REVIEW ARTICLE

Use of Bipolar Radiofrequency Catheter Ablation in the Treatment of Cardiac Arrhythmias

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Abstract: ***Background***: Arrhythmia management is a complex process involving both pharmacological and non-pharmacological approaches. Radiofrequency ablation is the pillar of non-pharmacological arrhythmia treatment. Unipolar ablation is considered to be the gold standard in the treatment of the majority of arrhythmias; however, its efficacy is limited to specific cases. In particular, the creation of deep or transmural lesions to eliminate intramurally originating arrhythmias remains inadequate. Bipolar ablation is proposed as an alternative to overcome unipolar ablation boundaries.

Results: Despite promising results gained from in vitro and animal studies showing that bipolar ablation is superior in creating transmural lesions, the use of bipolar ablation in daily clinical practice is limited. Several studies have been published showing that bipolar ablation is effective in the treatment of clinical arrhythmias after failed unipolar ablation, however, there is inconsistency regarding the safety of bipolar ablation within the available research papers. According to research evidence, the most common indications for bipolar ablation use are ventricular originating rhythmic disorders in patients with structural heart disease resistant to standard radiofrequency ablation.

Conclusion: To allow wider clinical application the efficiency and safety of bipolar ablation need to be verified in future studies.

Keywords: Bipolar radiofrequency ablation, arrhythmias, efficacy, safety, heart disease, radiofrequency ablation.

1. INTRODUCTION

Radiofrequency Ablation (RFA) is widely accepted as a reliable approach to treating pharmacoresistant arrhythmias [1, 2]. However, despite massive technical progress in the electrophysiology field, the recurrence rates for standard Unipolar Ablation (UPA) remain in particular arrhythmias relatively high. The reported recurrence rates for Atrial Fibrillation (AF) are 12-34% depending on the type of AF [3]. The recurrence rates of Ventricular Tachycardia (VT) ablation reaching 12-47% [4, 5]. Factors that might contribute to ablation treatment failure and the high recurrence rates are inadequate lesion size or inability to create a transmural lesion. Bipolar Ablation (BPA) has been proposed as an appealing alternative, which may overcome UPA boundaries [6-10].

Due to the nature of the lesions formed by BPA, particularly the high rate of achieved transmurality, this method can be a good alternative to standard UPA in refractory arrhythmias [11-14]. Although BPA seems to be a promising strategy in the treatment of refractory arrhythmias, its exact role in non-pharmacological treatment is not yet defined. The purpose of this review is to summarize current knowledge on the use of BPA settings in Supraventricular Tachycardia (SVT) and VT arrhythmias treatment.

2. TECHNICAL ASPECTS OF BP ABLATION

Radiofrequency catheter ablation uses the principle of resistive heating generated by the RF current flow into tissues. In UPA, where the radiofrequency current is applied between the tip of the ablation catheter and a ground electrode attached to the patient's skin, radiofrequency current density decreases by dispersion with distance from the catheter-tip, preventing UPA from creating deeper lesions and terminating intramural originating arrhythmias.

In contrast, bipolar devices focus ablation energy between two closely opposed electrodes, which maintain relatively high current density (Fig. **1**) [11-14].

Focused ablation energy causes rapid tissue temperature rise producing contiguous thermal injury [11-14]. This is one of the mechanisms by which BPA may improve lesion transmurality, while minimizing the possibility of adjacent

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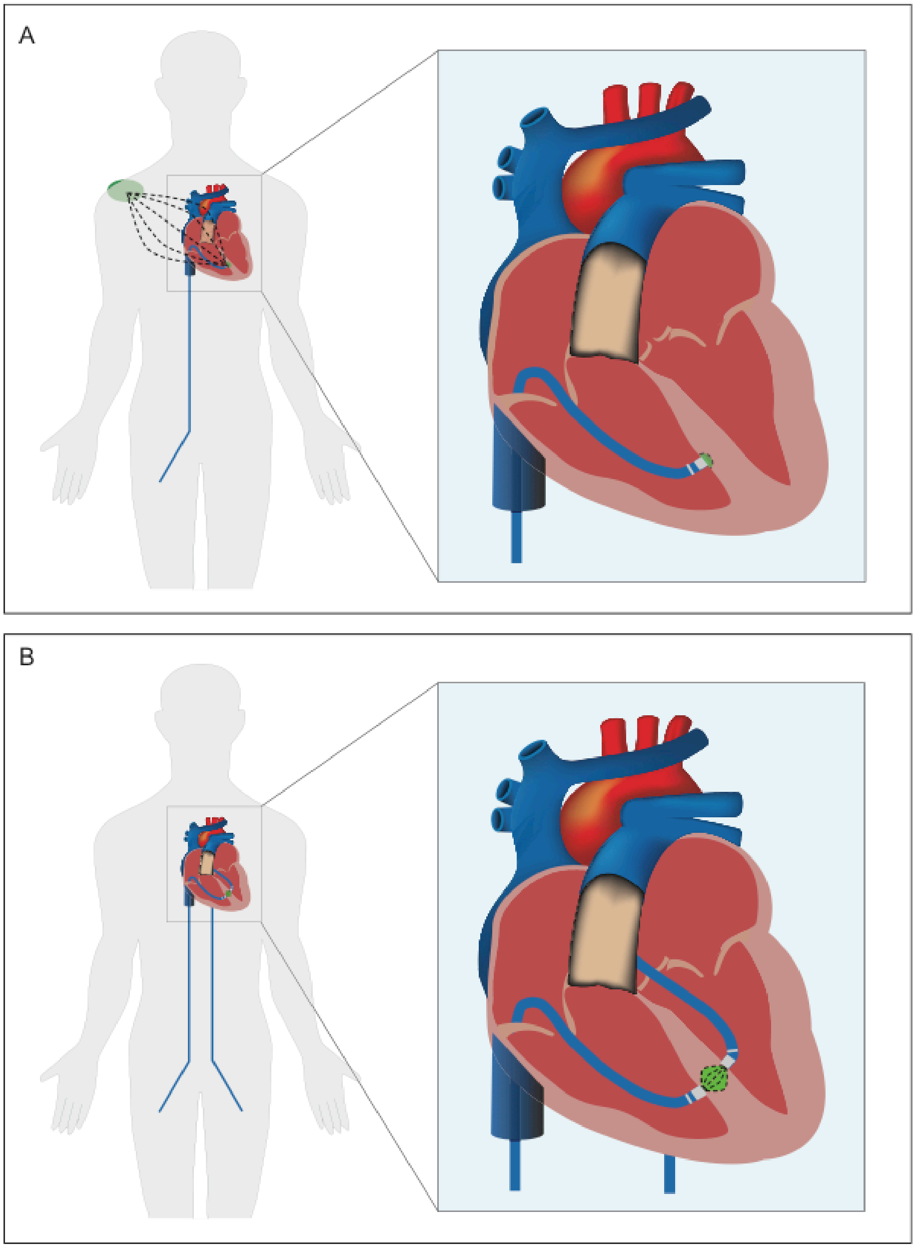

Fig. (1). Principle of unipolar *vs.* biplolar radiofrequency ablation. **A** - unipolar ablation; the energy is applied between the tip of the ablation catheter and a ground electrode attached to the patient's skin. **B –** bipolar ablation**,** the energy is focused between two opposed catheters.

organ injury, which is rarely observed in unfocused UPA [15].

On the other hand, some disadvantages need to be acknowledged. The difficulty of positioning and maintaining the stability of two catheters instead of one should be taken into account. In addition, the fact that BPA produces narrower lesions may, as a consequence, lead to ablation failure. Also, the financial aspect of using two catheters while performing BPA, instead of one with UPA needs to be taken into account.

3. SAFETY OF BIPOLAR ABLATION

In reference to the safety of BPA, there is substantial inconsistency within the available research papers. Steam cavitation effect so-called "pop" during ablation is a major complication, sometimes leading to VT and/or cardiac tamponade. Some *ex vivo* studies claimed the steam pop incidence was lower in BPA, while some found the opposite result (Table **1**).

On the other hand, published clinical studies did not report any significant complications while using BPA in the treatment of various arrhythmias, suggesting reasonable safety of this method (Table **2**).

4. PRECLINICAL TISSUE MODEL EXPERIENCE AND ANIMAL BPA STUDIES

Despite all of the technical progress, the ability of UPA to create transmural lesions and eradicate deep myocardial originating arrhythmias remains limited [4, 5]. A number of methods have been studied in order to overcome the boundaries of current ablation strategies, including alcohol ablation, surgical treatment or use of alternative energy sources [16-

Table 1. Comparison of bipolar *vs.* unipolar ablation *in vitro* studies (lesion transmurality x steam pop occurrence).

Study	Animal Model/Ablation Site		Power (W)	Lesion Transmurality (%)			Steam Pop Occurence (%)		
				UPA	BPA	p value	UPA	BPA	p value
Bugge *et al.* [12]	Ovine	Left atrium	30	33.3	99.3	< 0.05	-	-	-
		Right ventricle	30	16.7	28.6	NS	-	-	-
Nagasmina *et al.* [11]	Swine	Interventricular septum	30	7.7	50	< 0.05	15.4	3.6	NS
			50	8.3	46.7	< 0.05	45.8	6.7	< 0.001
			70	0	71.4	< 0.01	66.7	14.3	< 0.01
Koruth *et al.* [7]	Swine	Ventricular tissue	30-50	33	82	< 0.001	-	-	-
Ohkubo *et al.* [16]	Swine	Left atrium to the coronary sinus	25	0	75	< 0.01	0	37.5	NS
Nagasmina *et al.* [19]	Swine	Left ventricle epicardial-to-endocardial	25	0	45.5	< 0.001	28.9	9.1	< 0.05

BPA = Biploar Ablation; UPA = Unipolar Ablation; W = Watt.

Table 2. Use of Bipolar ablation in clinical arrhythmias treatment.

	Ablation Site/Type of Arrhythmia	Acute Success Rate (%)	Follow-up (Months)	Recurrence Rate (%)	Complications (%)
Bashir *et al.* [25]	Postero-septal pathways	100	8 to 36	0	0
Koruth *et al.* [7]	Septum-related atrial flutter	100	2	100	0
	Septal VT ablation	100	12.8	50	0
	free-wall VT ablation	50	12	0	0
Koruth *et al.* [8]	Outflow tract premature ventricular contractions	75	4	0	0
Gizurarson *et al.* [9]	Recurrent VT inter-ventricular septum	100	12	0	0
Nguyen *et al.* [32]	Recurrent VT septal and papillary muscles	93	14.6 ± 6.2	30	0

VT = Ventricular Tachycardia.

18]. However, the majority of these methods appeared to have only limited use in clinical practice. Regarding BPA there has been published a number of in vitro and in vivo studies reporting possible advantage in the treatment of intramurally originating arrhythmias (Table **1**). Most of the publications are suggesting the use of BPA in the treatment of ventricular originating arrhythmias, only a few reports showing the possible benefit of BPA in SVT treatment. *In vitro*, it has been reported that BPA is superior to UPA in creating transmural lesions from the endocardial left atrium to the Coronary Sinus (CS) along the mitral annulus in explanted swine hearts [19]. This technique for improved lesions may offer an option for ablation of focal AF originating within CS. Moreover, Anfinsen *et al.* [14] proposed an animal study comparing BPA *vs.* UPA in the porcine right atrium. The lesions produced by BPA were significantly longer and wider compared to those created by UPA. The frequency of complications did not differ between the examined methods [14].

The first reference in the literature on the use of BPA in the treatment of VT was published in 1989 when Ring *et al.* [20] tested the effectiveness and safety of BPA and UPA in a closed-chest canine model. The energy was applied between two catheters across the Interventricular Septum (IVS).

Since then, following *in vitro* and animal studies have been published that compared the efficacy of BPA and UPA in the treatment of VT [6, 7, 13, 21]. Chang *et al.* [6] published an in vitro study on bovine myocardium showing that two electrodes placed in a bipolar configuration are more efficient at producing greater lesion sizes at same energy levels compared to catheters plugged in a parallel configuration. More recently, Kovoor *et al.* [21] tested the correlation between inter-electrode distance with lesion dimensions and continuity while using the BPA setting. In the study, intramural ablations on greyhounds were performed to ensure the proper contact of ablation electrode and adjacent myocardium. Lesions were created using temperature-controlled Radiofrequency (RF) delivery for 60 seconds to achieve 90 °C. The inter-electrode distance was positively correlated to lesion depth and negatively correlated to lesion width. The maximum inter-electrode distance to create a contiguous lesion was 3 mm [21].

Ventricular arrhythmias involving a reentrant circuit deep in the IVS remain a difficult ablation target. Effective transmural ablation lesion across the IVS even with the use of irrigated catheters is often not achievable. The study by Sivagangabalan *et al*. [13] compared the efficacy of BPA versus sequential UPA in creating a transmural ablation line along the IVS scar border, both in a phantom agar model and post-infarct sheep, and proved BPA to be highly effective in creating transmural lesions, while requiring less energy than UPA.

Moreover, Nagasmina *et al*. [11] compared 2-catheter bipolar septal ablation with sequential left and right unipolar septal ablation in vitro swine IVS and showed BPA achieving a higher level of lesion transmurality than UPA with constant power delivery. In addition, the incidence of steam pops was significantly lower in the BPA setting compared to UPA at the same energy levels [11]. The same group of authors published a related study describing a higher efficacy of bipolar epicardial-to-endocardial ablation in deeper formations and a higher likelihood of transmural lesions compared to standard UPA [22]. Again, the incidence of steam pop was lower when using BPA compared to UPA at the same energy level [22].

More recently, Gizurarson *et al*. [9] published a study examining bipolar lesion morphology in the human heart. *In vitro*, the ablation was performed on human hearts obtained at the time of the cardiac transplantation and showed that the two-catheter BPA technique is able to produce deeper lesions without affecting lesion width when compared to standard UPA.

5. BIPOLAR ABLATION IN ARRHYTHMIAS TREATMENT

5.1. Bipolar Ablation in the Treatment of Supraventricular Arrhythmias

Thus far, bipolar ablation, which is more routinely applied in the treatment of AF in patients undergoing cardiac surgery [23], has very limited use in catheter-based ablation of atrial arrhythmias. Following are specific situations where BPA was reported mostly as case studies.

5.1.1 Bipolar Ablation and Mitral Isthmus-related Arrhythmias

One of the potentially challenging areas for successful ablation remains Mitral Isthmus (MI). In addition to pulmonary isolation, MI ablation is a part of the complex ablation of atrial fibrillation, however, reconduction of MI after successful ablation remains relatively high, predisposing of clinical tachyarrhythmia. Therefore, new approaches for MI ablation such as the use of steerable or circular multielectrode ablation catheters, or CS occlusion by an air-filled balloon to diminish the cooling effect of blood flow have been proposed [24-26]. Regarding the clinical use of BPA along the mitral annulus, Yamagata *et al*. [10] presented a case report showing successful ablation of peri-mitral Atrial Flutter (AFL) using BPA, suggesting that such an approach might be an option for arrhythmias resistant to unipolar RFA in this location.

5.1.2. Bipolar Ablation of Accessory Pathways

RFA is the method of choice for treatment of symptomatic patients with accessory pathways. Posteroseptal accessory atrioventricular pathways are known as being less accessible for successful RFA than pathways in other locations, and UPA may fail in some patients. In these situations, bipolar ablation has been presented as an alternative approach [27, 28].

However, these results were published in early 90´s and BPA has not been commonly used in accessory pathways RFA since then. Thus the efficacy and safety of BPA in the treatment of accessory pathways remain a matter of case studies and preclinical research.

5.1.3. Bipolar Ablation and Septum-related Arrhythmias

The occurrence of AFL after ablation of AF is quite common, and septum-related AFLs may be particularly because of the relative thickness of the inter-atrial septum difficult to eradicate. With regard to clinical studies, Koruth *et al*. [7] reported the use of BPA after failed UPA for the treatment of septum-related AFL. Acute arrhythmia termination was achieved in all of the BPA ablated patients. As suggested by the authors, the success of BPA may be explained by attaining transmurality across the septum. Despite the acute success, all 3 patients suffered from recurrent atrial arrhythmias in follow-up. However, after additional UPA, two of the three patients had no further documented arrhythmia recurrences [7].

5.1.4. Bipolar Ablation and Atrial Fibrillation

Recently was introduced phased RFA for AF treatment using bipolar energy delivery [29]. The phased RF ablation system was developed to achieve simpler and faster pulmonary vein isolation. Phased RFA configuration facilitates simultaneous bipolar and unipolar delivery of energy in predefined modes: bipolar, unipolar, ratios of bipolar-to-unipolar energy. So far published reports on phased RFA have shown lower procedure and fluoroscopy times with similar success rate for both paroxysmal and persistent AF in comparison to other AF ablation methods [29, 30].

5.2. Bipolar Ablation and Ventricular Arrhythmias

Ventricular arrhythmias include a variety of rhythm disorders that range from non-sustained, asymptomatic arrhythmias to sustained arrhythmias, which can cause cardiac arrest. These arrhythmias are associated with a spectrum of cardiac disorders or might be present even in patients without heart structural abnormity. Coronary artery disease is the most common cardiac disease associated with VTs, especially related to post-infarction scar or aneurysm formation**.** Implantable Cardioverter-Defibrillators (ICDs) are the most effective tools in preventing sudden death due to VTs and have therefore become the pillar of VT treatment [31]; however, they cannot prevent recurrent VT episodes. Repeated ICD discharges for VT increase mortality and worsen the quality of life [32, 33]. RFA has been shown as an option to reduce the absolute incidence of ventricular tachycardia or

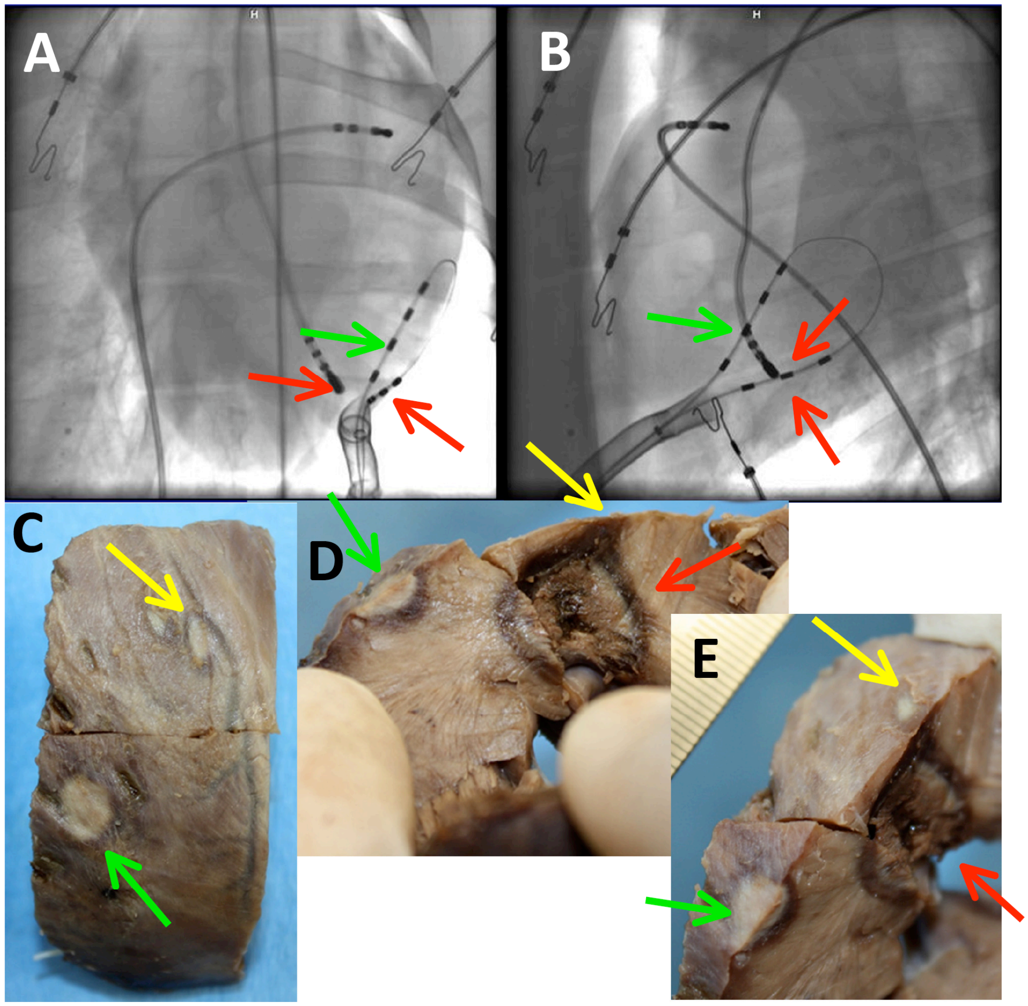

Fig. (2). Comparison of lesions created by bipolar (BP) and unipolar (UP) radiofrequency catheter ablations in the porcine heart during experimentation with novel epicardial pacing, defibrillation and ablation catheters [35]. **A** and **B** – X-ray pictures of the position of the catheters in the left ventricle and the pericardial space. A standard electrophysiological (EP) catheter is introduced retrogradely and endocardially to the apex of the left ventricle. An experimental multielectrode "fork" catheter is introduced epicardially to the apex of the left ventricle. UP ablation is provided between the second electrode of the right branch of the fork catheter (green arrow) and the disperse electrode. BP ablation is provided between the second electrode of the left branch of the fork catheter and the tip of the EP catheter (red arrows). **A** – anteroposterior view, **B** – left lateral view. **C - E** – Pictures of the anatomical specimen of the left ventricle apex myocardium with UP and BP ablation lesions from the epicardial view (**C**), 45-degree view (**E**) and cutting view (**D**). Flat and shallow UP lesions (green arrows) can be compared with very deep, transmural BP lesions (red arrows). The maximum volume of BP lesions is in the depth of the myocardium (red arrow) with a small epicardial surface lesion (yellow arrow). Applied energy was 40 watts for both bipolar and unipolar ablation, and the ablation time was 60 seconds. *(The color version of the figure is available in the electronic copy of the article).*

fibrillation and subsequently the number of appropriate ICD discharges.

RFA of ventricular tachycardia associated with structural heart disease is based on the identification and ablation of reentrant pathways and less frequently ectopic rhythm foci. The ventricular wall thickness and related inability to achieve transmural lesion using standard UPA is one of the factors which may contribute to high reported rates of VT recurrence after RFA reaching 12-47% [4, 5]. Due to the nature of the lesions formed by BPA (Fig. **2**), particularly the high rate of achieved transmurality, this method represents a vital alternative to standard UPA in refractory VT.

Koruth *et al*. [7] recently presented clinical experience of BPA in patients with VT after failed UPA. Of the 5 patients with VT who initially underwent bipolar VT ablation (4 septal VTs and 1 free-wall VT), 3 remained free of recurrent VT. One of the remaining two patients developed VT after 15 months of follow-up that was terminated with antitachycardia pacing. The last patient was referred for a repeated procedure due to recurrent VTs inducing ICD shocks. Because of multiple inducible VTs, the patient finally underwent alcohol septal ablation.

Subsequently, the same group of authors reported the potential use of BPA in the elimination of outflow tract Premature Ventricular Contractions (PVC) after standard UPA failed [8]. During the acute phase, BPA successfully abolished PVCs in 3 of 4 patients. There were no procedural complications with BPA reported. At the 4-month follow-up those patients with successful ablation were free of PVCs. Additionally, two patients who had decreased left ventricular function prior to the ablation procedure, experienced a significant improvement left global ventricular ejection fraction as a result of the elimination of the PVC.

Gizurarson *et al*. [9] presented the case of a patient with ischemic cardiomyopathy presenting with recurrent VT necessitating anti-tachycardia pacing and ICD discharges. After two failed attempts at a standard ablation, BPA across the IVS lead to the eradication of the arrhythmia, and the patient remained free of symptomatic or sustained arrhythmias at the one-year follow-up [9].

Finally, Nguyen *et al*. [34] recently published so far the largest reported series of BPA use for VT treatment, including the first reports on BPA used for the treatment of arrhythmias originating from papillary muscles. All patients had a history of failed UPA before the attempt of BPA. BPA was used to create lesions on septal sites in 11 procedures and on papillary muscles in 3 procedures. Acute success was achieved in 13 of 14 procedures (10 patients). Seven of the 10 patients were arrhythmia free in the mean follow-up of 14.6 ± 6.2 months, the remaining three patients had to return for repeat ablations [34].

CONCLUSION AND FUTURE ASPECTS

In light of the current research evidence, UPA remains the method of choice in the treatment of the majority of arrhythmias, nevertheless, BPA appears to be more effective at producing deeper and more transmural ablation lesions compared to standard UPA. Despite the broad evidence from *in vitro* and animal studies, the clinical use of BPA remains specific. BPA is currently indicated for a selected group of patients, who are resistant to the standard unipolar setting of radiofrequency ablation. The most common indication for BPA is VT related to structural heart disease. The efficacy and particularly, the safety of BPA treatment need to be verified in prospective studies, requiring multiple site cooperation, as no large cohorts of readily available at individual centers.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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