

Point density exclusion electroanatomic mapping for ventricular arrhythmias arising from endocavitary structures



Jared D. Miller, MD,¹ Thomas A. Dewland, MD,¹ Charles A. Henrikson, MD, MPH, FHRS, James Reiss, MD, MPH, FHRS, Ashit Patel, MD, FHRS, Babak Nazer, MD

From the Knight Cardiovascular Institute, Oregon Health and Science University, Portland, Oregon.

Introduction

Catheter ablation of ventricular arrhythmias (VA) arising from endocavitary structures such as the moderator band or papillary muscles is challenging and is associated with lower ablation success compared to outflow tract VA.¹⁻⁴ The inability of traditional electroanatomic mapping techniques to accurately identify endocavitary structures contributes to the reduced effectiveness of catheter ablation.

We describe a novel mapping strategy (point density exclusion, PDX) that allows for accurate endocavitary structure localization without the need for integration of intracardiac echocardiography (ICE) imaging or specific electroanatomic mapping software. This technique utilizes high-density mapping to identify a volume within the ventricular chamber that does not contain geometry points; this negative space is then assigned to the corresponding local endocavitary structure of interest, allowing for 3-dimensional (3D) visualization and activation mapping.

Methods

All VA ablation procedures that utilized PDX mapping at our institution between 2017 and 2019 were included. All procedures were performed using either the Precision or Velocity versions of the NavX electroanatomic mapping system (Abbott, Abbott Park, IL). PDX mapping was utilized intra-procedurally without offline processing or analysis. PDX mapping methods are detailed in [Figure 1](#).

To verify the accuracy of the PDX endocavitary anatomic model, contact force was closely monitored as the ablation catheter approached the border of the endocavitary structure ([Figure 2](#)), assessing for a force rise ≥ 8 grams with visual contact of the catheter on the endocavi-

tary structure model. In PDX cases, ICE was used at the operator's discretion, most often for left ventricular cases to guide transeptal puncture, as well as in the initial PDX experience to validate the method. In these cases, ICE did not guide geometry creation, but was simply used to confirm catheter stability prior to ablation. Radio-frequency ablation was performed after local activation timing (LAT), unipolar signal morphology, and pace mapping results. Ablation success was defined as the absence of VA with isoproterenol infusion, ventricular burst pacing, and ventricular extrastimulus pacing over a 30-minute postablation waiting period.

Long-term ablation success was defined as the absence of arrhythmia-related symptoms, no clinical VA on follow-up electrocardiogram (ECG), a premature ventricular complex (PVC) burden $< 1\%$, and no sustained VA on ambulatory ECG monitoring and pacemaker/defibrillator interrogation.

To provide a comparator group, 10 PVC/VT ablation procedures that were performed using ICE integration with CartoSound (Biosense-Webster, Diamond Bar, CA) by the same electrophysiologists during the same time interval (2017–2019) were selected.

Continuous variables are presented as mean \pm standard deviation for normally distributed data, and median (interquartile range [IQR]) when not normally distributed. Comparisons were made using Student *t* test. The study was approved by the Oregon Health & Science University Institutional Review Board and informed consent was waived owing to the retrospective study design with anonymization of patient data. This study adhered to the Helsinki Declaration as revised in 2013.

Results

Baseline characteristics were largely similar between PDX mapping and ICE integration groups ([Table 1](#)).

For PDX mapping, high-density mapping was performed using a deflectable duodecapolar catheter (2 mm electrodes with 2 mm spacing) in 12 cases and an Advisor HD Grid catheter in the remaining 3 cases (Abbott). ICE was used in 9 procedures. An average of 15.9 ± 6.8 minutes was required

KEYWORDS Electroanatomic mapping; Premature ventricular contractions; Papillary muscles; Radiofrequency ablation; Ventricular tachycardia (Heart Rhythm 0² 2020;1:394–398)

¹The first 2 authors contributed equally to this manuscript. **Address reprint requests and correspondence:** Dr Babak Nazer, Knight Cardiovascular Institute, 3303 SW Bond Ave, Portland, OR 97239. E-mail address: nazer@ohsu.edu.

KEY FINDINGS

- Catheter ablation of ventricular arrhythmias arising from endocavitary structures such as the papillary muscles or moderator band pose mapping/visualization challenges that are often overcome by integration of intracardiac echocardiography (ICE) with electroanatomic mapping (EAM). Point density exclusion (PDX) mapping is a novel EAM method that does not require ICE, but utilizes areas of absent 3-dimensional points within the ventricular lumen to create geometries with activation and/or voltage maps of these endocavitary structures rapidly and in real time.
- We present data on 15 patients who underwent PDX mapping for ventricular tachycardia or premature ventricular complex ablations. Endocavitary structure surface was confirmed by rise of contact force as the ablation catheter approached the PDX-mapped surface. PDX mapping facilitated acute success in all 15 cases and long-term success in 13 of 15 cases.
- In comparison with a group of 10 ICE-integrated cases, PDX mapping generated similar local activation time, pace map score, number of radiofrequency lesions, fluoroscopy time, and likelihood of acute and long-term procedural success. Procedure time was shorter in the PDX group (170 ± 83 minutes) than in the ICE-integrated group (268 ± 92 minutes, $P = .02$).

to obtain overall ventricular geometry, construct the endocavitary structure of interest, and perform activation mapping. A median of 2525 (IQR 513, 3238) 3D sampled points (including internal points) were collected for the chamber of interest in each procedure. Of these, median 934 (IQR 433, 1688) were used to delineate the ventricular endocardial surface, and median 276 (IQR 94, 329) were used to define the endocavitary structure. The left ventricular papillary muscles were the sites of VA origin in 11 cases (5 anterolateral, 6 posteromedial), while the remaining 4 VAs arose from the right ventricle (3 moderator band, 1 anterior papillary muscle).

PDX-mapped VA LAT at the site of ablation was a mean 36 ± 9 milliseconds pre-QRS with an average pace map score of $93\% \pm 7\%$. A mean 16 ± 12 ablation lesions were delivered. Contact force achieved at the time of ablation was 14 ± 5 grams as the catheter was manipulated against the PDX-mapped endocavitary structure surface. Median fluoroscopy time was 5 (IQR 2.5, 13.5) minutes. Acute procedural success was achieved in all cases (100%) and long-term success was present in 13 of 15 (87%) patients at a mean 17 ± 14 months of follow-up. In the 6 PDX-mapped PVC ablation patients who had ambulatory ECG

monitoring pre- and post-procedure, PVC burden decreased from $24.0\% \pm 8.5\%$ to $2.6\% \pm 4.8\%$ ($P = .001$), with 5 of 6 patients achieving PVC $<1\%$ post-ablation.

In the 10-patient ICE-integrated comparator group, mapping was performed using an ablation catheter in 9 patients and a Pentaray catheter (Biosense-Webster) in the remaining patient. LAT, pace map score, number of radiofrequency lesions, fluoroscopy time, and likelihood of acute and long-term procedural success were generally similar between the PDX and ICE-integrated mapping approaches (Table 2). Procedure time was shorter in the PDX group (170 ± 83 minutes) than in the ICE-integrated group (268 ± 92 minutes, $P = .02$).

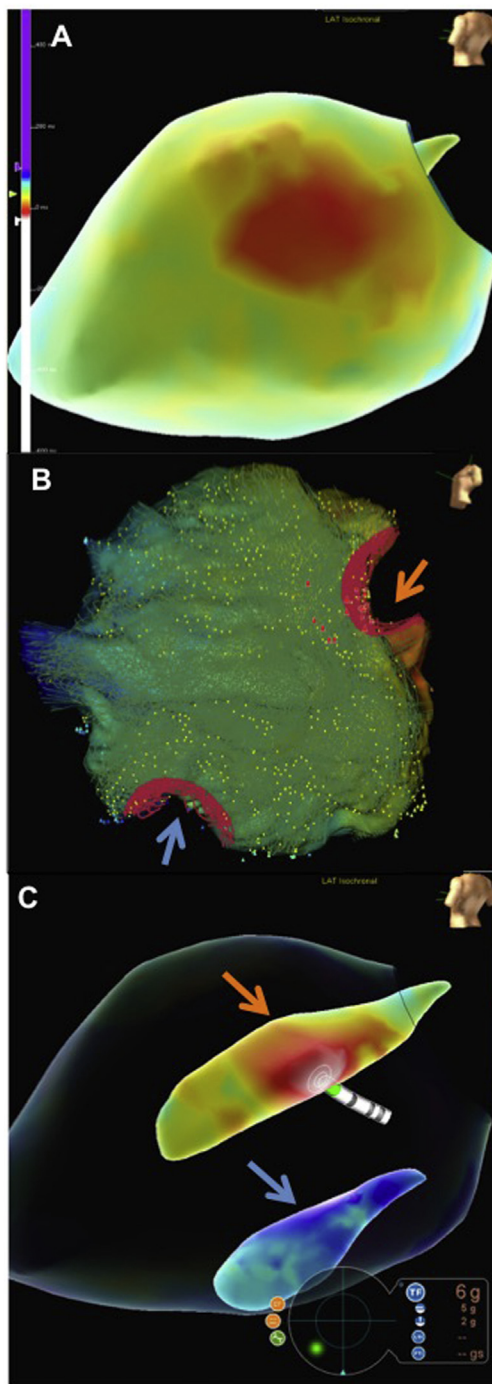
Discussion

PDX mapping has several advantages compared to an ICE-integrated method, including the efficient, simultaneous recording of data for the ventricular lumen and endocavitary structure. In our series, mean 15.9 minutes was spent PDX mapping the ventricle of interest, which generated a near-complete activation map of both ventricular lumen and endocavitary structure, requiring only minimal additional activation mapping by the ablation catheter. PDX mapping therefore has the potential to reduce procedure time compared to techniques that require additional ultrasound imaging. Indeed, mean procedure time in our PDX group (170 minutes) was considerably shorter than in the ICE-integrated cohort (268 minutes). Notably, this ICE-integrated procedure time was comparable to that observed during prior endocavitary VA ablation series (258–305 minutes) and dedicated studies of ICE-integrated mapping (213–240 minutes).^{2,3,5–7}

In addition to enhanced procedural efficiency, PDX mapping is electroanatomic mapping platform neutral and does not require the purchase of specialized software or catheters, of particular use to labs that do not have multiple mapping systems, as well as during ablation procedures in which the VA was not previously expected to arise from an endocavitary structure.

In all PDX mapping cases, definition of the endocavitary structure of interest was sufficiently precise to facilitate successful catheter ablation. The use of contact force catheters allowed for further, real-time feedback regarding the accuracy of the model; in all cases, a contact force of ≥ 8 grams could be achieved at time of ablation on the endocavitary structure border.

Our investigation has several limitations. ICE (but not ICE integration) was used in some PDX cases to confirm catheter stability on the endocavitary structure (which it did simultaneously with the catheter making contact with the structure on the map), so our data do not support eliminating the use of ICE in these complex cases. The overall number of patients treated with PDX mapping was not large, and our



PDX Mapping Approach

1. Map chamber of interest (panel A) using high-density multi-electrode mapping catheter to acquire simultaneous geometric model and local activation time (LAT).
2. Reduce chamber surface fill to 10%, and dynamically adjust internal (4-11 mm) and external (<4 mm) projections to aid in visualizing “negative space” within 3D internal points (panel B).
3. Adjust surface translucency to allow identification of early “internal” (within ventricular lumen) LAT points (red areas; panel B) surrounding the areas of “negative space.”
4. Copy these “internal points” surrounding the “negative space” to create a new surface model corresponding to the specific endocavitary structure (panel C).
5. Increase surface fill and apply the same LAT color map to both the ventricular lumen (panel A) and endocavitary structure (panel C).

Figure 1 Point density exclusion (PDX) mapping of anterolateral (orange arrow) and posteromedial (blue arrow) PMs. **A:** Left ventricle endocardial activation map with relatively diffuse area of early activation. **B:** Areas of absent internal points and their surrounding local activation time (LAT) points (red). **C:** Final PDX-mapped papillary muscles with earliest activation over the anterolateral papillary muscle.

experience requires replication at other centers. Expertise of the mapping technician is an acknowledged critical element of the technique. Differences in high-density mapping

catheter use, intraprocedure PVC frequency, hardware set-up time, and other factors that are difficult to retrospectively quantify and control for may confound our comparison with

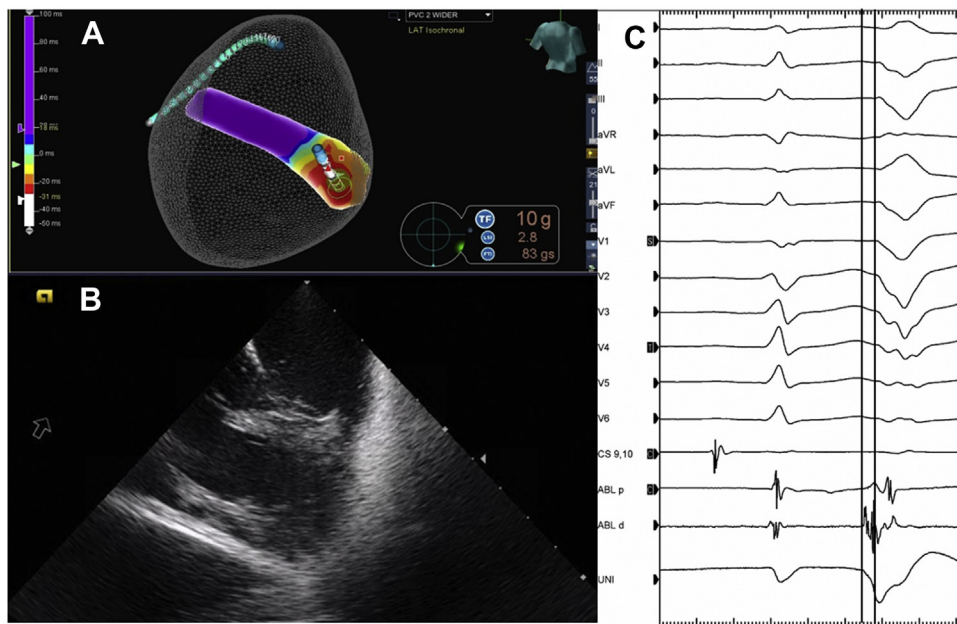


Figure 2 A: Activation map projected on moderator band contour made using point density exclusion (PDX) mapping for a patient with premature ventricular complex–triggered ventricular fibrillation. Note contact force rise as ablation catheter is advanced to earliest site of activation prior to ablation. B: Catheter contact on moderator band seen on intracardiac echocardiography. C: Earliest activation (34 ms pre-QRS) is recorded on the distal ablation catheter channel.

ICE integration. Nevertheless, the contemporary ICE-integrated cohort included in this study provides a useful benchmark and suggests that PDX mapping is associated with reasonably similar results. Furthermore, as PDX mapping was acutely successful in all 15 of the consecutive cases included in this analysis, and because it can be employed without additional procedural cost, risk, or data collection, we believe it would be reasonable to consider integration of this technique into standard mapping approaches for all endocavitary VA.

Conclusion

Electroanatomic mapping of endocavitary structures using 3D reconstruction of negative space is feasible and

clinically accurate. This technique can help to facilitate the often challenging ablation of VA arising from endocavitary structures.

Acknowledgments

The authors would like to thank Brock Gambill, George Crowell, Stephanie Mitcham, and Austin Cummings for their assistance with figures and technical details of PDX mapping.

Sources of Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Table 1 Baseline patient characteristics

Characteristic	PDX mapping (n = 15)	ICE-integrated mapping (n = 10)
Age (years, mean \pm SD)	58 \pm 10	50 \pm 17
Arrhythmia, n (%)		
PVC only	6 (40%)	9 (90%)
PVC-triggered VF	2 (13%)	1 (10%)
VT and PVC	4 (27%)	0 (0%)
VT only	3 (20%)	0 (0%)
Prior ablation, n (%)	3 (20%)	2 (20%)
ICD, n (%)	6 (40%)	1 (10%)
Cardiomyopathy, n (%)		
Ischemic	4 (27%)	1 (10%)
Nonischemic	3 (20%)	5 (50%)
LVEF (percent, mean \pm SD)	51 \pm 14	46 \pm 16
<50%, n (%)	6 (40%)	5 (50%)

ICD = implantable cardioverter-defibrillator; ICE = intracardiac echocardiography; LVEF = left ventricular ejection fraction; PDX = point density exclusion; PVC = premature ventricular complex; SD = standard deviation; VF = ventricular fibrillation; VT = ventricular tachycardia.

Table 2 Point density exclusion mapping procedural data

	PDX mapping (n = 15)	ICE-integrated mapping (n = 10)	P values
Earliest VA LAT (ms, mean ± SD)	36 ± 9	29 ± 7	.10
Pace map score (percentage, mean ± SD)	93 ± 7	96 ± 4	.36
RF applications (mean ± SD)	16 ± 12	26 ± 14	.07
Fluoroscopy time (minutes), median (IQR)	5.0 (2.5, 13.5)	16.6 (9.9, 20.0)	.07
Procedure time (minutes, mean ± SD)	170 ± 83	268 ± 92	.02
Acute success	15 (100%)	9 (90%)	.40
Long-term success [†]	13 (87%)	6 (60%)	.13

ICE = intracardiac echocardiography; IQR = interquartile range; LAT = local activation time; PDX = point density exclusion; RF = radiofrequency; SD = standard deviation; VA = ventricular arrhythmia.

[†]Mean follow-up was 17 ± 14 months in the PDX mapping group and 11 ± 8 months in the ICE-integrated group.

Disclosures

Dr Nazer has received consulting fees and investigator-initiated research support from Biosense Webster and investigator-initiated research support from Abbott Medical. The current project was not supported by industry funding. The authors have no conflicts of interest to disclose.

References

1. Good E, Desjardins B, Jongnarangsin K, et al. Ventricular arrhythmias originating from a papillary muscle in patients without prior infarction: A comparison with fascicular arrhythmias. *Heart Rhythm* 2008;5:1530–1537.
2. Sadek MM, Benhayon D, Sureddi R, et al. Idiopathic ventricular arrhythmias originating from the moderator band: Electrocardiographic characteristics and treatment by catheter ablation. *Heart Rhythm* 2015;12:67–75.
3. Yokokawa M, Good E, Desjardins B, et al. Predictors of successful catheter ablation of ventricular arrhythmias arising from the papillary muscles. *Heart Rhythm* 2010;7:1654–1659.
4. Yamada T, Doppalapudi H, McElderry HT, et al. Idiopathic ventricular arrhythmias originating from the papillary muscles in the left ventricle: prevalence, electrocardiographic and electrophysiological characteristics, and results of the radiofrequency catheter ablation. *J Cardiovasc Electrophysiol* 2010; 21:62–69.
5. Enriquez A, Shirai Y, Huang J, et al. Papillary muscle ventricular arrhythmias in patients with arrhythmic mitral valve prolapse: Electrophysiologic substrate and catheter ablation outcomes. *J Cardiovasc Electrophysiol* 2019;30:827–835.
6. Khaykin Y, Skanes A, Whaley B, et al. Real-time integration of 2D intracardiac echocardiography and 3D electroanatomical mapping to guide ventricular tachycardia ablation. *Heart Rhythm* 2008;5:1396–1402.
7. Proietti R, Rivera S, Dussault C, et al. Intracardiac echo-facilitated 3D electroanatomical mapping of ventricular arrhythmias from the papillary muscles: assessing the 'fourth dimension' during ablation. *Europace* 2017;19:21–28.