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## Ventricular automaticity: A path to premature ventricular contraction ablation success

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## 1. Introduction

Radiofrequency (RF) ablation is a commonly utilized treatment modality for frequent premature ventricular contractions (PVCs) that cause symptoms or left ventricular dysfunction. During RF ablation of PVCs, it is not uncommon to observe an accelerated ventricular response (AVR). In their retrospective study, Patloori and colleagues investigate the prognostic value of accelerated or repetitive ventricular responses observed during RF ablation of PVCs [1]. Accelerated ventricular responses were ultimately found to be associated with favorable long-term ablation outcomes, evidenced by lower PVC recurrence rates [1]. This novel finding provides insights into the prognostic value of AVR and provokes discussion regarding the underlying mechanism of ablation-induced ventricular ectopy.

## 2. Mechanisms of ventricular arrhythmias during ablation

To better understand the significance of ablation-induced AVR, we need to examine putative mechanisms for ventricular

arrhythmias during catheter ablation. Ventricular arrhythmias during catheter ablation often result from the mechanical force of the catheter. Catheter-induced ectopy can be recognized by its persistence despite discontinuation of energy delivery, very early near-field signal on the electrodes (i.e. unless mechanical effect is related to the proximal electrode or shaft of the catheter) and resolution of ectopy after withdrawing the tip of the catheter. Alternatively, ventricular arrhythmias during catheter ablation can be caused by automaticity resulting from delivery of thermal energy to the myocardial or Purkinje tissue at or near the origin of the PVC exit.

### 2.1. Automaticity and accelerated ventricular activity

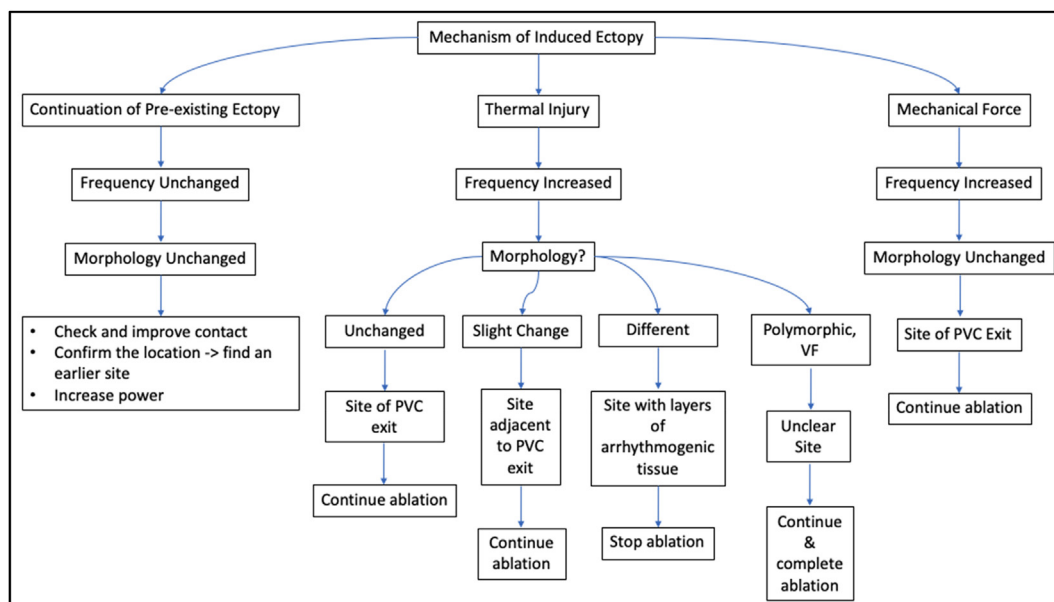
Automaticity or the ability of cardiac cells to spontaneously depolarize and initiate action potentials is a property typically reserved for specific pacemaker or nodal cells within the heart, under normal physiologic conditions [2,3]. When atrial and ventricular myocardial cells are isolated from the electrical impulses arising from the sinoatrial node, they may also demonstrate intrinsic automaticity. Such is the case during RF ablation, as thermal energy is delivered to myocardial tissue and propagating sinus impulses are blocked within the actively infarcting myocardium (entrance block) [4]. Automaticity is then unmasked within the compromised cardiac tissue and manifests as spontaneous beats

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**Table 1**  
Arrhythmic effects of catheter ablation.



that are referred to as AVRs. On a cellular level, application of thermal energy is thought to increase the slope of phase 4 spontaneous depolarization and shorten the action potential duration, resulting in enhanced automaticity [5]. The morphology and frequency of induced ectopy can be helpful in targeting and ablating the PVC of interest (Table 1). Ventricular ectopy of identical morphology and increased frequency is suggestive of heat induced automaticity with direct thermal injury delivered to the tissue of interest. The same response with slightly different morphology likely represents injury to nearby tissue just adjacent to the PVC site of exit. Lastly, induction of different morphologies during ablation can be due to ablation through multiple layers of arrhythmogenic tissue.

An important question to ask is why ablation induced automaticity does not occur in all the patients. One explanation could be rapid rise in the tissue temperature resulting in instantaneous necrosis of the tissue and another could be ablation injury related exit block. Alternatively, AVRs may arise from myocardium, adjacent to the immediate site of energy delivery. Heat transmitted to surrounding tissue may demonstrate enhanced automaticity by the mechanism described above. This would result in ventricular ectopy with similar location and subsequently morphology as the targeted PVC.

**2.2. Automaticity and source of ablation Energy**

As described above, the mechanism of ectopy in ablation-induced AVR is thought to be thermally mediated. Enhanced automaticity requires a decrease in resting membrane potential that allows for a reduced action potential threshold [3]. Although this is conventionally achieved with delivery of thermal energy in the form of radiofrequency ablation (Fig. 1), alternative mediums of energy delivery, such as electroporation, may have similar effects on cardiomyocyte membranes. Selective permeabilization of cellular membranes with electroporation has been shown to reduce the resting membrane potential of cardiac cells. Pulse field ablation involves irreversible electroporation and its role in the management of PVCs remains to be seen [6]. This transient

decrease in resting membrane potential may similarly lead to increased automaticity of the affected cells, as seen with RF ablation. Anecdotally, we have seen such ventricular ectopy with electroporation ablation in canine models (Fig. 2). However, the absence of heat generation may suggest a different ectopy mechanism than heat-induced automaticity.

Cryoablation is another alternative energy source which is often employed with ablation in high-risk areas (e.g. peri-Hisian or fascicular PVCs) or when better contact is desired (e.g., papillary muscle PVCs) [7]. Direct cell injury with hypertonic stress and formation of intracellular ice, results in membrane damage and cellular death. To the best of our knowledge, the occurrence of AVRs is not described in the literature with cryoablation. Perhaps the lack of thermal energy with cryoablation explains this absence of ablation-associated ectopy.

**2.3. Modes of Energy delivery**

RF energy can be delivered by way of irrigated and non-irrigated ablation catheters. In this study, cases using both types of radiofrequency ablation catheters were included. Irrigated tip catheters were more commonly utilized and the percentages of non-irrigated to irrigated catheters were similar in the group of cases which resulted in AVR and those that did not. However, there was not a comparison of ablation-induced ventricular ectopy rates between the different catheter types. Irrigated-tip catheters cool the tissue at the site of energy delivery which allows for increased energy delivery without associated temperature rise. Ultimately, this results in deeper and more efficacious ablation lesions. Given the potential significance of heat delivery in the induction of AVR, comparison of outcomes between catheter types is highly pertinent and important. Theoretically, differences in thermal energy delivery can affect the change in resting membrane potential and subsequently the degree of automaticity within the incident myocardium. This may ultimately influence the induction of AVR and potentially longitudinal ablation outcomes.

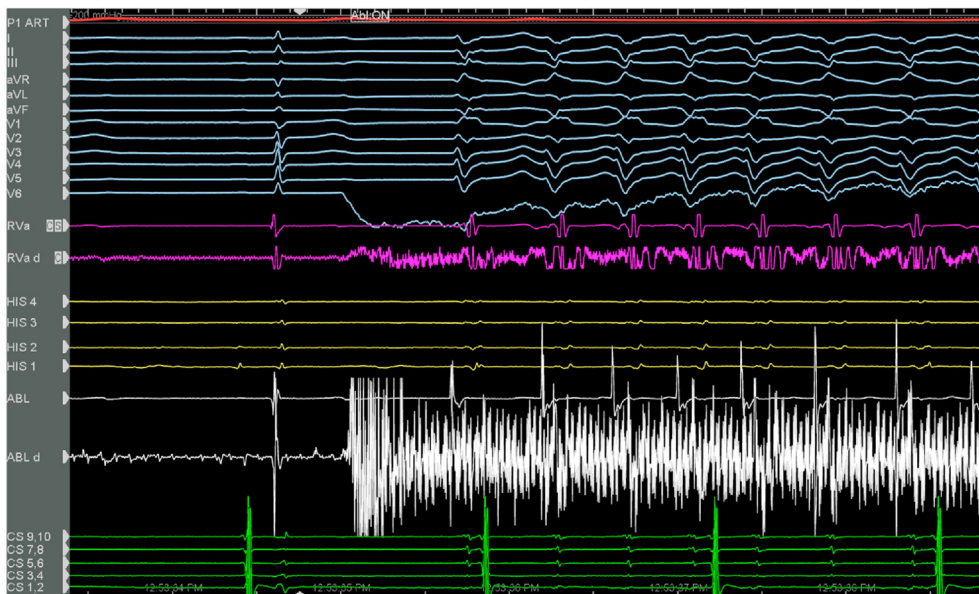


Fig. 1. Accelerated ventricular rhythm observed during radiofrequency ablation.



Fig. 2. Ventricular tachycardia induced during electroporation.

### 3. Clinical significance of AVR during RF ablation of PVC

Automatic accelerated junctional rhythm occurs during slow pathway ablation of atrioventricular nodal reentrant tachycardia and is a predictor of long-term success [8,9]. Furthermore, there is a positive correlation between the duration of accelerated junctional rhythm and acute success of AVNRT ablation [10]. Patloori et al. in their study demonstrated the importance of AVR during RF ablation of PVCs for prediction of both acute and long-term success. The patients with AVR were younger (mean age 38.7 vs. 47.2 years), while those without AVR had PVCs with multiple morphologies (31% vs. 9.1%) or origin from the aortic sinus of Valsalva (27.6% vs. 3.0%). The acute success rate of PVC ablation in all patients was 88.7%. AVR was observed in 60% of acutely successful procedures. In the presence of AVR, the rate of recurrence was significantly lower

with long-term success rate of 87.5% at 12 months. The authors therefore concluded that AVR during RF ablation is a strong predictor of acute and long-term success. Though a multivariate analysis was performed, other predictors of successful ablation were not taken into consideration. In addition, their study did not look into the effects of amount, duration or cycle length of AVR.

#### 3.1. Location of PVC origin or exit

Patloori et al. define an accelerated ventricular response as 3 or more consecutive ventricular beats induced during radiofrequency application with QRS morphology similar to the targeted clinical PVC (>10/12 lead match). Therefore, the ventricular ectopy elicited by RF ablation is thought to arise from a similar location as the targeted PVC. In this study, location of the premature ventricular

contraction does not appear to be a key determinant of AVR. The most common PVC location in both the absence and presence of AVR was the right ventricular outflow tract. There was no significant difference in PVC sites between cases that yielded ventricular ectopy and those that did not, with the exception of PVCs originating from the aortic sinus of Valsalva which were more commonly associated with the absence of AVR [1]. This is an interesting finding considering our contemporary understanding of PVC origin/exit and underlying arrhythmia mechanism. For example, outflow tract PVCs and associated ventricular tachycardia are commonly due to cyclic-adenosine monophosphate-mediated triggered activity, resulting in delayed after-depolarizations [8]. This suggests that the mechanism of ablation-induced ectopy can be independent of mechanism of clinical PVC. As such, the presence of AVR during ablation may be a favorable prognostic factor regardless of the underlying mechanism of PVC.

### 3.2. Can ablation induced AVR be harmful?

Although rare, PVC ablation can induce malignant arrhythmias such as sustained ventricular tachycardia, rapid polymorphic ventricular tachycardia, or even catastrophic ventricular fibrillation. This is especially true with ablation of the conduction system – fascicular or Purkinje tissue in either ventricle. Only 3 (4.8%) of the patients in the Patloori et al. study included PVCs originating from anterior papillary muscle and it is not clear whether Purkinje signals were present at the sites of ablation. Therefore, the significance of AVR in ablation of myocardial PVCs versus conduction system PVCs remains unknown.

## 4. Conclusion

Catheter ablation offers an effective and definitive alternative to pharmacological therapy with an overall high success rate [9]. Accelerated or repetitive ventricular response is a frequently observed rhythm during radiofrequency ablation of PVCs. Accelerated ventricular responses when observed at the time of ablation are associated with favorable ablation outcomes, particularly when the morphology is similar to the clinical PVC. At this time however, the underlying mechanisms of ablation-induced ventricular ectopy are incompletely understood. Thus, there remains a need for further investigation and exploration into the mechanisms and to differential effects of ablation-induced induced AVR.

### Declaration of competing interest

Dr. Agboola and Dr. Karki – Disclosures none.  
Dr. Asirvatham.  
Relevant financial relationship(s) with industry

- I receive royalties for work licensed through Mayo Clinic to a privately held company for contributions related to the use of

nerve signal modulation to treat central, autonomic and peripheral nervous system disorders, including pain. Mayo Clinic receives royalties and owns equity in this company. The company does not currently license or manufacture any drug or device in the medical field.

- Co-patent holder for technique to minimize coagulum formation during radiofrequency ablation
- Products or techniques related to the above disclosures are not being discussed in this presentation
- Pertains to inventions/startup companies that include Nevro, Aegis and the Phoenix Corp

### Honoraria/speakers

- Abiomed, Atricure, Biotronik, Blackwell Futura, Boston Scientific, Medtronic, Medtelligence, Spectranetics, St. Jude, Zoll

### Consulting

- Aegis, ATP, Nevro, Sanovas, Sorin Medical, FocusStart

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