ABSTRACT. The Rhythmia™ system (Boston Scientific, Natick, MA, USA) facilitates the rapid acquisition of high-resolution electroanatomical and activation maps. However, there are limited data on its efficacy and safety in pediatric and adult congenital heart disease (CHD) patients. In a retrospective, observational cohort study, adult CHD and pediatric patients followed by pediatric cardiology underwent electrophysiologic study using the Rhythmia™ electroanatomic mapping system. Variables examined included the number of electroanatomical maps required, acquisition time, procedure time, fluoroscopy time, radiation dosage, and rate of recurrent arrhythmia. Twelve consecutive patients, including six male patients (50%), were included with an average age of 27.7 years (range: 11–64 years). Seven (58%) of these patients had a diagnosis of CHD [moderate complexity in two (17%) and great complexity in five patients (42%)] and 10 (83%) patients underwent ablation. A total of 37 high-density maps were created in 12 procedures, with a median of 8,140 mapping points, taking a median of 631 seconds. The median procedure time was 189.5 minutes. The median fluoroscopy time was 0.9 minutes, with eight (67%) patients receiving no fluoroscopy at all. Recurrence occurred in one patient (8%) over a median follow-up duration of 16 months (interquartile range: 12.8–17.3 months). No adverse periprocedural events were recorded. This study suggests the use of high-density electroanatomic mapping in adult CHD patients showed potential for rapid acquisition of highly detailed maps with minimal fluoroscopy time or risk of periprocedural events in the studied population.

KEYWORDS. Adult congenital heart disease, congenital heart disease, electroanatomical mapping, fluoroscopy, Rhythmia.
Prior to diagnostic catheter placement, as described by ping was conducted with minimal or no fluoroscopy parable mapping and ablation catheters. Chamber map- through an 8-French (Fr) sheath, which is similar to com- The INTELLAMAP ultrasound guidance. Diagnostic catheters were posi- tioned to serve as timing references. The INTELLATIP MIFI™ open-irrigated catheter (Boston Scientific) was placed with the ablation catheter. Phrenic nerve test- ing was performed before ablation in the posterior right atrium (RA) when appropriate.

Ablative intervention

The INTELLATIP MIFT™ open-irrigated catheter (Boston Scientific) was used for ablation during procedures. Radiofrequency ablation (RFA) was performed at a maximum power of 30 to 40 W. After ablation procedures were completed, repeat programmed extrastimuli, isoproter- enol, and/or IV calcium were used to provoke arrhyth- mias until myocardial refractoriness or a 200-ms CL was achieved. Bidirectional block was confirmed in cases where RFA was used to disrupt macro-reentrant circuits. Acute procedural success was defined as noninducibility of the targeted clinical arrhythmia and/or achievement of bidirectional block.

Follow-up

Patients were followed up with at outpatient clinical visits one to six months after their index procedure. When present, pacemakers and implantable cardioverter-defibrillators were assessed through remote monitoring, while ambulatory monitoring was conducted in patients without implantable devices. Twelve-lead electrocardiograms were obtained at outpatient office visits. Recurrence was defined as any arrhythmia episode lasting 30 seconds or longer noted on implantable device monitoring or Holter electrocardiogram. If there was a concern for recurrence based on clinical symptoms or his- tory, additional outpatient clinical visits and continuous monitoring were offered.

Offline analysis

Maps of the clinical arrhythmias were reviewed and cataloged offline using the Rhythmia™ software. Data stored included the volume mapped (calculated automatically by the system), areas of dense scar (sum- mation of all distinct areas of voltage < 0.05 mV) low...
voltage (0.05–0.5 mV), and characteristics and timing of electrogams for use in Boston Scientific’s Lumipoint™ algorithms.

**Statistical analysis**

Continuous variables are expressed as median values with the first and third quartiles [interquartile range (IQR)]. If clinically relevant, minimum and maximum values are also indicated. Comparative statistics were established using the Mann–Whitney U nonparametric test. Results were considered statistically significant if the p-value was less than 0.05.

**Results**

**Patients**

We evaluated 12 consecutive pediatric or CHD patients who underwent an electrophysiologic study with the Rhythmia™ mapping system [average age: 27.7 years (range: 11–64 years)]. Six (50%) participants were male. Seven (58%) patients had a diagnosis of CHD, and 10 (83%) patients underwent ablative procedures. CHD conditions consisted of moderate complexity in two patients (17%) and great complexity in five patients (42%). Patient characteristics are outlined in Table 1.

**Arrhythmias**

Aside from the two patients with premature ventricular contractions, all other patients’ clinical arrhythmias were supraventricular in origin. Amongst CHD patients, surgical scar from prior baffling, atriotomy, and shunts were often found to contain the site of earliest activation. A total of 16 arrhythmias were treated with ablation in 10 patients. Arrhythmias could not be induced in four cases, and substrate mapping was only performed in sinus rhythm.

Atrial tachyarrhythmias were mapped and/or treated within the RA in most (six of eight) cases, though scar within a Fontan conduit and a Mustard baffle were also culprit sites. The median CL of mapped atrial tachyarrhythmias was 350 ms (IQR: 288.3–441 ms). In three of five cases, atrial flutter was typical with a cavotricuspid isthmus–dependent circuit. The median CL of mapped atrial flutters was 275 ms (IQR: 251.5–275.5 ms).

A median of 14 (IQR: 8–27) RFA applications were applied per arrhythmia treated. Acute procedural success, defined as noninducibility by pacing or isoproterenol, was achieved in all patients who underwent ablation (Table 2).

**Table 2: Procedural Characteristics and Outcomes**

| Table 1: Patient Characteristics |
|----------------------------------|
| Characteristics                  |
| Age, years                       | 28 ± 16.4 |
| Male sex, n (%)                  | 6 (50%)  |
| Height, cm                       | 164.9 ± 13.9 |
| Weight, kg                       | 69.4 ± 23.2 |
| Body mass index, kg/m²           | 25.1 ± 7.3 |
| Arrhythmia indicating study, n (%) |
| Atrial tachycardia               | 8 (67%)  |
| Atrial flutter                   | 5 (42%)  |
| Supraventricular tachycardia not otherwise specified | 1 (8%) |
| Premature atrial contractions    | 1 (8%)  |
| Premature ventricular contractions | 2 (17%) |
| Prior ablation                   | 4 (33%)  |
| CHD, n (%)                       | 7 (58%)  |
| Moderate complexity              | 2 (17%)  |
| Great complexity                 | 5 (42%)  |
| Medication, n (%)                |          |
| Class I antiarrhythmic           | 1 (8%)  |
| Class II antiarrhythmic          | 3 (25%) |
| Class III antiarrhythmic         | 6 (50%)  |
| Class IV antiarrhythmic          | 2 (17%)  |
| Anticoagulation                  | 7 (58%)  |
| Device, n (%)                    |          |
| Permanent pacemaker              | 2 (17%)  |
| Implantable defibrillator        | 2 (17%)  |
| Anatomic structure mapped, n (%) |
| Atrium                           | 7 (58%)  |
| Atrial baffle                    | 2 (17%)  |
| Fontan                           | 2 (17%)  |
| Right ventricle                  | 2 (17%)  |
| Chamber volume, mL (IQR)         |
| Atria                            | 125 (115–140.5) |
| Atrial baffle                    | 66.5 (59.3–73.8) |
| Fontan                           | 51.5 (47.8–55.3) |
| Arrhythmia cycle length, ms (IQR) |
| Atrial tachycardia               | 350 (288.3–441) |
| Atrial flutter                   | 275 (251.5–275.5) |
| Intracardiac echocardiography, n (%) |
| Intraoperative transesophageal echocardiography, n (%) |
| Fluoroscopic time, min (IQR)     |
| Air kerma, mGy (IQR)             |
| Procedure time, min (IQR)        |
| RFA applications per arrhythmia (IQR) | 14 (8–27) |
| Mapping time, s (IQR)            |
| Mapping points (IQR)             |
| Procedural outcomes, n (%)       |
| Recurrent arrhythmia             | 1 (8%)  |
| Discontinued antiarrhythmic drugs | 2 (17%) |

IQR: interquartile range.
**Procedural characteristics: congenital heart disease and pediatric patient groups**

Individual demographics, structural cardiac diagnoses, prior surgeries, catheterization interventions, ablation history, clinical arrhythmias, medical therapy, procedural characteristics, and ablation targets for included patients with and without CHD are detailed in Tables 3 and 4, respectively. There were no statistically significant differences between these groups with regard to procedure time [190 (135–298) vs. 189 (383–320) minutes; p = 0.749], fluoroscopy time [10.3 (0–11.4) vs. 0 (0–1.9) minutes; p = 0.682], or air kerma [0.02 (0–0.03) vs. 0 (0–0.01) mGy; p = 0.682].

**Procedural characteristics: fluoroscopy and radiation**

The median fluoroscopy time of our cohort was 0.95 minutes, with eight (67%) of our patients receiving no fluoroscopy at all. The median air kerma was 0.005 mGy (IQR: 0–0.03 mGy).

**Procedural characteristics: structural congenital heart disease considerations**

**Tetralogy of Fallot.** An atrial tachycardia was targeted in one patient with previously repaired tetralogy of Fallot (patient 1). The Orion™ catheter was used to map the inferior vena cava (IVC), RA, and superior vena cava (SVC) with an FJ bidirectional decapolar catheter (Bio-sense Webster, Diamond Bar, CA, USA) in the coronary sinus and a quadripolar catheter in the right ventricular apex. RA burst pacing, programmed extrastimuli, high-dose isoproterenol, and IV calcium were unable to induce sustained atrial tachycardia. As such, mapping was only performed in normal sinus rhythm.

**Fontan palliation.** A total of three arrhythmias were treated in two patients with prior Fontan palliation, though clinical arrhythmia was only induced in one patient.

In the case where arrhythmia was induced (patient 2), two arrhythmias were treated. A focal atrial tachycardia (CL ~250 ms) was mapped with earliest local activation at the anterolateral aspect of the Fontan and was easily ablated. Subsequent atrial burst pacing induced an atrial flutter (CL ~280 ms) that was mapped within the Fontan to be anterior and inferior to a plugged fenestration. Ablation at the site did not terminate the tachycardia. As such, transseptal access was obtained into the RA using a Mullins sheath (Medtronic, Minneapolis, MN, USA) and a BRK needle (Abbott, Chicago, IL, USA) with electrocautery. RA mapping showed a tricuspid isthmus-dependent atrial flutter (counterclockwise), and the MIFIT™ catheter was used to create an RFA line from the tricuspid annulus to the baffle, which terminated the atrial flutter, as seen in Figure 1. Bidirectional block was confirmed with sinus activation and voltage mapping.

In the second case (patient 3), ultra–high-density mapping was performed in sinus rhythm given the inability to induce clinical arrhythmia, as seen in Video 1. An empiric RFA lesion was created from an anterolateral Fontan scar to the superior border of the IVC. After the ablation, the Orion™ catheter was placed back in the Fontan circuit and sinus activation showed a clear block across the RFA lesion, as seen in Figure 2 and Video 2.

**D-transposition of the great arteries with atrial baffling.** Two patients with prior atrial-switch procedures for D-transposition of the great arteries were studied and treated, including one with symptomatic premature atrial contractions (PACs) with paroxysms of sustained supraventricular tachycardia (SVT) and the other with multiple SVTs leading to hospitalization. Both had a prior history of atrioventricular (AV) nodal reentrant tachycardia ablation. The patient with PACs also had undergone a prior ablation for atrial tachycardia within the systemic venous baffle.

In the case of symptomatic PACs (patient 4), the Orion™ catheter and a decapolar catheter were placed in the systemic venous baffle. There was initial difficulty advancing the Orion™ catheter into the SVC baffle, so it was exchanged for the MIFIT™ ablation catheter to create a matrix, which was used to find a pathway to advance the Orion™ catheter. An activation map of the PAC showed earliest local activation at the anterosuperior aspect of the baffle. RFA delivered at the site immediately suppressed PACs, as seen in Figure 3.

The other patient (patient 5) presented to the electrophysiology lab with refractory SVT (CL ~450 ms). The Orion™ catheter initially was used to map the IVC, systemic venous baffle, left (systemic venous) atrium, and mitral valve annulus. A region of earliest activation was mapped on the superior margin of the baffle, and ablation terminated the tachycardia, as seen in Figure 4. Moments later, a faster narrow complex tachycardia spontaneously initiated with a different activation pattern (CL ~390 ms). The systemic venous portions of the heart were mapped again, but the regions of earliest activation appeared more widespread in the region of the baffle. Transseptal access was pursued using a small curve Agilis sheath (Abbott) with a transseptal needle, and the Orion™ catheter was advanced into the pulmonary venous atrium. Mapping showed areas of activation 30 and 40 ms pre-P-wave from the ridge just outside of the appendage. The area was ablated but this did not alter the tachycardia; a second activation map showed a region of early-meets-late wavefront just outside of the ridge, and an RFA ablation line extending from a region of scar superior to the ridge all the way down to the ridge’s inferior margin terminated the tachycardia. Repeat programmed extrastimulation induced an even faster narrow complex tachycardia with an atrial CL of approximately 290 ms. A new activation map of the left-sided pulmonary venous atrium showed an atrial flutter rotating in a clockwise fashion and the left posteroinferior atrium in the pulmonary venous atrium, and a lesion was attempted through this corridor. As we
### Table 3: Congenital Heart Lesions, Prior Surgeries, Catheterization Interventions, Ablation History, Arrhythmia, and Ablation Target

| Patient Number | Age, years | CHD Diagnoses | ACHD AP Classification | Prior Surgical Treatment(s) | Prior Catheter Treatment(s) | Prior Ablation Treatment(s) | Arrhythmia(s) Indicating Study | Antiarrhythmic Drug(s) | Anticoagulation Device | Fluoroscopy Time, min | Air Kerma, Gy | Intraprocedural Imaging | Anatomic Arrhythmia Target(s) | Ablation Target(s) |
|----------------|------------|---------------|------------------------|-----------------------------|----------------------------|----------------------------|-------------------------------|--------------------------|----------------------|---------------------|----------------|----------------|-------------------|--------------------------|----------------|
| 1              | 43         | tetralogy of Fallot | IIb                    | Right-sided Blalock-Taussig shunt | Complete repair | Percutaneous valve placement in the left and right pulmonary arteries (failed attempt at percutaneous valve replacement due to large annulus) | Atrial flutter (RA free wall) | Metoprolol | None | None | 0 | 0 | ICE | None | Unable to induce | None |
| 2              | 24         | Hypoplastic left heart syndrome | IIIc | Norwood operation | Bidirectional cavo-pulmonary anastomosis | Percutaneous closure of Fontan fenestration | Vascular plug in a baffle leak | Sotalol | Warfarin | Epicardial DC-ICD | 11.3 | 0.03 | ICE | Anterolateral aspect of Fontan | Targets ablated |
| 3              | 23         | Hypoplastic left heart syndrome | IIIid | Norwood operation | Repair of anomalous left coronary artery | Rashkind atrial septostomy | Fontan fenestration closure | Sotalol | Verapamil | Warfarin | 0 | 0 | None | Unable to induce | None |
| 4              | 35         | d-transposition of the great vessels | IIIb | Mustard procedure | Rashkind atrial septostomy | SVC stenting | AV nodal slow pathway modification | Sotalol | Apixaban | DC-PPM | 0 | 0 | None | Anterosuperior aspect of the SVC/systemic venous baffle | Target ablated |
| 5              | 48         | d-transposition of the great vessels | IIIc | Mustard procedure | Glenn procedure | AVNRT ablation | Atrial tachycardia | Nadolol | Apixaban | 15.4 | 0.06 | ICE | Superior margin of the systemic venous baffle | Targets ablated |
| Patient Number | Age, years | CHD Diagnosis(es) | ACHD AP Classification | Prior Surgical Treatment(s) | Prior Catheter Treatment(s) | Prior Ablation Treatment(s) | Arrhythmia(s) Indicating Study | Antiarrhythmic Drug(s) | Anticoagulation | Device | Fluoro Time, min | Air Kerma, Gy | Intraprocedural Imaging | Anatomic Arrhythmia Target(s) | Ablation |
|----------------|------------|-------------------|------------------------|-----------------------------|-----------------------------|-----------------------------|-------------------------------|------------------------|-----------------|---------|---------------|--------------|----------------------------|--------------------------|----------|
| 6              | 11         | • Situs inversus  | IIc                    | • Repair of total anomalous pulmonary venous return | • Bilateral pulmonary artery stenting | • SVT | • Sotalol | Warfarin | Single-chamber, atrial PPM (implanted during the Rhythmia™ procedure) | 10.3 | 0.02 | TEE | • Unable to induce | None |
| 7              | 64         | • Coarctation of the aorta | IIb | • Patent ductus arteriosus ligation | • Transcatheter pulmonary valve replacement | • Atrial flutter | • Mexiletine | Warfarin | DC-ICD | 11.5 | 0.03 | None | • Right atrial scar from prior atriotomy and posteroseptal scar | Horizontal RFA line from the posteroseptal scar to the atriotomy scar, then another vertical RFA line down to the IVC |

ACHD: adults with congenital heart disease; AP: anatomic and physiological; AV: atrioventricular; CHD: congenital heart disease; DC-PPM: dual-chamber permanent pacemaker; DC-ICD: dual-chamber implantable cardioverter-defibrillator; ICE: intracardiac echocardiography; IQR: interquartile range; IVC: inferior vena cava; RA: right atrium; s/p: status post; SVC: superior vena cava; SVT: supraventricular tachycardia; TEE: transesophageal echocardiography.
**Table 4:** Patients Without Structural CHD

| Patient Number | Age, years | Cardiac Diagnosis(es) | Prior Ablation | Arrhythmia(s) Indicating Study | Antiarrhythmic Drugs | Antiarrhythmic Device | Fluoro Time, min | Air Kerma, Gy | Intraprocedural Imaging | Anatomic Arrhythmia Target(s) | Ablation |
|----------------|------------|-----------------------|----------------|--------------------------------|----------------------|-----------------------|------------------|----------------|------------------------|--------------------------------|---------|
| 8              | 20         | Tachycardia-mediated cardiomyopathy | None | None | None | None | None | 0 | 0 | None | Mid-posterior wall of the right atrium | Target ablated |
| 9              | 17         | Familial-dilated cardiomyopathy | None | Atrial flutter | None | None | None | 1.9 | 0.01 | ICE | Cavotricuspid isthmus | Target ablated |
| 10             | 16         | Sinus node dysfunction | None | Atrial flutter | None | Warfarin | Single-chamber, ventricular PPM | 43 | 0.1 | ICE | Unable to induce | Empiric RFA line to the cavotricuspid isthmus |
| 11             | 19         | PVC-mediated cardiomyopathy | Failed PVC ablation | PVCs | Verapamil | None | None | 0 | 0 | None | Basal inferolateral RV near the tricuspid valve | Target ablated |
| 12             | 12         | Dilated cardiomyopathy | None | PVCs | None | None | None | 0 | 0 | None | Postero-septal aspect of RVOT | Target ablated |

ICE: intracardiac echocardiography; IQR, interquartile range; PPM: permanent pacemaker; PVC: premature ventricular contractions; RFA: radiofrequency ablation; RV, right ventricle; RVOT, right ventricular outflow tract.

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**Discussion**

We report our initial experience with the Rhythmia™ mapping system in pediatric patients and patients with multiple congenital heart disease. The Rhythmia™ system allows for the rapid generation of high-density catheter electroanatomic maps with the Orion™ steerable ablation catheter and the Orion™ echo catheter, which can be used to guide ablation procedures in the catheterization laboratory. The system provides real-time 3D images of the heart with detailed anatomical and electroanatomical information, facilitating the planning and execution of ablation procedures.

**Follow-up**

Over a median of 16 months (IQR: 12.8–17.3 months), only one patient in the cohort experienced recurrence of their clinical arrhythmia. Two patients (17%) were able to discontinue all antiarrhythmic therapy. No patients experienced acute complications or late postprocedural adverse events. The patient who experienced recurrence was an adult patient (patient 10) with a history of atrial flutter and atrial standstill caused by an inherited SCN5A pathogenic variant. She underwent empirical RFA at the cavotricuspid isthmus and experienced an episode of syncope and collapse. Device interrogation at the time of the event showed two episodes of very high ventricular rates, with a minimum of 245 bpm, and areas of continuous low-amplitude fractionated signals. She underwent placement of an atrial lead to prevent bradyarrhythmias-induced arrhythmias.

**Diagnoses with multiple congenital heart disease**

- A pediatric patient (patient 6) with situs inversus, AV canal defect, total anomalous pulmonary venous return, malposed great arteries, pulmonary atresia, and major aortopulmonary collateral arteries required multiple surgical interventions. The patient was referred for a repeat electrophysiology study due to recurrent symptomatic arrhythmias.

- An adult patient (patient 7) with a history of atrial flutter and atrial standstill was referred for a repeat electrophysiology study due to recurrent symptomatic arrhythmias. The patient underwent an additional RFA procedure, which was successful in eliminating the arrhythmia.

**Additional Notes**

- The Rhythmia™ system offers a comprehensive approach to mapping and ablation, allowing for precise targeting of arrhythmia origins and improving procedural outcomes.

- The use of the Rhythmia™ system in pediatric and adult patients with multiple congenital heart disease highlights the versatility and efficacy of the system in managing complex arrhythmias.

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Early Experience with High-density Electroanatomical Mapping

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CHD. Our approach in this cohort was unique in that we mapped the target chamber with the Orion™ catheter with minimal or no fluoroscopy and without internal reference catheters. In our initial experience, we found this technique to be both fast and effective while minimizing fluoroscopy and procedure times.

A total of 37 high-density maps were created, with a median of 8,140 mapping points within a median of 631 seconds. Our median procedure time in this cohort was 189.5 minutes, which is comparable to previous experience with this technology17,18 [Mantziari et al.: 285 (IQR: 194–403) minutes; Ernst et al.: 184 (IQR: 155–298) minutes]. Of note, provider unfamiliarity with the software and hardware likely contributed to increased procedure times and will likely improve with increased familiarity. No manual annotation was required during map creation, which is consistent with previous reports.8,12,17

No internal reference catheters were required in this experience as the Rhythmia™ mapping system allowed for the external surface electrode to serve as a reference instead.

We report a high success rate and minimal symptomatic arrhythmia recurrence over a median follow-up period of 16 months. In addition, two patients were able to de-escalate off all antiarrhythmic medications. Our patient selection being based on complex and/or multiple flutter circuits or anatomical constraints that could limit the ability to map precluded a straightforward comparison to a propensity-matched control. It should be noted that our outcomes were significantly better compared to similar cohorts18; however, our small sample size and differing techniques limit the significance of this finding.

Our one documented episode of symptomatic recurrence occurred in a patient with SCN5A channelopathy. SCN5A pathogenic variations are thought to have variable expressivity and can cause variable phenotypes,

Figure 1: The case of a patient (patient 2) with hypoplastic left heart syndrome post-lateral Fontan. Images show electrograms, isochronic activation mapping (red indicating the earliest activation and purple indicating the latest scaled in milliseconds), and ablation sites (red points) of a tricuspid isthmus–dependent atrial flutter within the RA (upper six images, right anterior oblique (RAO) and left anterior oblique (LAO) projections) and a focal, automatic tachycardia in the lateral Fontan (bottom three images, RAO and LAO projections). The electrogram ablation catheter tracing signal is well before the atrial and the coronary sinus tracings, and the unipolar catheter tracing shows a Q-wave, all suggesting placement at the origin of the atrial tachycardia.
including Brugada syndrome, long QT syndrome, and cardiac conduction disease, depending on the type of mutation and patient factors. SCN5A channelopathies are unlikely to respond to endocardial ablation in the long term and often require epicardial intervention or other alternative therapies.

The Rhythmia™ mapping system requires induction of a sustained arrhythmia in order to create an accurate activation sequence map. The most apparent advantage of the Rhythmia™ mapping system with the Orion™ catheter is the rapid acquisition of activation, which is imperative in cases where the arrhythmia of interest is difficult to induce or sustain, or in patients with CHD due to heterogeneous anatomy and scar/fibrosis. In cases where arrhythmias could not be induced, high-resolution maps were obtained in sinus rhythm, used to identify scar, and empiric scar modification was performed (patients 3 and 7). If areas of the targeting arrhythmia were still inducible, defining the precise location of anatomical “breakthrough” was facilitated by electroanatomic remapping, which is often rapid and easy to define. Given the high number of electroanatomic points generated rapidly during mapping, both the clinical operator and the Rhythmia™ representative constantly checked the electrical signals to ensure consistency, removing or modifying points as needed.

Catheter visualization is occasionally a challenge due to external impedance reference, with the mapping catheter occasionally displayed as moving erratically when actually still, even completely, disappearing from the software display at times. In discussion with Boston Scientific, this was thought to be a result of inconsistent impedance through the chest wall and is an area for improvement for future iterations of this technology. With these current difficulties with catheter localization with external impedance references, we recommend utilizing internal impedance reference catheters until these issues are resolved.

Figure 2: The case of a patient (patient 3) with hypoplastic left heart syndrome post-fenestrated Fontan who developed an atrial flutter. The voltage maps (top two images, RAO and LAO projections) of the SVC, RA, IVC, and left pulmonary artery seen here show a scar below the sinus node and low-voltage area down to the IVC at the anterolateral RA. The isochronic activation maps (bottom two images) show the RA in an RAO projection in sinus rhythm after treatment, with no wave progression through ablation lesions (red points). The scale for the voltage maps is from 0.01 (red) to 20 mV (purple). The isochronic activation maps indicate the earliest activation with red color and the latest activation with purple color in milliseconds.
There is a significant learning curve with the Orion™ catheter and the Rhythmia™ mapping system due to differences in steering and pressure indication when compared to other mapping systems, with a detrimental effect on the ease of use. The recent addition of the INTELLANAV MIFI™ XP Ablation Catheter (Boston Scientific) claims to improve upon both of these issues.24

The use of fluoroscopy in our patient cohort was mostly to facilitate transseptal or transbaffle puncture. Our technique of minimal or no fluoroscopy results in significantly less fluoroscopy time than similar cohorts.17,18 Adult CHD patients are exposed to a significant cumulative effective dose of radiation.25 With increased radiation exposure due to diagnostic and therapeutic interventions, adult CHD is associated with an increased prevalence of cancer.25,26 Even low-dose ionizing radiation was found to be independently associated with an increased odds of cancer in adult CHD patients.27 This is of particular concern as the frequency of these procedures is increasing and starting to be performed in progressively younger patients, thus increasing the cumulative radiation exposure and risk for cancer.25 This technology in combination with intracardiac echocardiography (ICE) presents a promising path to reducing procedural radiation exposure in adult CHD patients associated with RFA.

Boston Scientific requires universal use of anticoagulation with the Orion™ basket catheter, with a suggested goal activated clotting time of more than 300 seconds.29 The main drawback of universal anticoagulation is the theoretical increase in hematoma risk at vascular access points, although this was not seen in our cohort. The necessity of heparin in all cases with Orion™ catheters complicates the decision to place additional catheters midprocedure, and practitioners should be cognizant of the potential need for additional catheters. It is our institutional practice to use ultrasound guidance for all arterial access in our electrophysiology labs. Ultrasound guidance was used in all procedures, which has been

Figure 3: The case of a patient (patient 4) with D-transposition of the great vessels post–Mustard procedure. Image shows electrograms, isochronic activation mapping, and ablation lesions (red points) within the IVC, SVC, and systemic venous Mustard baffle from the RAO and LAO projections. An atrial tachycardia with earliest local activation at the anterosuperior aspect of the baffle was ablated. The electrogram shows earliest activation in the coronary sinus leads. A Q-wave is seen in the unipolar lead, suggesting that this is the site of exit for the focal atrial tachycardia. The isochronic activation maps indicate the earliest activation with red color and the latest activation with purple color in milliseconds.
shown to significantly improve procedural success and reduce complications.\textsuperscript{30} In cases that would benefit from the Orion™ catheter, there is an argument to start select cases with arterial access with a 4-Fr catheter to allow for upsizing if needed midprocedure.

Our cohort includes a large proportion of great complexity CHD cases and a similar to larger proportion of great-complexity CHD cases than seen in previous cohorts.\textsuperscript{17,18} Ernst et al.\textsuperscript{18} conducted a similar case series; however, they avoided procedures requiring transbaffle or retrograde access due to concerns for increased procedure time and fluoroscopy time. We elected to perform transbaffle mapping and ablations in two of our patients due to arrhythmia severity and given our methodology of mapping without fluoroscopy and the use of ICE. We found that transbaffle mapping was feasible and, in complex CHD, easily facilitated with ICE imaging. We again advocate minimal fluoroscopy in addition to utilization of ICE for all our congenital patients as able to avoid unnecessary procedural radiation and to assist in defining anatomy.

We reported no procedural complications in our cohort, including in patients with complex CHD.

**Future directions**

This initial report shows promising efficacy; however, larger prospective trials are needed to determine the efficacy and safety of this product.

**Limitations**

This retrospective cohort study reflects a preliminary, single-center experience using the Rhythmia™ mapping system in an adult CHD population. We had high rates of success in a variety of adult CHD cases, but our findings are limited by the small number of enrolled patients.
Operator unfamiliarity with the Orion™ catheter and Rhythmia™ mapping software may have influenced the procedure times. The cohort presented is heterogeneous in their anatomy and presenting arrhythmia, which limits the ability to generalize these findings.

Conclusions
This preliminary cohort study of the use of the Rhythmia™ high-density mapping system in adult CHD patients demonstrates the potential for rapid acquisition of highly detailed maps and quick conversion to scar modification, with minimal procedure and fluoroscopy times. Our technique mapping without fluoroscopy was not only fast and effective but significantly decreased fluoroscopy time in combination with ICE. Due to catheter display errors in the current implementation of Rhythmia™ with an external impedance reference, we recommend internal impedance reference catheters at this time.

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