The feasibility and safety of pulsed field ablation for persistent atrial fibrillation: a prospective study

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Abstract

Introduction: Pulsed field ablation (PFA) is a novel nonthermal ablation approach using rapid electrical pulses to cause cardiac cell apoptosis via electroporation. Our study aims to investigate the feasibility and safety of PFA for persistent atrial fibrillation (PeAF). **Methods:** 32 consecutive patients diagnosed with PeAF were enrolled in our study. All patients underwent PFA treatment using the strategy including pulmonary vein isolation (PVI), left atrial posterior wall (LAPW) isolation, cavotricuspid isthmus (CTI) block, and mitral isthmus (MI) block. Acute and follow-up procedure outcomes were evaluated, and adverse events related to the ablation procedure were also observed. **Results:** One-year survival free from atrial tachyarrhythmia post-ablation was 65.6%. Acute success rates for PVI, LAPW isolation, CTI block, and MI block were 100%, 100%, 96.9%, and 81.3%, respectively. Eleven cases (34.4%) experienced atrial tachyarrhythmia recurrence, with 8 cases being atrial fibrillation recurrence and 3 cases being atrial flutter recurrence. Three patients underwent repeat ablation. Minor complications were encountered in 4 patients with asymptomatic cerebral lesions. Vagal responses were commonly observed during the procedure. No severe coronary vasospasm or severe haemolysis occurred in our cohort. **Conclusion:** PFA with the strategy including PVI, LAPW isolation, CTI block, and MI block is feasible, safe, and associated with a high rate of freedom from atrial tachyarrhythmia recurrence at 1 year in patients with PeAF.

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KEYWORDS

pulsed field ablation, persistent atrial fibrillation, feasibility, safety, durability.

1 | INTRODUCTION

Thermal ablation, including radiofrequency (RFCA) and cryoablation, remains the conventional technique in the treatment of drug-refractory symptomatic atrial fibrillation (AF). Extensive ablation may cause adjacent tissue damage.[1] For safety, reduced energy is usually required, with a compromise in lesion depth and durability. Pulsed field ablation (PFA) represents a novel nonthermal ablation approach using rapid electrical pulses to induce cardiac cell apoptosis via electroporation. PFA is characterized by high tissue selectivity that could potentially protect neighboring tissue from unintended injury.[2-6] Recent works have demonstrated the feasibility and safety of PFA for pulmonary vein isolation (PVI) in paroxysmal AF.[7,8] But the long-term efficacy and safety of PFA for persistent atrial fibrillation (PeAF) remain unknown.

PVI is considered the cornerstone for the treatment of PeAF.[9] But PVI alone may be insufficient to maintain sinus rhythm in these patients. Linear ablation is one of the most common procedures used in addition to PVI. In our previous study, the "2C3L" approach including bilateral PVI and three linear ablation lesion sets across the mitral isthmus (MI), left atrial (LA) roofline and cavotricuspid isthmus (CTI) is comparable to stepwise ablation in terms of arrhythmia-free survival.[10] However, only limited studies have demonstrated the feasibility and safety of PFA for part linear ablation, such as MI block, left atrial posterior wall (LAPW) isolation, or CTI block, in addition to PVI in PeAF patients.[11,12] Despite the clinical data was still insufficient, these preliminary findings bolster our confidence in advocating for the application of PFA in PeAF.

The present study aims to describe the feasibility and safety of PFA using the strategy including PVI, LAPW isolation, CTI block, and MI block in patients with PeAF.

2 | METHODS

2.1 | Study population

This prospective study registered at the Chinese Clinical Trial Registry (ChiCTR2300068980) was conducted in accordance with the principles outlined in the Helsinki Declaration and approved by the ethics committee of Beijing Anzhen Hospital. Informed written consent was obtained from all participants before enrollment. Patients with drug-refractory PeAF undergoing their initial PFA procedure at Beijing Anzhen Hospital were prospectively enrolled. The study flowchart is depicted in Figure 1. The inclusion and exclusion criteria were as follows. Inclusion criteria: 1) Age over 18 years and less than 80 years; 2) AF duration between 3 months to 3 years; 3) No previous history of AF ablation; 4) Willingness to provide written informed consent and participate in follow-up assessments; 5) Cardiac thrombus excluded by transesophageal echocardiography or intracardiac echocardiography. Exclusion criteria: 1) Previous history of AF ablation; 2) Previous history of left LA surgery; 3) LA diameter > 55mm; 4) Other serious heart disease, or other serious arrhythmias except AF, atrial flutter (AFL) and atrial tachycardia (AT); 5) Contraindications for ablation, such as atrial thrombus, tumor, infection, or other terminal illnesses.; 6) Significant bleeding event, or can not tolerate anticoagulation therapy.

2.2 | Procedure

Anticoagulation therapy was initiated at least 3 weeks before the procedure. An electrophysiological study and ablation procedure were conducted under conscious sedation with fentanyl and midazolam. A 6 French decapolar catheter (Promapper Nav; Jinjiang Electronic Medical Device Technology Co., Ltd, Sichuan, China) was positioned in the coronary sinus (CS). Operators performed transseptal puncture and introduced an 8.5 French long sheath (SL1; St. Jude Medical) into the left atrium (LA) over a guidewire under the guidance of fluoroscopy and intracardiac echocardiography (Cartosound, Biosense Webster Inc.). Continuous heparinized saline flush (20 ml/h) was maintained through the transseptal sheath, and heparin was administered to maintain activated clotting time (ACT) >300s throughout the procedure, with monitoring every 30 minutes.

The LEAD-PFA system (Jinjiang Electronic Medical Device Technology Co., Ltd, Sichuan, China) employed in our study integrates the PFA system and a cardiac 3-dimensional electroanatomic mapping system (LEAD-Mapping, Jinjiang Electronic Medical Device Technology Co., Ltd, Sichuan, China) for magnetic navigation, localization, mapping, and ablation. LA and pulmonary vein (PV) were reconstructed under the guidance of that 3-dimensional electroanatomic mapping system using a circular PFA catheter (Jinjiang Electronic Medical Device Technology Co., Ltd, Sichuan, China) (Figure 2A). The PVI and LAPW ablation were performed with the circular PFA catheter. Each application consisted of 4 biphasic pulse trains lasting 200 ms at 1800 V. The circular PFA catheter was positioned at each pulmonary vein ostium. After each application, the catheter was rotated circumferentially to a new position to achieve full circumferential isolation. After PVI, LAPW was then ablated with the circular PFA catheter. CTI and MI ablation were performed with a focal contact force PFA catheter (Jinjiang Electronic Medical Device Technology Co., Ltd, Sichuan, China) (Figure 2B). Each point-by-point application consisted of 4 biphasic pulse trains lasting to 200 ms at 1800 V. If AF persisted after these steps, electrical cardioversion would be performed to restore sinus rhythm. If an organized AFL occurred during the procedure, mapping-guided ablation would be performed.

2.3 | Acute endpoints

The acute endpoints of the procedure include complete PVI, LAPW isolation, and bidirectional linear block (CTI block and MI block) after a 20-minute waiting period. PVI and LAPW isolation were confirmed by the absence of electrograms in PV and LAPW (Figure 2C). Bidirectional MI block was confirmed by the following criteria: 1)Proximal-to-distal CS activation pattern when pacing at the left lateral ridge; 2) Longer SA interval at the left lateral ridge when pacing at the distal CS compared to pacing at the proximal CS (Figure 3). Bidirectional CTI block was confirmed by the activation from the right atrium lateral wall to the ablation line when pacing at proximal CS. The SA interval near the ablation line was longer than at the right atrium lateral wall when pacing at proximal CS (Figure 4).

2.4 | Follow-up

All patients were discharged with an antiarrhythmic medication and an oral anticoagulant. Antiarrhythmic medications were discontinued 3 months post-ablation if the patient remained free from atrial tachyarrhythmia recurrence, while anticoagulant therapy was continued based on individual thromboembolic risk. Follow-up assessments were conducted at discharge, and at 3, 6, and 12 months post-procedure either via telephone or in the outpatient clinic. A 7-day Holter recording was performed at 3, 6, and 12 months after ablation. Recurrence was defined as any episode of atrial tachyarrhythmia lasting more than 30 seconds. The primary outcome of the observation was freedom from AF/AFL/AT recurrence with or without antiarrhythmic medications during follow-up after a single ablation. Adverse events were also monitored before discharge and throughout the follow-up period. Brain magnetic resonance imaging (MRI) was evaluated for the assessment of silent cerebral lesions (SCLs). Subjects with documented SCLs will undergo prespecified neurologic assessment before discharge.

Redo ablation procedures were initiated upon documentation of persisting AF, AFL, or AT. During reablation, electroanatomical mapping was performed to assess the durability of the lesions.

2.5 | Statistical analysis

Continuous variables are expressed as mean ± standard deviation (SD). Categorical data are presented as counts and percentages.

3 | RESULTS

3.1 | Baseline characteristics

Finally, 32 consecutive patients with PeAF underwent their first PFA procedure with PVI, LAPW, CTI, and MI ablation. The mean age was 57.8±8.8 years (78.1% male). The mean duration of AF was 14.5±8.9 months. The mean LA diameter was 43.1±4.3 mm, the LA volume was 125.5±29.1 ml, and the left ventricular ejection fraction was 60.4%± 5.5%. Other baseline characteristics are detailed in Table 1.

3.2 | Acute results

The acute procedure outcomes are summarized in Table 2. The mean number of right pulmonary vein (RPV) applications was 29.4±11.7, 29.9±12.7 applications for left pulmonary vein (LPV), 8.5±4.2 applications for LAPW ablation, 22.5±9.0 applications for CTI ablation, and 61.0±27.6 applications for MI ablation. The mean ablation times of RPV, LPV, LAPW, MI, and CTI were 9.3±5.4, 12.0±6.7, 1.7±1.4, 17.6±11.0, and 6.4±5.7 mins, respectively. PV and LAPW were both successfully isolated in all 32 patients (100%). Complete bidirectional CTI block and MI block were achieved in 31 (96.9%) and 26 patients (81.3%), respectively. The mean fluoroscopy time was 4.4±1.4 mins, and the total procedure time was 78.6±31.3 mins.

Direct conversion of AF to sinus rhythm (SR) occurred in 7 (21.9%) patients, while in 5 (15.6%) patients, AF was first converted into atrial flutter (3 [9.4%] atypical flutter and 2 [6.2%] typical atrial flutter) and then into SR. Electrical cardioversion was performed in the remaining cases (20 [62.5%]) where ablation did not restore SR. (Figure 1)

3.3 | Follow-up

3.3.1 | Primary effectiveness endpoint

After a mean follow-up of 10.7±2.6 months (Table 3), freedom from atrial tachyarrhythmia recurrence was achieved in 21 (65.6%) patients. Eleven cases (34.4%) experienced atrial tachyarrhythmia recurrence, with 8 cases (25%) being AF recurrence and 3 cases (9.4%) being AFL recurrence. The mean ablation-to-recurrence time was 5.2±2.9 months. Three patients underwent a redo procedure, of whom 2 had AF recurrence and 1 had typical AFL recurrence, which was determined to be peri-tricuspid flutter during the redo procedure. All three patients presented the reconnection sites of LPV and RPV located at the anterior and posterior carina. LAPW reconnection occurred in one case, while both MI and CTI were reconnected in all three cases.

3.3.2 | Procedure-related complications

Of all patients underwent cerebral MRI before and after ablation, four (12.5%) developed new postprocedural SCLs (Table 4). These cerebral lesions were negligible changes. Severe coronary artery spasm or incidental ST-segment elevation was not detected during ablation. No serious complications such as acute kidney injury, severe haemolysis, death, pericardial effusion/cardiac tamponade, thromboembolic events, esophageal injury, myocardial infarction, pulmonary vein stenosis, or phrenic nerve palsy related to the PFA procedure were reported. In our series, pulsed-field applications induced vagal response in 25 sites of 22 patients (68.8%), including the left superior pulmonary vein (n=19), right superior pulmonary vein (n=3), and left inferior pulmonary vein (n=3).

4 | DISCUSSION

Thermal ablation methods have the potential for adjacent tissue damage.[1] New energy sources have been developed to address these issues. Despite the promising results in terms of efficacy and safety of PVI with PFA in paroxysmal AF,[7,8] the PVI-only strategy may be insufficient for PeAF. Only a few studies have demonstrated that PFA was a feasible and safe ablation approach for part linear ablation in addition to PVI in PeAF patients.[11,12] Our study sought to evaluate a comprehensive ablation strategy involving PVI, LAPW isolation, CTI block, and MI block, with rigorous follow-up monitoring. The key finding of the present study is that PFA, under the guidance of a 3-dimensional mapping system, is effective and safe for PVI, linear block, and posterior wall isolation, but the long-term durability of PFA lesions is unsatisfying.

4.1 | Clinical efficacy

Our study showed a high rate of acute success in achieving PVI, LAPW isolation, CTI block, and MI block, along with a high rate of atrial tachyarrhythmia-free survival (65.6%) at 1 year post-ablation. Energy delivery for PVI and LAPW isolation was completed within several minutes, resulting in a shorter procedure time compared to studies using RFCA. The shorter procedure duration and reduced LA dwell time may contribute to decreased thrombus formation during the procedure. Besides, operators in our study were not experienced with PFA technology before, but application time and total procedure time still were reasonable.

4.2 | The feasibility of PVI

Durable PVI is the cornerstone for PeAF ablation.[9] The efficacy and safety of PVI with PFA in paroxysmal AF had been demonstrated absolutely in previous studies.[7,8] In our study, the acute successful PVI of PFA was excellent despite the unsatisfying PVI durability which might be due to inadequate contact of the circular PFA catheter located at the anterior or posterior carina in PV. The utilization of a steerable sheath may be a promising approach to improve the contact of the circular PFA catheter. Thus, ensuring stable PFA catheter contact, along with adequate energy delivery and sufficient applications, is crucial to enhance PVI durability.

4.3 | The feasibility of LAPW isolation

Our study demonstrated the excellent efficacy of PFA in isolating the LAPW within a short procedure time without esophageal injury. However, further investigation is warranted to assess the transmurality of PFA lesions in the LA dome. Ablating atrial tachycardias within the LAPW, particularly the epicardial roof-dependent macro-reentrant tachycardias associated with the septopulmonary bundle, is a challenge.[13] Progressive RFCA to achieve transmural lesions can cause the risk of esophageal injury. The mechanical esophagus deviation is promising to protect the esophagus from thermal injury. However esophagus deviation itself brings about mechanical injury to the esophagus mucosa. LAPW isolation with PFA may be a good strategy for the tissue selectiveness of PFA that selectively spares the esophagus. One recent case has reported that in some patients, LAPW epicardial conduction cannot be blocked via repeated PFA, which was eventually ablated by ethanol infusion into the vein of Marshall.[14] Therefore, evaluating the transmuralilty of PFA lesions in the posterior wall still requires further studies.

4.4 | The feasibility of MI block

In the Marshall-PLAN study by Derval et al,[15] it was demonstrated that achieving a complete and durable

MI block is crucial for improving atrial tachyarrhythmia-free survival in PeAF ablation. However, obtaining a complete MI block for RFCA is a challenge due to anatomical complexities such as tissue thickness, local blood flow, and epicardial musculature connections, including CS sleeves or a Marshall bundle.[16] Additional techniques, such as ablation inside the CS and ethanol infusion into the vein of Marshall, are usually necessary. PFA is a nonthermal ablation method. The main challenge of MI block for PFA is tissue thickness and epicardial connections, excluding the temperature weakening of the blood flow.

A recent study proved MI block with PFA was successfully achieved in a high percentage (100%), but 2 patients developed severe coronary vasospasm of the circumflex artery.[12] In our cohort, MI block was achieved in 81.3% of cases. The different success rates might be due to the different PFA catheter electrode configurations and energy waveforms from different manufacturers' systems. We hypothesized that increasing electrode number, catheter contact surface area, application number, and energy output could improve the acute success rate of MI block, but bring about a higher risk of severe coronary vasospasm or severe haemolysis which was not observed in our study. Further studies with more cases are required to adjust the energy parameters and catheter electrode configuration to optimize efficacy and minimize procedural risks. Can focal PFA catheter ablation inside the CS damage the epicardial connections and bring about risks of coronary vasospasm, still needs further investigation. Both our study and the study by Baptiste Davong et al, PFA achieved a high success rate of acute MI block without ethanol infusion into the vein of Marshall or epicardial ablation in CS. Therefore, PFA could be a good alternative to obtain an MI block when RFCA fails, especially in cases without the vein of Marshal or the vein of Marshall cannot be catheterized. Thus, PFA could be recommended for perimitral left atrial flutter cases.

4.5 | The feasibility of CTI block

In our study, CTI block with PFA was successfully achieved in a high percentage of patients (96.9%). CTI ablation using a focal PFA catheter routinely provokes subclinical right coronary vasospasm,[17,18] which was not observed for no coronary angiography was performed in our series. Pouches among CTI were commonly observed via intracardiac echocardiography during the procedure.[19] These pouches increase the difficulty of obtaining a complete CTI block, which are potential risk of cardiac tamponade for RFCA. PFA could be a good alternative to obtain CTI block when pouches were observed in CTI. So PFA could be recommended in the case of typical atrial flutter.

4.6 | The long-term durability of PFA lesions

Despite our study showed a high rate of atrial tachyarrhythmia-free survival at 1-year post-ablation, reconnections were commonly observed in redo cases. In our cohort, we had three patients who underwent a redo procedure. All three patients presented the reconnection sites of LPV and RPV located at the anterior and posterior carina. LAPW was reconnected in one case. MI and CTI were reconnected in all cases. In a recent study by Baptiste Davong et al,[12] four patients underwent a redo procedure. two of them showed reconnection of the left superior pulmonary vein, and the other two presented with reconnection of the right inferior pulmonary vein. LAPW was reconnected in one case. MI was reconnected in all cases. The long-term durability of PFA lesions was barely satisfactory. To improve durability, a multielectrode catheter with a biphasic bipolar high-energy waveform, sufficient applications, and stable contact via a steerable sheath should be recommended, which simultaneously has the concerns of severe coronary vasospasm and severe haemolysis. These complications could hinder the use of PFA for PeAF or AFL, where MI or CTI ablation is necessary. During a PFA procedure with a multielectrode catheter and high energy output adjacent to the coronary artery, such as CTI or MI ablation, routine prophylactic parenteral nitroglycerin, either intracoronary or intravenous, should be recommended to prevent severe coronary spasm before the PFA applications.[17,18,20,21] Additionally, haemolysis-induced acute kidney injury was observed in some PeAF patients who received a high number of PFA applications with a pentaspline PFA catheter.[22] Hydration with high amounts of fluid infusion immediately after the procedure should be recommended in these patients to prevent severe acute kidney injury related to haemolysis.[23] Therefore, further large-scale studies with longer-term follow-up periods are required to optimize the parameters and PFA catheter design, ultimately improving long-term durability and minimizing risks.

4.7 | Clinical safety

Assessing safety endpoints is a challenge for some complications occur rarely. Thermal ablation modalities may cause injury in neighboring tissues.[1] Optimizing the safety of AF ablation remains necessary in clinical practice. Our study exhibited a favorable safety outcome.

In our series, vagal responses and diaphragmatic contractions were common during the procedure. However, we did not observe persistent diaphragmatic weakening or obvious heart rate variability indicative of nerve injury after ablation. Some studies demonstrated that PFA does not induce nerve injury during the PFA procedure.[5,6] So we concluded that the vagal responses and phrenic activation are neurological stress responses due to electrical stimulation, but not nerve damage. However, the cardiac autonomic nerve may participate in the initiation and maintenance of AF, and some researchers hypothesize that thermal ablation is advantageous for its ability to destroy the ganglionic plexi simultaneously.[24] Therefore, whether ganglionated plexus ablation is required in addition to PFA remains unknown.

The incidence of SCLs was relatively low in the present study. The mechanism of SCLs formation is multifactorial, which may be due to the air or thrombus entry via sheaths, coagulum form on catheter or ablation lesions, and bubble formation during ablation.[25]Current evidence suggests that the majority of cerebral lesions are asymptomatic and resolve over a short period.[8,26,27]Echogenic microbubbles were common with intracardiac echocardiography during the application of PFA, however, this was not the main cause of cerebral injury. Careful management of sheaths, continuation of anticoagulation, and maintenance of ACT >300 s may help reduce the risk of cerebral lesions.

Overall, our study's safety findings should largely alleviate safety concerns regarding PFA. However, larger studies will be needed to reveal rare unanticipated safety issues.

5 | STUDY LIMITATIONS

The main limitations include the small sample size and single-center experience, which may limit the validation of the reproducibility of study results to assess the efficacy and complications. No coronary angiography was performed in our series. Some subclinical coronary vasospasms were not observed during the procedure. Assessments of haemolysis and acute renal injury after the procedure were not performed in our enrolled patients. The other limitation of the present study is the short duration of follow-up and the small size of redo patients. The long-term durability of the lesions and recurrence rate after ablation need to be evaluated specifically in prospective studies.

6 | CONCLUSIONS

PFA with the ablation strategy including PVI, LAPW isolation, CTI block, and MI block is feasible, safe, and associated with a high rate of freedom from atrial tachyarrhythmia recurrence at 1 year in patients with PeAF. Nevertheless, the PFA systems still need to optimize catheter design and ablation parameters to enhance acute success rates, reduce reconnections, improve transmural lesion durability, and minimize risks.

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Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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TABLE 1 Baseline characteristics

Age (years) 57.8±8.8
Male, n (%) 25(78.1)
BMI (kg/m^2) 26.9±3.4
Mean duration of AF (months) 14.5±8.9
LA diameter (mm) 43.1±4.3
LA volume (ml) 125.5±29.1
LVEF, % 60.4±5.5
CHADS2-Vasc score, n (%)
0,1 14(43.7)
2 10(31.3)
[?]3 8(25.0)
Comorbidity,n (%)
HTN 21(65.6)
CAD 2(6.3)
Diabetes mellitus 4(12.5)
Hyperlipoidemia 10(31.3)
Heart failure 2(6.3)

Abbreviations: BMI, body mass index; AF, atrial fibrillation; LA, left atrium; LVEF, left ventricular ejection fraction; CAD, coronary artery disease; HTN, hypertension.

Total procedure time, min 78.6±31.3
Total fluoroscopy time, min 4.4±1.4
Circular PFA catheter
RPV applications 29.4±11.7
RPV isolation time, min 9.3±5.4
LPV applications 29.9±12.7
LPV isolation time, min 12.0±6.7
LAPW applications 8.5±4.2
LAPW ablation time, min 1.7±1.4

Focal contact force PFA catheter	
CTI applications	22.5±9.0
CTI ablation time, min	6.4±5.7
MI applications	61.0±27.6
MI ablation time, min	17.6±11.0
Acute endpoints, n (%)	
PVI success rate	32(100)
LAPW isolation success rate	32(100)
MI block success rate	26(81.3)
CTI block success rate	31(96.9)

TABLE 2 Procedure characteristics

Abbreviations: PFA, pulsed field ablation; RPV, right pulmonary vein; LPV, left pulmonary vein; LAPW, left atrial posterior wall; CTI, cavotricuspid isthmus; MI, mitral isthmus; PVI, pulmonary vein isolation.

TABLE 3 Follow-up data

Follow-up duration, months	10.7±2.6
Recurrence of any atrial arrhythmia, n(%)	11(34.4)
AF recurrence, n(%)	8(25)
AFL, n(%)	3(9.4)
AT, n(%)	0(0)
Ablation-to-recurrence time, months	5.2±2.9
Patients undergoing redo procedure, n(%)	3(9.4)
Redo findings, n(%)	
AF/AFL	2(6.3)/1(3.1)
LPV reconnected	3(9.4)
RPV reconnected	3(9.4)
CTI reconnected	3(9.4)
MI reconnected	3(9.4)
LAPW reconnected	1(3.1)
Success in re-isolation or re-block	3(100)

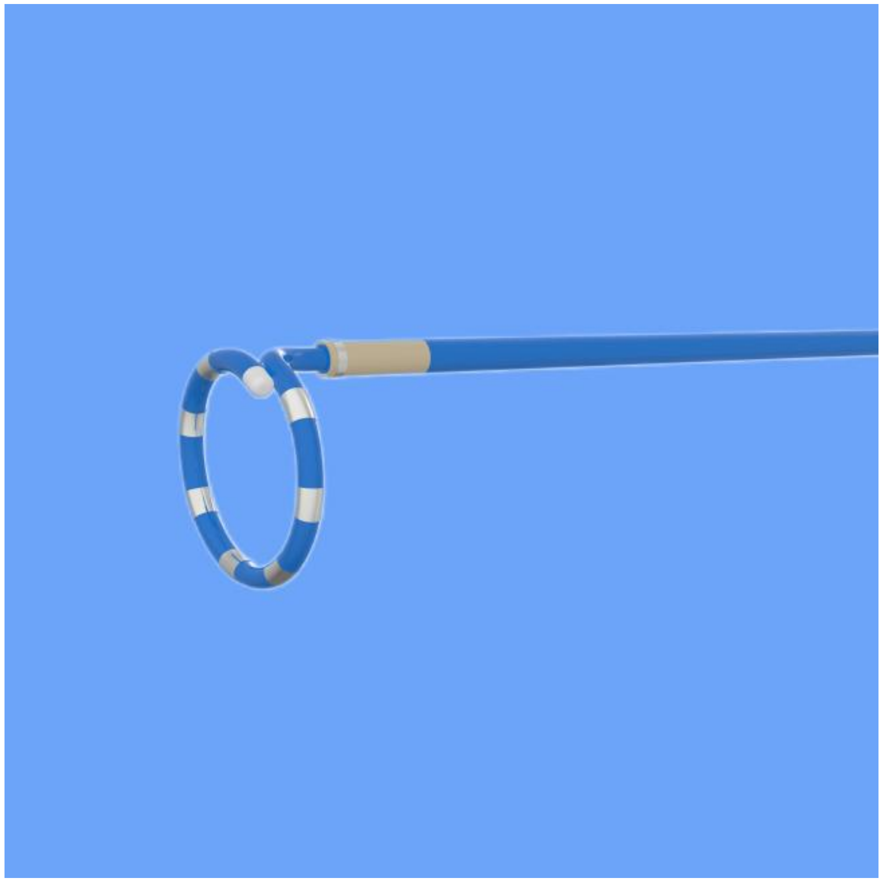
Abbreviations: AF, atrial fibrillation; AFL, atrial flutter; AT, atrial tachycardia; RPV, right pulmonary vein; LPV, left pulmonary vein; CTI, cavotricuspid isthmus; MI, mitral isthmus; LAPW, left atrial posterior wall.

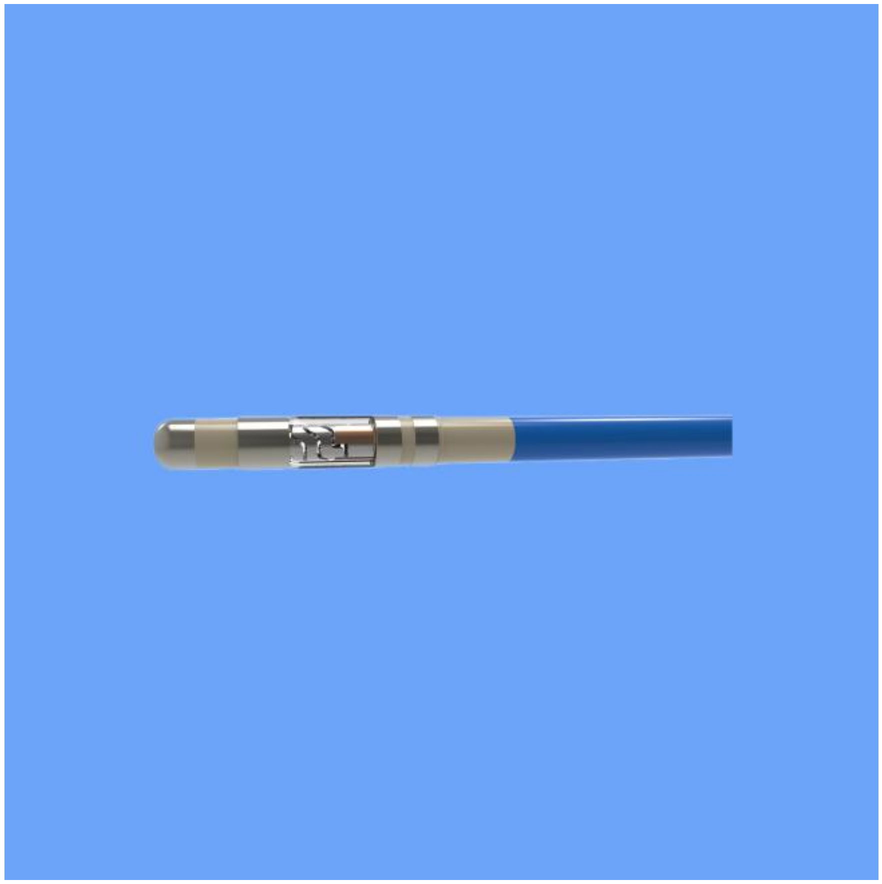
TABLE 4 Complications

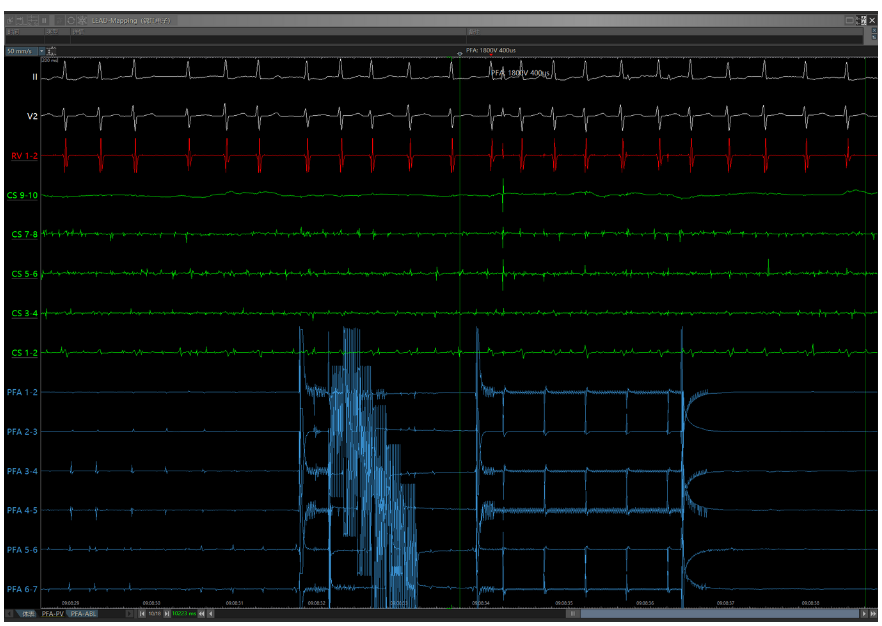
Total no. of complications	4 (12.5%)
Asymptomatic cerebral lesions	4 (12.5%)
Stroke or TIA	0(0)
Severe coronary spasm	0(0)
Severe haemolysis	0(0)
Cardiac tamponade/perforation	0(0)
Vascular access complication	0(0)
Diaphragmatic paralysis	0(0)
Atrio-esophageal fistula	0(0)
Thromboembolic events	0(0)
Pulmonary vein stenosis	0(0)

Death 0(0)

Abbreviations: TIA, transient ischemic attack.






PFA: 1800V 400us
II
V2
RV 1-2
CS 9-10
CS 7-8
CS 5-6
CS 3-4
CS 1-2
PFA 1-2
PFA 2-3
PFA 3-4
PFA 4-5
PFA 5-6
PFA 6-7
PFA-PV
PFA-ABL

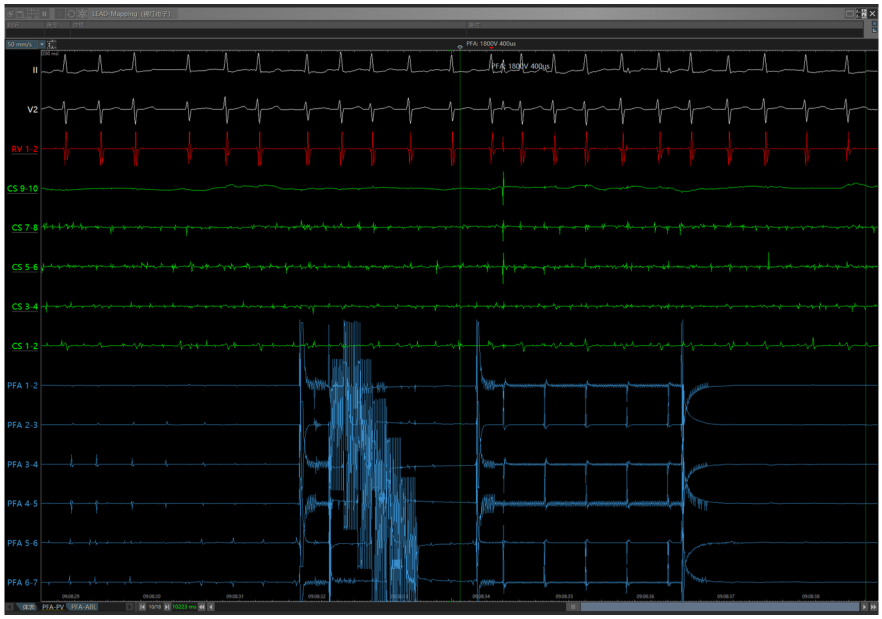
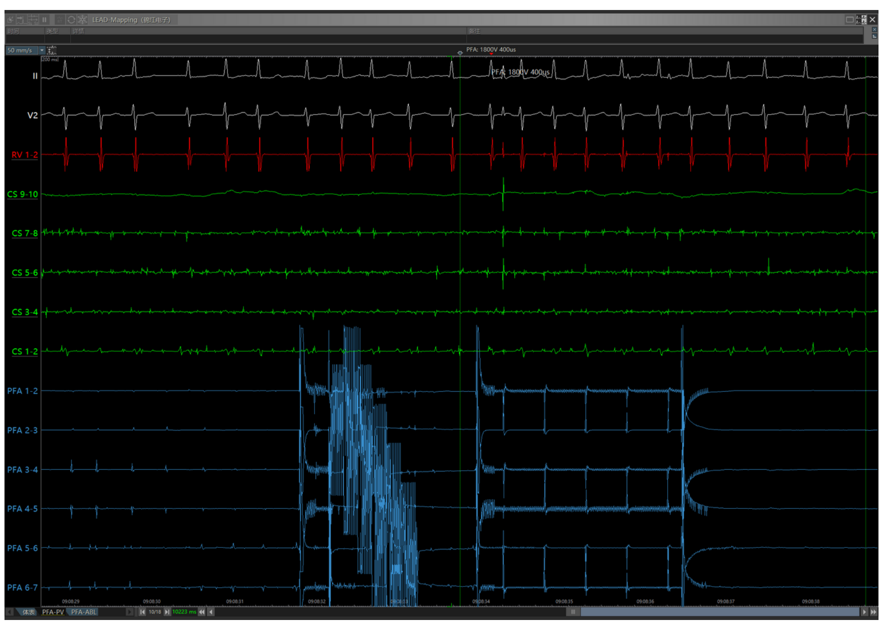
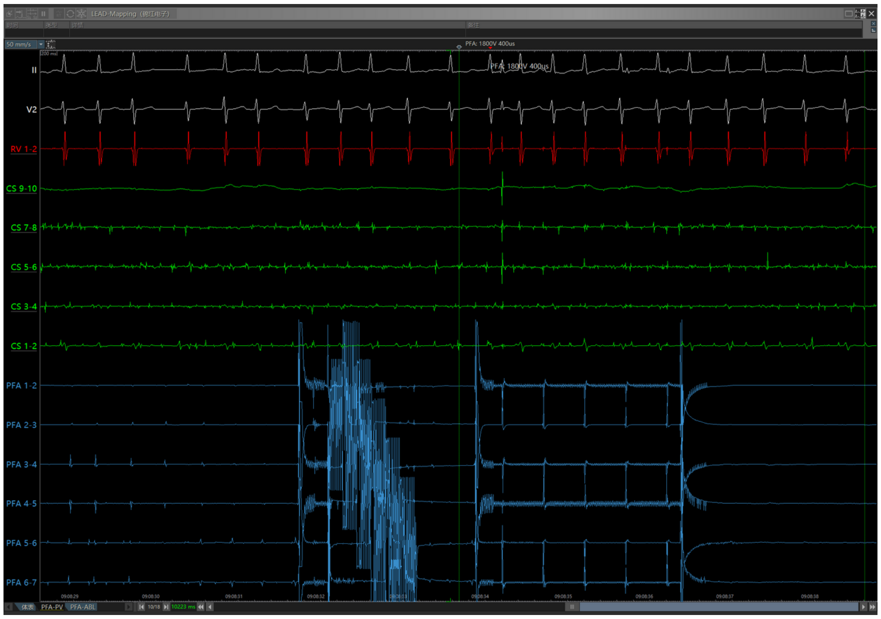
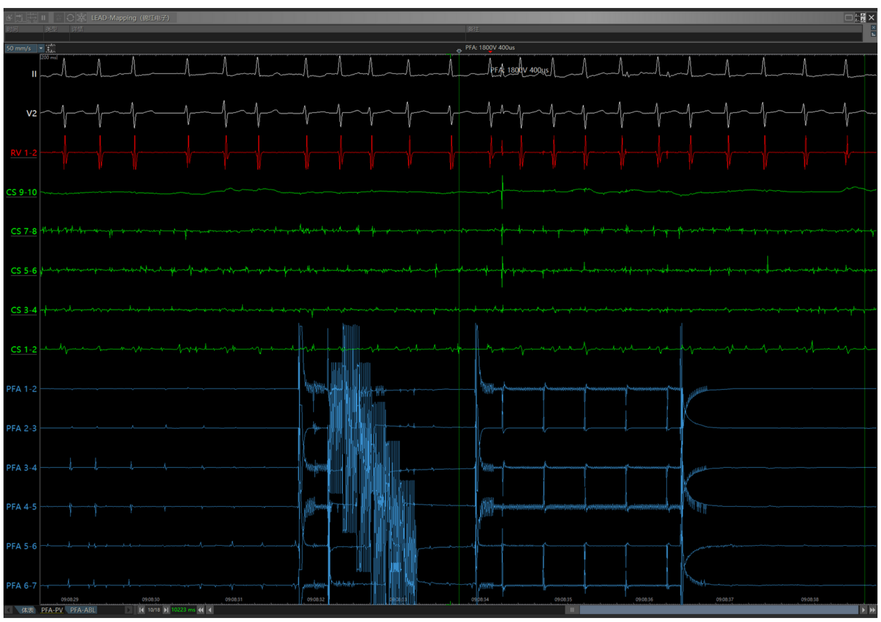
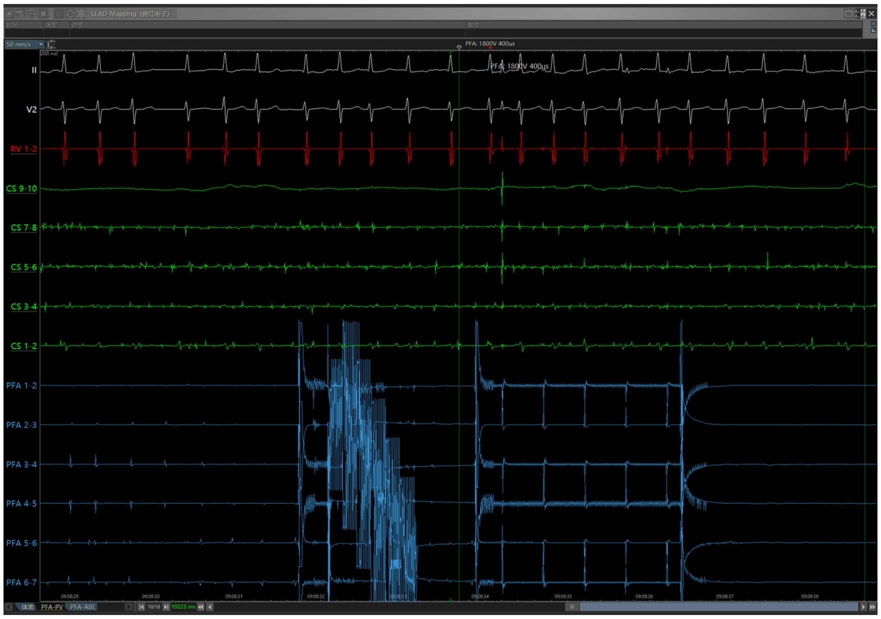


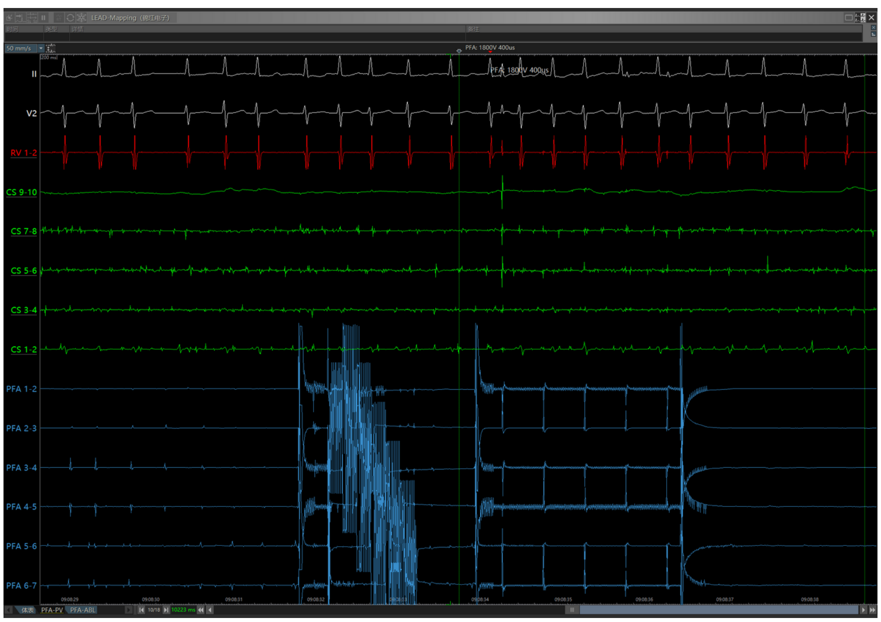
FIGURE 2 PFA Catheters. (A) Circular PFA catheter with 7 electrodes. (B) Focal contact force PFA catheter. (C)Bipolar electrograms from the distal electrodes (PFA catheter electrograms) positioned in PV or LAPW pre/post ablation. The chaotic atrial fibrillation electrograms are eliminated after PFA application. The coronary sinus (CS) electrograms demonstrate continuous atrial fibrillation. PFA, pulsed field ablation; PV, pulmonary vein; LAPW, left atrial posterior wall.

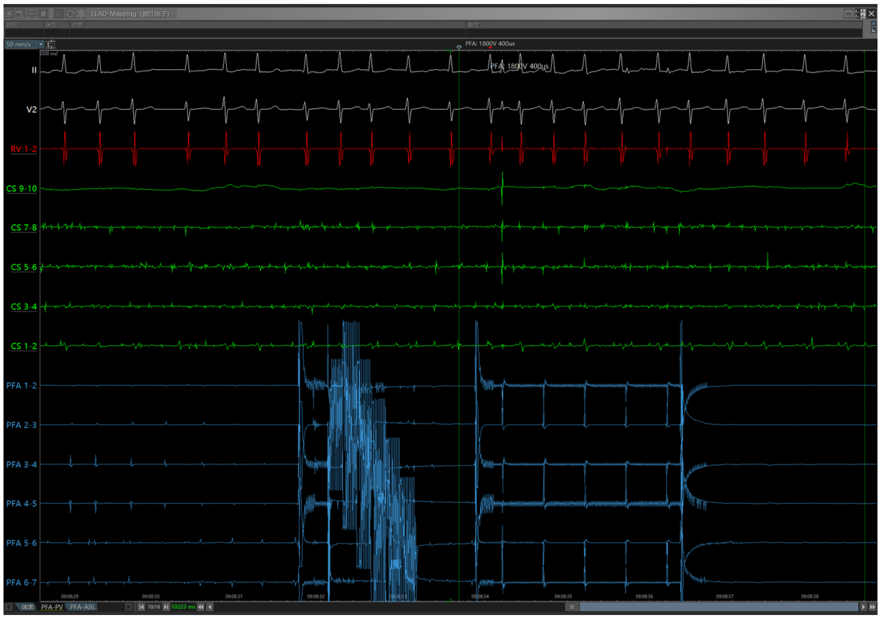


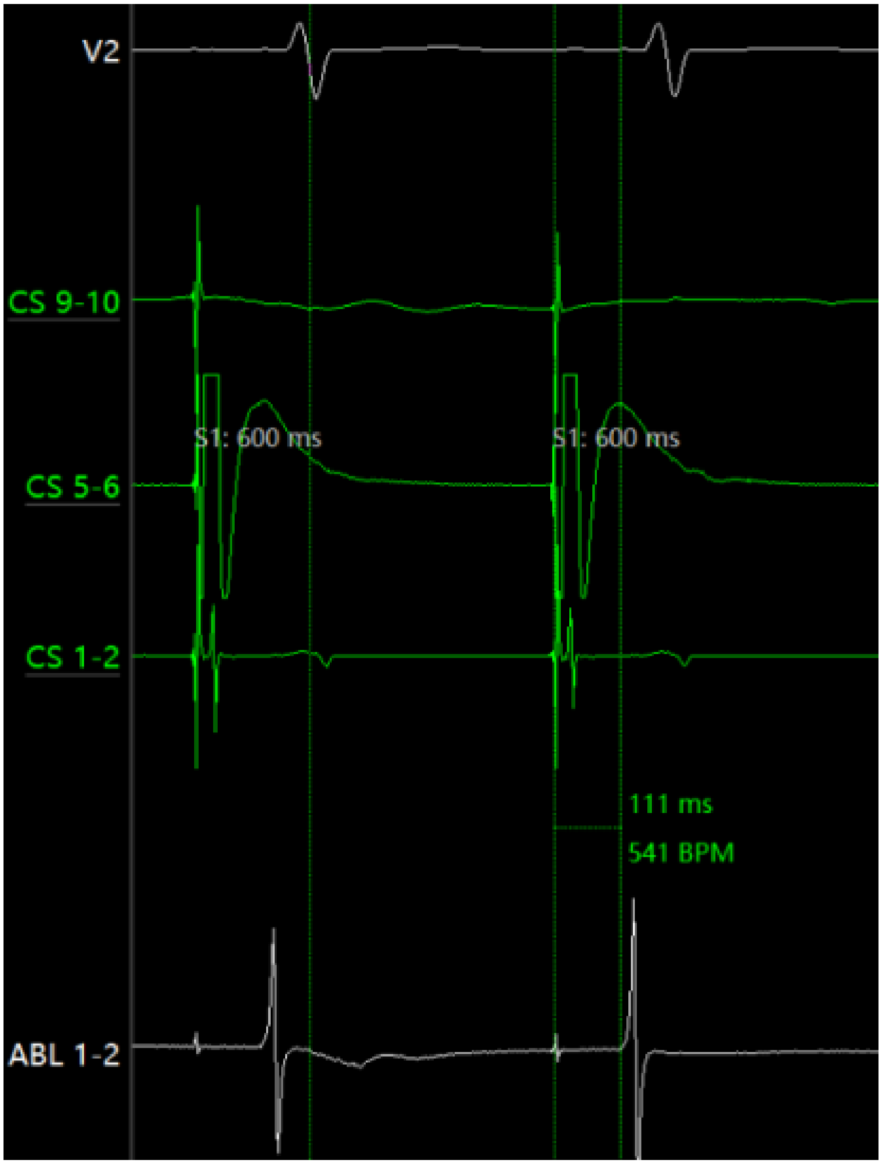

PFA: 1800V 400us
II
V2
RV 1-2
CS 9-10
CS 7-8
CS 5-6
CS 3-4
CS 1-2
PFA 1-2
PFA 2-3
PFA 3-4
PFA 4-5
PFA 5-6
PFA 6-7
PFA-PV
PFA-ABL

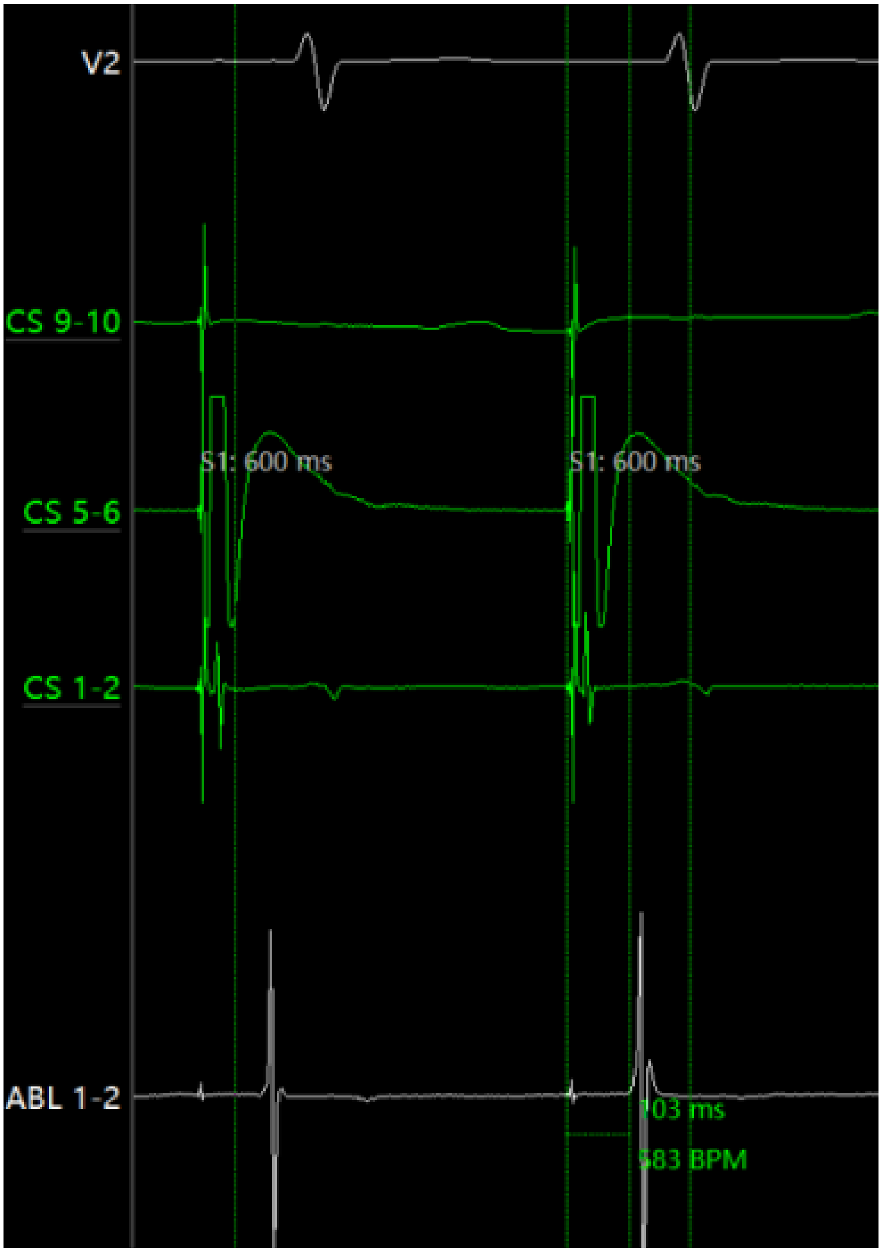

PFA: 1800V 400us
II
V2
RV 1-2
CS 9-10
CS 7-8
CS 5-6
CS 3-4
CS 1-2
PFA 1-2
PFA 2-3
PFA 3-4
PFA 4-5
PFA 5-6
PFA 6-7
PFA-PV
PFA-ABL


PFA: 1800V 400us
II
V2
RV 1-2
CS 9-10
CS 7-8
CS 5-6
CS 3-4
CS 1-2
PFA 1-2
PFA 2-3
PFA 3-4
PFA 4-5
PFA 5-6
PFA 6-7
PFA-PV
PFA-ABL


PFA: 1800V 400us
II
V2
RV 1-2
CS 9-10
CS 7-8
CS 5-6
CS 3-4
CS 1-2
PFA 1-2
PFA 2-3
PFA 3-4
PFA 4-5
PFA 5-6
PFA 6-7
PFA-PV
PFA-ABL


PFA: 1800V 400us
II
V2
RV 1-2
CS 9-10
CS 7-8
CS 5-6
CS 3-4
CS 1-2
PFA 1-2
PFA 2-3
PFA 3-4
PFA 4-5
PFA 5-6
PFA 6-7
PFA-PV
PFA-ABL


V2
CS 9-10
S1: 600 ms
S1: 600 ms
CS 5-6
CS 1-2
111 ms
541 BPM
ABL 1-2


V2
CS 9-10
S1: 600 ms
S1: 600 ms
CS 5-6
CS 1-2
ABL 1-2
103 ms
583 BPM