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# Three-dimensional electroanatomically guided slow pathway elimination is associated with procedural improvements and clinical benefit in atrioventricular node reentrant tachycardia patients

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## Abstract

**Background:** Slow pathway (SP) ablation, in the context of atrioventricular node reentrant tachycardia (AVNRT) treatment could result in either complete elimination or only modification of the SP with ambiguity regarding associated benefits. Three-dimensional electroanatomical mapping (3D-EAM) may be used adjunctively aiming to complete SP elimination. Our purpose was to compare a 3D-EAM-based strategy targeting SP elimination to the conventional fluoroscopic approach with respect to clinical outcomes.

**Methods:** One hundred and two consecutive AVNRT patients (36 males, mean age 53.2 ± 13.7 years) underwent in two successive periods a conventional fluoroscopic ablation approach ($n$ = 42) or a 3D-EAM-guided ablation focusing on complete SP elimination ($n$ = 60).

**Results:** Several procedural parameters improved with 3D-EAM use, including fluoroscopy time (2.4 ± 4.7 min vs. 13 ± 4.5 min), dose-area product (1061 ± 3122 μGy × $m^2$ vs. 5002 ± 3032 μGy × $m^2$) and slow pathway elimination frequency (95% vs. 50%, all $p < .001$). Procedural time was slightly prolonged in the 3D-EAM group (101 ± 31 min vs. 87 ± 24 min, $p$ = .013). Two major complications occurred in the conventional group. Altogether, over a mean follow-up of approximately 2.7 years, recurrence occurred in 6 of 42 (14.3%) in the conventional group as compared to 1 of 62 (1.7%) in the EAM-based group ($p$ = .019). In the Kaplan–Meier analysis, time-to-event was significantly longer for the EAM-based patients ($p < .030$). Moreover, the EAM-based strategy was associated with less redo procedures' rates (9.5% in the non-EAM group vs. 0% in the EAM group, $p$ = .026).

**Conclusions:** The present study showed that an EAM-based SP elimination strategy is not only feasible and safe but it is also accompanied by improved clinical outcomes in the setting of AVNRT ablation.

KEYWORDS
atrioventricular node reentrant tachycardia, electroanatomical mapping, fluoroscopy time, recurrence, slow pathway elimination

## 1 | INTRODUCTION

Atrioventricular nodal reentrant tachycardia (AVNRT) is the commonest regular supraventricular tachyarrhythmia.[1] Targeting the slow pathway (SP) has emerged as the superior form of treatment for AVNRT for more than two decades appearing to be effective and associated with a low complication rate.[2] SP ablation could result in either complete elimination or only modification of the SP. Although SP modification has already been accepted as a reliable end-point of successful AVNRT ablation,[3,4] in the long-term a higher recurrence rate has been observed in such patients.[5,6] Notably, no difference in procedural success rates with complete or incomplete SP ablation was observed if isoproterenol was used uniformly after ablation to verify success in a meta-analysis combining 10 studies and 1204 patients. In contrast, in studies in which isoproterenol was not used uniformly after ablation, incomplete SP ablation resulted in higher recurrence rates.[4]

More recently, alternative ablation strategies have been introduced including the use of three-dimensional electroanatomic mapping (3D-EAM) with the goal of reducing procedural complications and radiation exposure.[7,8] 3D-EAM has allowed visualization of the antegrade fast and slow pathway inputs in patients with AVNRT, as well as the anatomical location producing adequate ablation without an excessively accelerated junctional rhythm based on the angle from the His potential.[9,10] The purpose of the present study is to compare a 3D-EAM-based strategy targeting SP elimination to the conventional fluoroscopic approach focusing on SP modification with respect to clinical outcome.

## 2 | MATERIALS AND METHODS

### 2.1 | Patients and ablation protocol

This was an observational and cross-sectional study that included patients with typical AVNRT who underwent radiofrequency ablation in Athens Heart Center in two successive periods. All demographic, clinical and periprocedural parameters were collected retrospectively. The study had the approval of the local ethics board and the study protocol conforms to the Ethical Guidelines of the 1975 Declaration of Helsinki. All patients (>18 years old) gave written informed consent. Patients were weaned off of all anti-arrhythmic drugs for at least five half-lives. The procedure was performed with local anesthesia or under conscious sedation according to patient age and preference, and at the discretion of the operator.

From January 2016 to December 2018 all ablation procedures were performed by the same team using a conventional fluoroscopic method. In total four sheaths were introduced using both femoral veins. A decapolar catheter was positioned in the coronary sinus and two quadripolar catheters were positioned in the His position and right ventricle. Standard atrial and ventricular stimulation was performed to induce the clinical arrhythmia and verify AVNRT diagnosis.[11,12] Isoproterenol infusion up to 5 μgr/kg/min was used, when necessary. Typical jump was defined as a sudden prolongation of AH interval >50 ms with a decrease of 10 ms of S1S2 interval during programmed atrial pacing.[11]

In such cases of fluoroscopic mapping, borders of the triangle of Koch were demarcated by catheters located in the His bundle region and within the coronary sinus. Ablation was performed using a 4 mm radiofrequency (RF) ablation catheter (Blazer PrimeTM, Boston Scientific) with power set at 25–50 Watts and temperature at 60°C. We always started the ablation from the low Koch triangle (close to the ostium of the coronary sinus) and subsequently placed the ablation catheter in a higher position (mid to high Koch triangle) toward the His area if previous applications had been ineffective.

In January 2019, it was decided to switch to 3D-EAM use in all SVT procedures and SP elimination constituted the ablation strategy thereafter. Accordingly, from January 2019 to April 2021 all AVNRT ablation procedures were performed by the same team using Rhythmia HDx Mapping System (Boston Scientific) and all patients had at least 1 year follow-up. In total, three sheaths were introduced using only the right femoral vein since the IntellaNav ST (Boston Scientific), a 4 mm tip ablation catheter with a standard curve was used for identification and tagging of His potentials at the anterior-inferior end of the interatrial septum (His cloud). Boundaries of the triangle of Koch, along with coronary sinus anatomy, were also marked as a field map. SP potentials were identified in the base of the triangle of Koch, as expected, with the help of Rhythmia HDx (Figure 1).

RF applications were delivered with settings on Maestro 4000 RF Generator (Boston Scientific), with power set at 25–50 Watts and temperature at 60°C. RF energy was applied at sites with an ideal SP potential and if nodal beats or rhythms were induced, we continued the application for at least 1 min and red tags were placed (Figure 2). If junctional beats were not evident after 15 s of RF,

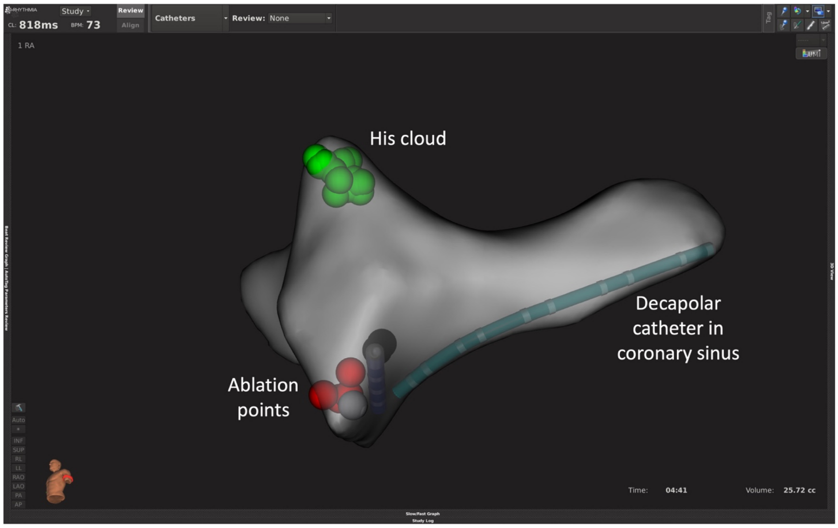


**FIGURE 1** Electroanatomical mapping of the triangle of Koch and annotation of His cloud and ablation points. A 4 mm tip ablation catheter with a standard curve was used for identification and tagging of His potentials (green tags) at the anterior-inferior end of the interatrial septum (His cloud). Boundaries of the triangle of Koch, along with coronary sinus anatomy, were also marked as a field map. RF energy was applied at sites with an ideal slow pathway potential and if nodal beats or rhythms were induced, red tags were placed. If junctional beats were not evident after 15 s of RF, these sites were tagged gray. Black tags were used if any prolongation of the atrio-ventricular interval or blocking of a P wave occurred and in areas of fast junctional rhythm.

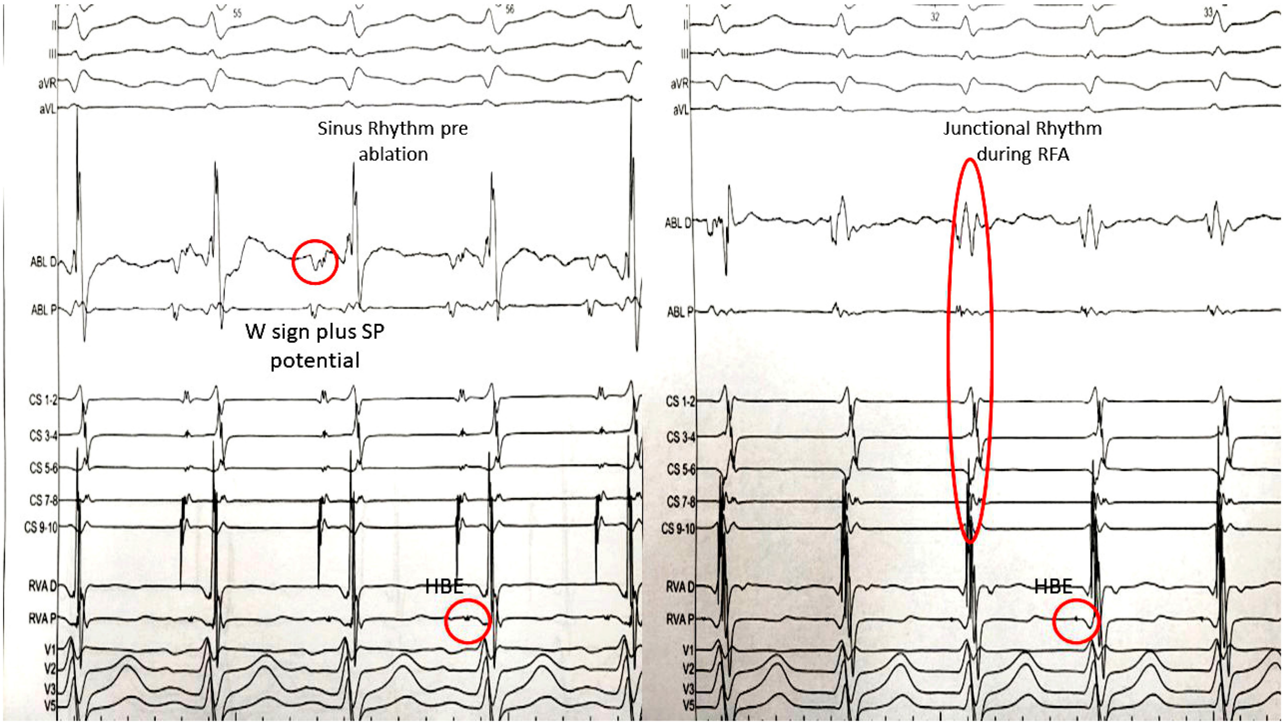


**FIGURE 2** Slow pathway potential and subsequent slow junctional rhythm during RF ablation.

energy application was stopped and these sites were tagged gray. Black tags were used if any prolongation of the atrio-ventricular interval or blocking of a P wave occurred and in areas of fast junctional rhythm. Ablation was continued till complete SP elimination (absence of AH jump) or at the discretion of the operator when this primary goal could not be achieved.

### 2.2 | Study outcomes

After ablation, we repeated all EP study with analysis of anterograde and retrograde conduction. The primary outcome was defined as noninducibility of AVNRT without the presence of residual jump and/or echo (SP elimination), or the presence of only a single jump and/or echo (SP modification). Notably, SP elimination was aimed for in all cases with EAM use, while SP modification with noninducibility was sufficient under the conventional approach. The secondary outcome of the study was long-term success of the procedure, that is, survival free from AVNRT recurrence.

It has been our institution's practice to arrange for a clinical follow-up at 4 weeks postprocedure. Long-term success was defined as no recurrence of supraventricular tachycardia based on the last available clinical follow-up. Recurrences were considered documented if an ECG was recorded and nondocumented if clinical characteristics were present based on previous patients' experience. Duration of the recurrent episode, mode of termination and number of recurrences were also recorded.

Major complications were defined as death, stroke, vascular access complications requiring an intervention or blood transfusion, heart block requiring a permanent pacemaker, or pericardial effusion requiring an intervention within 30 days of the procedure.

### 2.3 | Statistical methods

Continuous variables are presented as mean ± standard deviation, while categorical variables as frequencies. When distribution normality assumption was violated (as evaluated using the Shapiro–Wilk test), a two-step transformation algorithm[13] was used to achieve normalization. In cases of persistently non-normally distributed parametric variables, as well as ordinal ones, Mann–Whitney U test was used, with chi-square reserved for dichotomous variables. Survival free from arrhythmia recurrence was compared using the logrank approach in order to compare Kaplan–Meier curves. A two-sided *p*-level of ≤.05 was considered to denote statistical significance. Statistical Product and Service Solutions (SPSS®) software version 23 (IBM) was used for all analyses.

## 3 | RESULTS

Baseline and procedural characteristics are shown in Table 1, with survival curves depicted in Figure 3. Evidently, as expected, fluoroscopy time and radiation exposure were significantly lower in the EAM (+) group. Moreover, max power used was higher (certainty regarding His bundle location) and number of sheaths reduced by 1 (no catheter parked at His electrogram site), at the cost of slightly (on average 15 min) increased procedural duration, mainly attributed to prolonged mapping time. Mean mapping time including anatomy creation and distinct tagging of ablation points was 12 minutes in the EAM (+) group. The primary goal of the EAM-based strategy focusing on complete SP elimination was achieved in 95% of cases, as opposed to the significantly lower percentage of complete SP elimination (52.4%, $p < .001$) with the conventional approach.

Documented clinical recurrences were observed in three patients in the conventional arm and nondocumented multiple episodes in 1. These four patients finally underwent a repeat procedure. Nondocumented single episodes were reported in two patients in

**TABLE 1** Clinical and procedural characteristics of the study cohort

| Parameter | Cohort, *n* = 102 | Conventional group, *n* = 42 | EAM-based group, *n* = 60 | *p* for difference |
|---|---|---|---|---|
| Age (years) | 53.2 ± 13.7 | 54.4 ± 11.8 | 52.3 ± 15 | .441 |
| Gender (% male) | 35.3 | 35.7 | 35 | 1 |
| Medication prior (% yes) | 29.4 | 38.1 | 23.3 | .083 |
| Sheath number | **3.4 ± 0.5** | **4** | **3** | **<.001** |
| Procedure time (min) | **95.25 ± 28.9** | **86.8 ± 23.6** | **101.2 ± 31** | **.013** |
| Dose-area product (μGy × m²) | **2727 ± 3639** | **5002 ± 3032** | **1061 ± 3122** | **<.001** |
| Fluoroscopy time (min) | **6.7 ± 7** | **13 ± 4.5** | **2.4 ± 4.7** | **<.001** |
| Ablation duration (min) | 8 ± 8.2 | 7.4 ± 7.3 | 8.8 ± 9.2 | .534 |
| Max power (W) | **35.4 ± 11** | **29.2 ± 3.3** | **39.8 ± 12** | **<.001** |
| EPS findings pre (%) | Jump (only): 19.6<br>Echo beats: 33.3<br>Sustained AVNRT:47.1 | Jump (only): 21.4<br>Echo beats: 31<br>Sustained AVNRT: 47.6 | Jump (only): 18.3<br>Echo beats: 35<br>Sustained AVNRT: 46.7 | .884 |
| EPS findings post (%) | **Absent SP: 77.4<br>Jump: 19.6<br>Echo beats: 2<br>Sustained AVNRT: 1** | **Absent SP 52.4<br>Jump: 45.2<br>Echo beats: 0<br>Sustained AVNRT: 2.4** | **Absent SP: 95<br>Jump: 1.7<br>Echo beats: 3.3<br>Sustained AVNRT: 0** | **<.001** |
| Complete SP elimination (%) | **77.4** | **52.4** | **95** | **<.001** |
| Major complications (*n*) | 2 | 2 | 0 | .167 |
| Follow-up duration (years) | **2.7 ± 1.6** | **4 ± 1.7** | **1.9 ± 0.7** | **<.001** |

*Note*: Statistically significant differences are denoted with bold font.

Abbreviations: AVNRT, atrioventricular nodal reentrant tachycardia; EAM, electroanatomic mapping, EPS, electrophysiologic study.

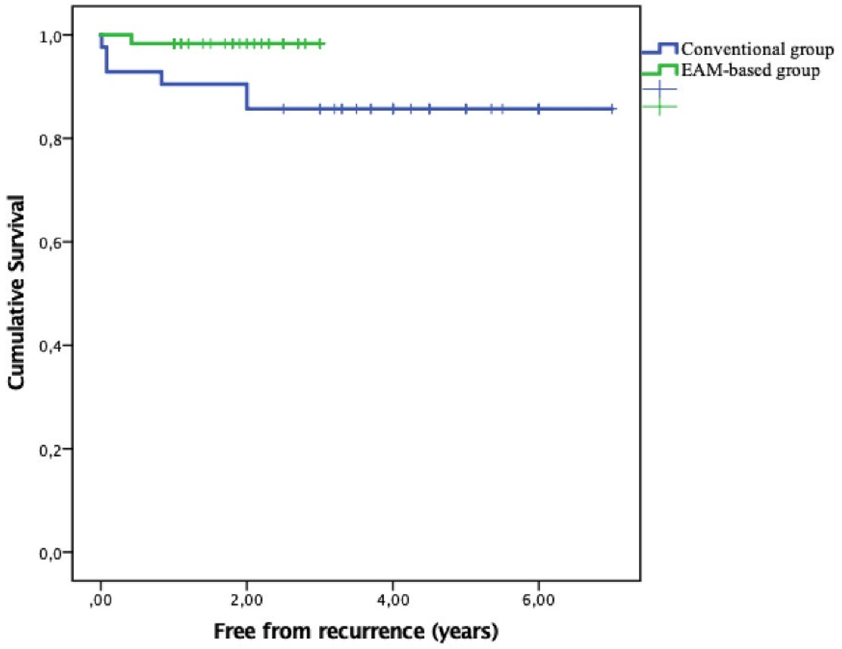


FIGURE 3 Survival curves for the freedom from arrhythmia recurrence. Kaplan–Meier curves for survival free from arrhythmia recurrence. Note early curve separation, despite shorter follow-up in the EAM (+) group (slow pathway recovered early).

the conventional arm and in one patient in the EAM-based strategy. All recurrences occurred in the first 24 months postablation.

Altogether, over a mean follow-up of approximately 2.7 years, the primary outcome event (recurrence) occurred in seven of 102 patients (6.9%), six of 42 (14.3%) in the conventional group as compared to one of 62 (1.7%) in the EAM-based group ($p$ = .019). In the Kaplan–Meier analysis, time-to-event was significantly longer for the patients in the EAM-based strategy ($p < .030$, Figure 3). Moreover, the EAM-based strategy was associated with less redo procedures' rates (9.5% in the non-EAM group vs. 0% in the EAM group, $p$ = .026).

We also compared separately the group of patients with complete SP elimination compared to that without irrespective of the EAM use. Complete SP elimination was achieved in 78 patients out of 102. Clinical recurrence was present in one patient in the group of complete SP elimination compared to six recurrencies among those without SP elimination ($p_{logrank} < 0.001$).

Although procedural duration was slightly longer in the EAM group, the same did not hold for ablation (lesion administration) time, which was similar between groups (101 ± 31 min vs. 87 ± 24 min, $p$ = .013, 7.4 ± 7.3 min vs. 9.2 ± 8.8 min, $p$ = .534, respectively).

Two major complications occurred in the conventional arm (one patient suffered a complete heart block requiring pacemaker implantation and 1 patient underwent vascular surgery due to femoral artery pseudoaneurysm).

## 4 | DISCUSSION

The present study showed that an EAM-based SP elimination strategy is not only feasible and safe but it is also accompanied by improved clinical outcomes in the setting of AVNRT ablation. The advantage of EAM use is not limited in the expected lower fluoroscopy time and the avoidance of complete heart block but it also accomplishes SP elimination at the cost of a prolonged procedure.

SP modification is effective and a combined anatomical and mapping approach is usually employed in current clinical practice.[14] This approach has a 2–4% recurrence rate in the first year and has been associated with a risk of AV block of <1% in previous reports.[15,16] Current guidelines do not support SP elimination compared to SP modification as the preferred end-point of the ablation procedure.[14] Nonetheless, there have been reports of a higher recurrence rate observed in the conservative approach of SP modification.[5,6] Heretofore, only one meta-analysis of studies, performed in the era of conventional fluoroscopic approach, has evaluated recurrence rates based on complete or incomplete SP ablation.[4] Pooled estimates revealed that 4.4% of patients with complete SP ablation, 6.8% of patients with a residual jump only and 6.5% of those with one echo beat had recurrences. With uniform isoproterenol use after ablation, there was no significant difference in recurrence rates among the endpoints. However, when isoproterenol was utilized after ablation only if needed to induce AVNRT before ablation, a significantly higher recurrence rate occurred in patients with a residual jump, a single echo, or the combined group of a residual jump and/or one echo. Notably, SP elimination was achieved in 640/1204 (53.1%) of patients, a highly similar rate to that observed in the conventional arm of our study (52.4%). In contrast, in a recent series of 45 AVNRT patients undergoing high-density mapping of the Koch triangle, SP elimination was reported in all patients to be associated with freedom from recurrence in all cases after 12 months of follow-up.[17] In our EAM-based strategy, the goal of SP elimination was achieved in 95% of cases even without the advantage of high-density mapping. The EAM strategy focusing on SP elimination was characterized by improved procedural parameters despite the increased duration of the whole procedure. Insertion of three instead of four sheaths was made from right femoral vein since a catheter for His annotation was redundant, improving patient comfort. Higher procedure duration was attributed to anatomy reconstruction and His cloud localization/tagging. Despite the explicit strategy aiming at slow pathway elimination, ablation time did not differ significantly. This is potentially attributable to the fact that the more demanding procedural end-point was offset by the improved targeting of sites of interest due to EAM. Nonetheless, increased procedural duration did not affect fluoroscopy time, which was minimal and significantly less compared to the conventional approach. EAM use allowed increased power use without increasing the risk of heart block due to annotation of significant points of interest such as His cloud and areas indicating injury of fast pathway and AV node (black tags were used if any prolongation of the atrio-ventricular interval or blocking of a P wave occurred and in areas of fast junctional rhythm).[10] Increased power use was also driven by the explicit endpoint of SP elimination, as opposed to mere modification.

### 4.1 | Limitations

This was a nonrandomized successive cohort study. Thus, although several obvious baseline features were similar across mapping approach groups, there is no assurance regarding more nuanced characteristics. Additionally, there is an unavoidable discrepancy regarding follow-up duration between patient groups, although arrhythmia recurrence within 2 years postprocedurally in all cases partly allays concerns for significant effects on findings. Only a randomized clinical trial may definitely determine superiority of the SP elimination approach over SP modification. However, the fact that all procedures were performed by the same operators in one center in two successive periods constitutes an advantage of our study.

## 5 | CONCLUSIONS

Use of 3D-EAM, even nonhigh density, is associated with improvements in procedural aspects of AVNRT ablation, including those pertaining to radiation exposure and sheath number. Moreover, certainty regarding His location allows for a more aggressive ablation approach with higher RF power delivery, in turn ensuring SP elimination. Contrary to current practice, a dedicated SP elimination strategy was per se associated with reduced recurrence rates and avoidance of redo procedures. Finally, and in conjunction with the above, over a relatively prolonged follow-up (mean 2.7 years), EAM use was found associated with a longer free from recurrence survival.

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### CONFLICT OF INTEREST

None declared.

### STATEMENTS AND DECLARATIONS

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