Received: 16 August 2023 | Revised: 28 December 2023 | Accepted: 20 January 2024

DOI: 10.1002/joa3.12999

ORIGINAL ARTICLE

Journal of Arrhythmia Open Access WILEY

Relationship between the atrial-activation pattern around the triangle of Koch and successful ablation sites in slow-fast atrioventricular nodal reentrant tachycardia

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Abstract

Background: The precise details of atrial activation around the triangle of Koch (ToK) remain unknown. We evaluated the relationship between the atrial-activation pattern around the ToK and success sites for slow-pathway (SP) modification ablation in slow-fast atrioventricular reentrant tachycardia (AVNRT).

Methods: Thirty patients with slow-fast AVNRT who underwent successful ablation were enrolled. Atrial activation around the ToK during sinus rhythm was investigated using ultra-high-density mapping pre-ablation. The relationships among features of atrial-activation pattern and success sites were examined.

Results: Of 30 patients (22 cryoablation; 8 radiofrequency ablation), 26 patients had a collision site of two wavefronts of delayed atrial activation within ToK, indicating a success site. The activation-search function of Lumipoint software, which highlights only atrial activation with a spatiotemporal consistency, showed non-highlighted area on the tricuspid-annulus side of ToK. In 23 of the patients, a spiky potential was recorded at that collision site outside the Lumipoint-highlighted area. Fifteen cryoablation patients with a success site coincident with a collision site outside the Lumipoint-highlighted area had significantly more frequent disappearances of SP after initial cryoablation (46.7% vs. 0%, $p=.029$), fewer cryoablations (3.7 ± 1.8 vs. 5.3 ± 1.3, $p=.045$), and shorter procedure times (170 ± 57 vs. 228 ± 91 min, $p=.082$) compared to the seven cryoablation patients without such sites. Four patients had transient AV block by ablation inside the Lumipoint-highlighted area with fractionated signals, but no patient developed permanent AV block or recurrence post-procedure (median follow-up: 375 days).

Conclusions: SP modification ablation at the collision site of atrial activation of the tricuspid-annulus side along with a spiky potential could provide a better outcome.

KEYWORDS
catheter ablation, electro-anatomical mapping, slow pathway modification

1 | INTRODUCTION

Radiofrequency (RF) catheter ablation for slow-pathway (SP) modification in slow-fast atrioventricular reentrant tachycardia (AVNRT) has been an established therapy. Recent studies have demonstrated that cryoablation has the same safety and efficacy as RF ablation. The most important advantage of cryoablation is the lowered risk of permanent AV block because of the stability of the contact with tissue from freezing adhesion, as well as the electrophysiological reversibility of the cardiac conduction system against cryothermal injury.[1,2] It has been reported that contrasting thermal energy sources, that is, RF ablation and cryoablation, may provide different optimal electro-anatomical indicators in SP modification. The electro-anatomical details of the reentrant circuit of slow-fast AVNRT have not been completely clarified. Ultra-high-density (UHD) mapping may help us to understand the electro-anatomical features of the triangle of Koch (ToK).

We conducted the present study to investigate the electro-anatomical relationship between successful ablation sites for suppressing tachycardia and the properties of atrial activation around the ToK and the pattern of SP modification in both RF ablation and cryoablation.

2 | METHODS

2.1 | Study population

We retrospectively investigated 33 patients with slow-fast AVNRT who underwent catheter ablation of the antegrade SP guided by UHD mapping between July 2018 and September 2022 at our institute. Patients having atypical AVNRT, including fast-slow AVNRT (one patient), were excluded. One patient who needed both forms of SP ablation by RF and cryoablation was excluded. Patients under 15 years of age and patients with congenital heart disease were also excluded. The retrospective study protocol was approved by the hospital's institutional ethics review board of Jichi Medical University. Informed consent was obtained in the form of opt-out on the website. This study conformed to the guidelines outlined in the Declaration of Helsinki.

2.2 | Electrophysiological study for slow-fast AVNRT

All patients underwent a detailed electrophysiological (EP) study for diagnosis of slow-fast AVNRT.

Antiarrhythmic agents were held for at least five half-lives before the ablation procedure. A multielectrode catheter was positioned inside the coronary sinus (CS) through the cervical vein. Electrode catheters inserted from the femoral vein were positioned in the high right atrium, His bundle region, and right ventricle (RV). Intracardiac electrograms were continuously recorded and analyzed on a polygraph (RMC-5000, Nihon Kohden; Tokyo, Japan). Bipolar and unipolar electrograms were filtered at frequencies of 50–300 Hz and 0.5-100 Hz, respectively.

The antegrade AV nodal conduction property was evaluated by atrial pacing and atrial extra-stimulation, and the retrograde ventricular-atrial (VA) conduction property was evaluated by ventricular pacing and ventricular extra-stimulation. An antegrade dual AV nodal pathway known as the “jump-up phenomenon” was defined as an abrupt A-H interval prolongation of ≥50 msec with a 10-msec decrement in the atrial extra-stimulation interval. AVNRT was defined based on a previous report according to the atrial-to-His (A-H) interval and the His-to-next-atrial-wave (H-A) interval; specifically, it was classified as slow-fast AVNRT if it had A-H/H-A ratio >1, an A-H interval of ≥200 msec and an H-A interval <70 msec along with a tachycardia induction mode including an antegrade jump-up phenomenon.[3,4] Patients with the possible existence of an accessory pathway along with AV and VA conduction without any decremental conduction properties were excluded. The absence of a resetting phenomenon by a single ventricular extra-stimulus during the tachycardia at a time point during the effective refractory period of the His bundle was confirmed to exclude the retrograde accessory pathway. Atrial and ventricular entrainment pacing was performed during the tachycardia to identify the VA linking inside the reentrant circuit for discrimination of the atrial tachycardia.[5]

2.3 | Ultra-high-density mapping around Koch of triangle

UHD mapping using Rhythmia system (Boston Scientific) was used to perform atrial activation around the ToK during sinus rhythm in patients diagnosed with slow-fast AVNRT by precise EP study. The atrial activation in the right atrial septum during sinus rhythm was precisely evaluated using a multielectrode basket catheter (INTELLAMAP ORION™, Boston Scientific) before ablation. We investigated relationship between the feature of the atrial activation patterns around the ToK obtained by UHD mapping and success sites.

The “Activation search” feature of the Lumipoint software module (Boston Scientific), which automatically could highlight the only reliable atrial activation at each point. That confidence level of the local potentials can be adjusted from 0% to 100%, "Activation search" with 100% of confidence level, which automatically highlights the only atrial potentials with a complete spatiotemporal consistency in local activation was applied in our study.

The "Complex activation" feature of the Lumipoint software automatically highlights areas with fractionated signals. The peak slider as an original parameter of Lumipoint indicates the number of components of fractionation, and it ranges from 1 to 15. The complex activation was also applied to evaluate the area with fractionated signals during sinus rhythm.

2.4 | Mapping for the slow pathway and ablation procedure

In cryoablation, ice mapping for SP potential was performed using a 6-mm-electrode-tip cryoablation catheter (Freezor Xtra; Medtronic) through a long sheath (8.5 Fr SL-0, Agilis, Abbott Laboratories). Mapping by cryoablation catheter around Koch's triangle (ToK) was performed with guidance by a 3D mapping system in all cases. Ice mapping was performed by cooling to −30°C for 60 s during sinus rhythm. Non-inducibility of AVNRT and/or disappearance of the SP was thought to be a good indicator for ice mapping. Following the ice mapping, cryoenergy application by cooling to −80°C (i.e., cryoablation) was performed for 4 min, and additional cryoenergy was applied for 4 min at the same site according to the freeze–thaw–freeze (FTF) method.[6] If AVNRT was induced after one cycle of FTF energy application, we performed ice mapping and applied ablation to other sites as guided by fluoroscopic imaging and a 3D mapping system.

In RF ablation, energy application was performed using an irrigated-tip contact force-sensing catheter (INTELLANAV STABLEPOINT™; Boston Scientific) with an RF power setting of 25–35 W for 60 sec, if junctional rhythm was found during RF energy application. When faster junctional rhythm or an AV conduction block was found, RF energy application was immediately stopped. The procedural endpoint of SP modification was the loss of inducibility of slow-fast AVNRT. In the waiting time >30 min after successful ablation, the high-dose isoproterenol venous injection and the repeated programmed stimulus were performed to confirm the SP conduction. The residual antegrade conduction of the SP and one echo after ablation was considered acceptable.

2.5 | Statistical analysis

Continuous data are expressed as means ± standard deviations for normally distributed variables or as medians [25th–75th percentiles] for non-normally distributed variables and were compared with Student's *t*-test and a Mann–Whitney analysis, respectively. Categorical data were analyzed by a chi-square test. A probability value of $p < .05$ indicated statistical significance. All the statistical analyses were conducted by SPSS software (ver. 27; SPSS, Chicago, IL). All electro-anatomical 3D mapping data were obtained automatically by RHYTHMIA HDx™ mapping system.

3 | RESULTS

3.1 | Baseline patient characteristics and ablation data

Thirty patients (mean age 54 ± 15 years, 13 males) who underwent ablation therapy for SP modification were enrolled after exclusion of three patients for various criteria. Characteristics of the EP study and ablation data are shown in Table 1. Mean whole procedure time including waiting time was 182 ± 71 min. UHD mapping time was 11 ± 5 min for high-density mapping around the ToK. In cryoablation, the median number of total cryoablations was four times with two cycles of FTF cryoablation while the median of total energy of RF ablation was 18,722 J. Although four patients had a transient AV block during procedure, no patient developed a permanent AV block and no patients had recurrence of slow-fast AVNRT during the post-procedure follow-up period (median, 375 days).

TABLE 1 Baseline and electrophysiological characteristics.

N = 30	Mean ± SD or *n* (%)
Age, y.o.	54 ± 15
Male gender	13 / 30 (43.0%)
Tachycardia cycle length, msec	353 ± 55
Cryoablation	22 / 30 (73.0%)
Procedure time, min	182 ± 71
Ultra-high-density-mapping time, min	11.2 ± 5.1
Transient AV block during procedure	4 / 30 (13.3%)
Permanent AV block	0 / 30 (0%)
Follow-up period, days, median [25th–75th percentiles]	375 [112–555]

Abbreviation: AV, atrioventricular.

3.2 | Ultra-high-density mapping around the ToK and the existence of a spiky potential

In 30 patients, detailed atrial activation mapping was obtained during sinus rhythm around the ToK including the His bundle potential recordable area. To identify the area of the retrograde fast pathway connecting to the right atrium, the earliest atrial activation during right ventricular pacing over the retrograde AV nodal fast pathway was projected onto the atrial activation mapping obtained during sinus rhythm. Of the 30 patients, 26 patients had a collision site of two wavefronts of delayed atrial activation within the ToK in the UHD mapping. Of these 26 patients, 23 had a spiky potential like His-bundle potential recorded at the collision site outside the Lumipoint-highlighted area.

A representative case of slow-fast AVNRT, presented in Figure 1, shows the atrial activation mapping around the ToK during sinus rhythm together with the area highlighted by the activation search algorithm of Lumipoint. Inside the ToK, the atrial activation pattern could be separated by the line (A) as a boundary of Lumipoint-highlighted area. Success site was located outside Lumipoint-highlighted area which was consistent with the collision site of two wavefronts of delayed atrial activation. As shown in Figure S1, an abrupt delay in the timing of local atrial activation as a spiky potential was identified over the line (A) from the inside to the outside of the Lumipoint-highlighted area. The delayed atrial activation had a collision of wavefront propagating horizontally over that line and the wavefront propagating from posterior to superior outside Lumipoint-highlighted area on the line (A) (Supplementary Movie S1), where the local potential could be recordable as a fragmented potential with a large-electrode-tip ablation catheter. Of 26 patients who had a collision site of two wavefronts of delayed atrial activation, 22 patients had a success site which consistent with the collision site outside of that highlighted area, which makes for a fragmented SP potential. Representative two cases are shown in Figure 2. The fractionated and small-amplitude SP potential was also recorded by a 6 mm electrode-tip cryoablation catheter at that site. That spiky potential recorded by a multielectrode mapping catheter seemed to be the spike component of the conventional parameter of the optimal SP potential recorded by the ablation catheter. We speculate that the spiky potential recorded at the collision site outside the Lumipoint-highlighted area may be the optimal targeting potential.

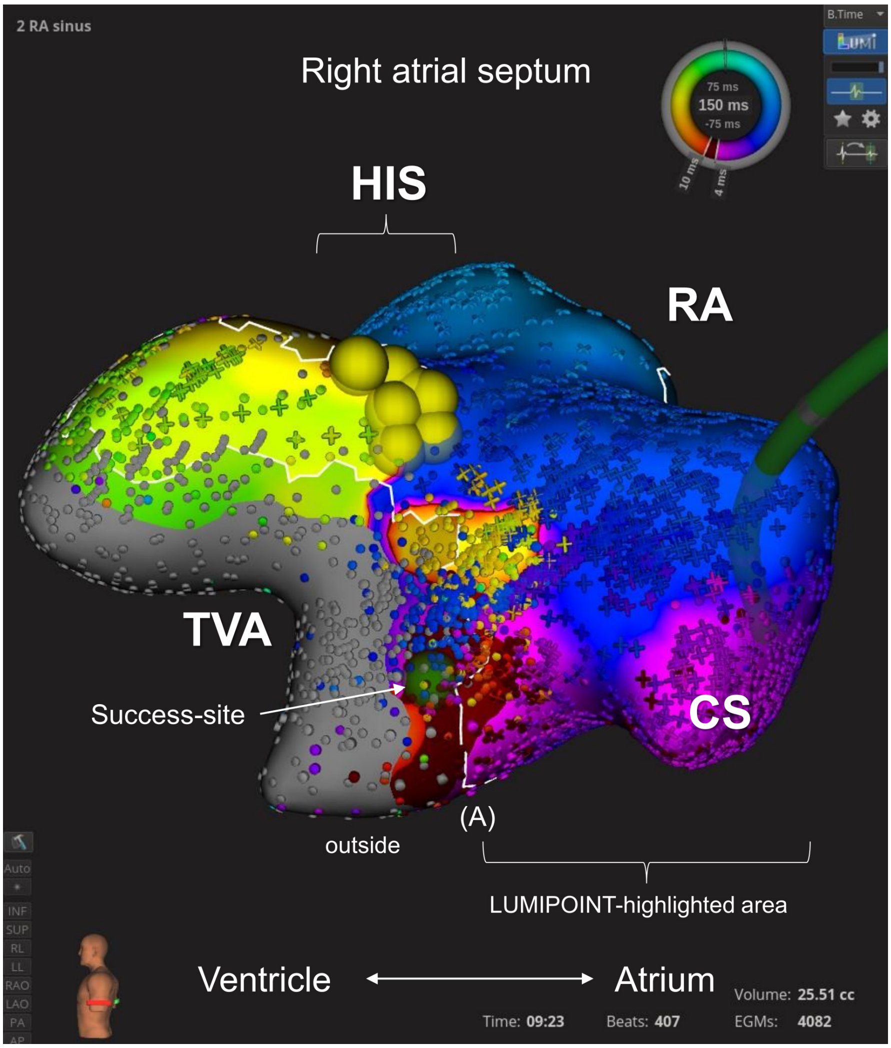

FIGURE 1 (Supplementary Movie S1) Lumipoint-highlighted area and successful cryoablation site. The activation search function of the Lumipoint algorithm (Boston Scientific) highlighted all electrograms indicating atrial activity within the mapping window. A confidence slider of 100% was applied to highlight the area with a complete spatiotemporal consistency in atrial activation. The right atrium is highlighted, and the tricuspid-annulus side of the ToK is not highlighted as shown by line (A) of the boundary of the highlighted area. Atrial activation showed a collision pattern of 2 wavefronts of delayed atrial activation with different propagation around the ToK. The collision site outside the Lumipoint-highlighted area coincided with the success site, where the spiky potential like His-bundle potential could be recorded. CS, coronary sinus; HIS, His bundle; RA, right atrium; ToK, triangle of Koch; TVA, tricuspid valvular annulus.

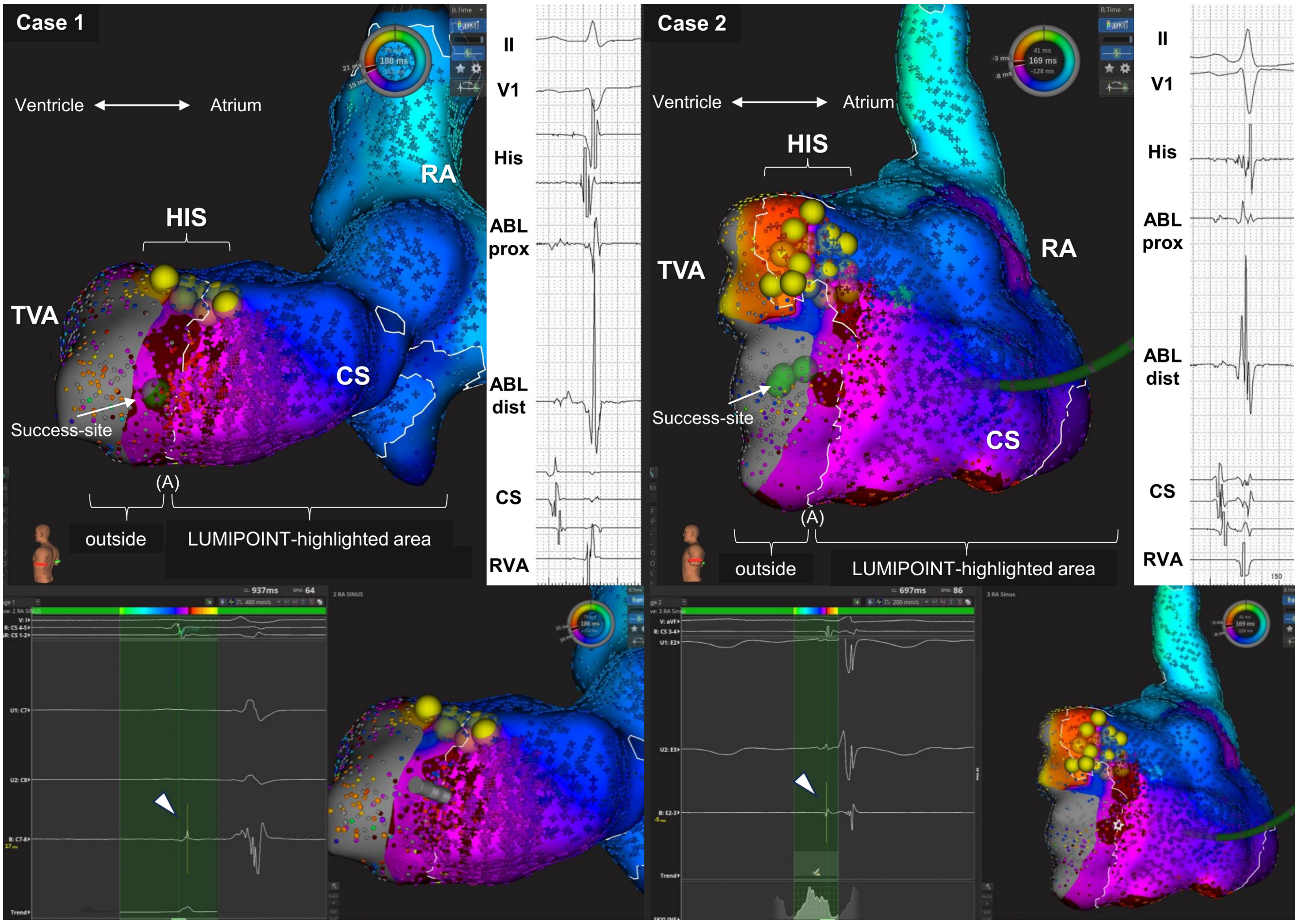

FIGURE 2 Two representative cases with success sites that coincided with a collision site outside the Lumipoint-highlighted area. The success sites (green tag) coincided with the area of collision sites of 2 wavefronts of the delayed atrial activation outside the Lumipoint-highlighted area (upper panel). While the spiky potential like His-bundle potential was recorded by multielectrode mapping catheter at the success sites (lower panel), the fractionated and tiny SP potential was recorded at that site by a cryoablation catheter. ABL, ablation catheter; CS, coronary sinus; HIS, His bundle; RA, right atrium; RVA, right ventricular apex; TVA, tricuspid valvular annulus.

TABLE 2 Comparison of SP modification in successful cryoablation between outside and inside the LUMIPOINT-highlighted area.

Cryoablation site	Collision site outside LUMI (15 cases)	Non-collision site inside LUMI (7 cases)	*p* value
Tachycardia cycle length, msec	364 ± 53	369 ± 69	.844
AV amplitude ratio	0.10 ± 0.05	0.28 ± 0.29	.142
SP disappearance after initial cryoablation	7/15 (46.7%)	0	.029
Presence of SP post-ablation	10/15 (33.3%)	4/7 (57.1%)	.290
Presence of a single echo beat post-ablation	5/15 (33.3%)	2/7 (28.6%)	.823
Total number of cryoablation, times	3.7 ± 1.8	5.3 ± 1.3	.045
Number of cycles of FTF cryoablation, cycles	1.5 ± 0.8	2.6 ± 0.5	.005
Procedure time, minutes	170 ± 57	228 ± 91	.082

Abbreviations: A, atrium; FTF, freeze–thaw–freeze; SP, slow pathway; V, ventricle.

3.3 | Relationship between SP modification and the collision site and Lumipoint-highlighted area

With respect to the cryoablation group, all 22 patients who underwent cryoablation subsequently had non-inducibility of slow-fast AVNRT. However, the SP modification pattern after cryoablation varied in each case. Of 15 patients with success sites coincided with the collision site outside Lumipoint-highlighted area, seven patients had a disappearance of antegrade SP conduction after initial cryoablation. On the other hand, no patient had a disappearance of SP after initial cryoablation in other seven patients (five patients: cryoablation at the collision site inside that highlighted area, two patients: cryoablation at the site with no collision pattern). Furthermore, 15 patients with a success site of collision site outside Lumipoint-highlighted area had a smaller number of cryoablation needed to suppress slow-fast AVNRT (3.7 ± 1.8 vs. 5.3 ± 1.3 times, $p = .045$) and shorter procedure time (170 ± 57 vs. 228 ± 91 min, $p = .082$) compared to those who underwent cryoablation at the non-collision sites inside that Lumipoint-highlighted areas shown in Table 2. The patients with cryoablation at the non-collision sites inside Lumipoint-highlighted area needed for larger number of cryoablation to suppress slow-fast AVNRT because slow-fast AVNRT could be induced repeatedly after several cryoenergy applications.

With respect to the RF ablation group, all eight patients who underwent RF ablation subsequently had non-inducibility of slow-fast AVNRT. Among these eight patients, seven patients had a successful RF ablation at the collision site outside the Lumipoint-highlighted area, and these seven patients had a junctional rhythm during RF energy application at that collision site, as shown in Figure 3 (Supplementary Movie S2). One patient who underwent RF ablation at a non-collision site inside the Lumipoint-highlighted area required larger RF energy (71,641 J) to suppress slow-fast AVNRT

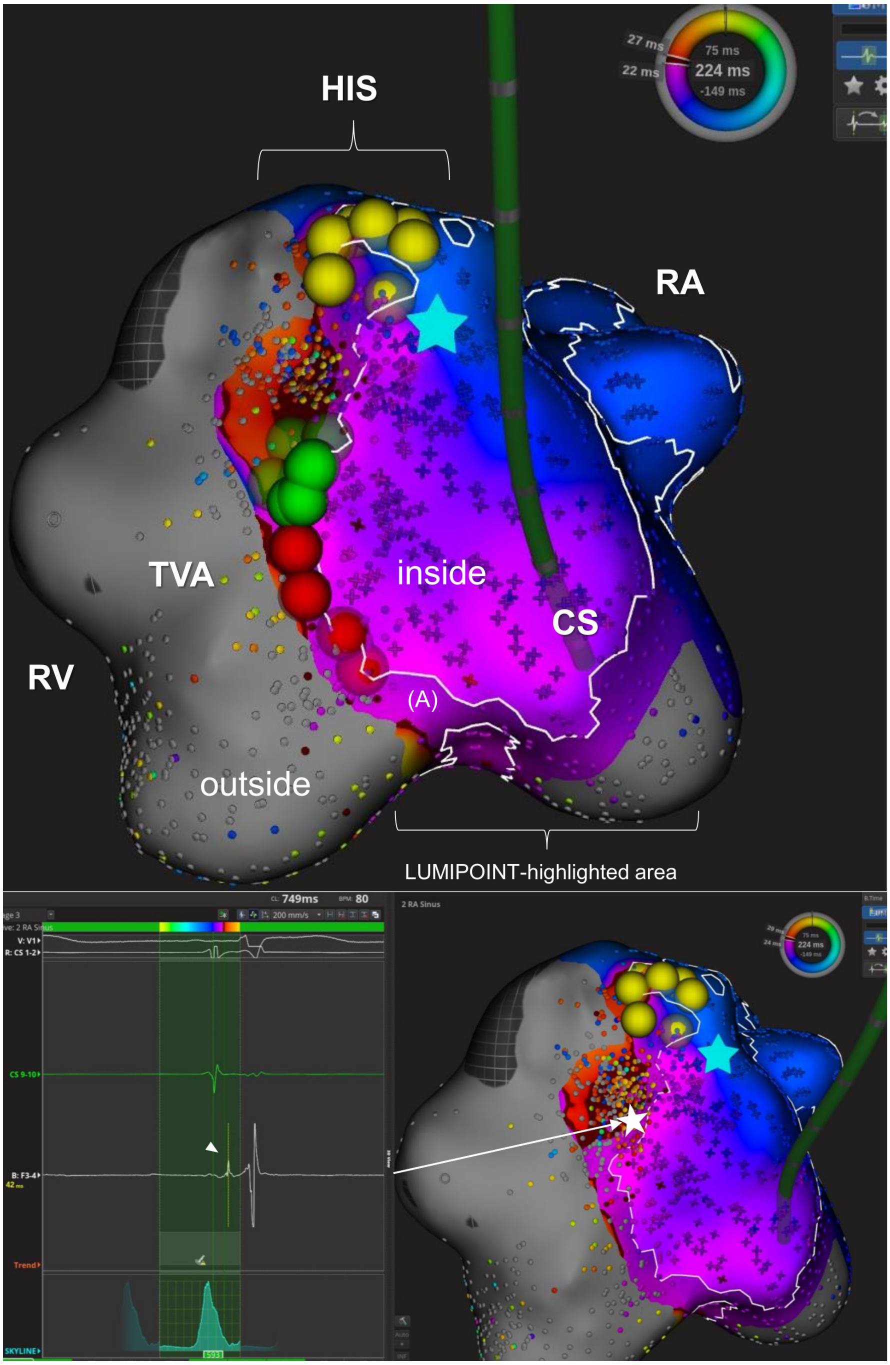

FIGURE 3 (Supplementary Movie S2) A representative case with junctional rhythm during RF energy application at the collision site outside the Lumipoint-highlighted area. Upper panel: The RF energy application was performed in a step-by-step fashion from the posterior to the anterior of the ToK (*red tag→ green tag*). In the RF ablation at the posterior ToK, junctional rhythm was not found during energy application (*red tags*). In contrast, junctional rhythm was observed after RF ablation at the collision site (*green tags*). A *blue star* indicates the earliest atrial activation site during slow-fast AVNRT. Lower panel: A spiky potential like His-bundle potential was recorded by a multielectrode mapping catheter at the success sites where well-junctional rhythm was obtained during RF energy application (*white star*). CS, coronary sinus; HIS, His bundle; RA, right atrium; RF, radiofrequency; RV, right ventricle; ToK, Koch of triangle; TVA, tricuspid valve annulus.

and a longer procedure time (278 min) compared to the other seven patients (median: 14,054 J and 175 min).

Collision site at the tricuspid-annulus side could make a better outcome in both cryoablation and RF ablation.

3.4 | Relationship between the disturbance of atrioventricular conduction and Lumipoint-highlighted area

Among the total 30 patients, four had a transient AV block during the procedure. All four of these patients had a transient AV block by ablation at the site inside the Lumipoint-highlighted area, where large atrial fractionated potentials were recorded during sinus rhythm. In the mapping of the complex activation feature of the Lumipoint software, which focuses and re-highlights only areas with fractionated signals, the AV block site was coincident with the area highlighted by complex activation (peak slider: 3.8–5.6; median: 4.7). On the other hand, 27 of the 30 patients without AV block also had a focused and re-highlighted area with a large atrial fractionated potential around the His bundle area and the anterior-, mid-, and posterior of the ToK during sinus rhythm, with the peak slider ranging from 3.8 to 9.7 (median: 5.8). Of these 27 patients, three patients had no AV block even though ablation energy was applied at that focused area with fractionated signals.

Two representative cases (Case 1: RF ablation, Case 2: cryoablation) with a transient AV block are shown in Figure 4. While there were success sites at areas outside the Lumipoint-highlighted area in these cases, AV block sites were located inside the Lumipoint-highlighted areas, especially a focused area by complex activation with a large atrial fractionated potential. In addition, the success site and AV block site were in close proximity. As we could not identify the location of the compact AV node, further investigation is necessary to find that site to avoid an energy application for the risk of AV block.

4 | DISCUSSION

4.1 | Main findings

This current study provides new insight into optimal cryoablation sites by evaluation of the atrial activation pattern around the ToK during sinus rhythm in UHD mapping. Our major findings are as follows: (1) The collision site of two wavefronts of delayed atrial activation during sinus rhythm outside a Lumipoint-highlighted area coincided with a successful ablation site, where a spiky potential could be recorded. (2) Patients with a success site coincided with collision site outside Lumipoint-highlighted area had more frequent disappearance of SP after initial cryoablation and they had a smaller number of cryoablation and shorter procedure time compared to those without. (3) The area with fractionated and large atrial potential inside the ToK during sinus rhythm may be best avoided for ablation by any energy application. (4) These novel UHD mapping could help us to lead to greater safety and efficacy in SP modification.

4.2 | What is the endpoint in SP modification?

Katritsis et al. reported that higher, mid-septal lesions away from the anatomical site of inferior extensions were not appropriate for ablation and that while successful ablation affects the tachycardia circuit, the complete abolishment of SP conduction is not required.[7,8] Our result also was in accordance with another previous report, in which disappearance of SP after cryoablation was not the procedural endpoint.

In terms of the procedural endpoint in SP modification using cryoablation, it has been suggested that disappearance of the SP or no echo beat after ablation is a better outcome as an endpoint of cryoablation for the SP.[9] On the other hand, a multicenter study demonstrated no impact of the continued presence of SP after cryoablation on outcomes in slow-fast AVNRT.[10] As there was no recurrence of slow-fast AVNRT during the follow-up period (median, 375 days), we also detected no impact on the recurrence of tachycardia of a residual SP or a one-echo beat at the end of the session in this study. Thus, the non-inducibility of slow-fast AVNRT but not disappearance of SP is necessary for SP modification using cryoablation.

4.3 | Ultra-high-density mapping around ToK

A previous study suggested the atrial activation input to the His bundle over the antegrade SP during slow-fast AVNRT as a possible pathway from CS ostium inside the ToK to the His bundle via left atrial activation, while atrial activation over the antegrade fast pathway was functionally blocked on the tendon of Todaro.[11] The atrial activation pattern in UHD mapping may support this hypothesis of antegrade AV nodal dual pathways as it showed an excitation of the right atrial anterior septum over the fast pathway conduction connecting to the His bundle, and then, delayed atrial excitation inside the ToK via the antegrade SP conduction.

A previous study demonstrated that mid-septum turnaround sites of atrial activation during sinus rhythm coincided with success site for SP modification in slow-fast AVNRT.[12] In accordance with their report, our study supported that collision sites of 2 wavefronts of delayed atrial activation coincided with success sites. Furthermore, our study indicated that the collision site of outside Lumipoint-highlighted area that is, tricuspid-annulus side was better for safety and efficacy in SP modification.

4.4 | Pathophysiological feature of slow pathway and slow pathway potential

The antegrade conductive pathway in SP has been thought to be longer during tachycardia with an anatomically longer distance via the left atrium and CS. On the other hand, pathophysiological study suggested the conductive velocity of the SP has faster conductive tissue paradoxically, based on cytologic features: the SP, a part of lower nodal

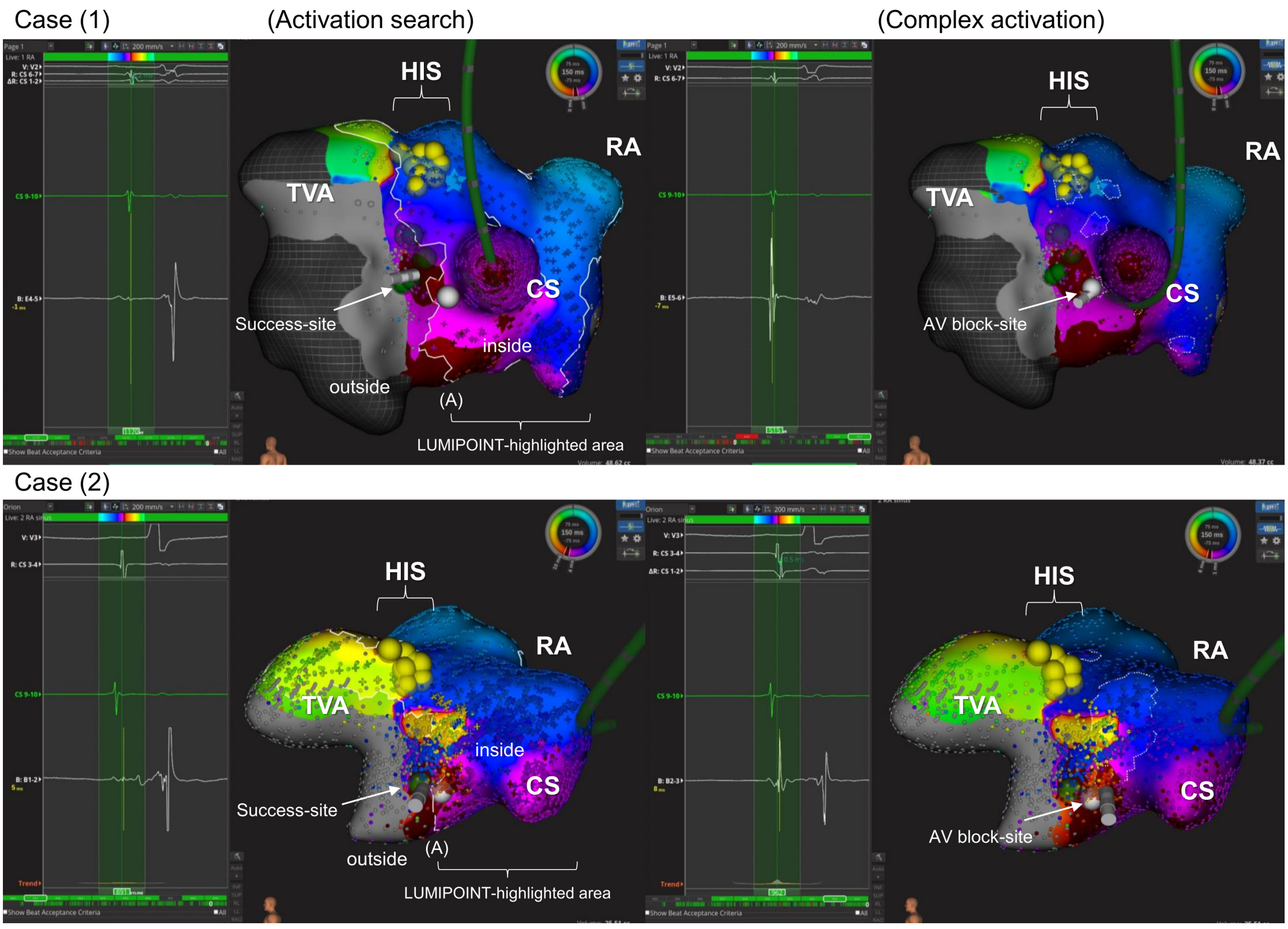

FIGURE 4 A representative case with a transient AV block during energy application inside the Lumipoint-highlighted area. Case (1) is an RF ablation case (upper panel) and Case (2) is a cryoablation case (lower panel). A successful RF ablation site was located outside the Lumipoint-highlighted area by the activation search function (*green tag*, *left panel*). The transient AV block site was inside the Lumipoint-highlighted area by the activation search function (*white tag*), and that area with fractionated signals was highlighted by the complex activation function (*right panel*). The success site was adjacent to the AV block site at the boundary of the Lumipoint-highlighted area by activation search in both cases. While a tiny SP potential was recorded at the successful ablation site, a large atrial fractionated potential was recorded in the AV block site adjacent to the success site. AV, atrioventricular; CS, coronary sinus; HIS, His bundle; RA, right atrium; TVA, tricuspid valvular annulus.

bundle, has extensive Connexin 43 tissue,[13] which has fast conductive property, while the compact AV node contains only slight Connexin 43 tissue, which presents slower conductive property.[14] Our results may suggest that the inconsistency in the cytologic pathophysiological features between SP and FP could make a possible collision pattern of two wavefronts of delayed atrial activation inside ToK. The collision pattern of atrial activation may be caused by the collided 2 wavefront with different conductive property based on the connexin 43 tissue.

The local electrogram in success site was possibly made of two components of atrial activation of far-field atrial potential via the fast pathway and near-field atrial potential via the SP with a collision pattern, which was consistent with previous findings, such as that the fractionated SP potential was a successful indicator in cryoablation.[15,16]

Among the 26 patients with a collision pattern of atrial activation, 23 had a spiky potential like His-bundle potential recorded at the collision site outside of the Lumipoint-highlighted area. That spiky potential could be recorded at the sites where is insulated from the sites around the peripheral tissue and it has a fast conduction property like His bundle with a rich of connexin 43. That spiky potential may be the potential of the lower nodal bundle which connects to the inferior nodal extension as a distal portion of SP conduction.[13] The area at the ventricular side of ToK is thought to be the atrioventricular septum where the high amplitude potential of left ventricle and the tinny far-filed potential of right atrium could be recorded. Thus, the smaller AV ratio could be recorded at that site.

However, because there is disagreement regarding the presence of lower nodal bundle in the human heart, the relationship between the electrical-conduction properties and features of the local potentials obtained by UHD mapping and that histological findings require careful interpretation and further investigation would be needed in the future.

4.5 | Lumipoint-highlighted area and slow pathway modification

Ablation at sites inside Lumipoint-highlighted area also achieved suppression of slow-fast AVNRT. However, our study indicated that the cases with ablation at sites inside Lumipoint-highlighted had a larger number of energy application to treat slow-fast AVNRT and a longer procedure time compared to those without because slow-fast AVNRT could be induced repeatedly after several energy applications by insufficient modification to antegrade conduction of SPs.

Lumipoint algorithm could not highlight the area of atrial activation of tricuspid-annulus side inside ToK because of automatic excluding of far-filed atrial potential. However, delayed and tiny SP potential could be recorded outside that highlighted area using a multielectrode basket catheter.

As shown in Supplementary Figure S1, the atrial excitation was abruptly delayed across the boundary of Lumipoint-highlighted area: line (A), suggesting the atrial activation area with an inconsistency in the timing of atrial excitation.

In 22 cryoablation patients, 15 patients had success sites that coincided with the collision site outside Lumipoint-highlighted area, it is noteworthy that those who had smaller number of cryoablation needed to suppress slow-fast AVNRT compared to those without. Of 15 cryoablation patients with success sites at collision sites outside Lumipoint-highlighted area, seven patients had disappearance of SP by the initial cryoablation. On the other hand, the remaining seven cryoablation cases had final success sites at the collision site of inside Lumipoint-highlighted or the sites of non-collision region, and they needed a larger number of ablations to suppress tachycardia. However, even if the final energy application inside Lumipoint-highlighted area suppressed tachycardia as a final success site, it is also possible that the multiple prior lesions created at other sites affected the effectiveness of SP modification. Although the strict definition of the success site to suppress tachycardia in such seven patients needed multiple ablations is difficult to interpret, the minimum number of ablation to suppress tachycardia would be better, considering the risk of AV block. The majority of the patients who had a collision pattern of atrial activation also had a spiky potential like His-bundle potential recorded at the collision site outside of the Lumipoint-highlighted area. Fifteen cryoablation patients and seven RF ablation patients had success sites that coincided with the collision site outside the Lumipoint-highlighted area.

Our study suggested that the spiky potential recorded at the collision site outside a Lumipoint-highlighted area could be the optimal targeting potential.

4.6 | Safe ablation for SP modification

Previous studies have reported an incidence of around 0.1%–0.4% of permanent AV block related with RF ablation for SP.[17–19] Cryoablation has the major advantage of entailing a low risk of permanent AV conduction disturbance for a reversible cryothermal effect. However, we have to keep in mind the risk of AV block, which occurs in some patients whose earliest atrial activation site over the retrograde AV nodal fast pathway lies inside the posterior ToK.[20] Individual anatomical variations around Koch's triangle may make it difficult to identify the location of the compact AV node during the procedure.[21] The representative cases had a transient prolongation of the PQ interval during ablation inside the Lumipoint-highlighted area in the posterior site of the ToK, as shown in Figure 4. Successful SP modification ablation was outside the Lumipoint-highlighted area. The success site outside the Lumipoint-highlighted area was found to be anatomically proximal to the site with occurrence of an AV block inside.

All four patients who were observed to have a transient AV block in this study underwent the SP modification ablation at the sites inside a Lumipoint-highlighted area, that is, at the more atrial side. Regarding safety, we propose that SP modification ablation outside of Lumipoint-highlighted areas, that is, at the ventricular side, is better even if any energy application is used. Radiofrequency energy application at that site with a larger AV ratio is to be avoided in particular.

When cryoablation was first introduced, the optimal parameters for SP modification using cryoablation were not established. By determining the physiological characteristics of the reversibility of the disturbance of AV conduction by the application of cryoenergy, cryoablation at the sites of larger AV ratios was acceptable. However, ablation at sites with a larger AV ratio around the ToK was at risk of advanced AV block, as several patients could have a compact AV node inside the posterior ToK as shown by our present analyses. It is well known that there is electro-anatomical variance inside the ToK.[20,21] In all, four patients with a transient AV block exhibited coincidence between the AV block sites and the area with fractionated and large atrial signals highlighted by complex activation inside the ToK. In contrast, 27 of the 30 patients without AV block also had a focused area highlighted by complex activation with a large atrial fractionated potential around the ToK during sinus rhythm. Of these 27 patients, three had no AV block despite the energy application at that focused area with fractionated signals. It remains unclear whether the fractionated and large atrial signals inside the ToK during sinus rhythm could help us identify areas with a possible risk of injury to AV conduction. Further careful and detailed investigations are necessary to address this question.

A previous study[22] suggested that the patients who underwent the SP ablation had more frequent requirement of pacing device during long-term follow-up after ablation. To avoid the adverse effect on AV conduction by multiple energy applications, energy application for the collision site of tricuspid-annulus side might have a better outcome in SP modification.

Our results could support that (i) the AV ratio of the sites of SP modification ablation could be used as a parameter of risk of AV block, and (ii) the fractionated atrial potential consisting of a far-field dull potential and a near-field spiky potential could be useful as a parameter of the efficacy of SP modification.

4.7 | Limitations

This was a single-center investigation with a small study population. The analysis of atrial-activation pattern using UHD mapping was performed in a small population with slow-fast AVNRT. No evaluation of control subjects without the antegrade SP pathway was performed in our study.

That spiky potential was not spatiotemporally consistent with the potential of local atrial activation, and Lumipoint algorism is applied in this study to make a difference to identify those potentials. It is not necessary to use the UHD mapping system in all SP ablation cases. However, a precise investigation of the electro-anatomical features around the ToK using UHD mapping would provide new insight and help us for optimal SP modification in slow-fast AVNRT. Further investigation is needed to find the optimal ablation site to avoid AV block and achieve better outcomes.

5 | CONCLUSIONS

The results of this study demonstrated that the collision site of delayed atrial activation in the ToK could be a successful ablation site under any energy application. SP modification targeting collision sites at the tricuspid-annulus side of ToK along with a spiky potential could provide a better outcome.

AUTHOR CONTRIBUTIONS

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All authors contributed to the study concept, design, data analysis and statistical interpretation, and drafting and revision of the article. All approved of the final article.

FUNDING INFORMATION

None.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICAL APPROVAL

The study protocol was approved by the hospital's institutional ethics review board. This study conformed to the guidelines outlined in the Declaration of Helsinki.

PATIENT CONSENT

Informed consent was obtained in the form of opt-out on the web-site.

CLINICAL TRIAL REGISTRATION

None.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Watanabe T, Hachiya H, Watanabe H, Anno K, Okuyama T, Harunari T, et al. Relationship between the atrial-activation pattern around the triangle of Koch and successful ablation sites in slow-fast atrioventricular nodal reentrant tachycardia. J Arrhythmia. 2024;40:363–373. https://doi.org/10.1002/joa3.12999