Pulsed field ablation for paroxysmal atrial fibrillation with mitral and cavotricuspid isthmus-dependent atrial flutter: A case report

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Abstract. Pulsed field ablation (PFA), a nonthermal ablative mechanism, has been proven to be effective and safe in clinical application. To date, PFA has been used for only atrial fibrillation (AF) ablation in limited clinical trials. The present study describes a case of paroxysmal AF in which mitral and cavotricuspid isthmus (CTI)-dependent atrial flutter was discovered incidentally during PFA operation and successfully ablated with PFA. This is the first medical record of PFA for AF combined with mitral and CTI atrial flutter. The present case report revealed that PFA can be independently used to treat complex arrhythmias, similar to radiofrequency (RF) ablation, without the need for assistance from other ablation methods. Concurrently, the present study, to the best of the authors' knowledge is the first to report a case using a point-to-point PFA ablation strategy for isthmus ablation. This highlights the potential of PFA in treating diverse arrhythmias across different regions, such as the mitral isthmus and other intricate areas, utilizing a point-to-point PFA ablation strategy.

Introduction

Pulsed field ablation (PFA) is a novel approach for cardiac ablation of atrial fibrillation (AF). PFA is a nonthermal ablative mechanism in which direct current electric energy is applied to cells, disrupting cell membranes by creating pores and preferentially ablating myocardial tissue (1). In contrast to all other contemporary ablative energy sources used in cardiac ablation, such as RF and cryothermy, PFA reduces the risk of collateral tissue damage without compromising its myocardial ablative efficacy (2,3).

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Given that PFA is a promising ablation method for eliminating paroxysmal AF, whether PFA can be successfully applied in more complex situations is unclear. This is the first medical record of PFA for AF combined with mitral and CTI atrial flutter. Similar to RF ablation, the present case study revealed that PFA can be utilized independently to treat complex arrhythmias, without the aid of other ablation techniques. Concurrently, the present study is the first, to the best of the authors' knowledge, to describe a case using a point-to-point PFA ablation technique for isthmus ablation. This highlights the potential of PFA in treating a variety of arrhythmias across various regions, including the mitral isthmus (MI) and other complex areas, by using a point-to-point PFA ablation technique.

Case report

The present study reports the case of a 76-year-old woman complaining of palpitations for 3 months. An electrocardiogram indicated paroxysmal AF. The comorbidities included hypertension, atrial premature beats, hyperlipidemia and type 2 diabetes mellitus. Echocardiography revealed a left atrial diameter of 45 mm and a normal ejection fraction (62%). Transesophageal echocardiography and cardiac computed tomographic angiography did not reveal a thrombus in the left atrial appendage. Cardiac magnetic resonance (CMR) imaging revealed delayed fibrotic enhancement at the anterior wall of the left atrium (Fig. S1).

The ablation procedure to treat paroxysmal AF was planned with 3D navigation and mapping system guidance (CARTO™ Version 7; Biosense Webster; Johnson & Johnson). The ventricular electrode and coronary sinus (CS) electrode were placed through the right femoral vein. A mapping electrode catheter invaded the left atrium, and a 3D model of the heart was established. The PFA ablation system used was an HT Viewer pro (APT Medical, Inc.). A circular ablation catheter (APT Medical, Inc.), which is a 7.5F catheter with 7 electrodes, was selected to carry out the pulmonary vein isolation (PVI). The successful isolation of all 4 pulmonary veins was achieved with a median output power (Fig. 1). AF induced by CS 9-10 with a cycle length of 260 msec was observed after PVI (Fig. 1B), which then soon evolved into an atrial flutter with a cycle length of 227 msec (Fig. 1C). Remapping was

applied, and electrical excitation was observed around the MI, indicating the atrial flutter was located at the MI (Fig. 1D). To complete the MI linear lesion, the ablation catheter was changed to a general pressure pulse catheter (APT Medical, Inc.), and a point-to-point ablation technique was used. Medium delivery power was used for ablation. After termination of the peri-mitral atrial flutter (PMF) (Fig. 1E), another atrial flutter occurred with a cycle length of 245 msec. The demonstration of transient entrainment at CS 9-10 (Fig. 1F) and termination of the atrial flutter at the right atrium free wall (Fig. 1G) suggested that atrial flutter is dependent on the CTI. Additional lesions were deployed to target the CTI (Fig. 1H), after which the sinus rhythm was ultimately restored. Before the MI block, the excitation of the atrium pacing at CS1-2 occurred earlier (Fig. 1I). Following MI block, the excitation of the atrium pacing at CS9-10 preceded (Fig. 1J), suggesting the occurrence of MI block. Pacing was initiated near the lower aspect of the right atrial free wall, >140 msec from CS9-10, indicating blockage at the tricuspid valve isthmus (Fig. 1K). A 1-year follow-up confirmed good sinus rhythm maintenance.

Discussion

PFA is based on the premise of applying ultrarapid (nanosecond to microsecond) electrical pulses to generate a strong electrical field, which is subsequently applied to the selected tissue of interest. PFA was first reported to treat paroxysmal AF in 22 patients by Reddy *et al* (1). To date, >400 patients with paroxysmal AF have been reported to receive PFA treatment in various studies, with 100% successful PVI and a pooled proportion of complications of 0.0223 (4). A 1-year follow-up of PFA for ablation of paroxysmal AF was previously reported. Remapping at 2-3 months after PFA revealed PVI durability in 84.8% of the patients, and 1-year freedom from any atrial arrhythmia reached 84.5±5.4% (5).

CMR was used to evaluate atrial structure and fibrosis. CMR is a noninvasive imaging modality that allows for detailed tissue characterization, provides high spatial resolution images and enables the visualization of ablation lesions. Cardiac MRI remains the gold standard for fibrosis assessment (6). In particular, late gadolinium enhancement MRI appears to be a promising alternative for pre-ablation scar visualization and quantification (7). The degree of left atrial fibrosis prior to ablation predicts prognosis; the more atrial fibrosis there is, the more likely the patient is for an atrial arrhythmia to recur after ablation (8). Therefore, several scholars have proposed MRI-guided fibrosis ablation, but the results have not been satisfactory (9). This may be because the ablation did not cover the preexisting left atrial fibrosis adequately (10). CMR has more frequently been studied in AF ablation but less in atrial flutter ablation. This is likely because the typical atrial flutter-dependent anatomy is relatively fixed and does not need to be localized with the additional aid of imaging. Catheter ablation can be successfully performed for atypical AF via a mapping system.

The concept of MI was first described when Luria *et al* (11) noted that inadvertent damage to a narrow 'isthmus' of myocardium between the lateral mitral annulus and the left inferior pulmonary vein (LIPV) could lead to intra-atrial conduction block. MI ablation is challenging from both an efficacy and a safety standpoint, as it may be associated with significant complications. There are several reasons for MI ablation difficulty. First, the thickness of the myocardium ranges from 1.4 to 7.7 mm at the level of the LIPV, from 1.2 to 4.4 mm in the mid-isthmus region, and up to 3.2 mm in the mitral annulus (12). The vastly divergent myocardial thickness limits the ease of bidirectional block through point-by-point ablation. Second, the CS and circumflex artery near the mitral annulus can reduce conductive heating of the sub epicardium and act as a 'heat sink', thereby limiting lesion transmurality (13). Third, the proximity of the left circumflex artery and CS increases the possibility of coronary injury, while ablation, myocardial sleeves and the vein of Marshall may act as epicardial bridges preventing MI blockage despite endocardial ablation.

The most widespread ablation strategy for PMF is MI ablation, with endpoints of PMF termination and blockage across the line (14). Reported success rates are widely distributed [56-96% for MI block (14-17) and 88-100% for PMF termination (17,18)]. Despite acute bidirectional MI conduction block, the recovery of conduction can reach 73%, which may lead to AT recurrence (19). Several studies have revealed that MI block has little impact on arrhythmia recurrence in patients with PMF after ablation for AF (18,20). Poor lesion durability was mostly recorded with thermal ablation. However, it was difficult to determine the reason why MI RF ablation strategies fail, but it could possibly be due to this approach being mechanistically ineffective or because mitral lines are typically not durable.

While the present case report illustrated the success of PFA for isthmus ablation, it also highlighted the challenges associated with this procedure. Although PFA has demonstrated safety and efficacy in preventing atrial arrhythmias (5), the risk of coronary spasms has emerged as a concern, particularly when energy is applied near coronary arteries (21). Gunawardene *et al* (22) reported successful MI ablation with PFA, but coronary artery spasm occurred in one patient and was resolved by nitroglycerin after eight PFA applications. Additionally, a case of ventricular fibrillation was encountered during tricuspid isthmus ablation with PFA, leading to emergency defibrillation and coronary artery dilatation (23). Another hurdle is the lack of homogeneity in PFA systems, with varying parameter settings among manufacturers, such as FARAPULSE™ (Boston Scientific), CENTAURI™ (Galaxy Medical) and PulseSelect™ (Medtronic), which makes it challenging for operators to fully comprehend their surgical tools. This lack of standardization may contribute to heterogeneity in clinical trials conducted by different manufacturers.

The present study provided the first case of AF, MI and CTI PFA. MI and CTI blockade with a median dose of power without any complications during the procedure was successfully achieved. Circular catheters were utilized to isolate pulmonary veins and transition to pressure catheters for point-to-point linear ablation of the MI and CTI. Previous studies commonly employed patterned or circular catheters for isthmus ablation, followed by additional point ablation using RF catheters (22,24). The present study suggested the efficacy of employing PFA for point-to-point ablation in challenging areas. Considering the enhanced selectivity of PFA for tissue damage and relatively greater tolerance for catheter stability,

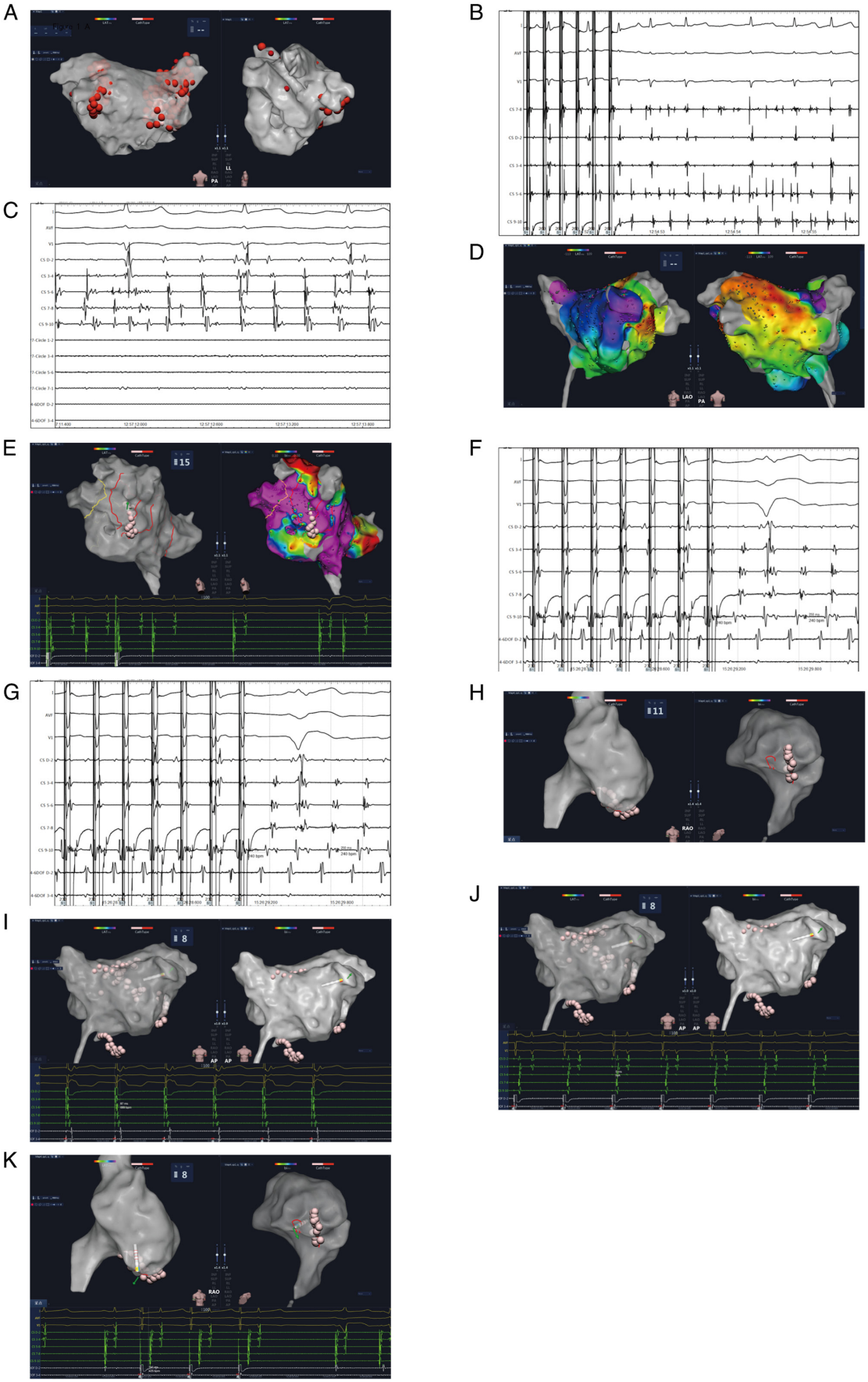

Figure 1. (A) Pulmonary vein isolation was achieved. (B) Induced AF. (C) AF transitioning to atrial flutter. (D) Excitation mapping suggested an MI-dependent atrial flutter. (E) MI ablation terminated atrial flutter. (F) Another atrial flutter occurred, which demonstrated transient entrainment at CS9-10. (G) Atrial flutter terminated at the right atrium free wall. (H) Cavotricuspid isthmus ablation. (I) Excitation of the atrium pacing at CS1-2 occurred earlier before MI blockade. (J) Excitation of the atrium pacing at CS9-10 after MI blockade. (K) Block of the cavotricuspid isthmus. AF, atrial fibrillation; CS, coronary sinus; MI, mitral isthmus.

using PFA may prove to be a safer, more effective, and easily implementable approach for ablation in areas such as the roof line and posterior line beyond the isthmus region.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

The manuscript was written by JLH, with ZZ, GSY, and DL performing the ablation. JLH participated in the operation, collected operation data, edited pictures, reviewed relevant literature and followed up patients. ZZ organized the operation and provided the design for this article. ZZ and GSY interpreted the data. JLH and SQX confirm the authenticity of all the raw data. JLH, SQX and XCY participated in submitting the manuscript. HXL organised the operation, was the chief operator and provided technical support. JLH and SQX reviewed the manuscript. YXY and GJH participated in the ablation, and HXL provided technical support. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

The present study has been approved by the Research Ethical Committee of The Third People's Hospital of Chengdu (Chengdu, China; approval no. 2023CD-045-07).

Patient consent for publication

Written informed consent was obtained from the patient for publication of patient data and associated images.

Competing interests

The authors declare that they have no competing interests.

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