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Clinical Investigation

PentaRay® Multielectrode Mapping Catheter for Atrial Tachyarrhythmia in Adults With Congenital Heart Disease

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Background: *Ablation of atrial tachyarrhythmia in adults with congenital heart disease (ACHD) is challenging because of complex anatomy and high scar burden. We proposed that the addition of high-density mapping with the PentaRay® (Biosense Webster, Inc) mapping catheter (EAM+P) to 3-dimensional electroanatomic mapping (EAM) allows for rapid acquisition of high-resolution maps and shorter procedure times.*
Methods: *In this single-center, retrospective cohort study of patients with ACHD who underwent atrial arrhythmia ablation, patients were divided those who underwent ablation with EAM and those who underwent ablation with EAM+P.*
Results: *Fifteen ablations were performed in 13 patients using standard EAM, and 11 ablations were performed in 10 patients using EAM+P. There was no difference in mean age or complexity of congenital heart disease. The procedure duration was 1.5 times longer in the EAM than in the EAM+P group (*P *= .015). The dose area product was 12 times higher in the EAM than in the EAM+P group (*P *= .001). A higher number of venous access sites were used for EAM cases than for EAM+P cases (*P *= .008). Acute success rates of ablation and recurrence rates at 1 year were similar in the 2 groups. There were no procedure-related complications in either group.*
Conclusion: *This is the first study to evaluate the use of the PentaRay® high-density mapping catheter for ablation of atrial tachyarrhythmia in patients with ACHD. The use of the PentaRay® high-density mapping catheter results in shorter procedure time, decreased radiation exposure, and fewer venous access sites.* ***(Tex Heart Inst J. 2022;49(5):e207535)***

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Arrhythmias are a major cause of morbidity and mortality in adults with congenital heart disease (ACHD).[1] Atrial tachyarrhythmia (AT) is the most common arrhythmia; it develops in 50% of patients with ACHD during their lifetime and is associated with a 3 times greater risk of cardiac interventions and a nearly 50% increase in mortality and morbidity.[2] For patients with ACHD with recurrent symptomatic intra-atrial reentrant tachyarrhythmia (IART), ablation therapy is recommended over long-term pharmacologic therapy (Pediatric and Congenital Electrophysiology Society/Heart Rhythm Society class IIa indication).[1] However, ablation therapy can be challenging because of complex anatomy, high burden of surgical scar, and ventricular dysfunction. Three-dimensional electroanatomic mapping (3D-EAM) allows volume reconstruction and real-time navigation and improves outcomes in patients with complex anatomy.[3,4] Adults with repaired congenital heart disease often have electrically diseased atria with low voltage and scar; detailed voltage maps allow for more defined delineation of scar that can be substrate for arrhythmias. High-density multielectrode mapping catheters, such as the PentaRay® catheter (Biosense Webster, Inc), have been demonstrated to improve mapping resolution within areas of low voltage in animal studies[5] and in postinfarction reentrant ventricular tachycardia (VT)[6] and have shortened mapping time in VT.[7] The PentaRay® multielectrode mapping catheter has five 3F splines each with 4 electrodes, with 2-6-2-mm interelectrode spacing. Case reports using the PentaRay® catheter in patients with

ACHD have been described,[8] but broader use of the PentaRay® has not been studied in the ACHD population. We sought to quantify the benefit of the PentaRay® catheter for mapping of AT in adults with repaired or palliated congenital heart disease compared with that with point-by-point activation mapping.

Patients and Methods

Study Population

This is a single-center retrospective cohort study of patients with ACHD who underwent ablation procedures for AT from December 1, 2013, to December 31, 2017. Patients were identified from the institutional electrophysiology (EP) database and included adults with congenital heart disease who underwent EP study and ablation for AT since 2013. There were 25 patients with ACHD who underwent EP study for AT during this time period, 2 of whom were noninducible at the time of the EP study and were excluded from further analysis. The study cohort was divided into 2 patient groups based on time period of ablation procedure and mapping approach used: (1) EAM: patients with ACHD who underwent EP study from 2013 to 2016 using 3D-EAM with point-by-point activation mapping (n = 13) and (2) EAM+P: patients with ACHD who underwent EP study after 2016 with 3D-EAM with the use of the PentaRay® multielectrode, high-density mapping catheter (n = 10). Delineation of mapping approach used represents the time at which our institution acquired an additional mapping system (CARTO 3; Biosense Webster, Inc) and the PentaRay® catheter. Procedures conducted before 2013 were not included in the analysis to minimize possible confounders because of various technology advancements. The study was approved by the institutional review board. Patient records were reviewed to obtain baseline demographic data and details of patient congenital heart disease and arrhythmia burden.

Electrophysiology Study and Mapping Procedure

Activation mapping during tachycardia was performed using a 4-mm tip radiofrequency ablation catheter in the EAM group and the PentaRay® mapping catheter in the EAM+P group. Electrophysiology study data were collected, including procedure duration, fluoroscopy use, catheter use, tachycardia mechanism, mapping techniques, and procedure outcome.

For both cohorts, scar was defined as <0.5 mV. Figure 1 shows an example of the activation map and angiograms of a patient with D-transposition of the great arteries (D-TGA) status post–Mustard repair in the EAM+P cohort. Atrial tachyarrhythmia mechanism was determined based on activation map, entrainment mapping, and diagnostic pacing maneuvers as needed. Atrial tachyarrhythmias were further classified as IART, focal atrial tachycardia, and atrioventricular nodal reentry tachycardia. In cases of D-TGA status post–atrial switch (Mustard or Senning), cavotricuspid isthmus (CTI) flutter was classified as an IART. Ablation procedures were performed using cryotherapy, radiofrequency ablation, or irrigated radiofrequency ablation therapy, based on the tachycardia mechanism. Procedure success was defined as no inducible AT following ablation. A procedure was considered a failure if there was an inability to eliminate the clinical AT. Clinically relevant arrhythmia was defined as present at the start of the case or inducible and sustained tachyarrhythmia of similar cycle length as for clinical tachycardia.

Follow-Up

Recurrence of AT was assessed through 1 year after the ablation procedure by review of clinic visits and noninvasive rhythm monitoring. In patients with implantable cardiac devices, device interrogations were reviewed to assess for recurrence of arrhythmia. Recurrence was defined as any sustained AT requiring intervention, including repeat ablation, medication changes, cardioversion, or overdrive pacing.

Statistical Analysis

Baseline parameters are presented as mean with SD and median with interquartile range for continuous variables and frequency with percentage for categorical variables. Comparisons between the 2 cohorts were done using Student *t* test, Fisher exact test, or Mann–Whitney *U* test where applicable and deemed appropriate. Given that the distributions of procedure duration, fluoroscopy duration, and dose area product (DAP) were right-skewed, log-transformed outcomes were modeled by linear regressions and the log differences between groups were estimated. As the log scale is not clinically interpretable, we back-transformed the estimates to the ratios of the original scale for interpretation. Because of the limited sample size, no covariates were adjusted in a multivariate analysis. $P < .05$ was statistically significant. Statistical analysis was performed using SAS v9.4 (SAS Institute).

Results

Patient Characteristics

During the study period, 26 EP studies for AT were performed in 23 patients with ACHD (Table I). Fifteen ablations were performed in 13 patients using standard EAM, and 11 ablations were performed in 10 patients using EAM+P. In patients with repeat ablations, data from the first ablation were used for the statistical analy-

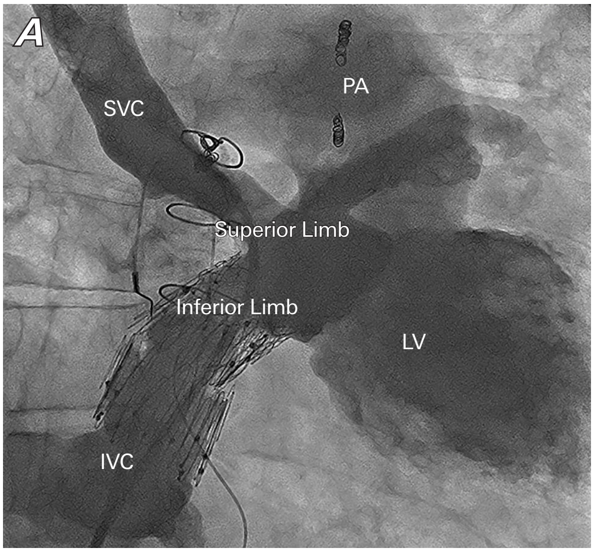
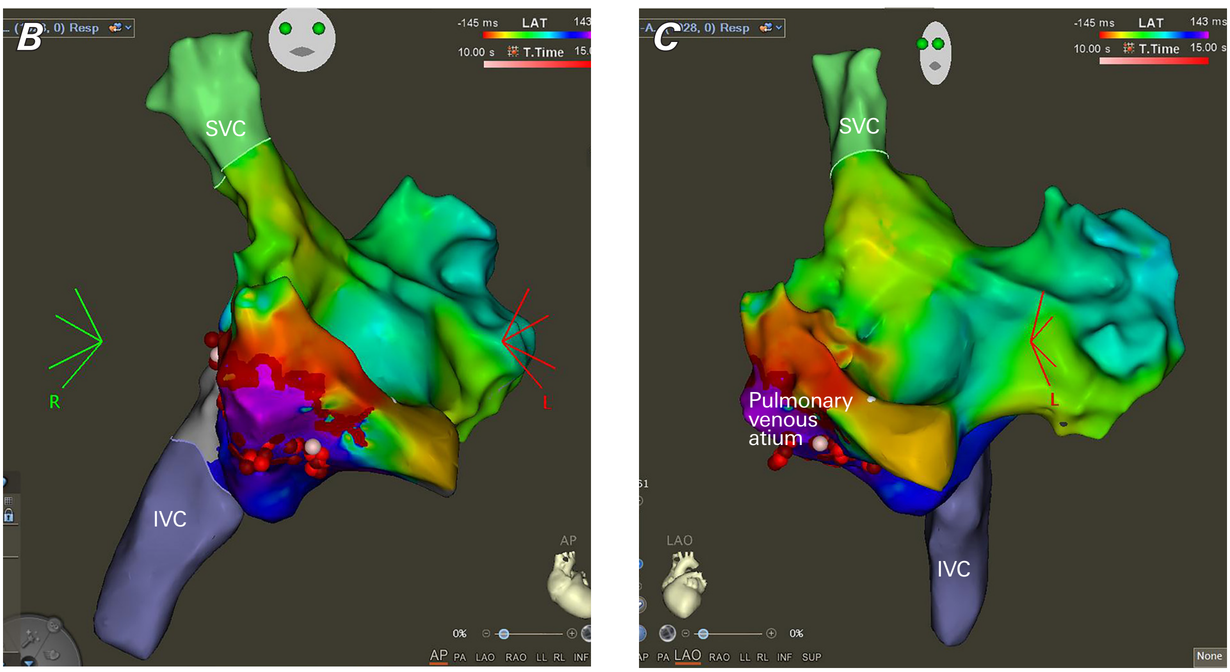


Fig. 1 ***A***) *Angiogram of a patient with D-transposition of the great arteries status post–Mustard repair demonstrating systemic venous baffle with stents.* ***B***) *AP view and* ***C***) *Pulmonary venous atrium view of activation map demonstrating early meeting late activation (red = early activation, purple = late), consistent with intra-atrial reentrant tachycardia; 1,942 activation points in 13:52 minutes.*
AP, anterior posterior; IVC, inferior vena cava; LAO, left anterior oblique; LAT, local activation time; LV, left ventricle; PA, pulmo-



sis. There was no statistical difference in mean age (40 vs 34 years), in complexity of congenital heart disease as defined by the ACHD guidelines,[9] or in the number of patients with a pacemaker or implantable cardioverter-defibrillator. The EAM group included D-TGA status post–atrial switch, repaired tetralogy of Fallot, Fontan palliation, rheumatic heart disease, and congenital aortic stenosis. The EAM+P group included tetralogy of Fallot, Fontan palliation, Ebstein anomaly, coarctation of aorta/ventricular septal defect, and D-TGA status post–Mustard palliation. A majority of the patients in both cohorts were classified as having New York Heart Association Functional Class II or greater and ACHD physiologic class C or D. There was no difference between the 2 cohorts in long-term use of anticoagulation therapy, history of cardioversion, or previous or current use of antiarrhythmic agents for AT.

Electrophysiology Study, Mapping, and Ablation

The proportion of patients who underwent combined catheterization and EP study vs EP study only was 53% in the EAM group and 20% in the EAM+P group (Table II). In the combined cases, the procedure time, fluoroscopy time, and DAP used in analysis was limited to the EP portion of the case. Procedure time was 1.5 times longer (P = .0153) in the EAM group than that in the EAM+P group. The median fluoroscopy time was 8.7 times longer (P = .0007) in the EAM group than that in the EAM+P group, and the median DAP was 12 times greater (P = .0013) in the EAM group than

TABLE I. Baseline Demographics

Patient characteristics	**EAM** (n = 13)	**EAM+P** (n = 10)	*P* value[a]
No. of patients	13	10	
No. of ablations	15	11	
Age, mean (SD), y	40 (10.6)	34 (9.6)	.16
Female sex, No. (%)	4 (31)	6 (60)	.22
Complex heart disease, No. (%)	9 (69)	6 (60)	.69
ICD/PM, No. (%)	9 (69)	7 (70)	.99
ACHD physiologic class, No. (%)			
A	0	0	.99
B	1 (8)	1 (10)	
C	11 (85)	8 (80)	
D	1 (8)	1 (10)	
Previous AT therapies, No. (%)			
Long-term AC for AT	6 (46)	7 (70)	.40
Previously on AA for AT	8 (62)	6 (60)	.65
History of CV for AT	9 (69)	6 (60)	.99
AA at time of ablation	10 (77)	6 (60)	.48

AA, antiarrhythmic therapy; AC, anticoagulation therapy, ACHD, adult congenital heart disease; AT, atrial tachycardia; CV, cardioversion therapy; EAM, electroanatomic mapping system; EAM+P, electroanatomic mapping system with PentaRay® high-density mapping catheter; ICD, implantable cardioverter-defibrillator; PM, pacemaker

[a] Age, *t* test. Fisher exact test was used for all categorical variables. $P < .05$ was considered statistically significant.

in the EAM+P group. The EAM+P cohort included a mean (SD) of 2 (1) activation maps with a mean (SD) of 3,956 (2,666) mapping points over a mean (SD) of 54 (28) minutes (Fig. 1). The average number of venous access sites was greater in the EAM group than that in the EAM+P group (4 vs 3, respectively; $P = .008$).

Almost half of the patients in both cohorts had multiple tachycardia mechanisms present at the time of the initial EP study (46% in the EAM group vs 50% in the EAM+P group). Overall, there was no substantial difference between the tachycardia mechanisms in both cohorts. The most common tachycardia mechanism was IART/CTI flutter followed by focal atrial tachycardia. Acute success rates of ablation were similar in the 2 groups, with 92% success in the EAM group and 100% success in the EAM+P group (Table II). The single patient in whom ablation was unsuccessful in the EAM group initially had IART that repeatedly degenerated to atrial fibrillation during mapping; therefore, ablation was not performed. There were no procedure-related complications in either group.

Follow-Up

Follow-up at 1 year demonstrated that 5 patients in the EAM cohort had recurrence (38%) vs 2 patients (20%) in the EAM+P group. Among all patients with recurrence, median time to recurrence was 64 days (interquartile range, 8-221 days). Recurrences occurred in 2 patients with D-TGA status post–atrial switch, 3 patients with tetralogy of Fallot, 1 patient with Fontan palliation, and 1 patient with Ebstein anomaly. All 7 patients in both cohorts with recurrence were ACHD physiologic class D, and all had multiple tachycardia mechanisms at the time of initial EP study. One patient in the EAM cohort was lost to follow-up and died of unknown causes within the first year of follow-up.

Discussion

This study demonstrated shorter procedure and fluoroscopy times for ablation of AT in patients with ACHD with the PentaRay® multielectrode mapping catheter than those with point-by-point activation mapping. Both of these findings may be of clinical importance in the consideration of ablation procedures in these complex cases, as oftentimes there is a clinical need to combine the EP study with a hemodynamic or interventional catheterization procedure. Risk of general anesthesia is known to increase with increased duration of anesthesia administration; therefore, a shorter procedure time may decrease the risks related to anesthesia, especially in patients with severe systemic ventricular dysfunction or multiple comorbidities. Despite the new use of the PentaRay® catheter at our institution,

TABLE II. Ablation Characteristics

Characteristic	**EAM** (n = 13)	**EAM+P** (n = 10)	***P* value**[a]
Procedure duration, median (IQR), min	207 (163-381)	183 (94-190)	.0153
Fluoroscopy duration, median (IQR), min	27 (20-54)	2 (1-6)	.0007
DAP, median (IQR), Gy·cm^2	7,954 (2,414-21,667)	523 (275-1,673)	.0013
Combined EP with cardiac catheterization, No. (%)	7 (53)	2 (20)	.20[b]
No. of venous access sites, mean (SD)	4 (1)	3 (1)	.008
Tachycardia at onset of ablation, No. (%)	0 (0)	6 (60)	.002[b]
Patients with >1 tachycardia, No. (%)	6 (46)	5 (50)	.85
Tachycardia mechanism, No.			
IART/CTI FL[c]	13	10	NA
FAT	5	6	.41
AVNRT	3	0	.23
Catheter used, No. (%)			
Irrigated RF	8 (62)	10 (100)	
Standard RF	4 (30)	0	
Cryotherapy	1 (8)	0	
Success rate, No. (%)	12 (92)	10 (100)	.99
1-y recurrence, No. (%)	5 (38)	2 (20)	.41

AVNRT, atrioventricular nodal reentry tachycardia; CTI FL, cavotricuspid isthmus flutter; DAP, dose area product; D-TGA, D-transposition of the great arteries; EAM, electroanatomic mapping; EAM+P, electroanatomic mapping system with PentaRay® high-density mapping catheter; EP, electrophysiology; FAT, focal atrial tachycardia; Gy, gray; IART, intra-atrial reentrant tachyarrhythmia; NA, not applicable; RF, radiofrequency

[a] $P < .05$ was considered statistically significant.
[b] Fisher exact test.
[c] In cases of D-TGA status post–atrial switch (Mustard or Senning), CTI FL was classified as an IART.

the shorter procedure time in the EAM+P group suggests that the learning curve with PentaRay® was steep. Use of the PentaRay® catheter has also shown a tendency toward shorter mapping times in ablation of VT,[10] suggesting that multielectrode mapping catheters can shorten procedures time for both ventricular and atrial tachyarrhythmias.

In a case-control study, Cohen et al[11] found that low-dose ionizing radiation exposure during cardiac procedures is associated with increased risk of malignancy in patients with ACHD; therefore, radiation exposure should be minimized when possible. The lower fluoroscopy dose and decreased fluoroscopy time with PentaRay® in our study was suspected to be a result of more comprehensive geometry acquisition obtained with PentaRay® at the initiation of the case, which helped to navigate the complex anatomy during the procedure. There were 3 different operators during this 5-year period, each of whom participated in cases in both groups, and it is not possible to evaluate each individual operator's use of geometry obtained using a mapping system vs fluoroscopy.

The 1-year recurrence rate was not statistically significant in the EAM group compared with the EAM+P group. Recurrences occurred in patients with multiple tachycardia mechanisms, which is known to be associated with higher risk of recurrence,[12] as well as those with ACHD physiologic class D. Although there is a known high incidence of multiple arrhythmia mechanisms in patients with ACHD, targeting all inducible tachycardia is sometimes difficult and needs to be balanced with the risks of longer procedure times. Therefore, using a multielectrode mapping catheter that shortens procedure times may allow for more complete mapping/ablation of all tachycardia mechanisms during a single procedure.

Similar to the PentaRay®, the INTELLAMAP ORION (Boston Scientific) multielectrode mapping catheter with the RHYTHMIA HDx (Boston Scientific) mapping system has demonstrated rapid acquisition with high accuracy; however, it has been reported to be limited by difficulty steering the catheter, which made mapping challenging in patients with large atrial volumes and resulted in a high percentage of incomplete maps.[13] We did not find similar difficulties in PentaRay® use in the ACHD population, including in patients with dilated and scarred atria.

The lower number of venous access sites used in the EAM+P group was an unexpected finding; this may be a result of more rapid activation mapping with the PentaRay® and the need for fewer intracardiac catheters. In using the PentaRay® for high-density mapping, it is possible to acquire a high-density map of the systemic venous atrium such that the other diagnostic catheters became redundant. The operators' practice did not change in that the operators still acquired a complete map of the systemic venous atrium; however, the map obtained from using the PentaRay® multielectrode mapping catheter replaced maps from multiple other diagnostic catheters. This is an important consideration, given the likelihood of vascular occlusion from numerous prior catheterizations in many adults with congenital heart disease. However, the use of an esophageal lead for a reference lead would also serve to decrease the number of access sites; esophageal reference leads were used in cases in both cohorts.

Ablations in patients with ACHD can be complex and, even with 3-dimensional mapping systems, can be challenging procedures. Atrial tachyarrhythmias are a substantial burden in patients with ACHD, and identifying advanced mapping and ablation techniques that improve the success rate of ablation therapy and decrease recurrence rates could have a substantial effect on the morbidity of tachyarrhythmias in this population.

Limitations

Our study has limitations inherent to a single-center, retrospective study, and the small cohort of patients limits the extent of analysis. This study is thus underpowered to detect other potentially substantial differences between point-by-point mapping and high-density catheter mapping techniques. However, there was no difference in number of patients with complex congenital heart disease and no difference in ACHD physiologic classification between the 2 groups. The heterogeneity of patients with ACHD is a challenge in any study because of anatomic heterogeneity and center-specific differences in surgical techniques; this contributes to the unavoidable potential for confounding bias.

Conclusion

The use of the PentaRay® multielectrode mapping catheter in ablation of AT in adults with repaired or palliated congenital heart disease was associated with decreased procedure time, decreased radiation dose, and decreased number of venous access sites. As with many technological advances in interventional electrophysiology, new technologies are often used in the population with complex congenital heart disease before a randomized comparison may be performed; however, future possible randomized comparisons between different high-density mapping catheters may serve to streamline the approach for ablation of AT in ACHD. Further evaluations of high-density arrhythmia mapping are necessary to evaluate potential effect on success and 1-year recurrence rates of AT in ACHD.

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