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Acute lesion extension following pulmonary vein isolation with two novel single shot devices: Pulsed field ablation versus multielectrode radiofrequency balloon

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Abstract

Introduction: Pulsed-field ablation (PFA) and the multielectrode radiofrequency balloon (RFB) are two novel ablation technologies to perform pulmonary vein isolation (PVI). It is currently unknown whether these technologies differ in lesion formation and lesion extent. We compared the acute lesion extent after PVI induced by PFA and RFB by measuring low-voltage area in high-density maps and the release of biomolecules reflecting cardiac injury.

Methods: PVI was performed with a pentaspline catheter (FARAPULSE) applying PFA or with the compliant multielectrode RFB (HELIOSTAR). Before and after PVI high-density mapping with CARTO 3 was performed. In addition, blood samples were taken before transseptal puncture and after post-PVI remapping and serum concentrations of high-sensitive Troponin I were quantified by immunoassay.

Results: Sixty patients undergoing PVI by PFA ($n = 28$, age 69 ± 12 year, 60% males, 39.3% persistent atrial fibrillation [AF]) or RFB ($n = 32$, age 65 ± 13 year, 53% males, 21.9% persistent AF) were evaluated. Acute PVI was achieved in all patients in both groups. Mean number of PFA pulses was 34.2 ± 4.5 and mean number RFB applications was 8.5 ± 3 per patient. Total posterior ablation area was significantly larger in PFA (20.7 ± 7.7 cm^2) than in RFB (7.1 ± 2.09 cm^2; $p < .001$). Accordingly,

Abbreviations: 3D, three-dimensional; AF, atrial fibrillation; LA, left atrium; LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; PFA, pulsed-field ablation; PV, pulmonary vein; PVI, pulmonary vein isolation; RF, radiofrequency; RFB, radiofrequency balloon; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein.

Ilaria My and Marc D. Lemoine contributed equally to this work.

Cardiovascular Research, from several drug and device companies active in atrial fibrillation, and has received honoraria from several such companies in the past, but not in the last 3 years. Paulus Kirchhof is listed as inventor on two patents held by University of Birmingham (Atrial Fibrillation Therapy WO 2015140571, Markers for Atrial Fibrillation WO 201601278). The remaining authors declare no conflict of interest.

posterior ablation area for each PV resulted in larger lesions after PFA versus RFB (LSPV 5.2 ± 2.7 vs. 1.9 ± 0.8 cm², LIPV 5.5 ± 2.3 vs. 1.9 ± 0.8 cm², RSPV 4.7 ± 1.9 vs. 1.6 ± 0.5 cm², RIPV 5.3 ± 2.1 vs. 1.6 ± 0.7 cm,² respectively; $p < .001$). In a subset of 38 patients, increase of hsTropI was higher after PFA (625 ± 138 pg/mL, $n = 28$) versus RFB (148 ± 36 pg/mL, $n = 10$; $p = .049$) supporting the evidence of larger lesion extent by PFA.

Conclusion: PFA delivers larger acute lesion areas and higher troponin release upon successful PVI than multielectrode RFB-based PVI in this single-center series.

KEYWORDS

atrial fibrillation, catheter ablation, pulmonary vein isolation, pulsed-field ablation, radiofrequency balloon, real-world, single shot

1 | INTRODUCTION

Pulmonary vein isolation (PVI) is the established endpoint for catheter ablation of atrial fibrillation (AF). The cryoballoon catheter was the first single shot device introduced for PVI. Compared to point-by-point radiofrequency (RF) ablation, it showed non-inferiority in clinical efficacy and safety with the benefits of shorter learning curves and better reproducibility.[1]

In the last years, several single shot devices incorporating different energy sources and catheter configurations for PVI have been released. The advent of such technologies aims at simplifying PVI procedures, improving efficacy, reducing procedure time, and increasing safety. Two of these are the nonthermal ablation based on pulsed field ablation (PFA) and the RF balloon catheter (RFB).

PFA is characterized by a nonthermal energy source in which electrical fields are used to induce cardiomyocyte-specific cell death, thus protecting adjacent anatomical structures.[2] Initial clinical observations in controlled trials recently reported data on safety, efficacy, and follow-up data of PFA-based PVI.[3,4] On the other hand, the RFB is a compliant balloon catheter compatible with a 3D electroanatomical mapping system (CARTO 3; Biosense Webster) and provides an established energy source; it allows for selective titration of RF energy delivery from each surface electrode to prevent collateral damage and to apply energy in a segmental area if needed.[5] Two multicenter trials (RADIANCE[5,6] and SHINE[7]) demonstrated the feasibility, safety, and 12-month outcome of this technology.

To date, studies assessing the lesion dimensions and lesion quality after different novel ablation technologies are sparse. Kawamura et al.[8] reported no difference between PFA isolation areas and conventional thermal ablation technologies (RF, Cryo- and Laser-balloon), whereas lesion quantification after RFB-PVI has not been described yet.

We performed a prospective single-center study to evaluate and compare acute lesion extension of PVI obtained by PFA and RFB according to 3D mapping and measured the postprocedural troponin release.

2 | MATERIALS AND METHODS

2.1 | Patient population

In this prospective single-center study, we enrolled consecutive patients referred for catheter ablation of paroxysmal or persistent AF, who underwent PVI using either the novel PFA pentaspline ablation catheter (Farawave®; Farapulse Inc.) or the compliant multielectrode RFB catheter (Heliostar™; Biosense Webster Inc.). Exclusion criteria were prior PVI and a left common ostium, due to difficulty in the latter case in defining the PV ostium and in standardizing the subsequent measurements (as described below). The study was performed in accordance with the Declaration of Helsinki of 2013, and it was designed as a prospective observational study approved by the ethics committee in Hamburg (NCT05521451, 2020-10066-BO).

2.2 | Procedural management

The procedure was performed under deep sedation applying propofol, fentanyl, and optionally midazolam. Following single transseptal puncture using a modified Brockenbrough technique, a SL1 sheath (8.5 F; St. Jude Medical) was advanced into the LA. After transseptal puncture, intravenous heparin bolus was administered to reach an activated clotting time of >300 s. Selective PV angiography was performed to identify each PV ostium.

A decapolar mapping catheter (Lasso NAV; Biosense Webster) was used for high-density voltage maps before and after ablation. The fill threshold used was 17 and a median of 2516 (IQR: 1987–3275) points for the RF Balloon group and 3672 (IQR: 2098–5582) points for the PFA group was acquired.

The SL1 sheath was changed over-the-wire for a steerable sheath (Faradrive, 13 F inner and 16.8 F outer diameter, or the GUIDESTAR, 13.5 or 14 F inner and 18.9 F outer diameter).

Afterwards, the corresponding ablation catheter, either the PFA multielectrode pentaspline catheter (Farawave; Farapulse) or the

28 mm compliant RFB (HELIOSTAR; Biosense Webster) was advanced via the sheath.

The size of the PFA catheter (diameter of 31 vs. 35 mm measured in flower configuration) was chosen based on PV visualization by angiography and LA size and procedures were performed as previously described by Lemoine et al.[4] by eight applications at each PV in two configurations with 2.0 kV. For the RFB procedures, to provide optimal electrode-tissue contact and catheter positioning, the following parameters were targeted: inflation index >0.8, impedance of 100 ± 20 Ohms across all electrodes, temperature variability across all electrodes <3°C with a maximum temperature of 31°C. RFB applications were delivered at a temperature-controlled unipolar energy mode of 15 W and a target electrode temperature of 55°C. Each application lasted 60 s for the electrodes facing the anterior, superior, and inferior aspects of the targeted PV and 20–30 s for electrodes facing the posterior wall.

2.3 | Ablation lesion characterization

For both technologies, PVI was defined as elimination of all PV signals as recorded by a circular mapping catheter. Comparative 3D high density voltage mapping data were collected from consecutive PFA and RFB procedures and extension of posterior wall antral isolation areas for each pulmonary vein was quantified. Ablation lesions were defined as low voltage areas (<0.1 mV) and measured from each PV ostium to the border between low and high voltage (>0.5 mV) at the posterior wall (Figure 1 and Supporting Information: Figure 1). As mentioned above, left common ostium was excluded due to difficulties in defining the PV ostium and consequently in standardizing the measurements of the low-voltage lesions in this subset of patients with anatomical variability.

Moreover, pre- and postprocedural peripheral blood samples were collected and serum concentrations of high-sensitive Troponin I (hsTnI) were quantified by Immunoassay (Architect i2000SR).

3 | RESULTS

3.1 | Patient and procedural characteristics

A total of 60 patients (n = 28 in the PFA group and n = 32 in the RFB group) with symptomatic paroxysmal or persistent AF (39% and 22%, respectively) were included into the study. Mean age was 69 ± 12 years in the PFA group and 65 ± 13 years in the RFB group, with male predominance in both groups (60% and 53%, respectively).

LA volume and left ventricular ejection fraction were either mildly abnormal (40.7 ± 12.4 mL/m^2 and 47.4 ± 12.9% in the PFA group) or normal (29.8 ± 10.8 mL/m^2 and 57.6 ± 4.8% in the RFB group, p < .05).

Acute PVI was achieved in all patients in both groups. The mean number of PFA pulses/patient was 34.2 ± 4.5 and the mean number RFB applications was 8.5 ± 3/patient.

Mean procedure time (defined as time from femoral access until sheath removal) did not differ among groups (87.3 ± 18.2 vs. 95.9 ± 23.8 min, p = .08), including pre- and postablation 3D voltage mapping time. Parallelly, fluoroscopy time was similar in both groups (19.5 ± 9.2 vs. 17.1 ± 4.9 min, p = .22). Detailed patient characteristics are summarized in Table 1.

3.2 | Ablation lesion quantification: High density 3D mapping and troponin release

The extent of total posterior-wall ablation area was significantly bigger in patient treated with PFA (20.7 ± 7.7 cm²) as compared to patients undergoing RFB-PVI (7.1 ± 2.09 cm²; p < .001).

Accordingly, posterior ablation area for each PV resulted in larger lesions after PFA versus RFB (LSPV 5.2 ± 2.7 vs. 1.9 ± 0.8 cm², LIPV 5.5 ± 2.3 vs. 1.9 ± 0.8 cm², RSPV 4.7 ± 1.9² vs. 1.6 ± 0.5 cm², RIPV 5.3 ± 2.1 vs. 1.6 ± 0.7 cm,² respectively; p < .001). Posterior-wall

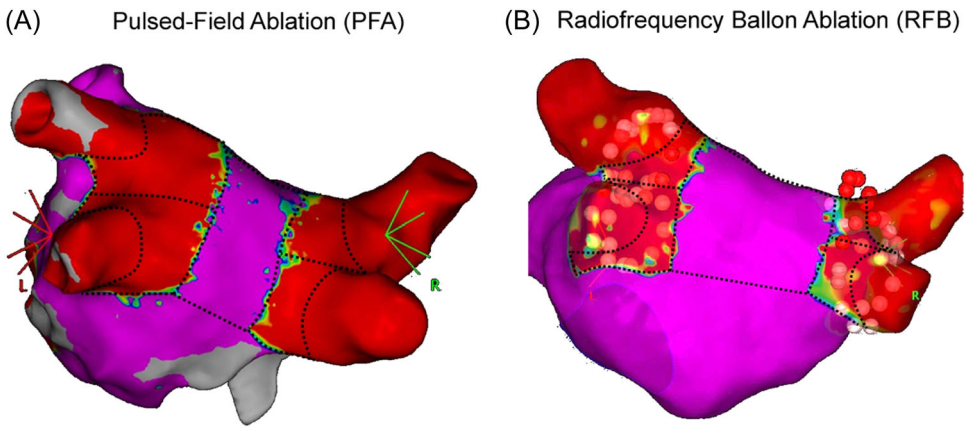

FIGURE 1 3D high density voltage mapping after pulmonary vein isolation using pulsed field ablation (PFA) and multielectrode radiofrequency balloon (RFB). (A) Example of 3D electroanatomical map and lesion measurement after PFA. (B) Example of 3D electroanatomical map and lesion measurement after RFB ablation.

TABLE 1 Detailed patient and procedural characteristics.

	Pulsed field ablation ($n = 28$)	Radiofrequency balloon ($n = 32$)	p Value
Age (years)	69 ± 12	65 ± 13	.27
Sex, male (%)	60	53	.65
Persistent AF (%)	39.3	21.9	.08
Mean LA volume index (mL/m^2)	40.7 ± 12.4	29.8 ± 10.8	.004
Mean LV EF (%)	47.4 ± 12.9	57.6 ± 4.8	<.001
Acute PVI (%)	100	100	-
Procedure time (min)	87.3 ± 18.2	95.9 ± 23.8	.08
Fluoroscopy time (min)	19.5 ± 9.2	17.1 ± 4.9	.22

Abbreviations: AF, atrial fibrillation; PVI, pulmonary vein isolation.

lesion distance was concordantly shorter in the PFA group compared to the RFB group (24.2 ± 10.6 vs. 31.4 ± 8.8 mm; $p = .005$).

Parallelly, in a subset of 38 patients increase of hsTnI was higher after PFA (625 ± 138 pg/mL, $n = 28$) as compared to RFB (148 ± 36 pg/mL, $n = 10$; $p = .049$), supporting a larger tissue damage following PFA-based PVI (Figure 2).

4 | DISCUSSION

The current study is the first to compare the lesion extent following PVI based on two novel single shot technologies: the pentaspline catheter with PFA and the compliant multielectrode RFB.

The main findings of this study are:

1. Total LA posterior ablation area and isolation area for each PV were significantly larger in the PFA group compared to the RFB group.
2. hsTnI release was higher after PFA compared to RFB based PVI.

Krisai et al.[9] and Lemoine et al.[10] already demonstrated higher postprocedural release of troponin T in patients treated with PFA compared to RF and Cryo groups. However, the reason for such difference remained unexplained.

We believe that both the catheter configuration and the energy source might play an important role in lesion dimensions. The catheter configuration of the pentaspline catheter with the basket and flower shape may play a role in the catheter-tissue contact and consequently on the size of the ablation lesions in the PFA group. So far, no data are available about the lesion dimensions and troponin release after RF Balloon-based PVI. This is the first study that describes a comparison between these two novel technologies. In the current patient cohort, the larger LA posterior ablation area might explain higher postprocedural circulatory levels of troponin.

Lesion size of PVI might vary between several technologies and strategies with potential impact on clinical outcomes. If the acute lesion dimensions obtained with PFA are also influenced by a penumbra of reversible ablation is still a matter of debate. One study reported no regression in isolation areas 3 months after PVI,[11] which should be confirmed in further studies. What is known from previous studies is that a wide antral approach is more effective than ostial PVI in achieving freedom from atrial tachyarrhythmia recurrence at long-term follow-up.[12] However, as recently described by Tohoku et al.,[13] PVI based on the pentaspline PFA catheter can be associated with postablation macro-reentrant atrial tachycardia with a critical isthmus at the LA posterior wall. Our data demonstrating 3D-mapping-based larger antral lesions in the PFA cohort are in line with the previous findings and provide an explanation for the higher number of postablation atrial tachycardia in the PFA group.[13] We believe that the higher occurrence of postablation atrial tachyarrhythmias in this group is dependent on lesion-size rather than on the energy source itself.

For a better understanding and characterization of the induced ablation lesions postprocedural cardiac-MRI might be desirable. Although the application of such technology in defining PV ablation lesion extensions is not yet standardized in clinical practice, there are preliminary studies describing scar quantification 3-month after PVI.[14]

Due to the large extent of ablation lesions along the posterior LA wall and the higher risk of LA-wall dependent macro-reentrant tachycardia it might be speculated that additional LA wall ablation or isolation following PFA-guided PVI might be reasonable to prevent iatrogenic tachyarrhythmias. Whether the larger extent of ablation lesions following PFA-based PVI also translates into better clinical outcome date needs further evaluation.

Regarding safety, a larger lesion extent along the posterior wall might be critical when applying RF due to the close anatomical proximity of the posterior wall and the esophagus and the potential risk of esophageal thermal injury or even atrioesophageal fistula. However, less or no effect on the esophagus is expected when applying PFA and inducing larger left atrial posterior wall lesion extent since, so far, no thermal damage of the esophagus was observed in any PFA study.

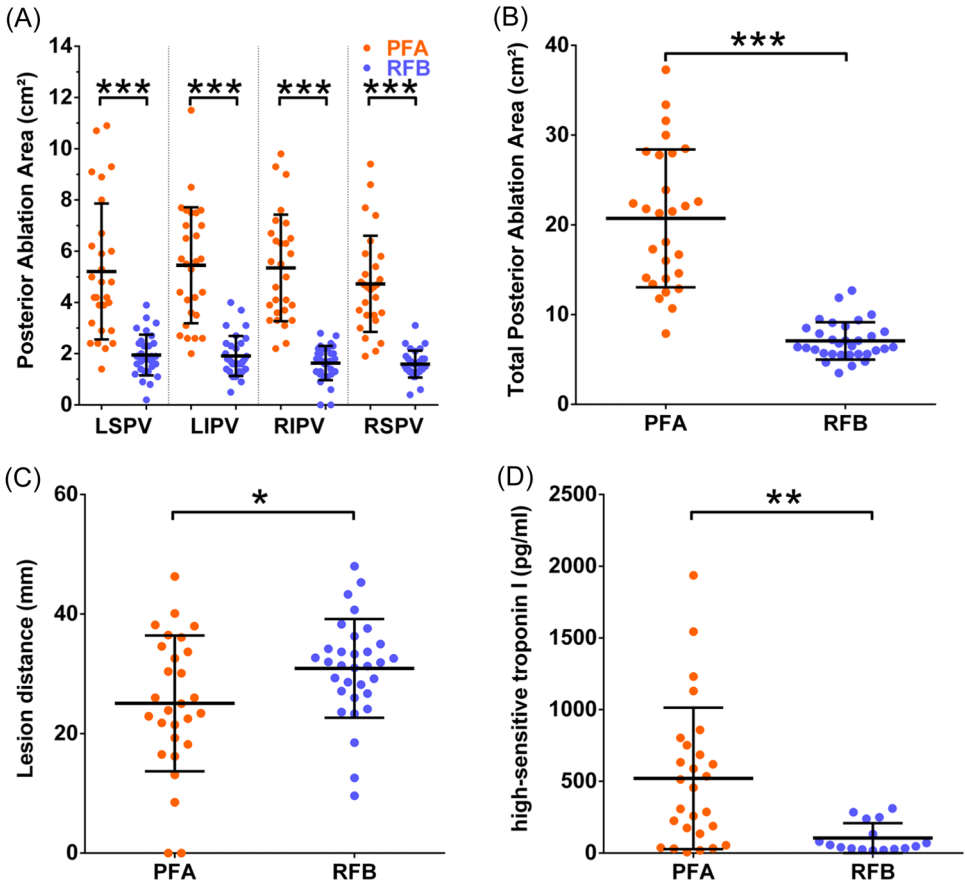

FIGURE 2 Acute lesion extent after pulmonary vein isolation using PFA compared to multielectrode RFB. (A) Posterior wall ablation area for each pulmonary vein. (B) Total posterior wall ablation area. (C) Distance between the septal and lateral lesions along the posterior wall. (D) Postprocedural high-sensitive troponin I release. LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; PFA, pulsed field ablation; RFB, radiofrequency balloon; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein.

5 | LIMITATIONS

The main limitation of the study is the single-center design and the rather small patient cohort. However, all procedures were performed in a tertiary center with a large experience with single-shot PVI devices. Follow-up data will be needed to evaluate long term lesion durability and effective impact on patient clinical outcomes.

6 | CONCLUSIONS

In a prospective cohort of patients undergoing PVI with two novel single-shot devices in a tertiary ablation center, PFA resulted in larger acute ablation areas and higher troponin release upon successful PVI compared to the multielectrode RFB.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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