This underscores the role of intracardiac echocardiography, which enables precise visualization of the lattice tip and its tailored placement. Theoretically, if prominent trabeculation is observed in the region of interest and ablation by the lattice-tip cannot eliminate the VT, complimentary use of a 4 mm-tip ablation catheter might be considered. Notably, scarring and remodelling after myocardial infarction lead mostly to thinning and smoothing of the myocardial wall and facilitate mapping and ablation with the lattice-tip catheter. Patients with non-ischaemic cardiomyopathy differ since their endocardial surface may have prominent trabeculations and variable thickness. The critical components of the substrate may be localized intramurally and may be more challenging to be recognized and ablated. However, it is yet to be determined, for which substrates this will be relevant and to what degree it will impact clinical outcomes.

The extent of myocardial damage

Studies assessing the troponin T dynamics in patients undergoing AF ablation have reported relatively high values of this biomarker.[26,27] Therefore, there was uncertainty about the extent of myocardial damage using PF on the ventricular level. Our data on the combined use of RF and PF for VT ablation suggest that myocardial damage was relatively moderate (about three times lower). This reflects a much lower number of PF deliveries compared to the average PF ablation for AF as well as targeting mainly scar tissue. The absence of excessive troponin is reassuring because, in patients with pre-existing SHD and impaired LV ejection fraction, extensive damage might lead to pump failure.

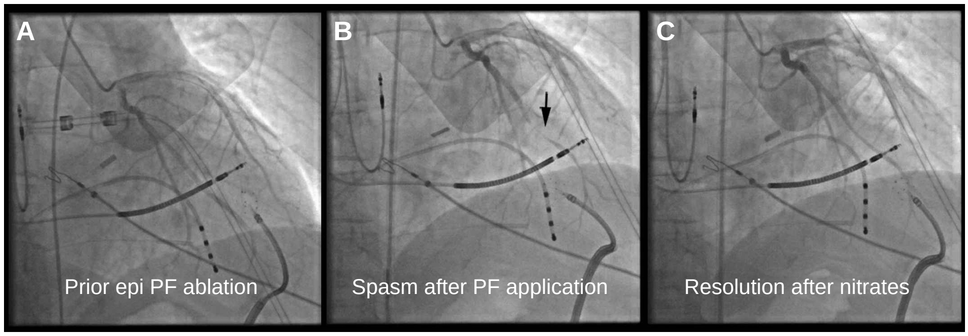


Figure 4 Example of coronary spasm induced by epicardial ablation on the lateral LV wall in vicinity of the marginal branch. Panel *A* shows preablation coronary angiography, panel *B* depicts the spasm of the marginal branch, and panel *C* shows the resolution of the spasm after intracoronary nitrate administration. Interestingly, no ECG changes were seen.

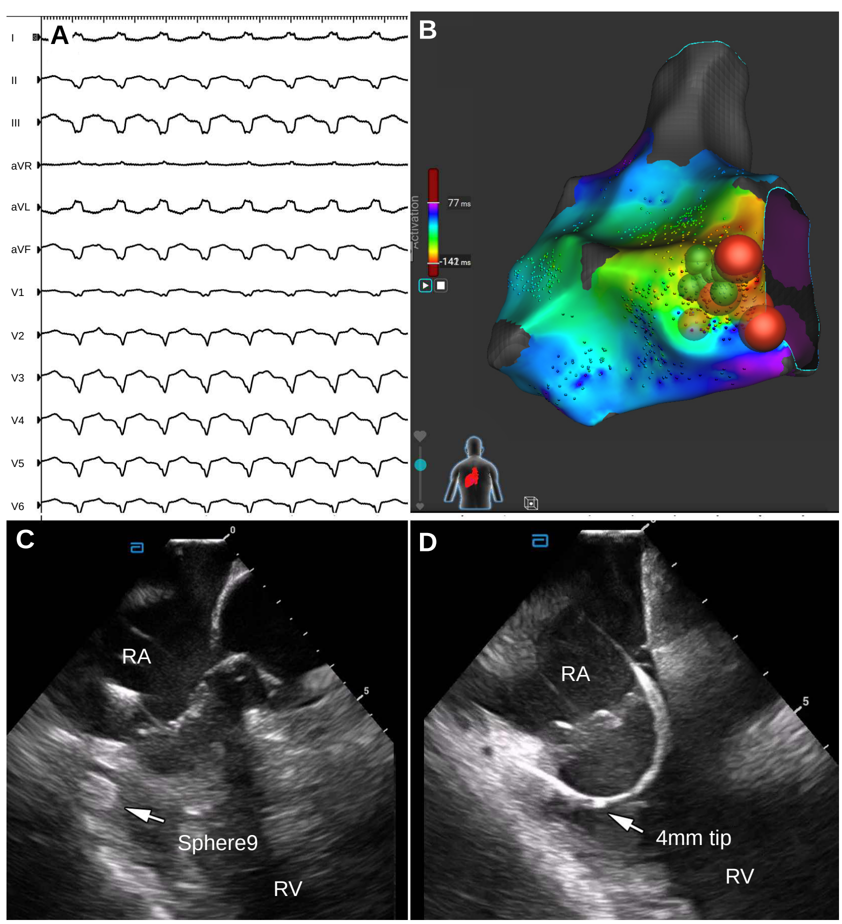


Figure 5 Panel *A* shows a 12-lead ECG of slow VT in a patient with non-ischaemic cardiomyopathy. Panel *B* shows an activation map during VT originating from RV inferoseptal processus. Despite extensive ablation, including the epicardial approach, VT recurred. During the re-ablation session, VT was successfully abolished by a conventional 4 mm irrigated-tip catheter inserted under the inferior leaflet of the tricuspid valve. Due to the larger size of the lattice tip, the catheter likely did not fit into the narrow space under the tricuspid valve, which could be then successfully cannulated and ablated with a 4 mm-tip catheter. Panels *C* and *D* show intracardiac echocardiography images with the position of the lattice-tip and 4 mm-tip close to the tricuspid annulus from the corresponding ablation sessions.

Study limitations

This prospective observational study described the initial experience with the novel electroanatomic mapping and ablation system in VT ablation. Therefore, we inherently investigated and ablated a broad spectrum of different VT substrates. Another limitation may be the combined use of high-energy RF and PF in most patients. A small number of patients may limit the validity of our observations. No nitrates were administered prophylactically before PF application in the epicardial space; thus, it is unknown whether such a strategy could prevent the occurrence of PF-induced spasms.

Conclusions

VT ablation using a dual-energy lattice-tip catheter and a novel electroanatomical mapping system is feasible and allows rapid mapping and effective substrate modification with good outcomes during short-term follow-up. Pulsed field applications in epicardial space were commonly associated with spasms of coronary arteries but not phrenic nerve palsy. Despite effective ablation, lesions did not result in excessive troponin release.

Authors contribution

Substantial contributions to the conception and design or the acquisition, analysis, or interpretation of the data: P.P., J.K. Substantial contributions to the drafting of the articles or critical revision for important intellectual content: P.P., D.W., P.S., J.K. Final approval of the version to be published: P.P., D.W., P.S., V.N., F.S., E.B., P.Š., J.M., J.H., J.K. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the article are appropriately investigated and resolved: P.P., J.K.

Funding

This paper was supported by the National Institute for Metabolic and Cardiovascular Research 'CarDia' (Programme EXCELES, ID Project No. LX22NPO5104)—funded by the European Union—Next Generation EU (KC). This work was also funded by the project (Ministry of Health, Czech Republic) for development of research organization 00023001 (IKEM, Prague, Czech Republic)—institutional support.

Conflict of interest: J.K. reports personal fees from Biosense Webster, Boston Scientific, GE Healthcare, Medtronic, and St. Jude Medical (Abbott) for participation in scientific advisory boards and has received speaker honoraria from Biosense Webster, Biotronik, Boston Scientific, Medtronic, ProMed CS, St. Jude Medical (Abbott), and Viatris. P.P. has received speaker honoraria from St. Jude Medical (Abbott) and Medtronic and has served as a consultant for Biotronik and Boston Scientific. V.N. is an employee of Medtronic. The remaining authors have no disclosures to declare.

Data availability

Data available on request.

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