Atrial pace mapping using automatic intracardiac pattern matching for ablation of non-sustained atrial tachycardia: a case report

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Introduction

Atrial pace mapping (APM) is a technique for pinpointing the source of typically focal arrhythmias that do not maintain stability during an electrophysiological study and are unsuitable for activation mapping.[1] This method uses pattern comparison between p-waves on a surface-electrocardiogram and intracardiac (IC) signals during atrial tachycardia (AT) and pacing from a suspected origin point. Traditionally, APM depended on subjective visual analysis of IC signals and paced P wave morphology. The CARTO® 3 system (Biosense Webster, Irvine, CA) has recently incorporated an automated intracardiac pattern matching (ICPM) algorithm which uses the unipolar signal from a reference electrode, typically placed in the coronary sinus (CS).[2,3] The APM employing dual chamber electrograms as a reference and a matching score calculated via ICPM software has been shown to have high differentiation accuracy. Ensite™X system (Abbott Laboratories, Abbott Park, IL) is a competing navigation system that does not provide an ICPM algorithm. Still, it allows the creation of automated ECG-score maps where specific ECG channels can be selected for pattern matching.[4] We report a first case of mapping and ablation of nonsustained AT, in which we used an automated ECG pattern-matching algorithm of the EnsiteX system using intracardiac unipolar atrial signals.

Case report

A 63-year-old man was referred to our facility for catheter ablation (CA) of highly symptomatic recurrent episodes of palpitations. The episodes of AT with a cycle length (CL) of 420 to 510 ms could be documented on the patient's smartwatch (Figure 1A). The patient had a history of hypertension and persistent AF with a CHA2DS2-VASc score of 1. He had normal cardiac function and no evidence of structural heart disease. The patient experienced early arrhythmia recurrence in the first month after initial pulmonary vein (PV) isolation with radiofrequency (RF) technique performed 6 months before the current admission.

The CA was performed under conscious sedation with an EnsiteX electroanatomic mapping system using a decapolar catheter in the CS and a quadripolar catheter in the high right atrium (HRA) as reference (Figure 1B). A high-density map of the left atrium (LA) and right atrium (RA) using a multipolar mapping catheter (HD-Grid, Abbott Laboratories) showed neither evidence for PV reconnection nor low-voltage areas. During an electrophysiologic study with atrial as well as ventricular programmed and burst pacing, neither AT nor AF could be induced. We induced short runs of nonsustained AT with 1:1 atrioventricular conduction, a CL of 420 ms and reproducible IC sequence by isoproterenol challenge (30 mcg/min intravenously) with programmed stimulation (Figure 1C). The similarity of the CL of induced nsAT and clinical AT suggested that the induced nsAT corresponded to the clinical one. Catheter manipulation during mapping in the RA resulted in mechanical bumping of the AT, which was already nonsustained. Therefore, the activation mapping of even shorter runs of AT could not be continued (Figure 2A).

To localize the origin of the AT, we performed APM with automated ICPM matching using the following technique. A decapolar and a quadripolar diagnostic catheter were positioned in the CS and HRA. Three poles of the CS catheter and three of the HRA catheters were connected to the precordial leads V1–V6 accordingly via a custom-made adapter (Supplemental Figure 1) to acquire and provide the unipolar signals to the EnsiteX system for further automated pattern matching (Figure 1D). When the short run of nonsustained AT was induced, the pattern of the intracardiac unipolar signals from CS and HRA catheters were acquired via ECG channels V1–V6 in the EnsiteX system. Other ECG channels were excluded from the pattern analysis. The pattern window and triggering criteria were set manually by the operator. APM was performed via a

KEYWORDS Catheter ablation; Atrial fibrillation; Atrial tachycardia; Non-pulmonary vein trigger; Atrial pace mapping; Automatic technique; Case report

(Heart Rhythm Case Reports 2024;10:794–797)

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https://doi.org/10.1016/j.hrcr.2024.07.022

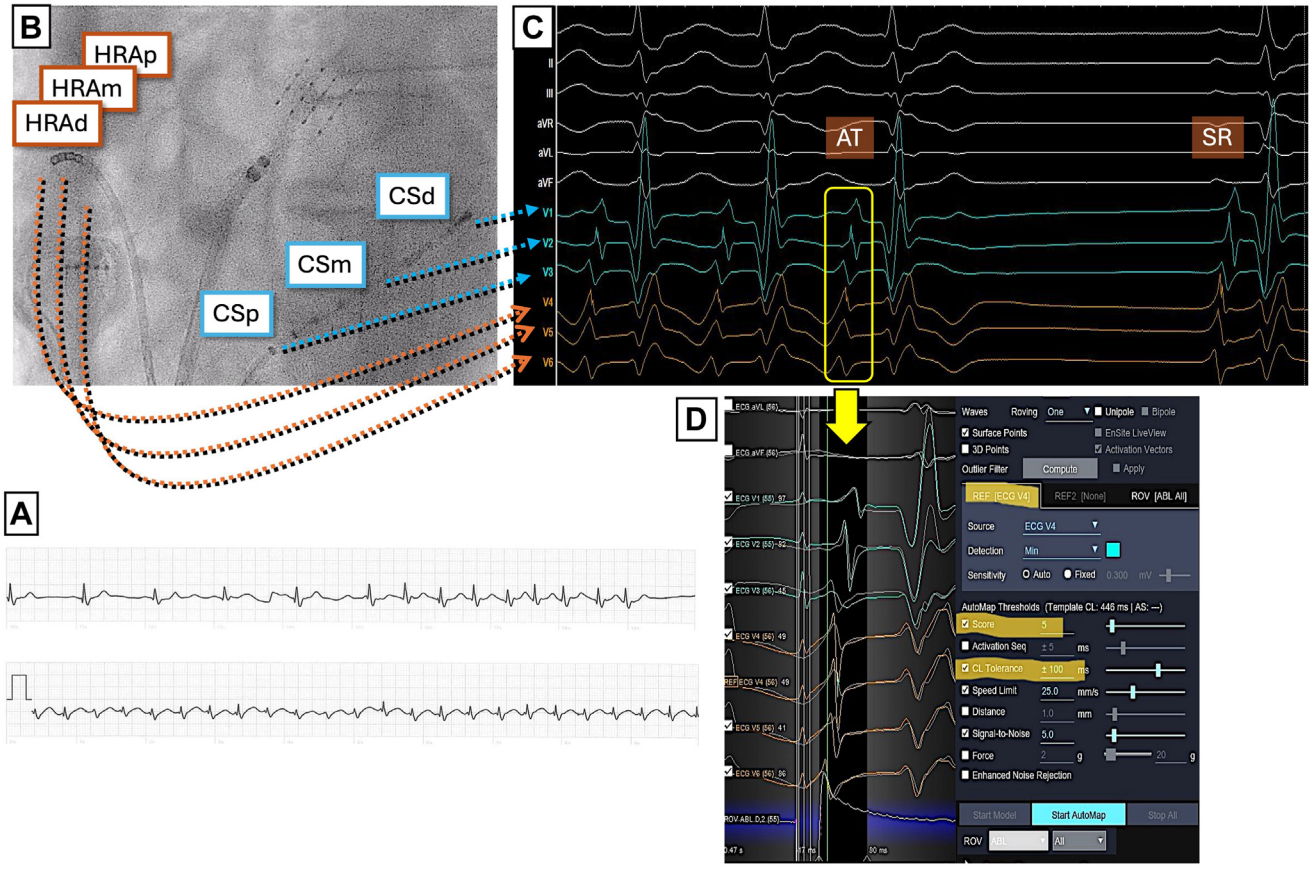

Figure 1 Atrial pace mapping workflow. **A:** Clinical AT episodes recorded by the smartwatch. Note the on/off phenomenon and variable cycle length (a short run with a variable cycle of 510–420 ms and a sustained episode with a stable cycle of 420 ms) and 1-to-1 atrioventricular conduction, suggestive of the ectopic character of the tachycardia. **B:** Fluoroscopic positions of the referent catheters in the CS and HRA. Three electrodes of the CS catheter and three of the HRA catheter are connected to the precordial leads to acquire the unipolar signals for the EnsiteX ECG pattern algorithm. **C:** Acquisition of the intracardiac unipolar signals during atrial tachycardia with 1-to-1 atrioventricular conduction and a cycle length of 420 ms induced by programmed atrial pacing with isoproterenol infusion. V1–V3 leads represent the signals from the CS catheter, and V4-V6 leads correspond to the signals from the HRA catheter. **D:** A setup for the pattern-matching score map using only V1–V6 leads representing the unipolar signals from the double-chamber referent. The reference trigger is set to the minimal deflection of the V4 (HRAd). This way, the trigger will align the referent with paced pattern windows. The pacing CL is set to the AT cycle length ±100 ms with corresponding CL Tolerance criteria, excluding all noncaptured beats. AT = atrial tachycardia; CS = coronary sinus; HRA = high right atrium; LAT = local activation time; SR = sinus rhythm.

contact-force enabled ablation catheter (Tactiflex, Abbott Laboratories) with the output 5 V/1 ms from different locations in the LA and RA using the automatic ECG pattern matching algorithm of the EnsiteX system. The isoproterenol infusion was continued during the pace mapping to promote an identical local and global conduction velocity as during pattern acquisition. Fluoroscopic control was also used to exclude macro dislocation of the referent catheters, and the initial position was confirmed by tracking the IC pattern during sinus rhythm. The points at each pacing site were automatically acquired and assigned to the "score map" when the pattern-matching score was positive, with only a few points needing to be reinspected manually to readjust the trigger for correct pattern alignment. The area of the best matching score was revealed at the posterior wall of the RA, with the highest score of 75% (Figure 2B). The area of the best 10% strata of the matching score was 0.1 cm^2. Detailed pace mapping with 50 points took 8 minutes, 41 seconds (Supplemental Video 1).

Six RF applications were delivered in this area with 50 W/10 seconds each (total RF time 45 seconds). Pacing in this area showed a loss of capture. The programmed and burst atrial pacing was repeated during continued isoproterenol infusion, and no AT was observed after the CA. No AF was induced during the whole procedure.

Finally, we performed a post hoc analysis of the pattern-matching distribution for the scenario with a single referent catheter in the CS. The maximal matching score with a single chamber referent was 94%, and the area of the best 10% strata of the matching score was >7 cm^2 (Figure 2C). After 6 months of follow-up, the patient was free from arrhythmia.

Discussion

The unstable nature of non-sustained focal AT or non-PV triggers does not allow local activation time mapping to reveal their site of origin.[5] Different methods of searching for arrhythmia have been reported but are limited in case

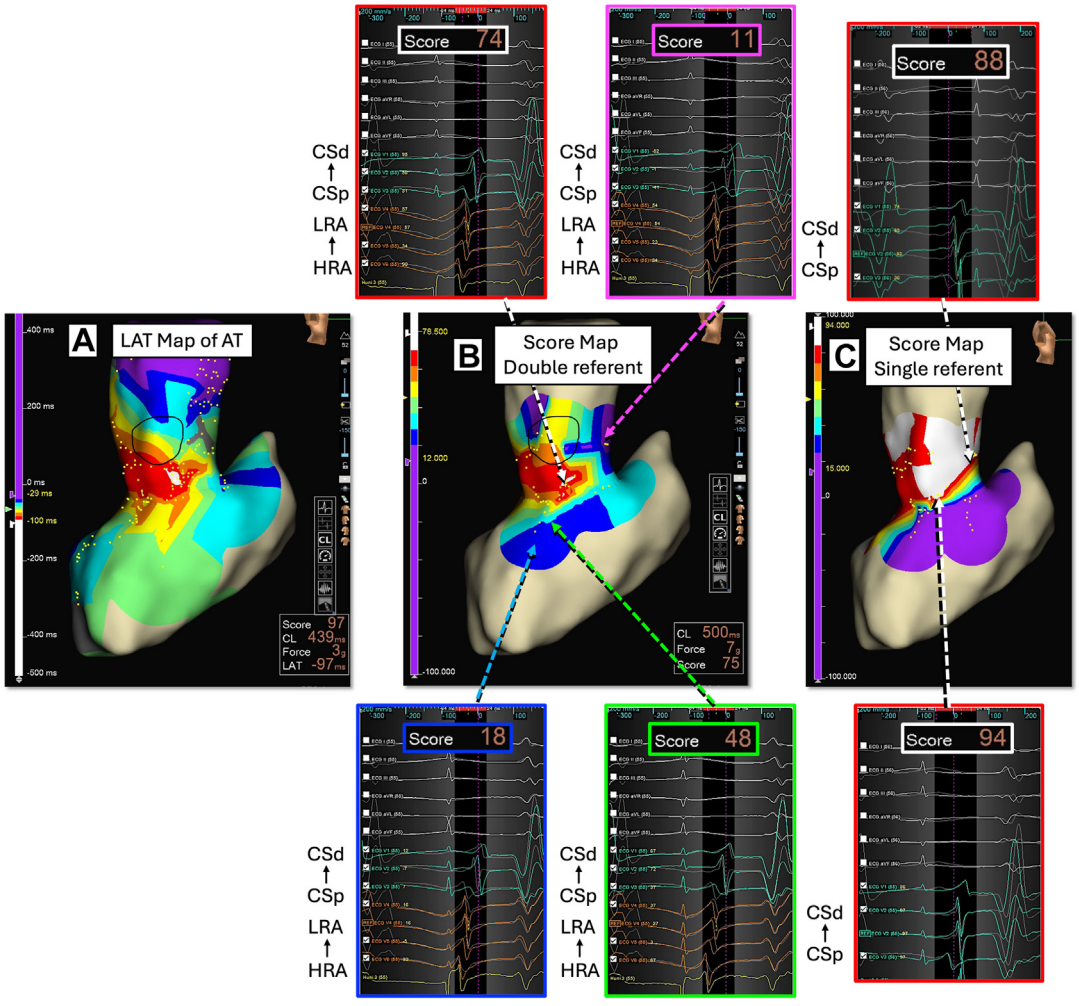

Figure 2 **A:** Local activation time map of the atrial tachycardia performed before bumping. The region above the earliest activation site (encircled by the black line) is not mapped. **B:** A score map created by atrial pace mapping with a double chamber reference and representative examples of different degrees of intracardiac pattern matching. Note the relatively low best matching score but a small area (0.1 cm^2) of the top 10% strata. Moderate matching scores inside the encircled area excluded the origin there. **C:** A score map created by atrial pace mapping with a single chamber reference and representative examples of different degrees of intracardiac pattern matching. Note the high pattern similarity score's large (>7 cm^2) area. AT = atrial tachycardia; CS = coronary sinus; HRA = high right atrium; LAT = local activation time; LRA = low right atrium.

of poor inducibility or AF initiation immediately from the single beat.[6–9] The spatial resolution for APM using a 12-lead ECG is 17 mm because of the high noise-signal ratio of the P waves.[10] This approach becomes even more challenging in the case of P wave–T wave fusion or patients with prior catheter ablation, cardiac surgery, or severe atrial fibrosis, in whom paced P-wave morphology can often be difficult to judge. To enhance the precision of the APM, Hayashi and colleagues[1] proposed combining the P wave morphology and bipolar EGM sequences recorded from multiple catheters.[1] However, this approach relies on the operator's subjective judgment of the timing and EGM morphology and is time-consuming. After an automated ICPM algorithm was introduced into the Carto3 mapping system to track the stability of the AT, Yamashita and colleagues[2,3] proposed an APM approach using ICPM with dual-chamber reference from CS and RA. As the Carto3 system does not provide a way to reflect the ICPM score on the 3-dimensional map, the authors described the workaround by manually assigning the scores to the timing of the LAT map, which is also time-consuming.

The EnsiteX system does not have an algorithm for ICPM, but it provides surface ECG pattern matching.[4] A user can select the ECG channels that should be included in the matching score calculation. Moreover, these matching scores may be directly reflected on the 3-dimensional "score map." In our case, to perform automatic ICPM, we connected 3 electrodes of the CS catheter and 3 electrodes of the RA catheter to precordial leads to acquire unipolar intracardiac signals into the matching algorithm (Supplemental Figure 1). We excluded the surface ECG channels from the analysis to neglect the T wave influence on the matching score. Pacing from the ablation catheter with a 3.5-mm tip electrode can capture a wider myocardial area than via a diagnostic catheter with smaller electrodes. On the other hand, contact force monitoring provides consistent capture with a more precise location of the pacing site and avoids catheter-induced arrhythmia.

The matching score calculation was highly dependent on the triggering of the reference and on the micromovement of the referent catheter during the breath cycle. Therefore, we observed beat-to-beat score fluctuations even without repositioning the pacing catheter.

There is no data on the optimal matching score threshold. The maximal matching score observed in our case was only 75%, with a centrifugal distribution of the matching scores. Therefore, several RF applications were delivered at the point of the highest matching score and 1.3 cm^2 around it to neglect a potential spatial imprecision of the APM.

The comparison of the score maps performed with single- versus double-chamber referent showed higher precision in the APM with double-chamber referent. This might reflect the preferential conduction along the CS and Bachmann bundle from the RA to the LA, which produces a similar conduction front in the LA despite the pacing from the different locations in the RA.

One potential advantage of this method that should be evaluated further might be the ability to map multiple origins sequentially when their IC patterns are captured, and IC reference catheters remain stable. A retrospective "TurboMap" with multiple IC patterns may significantly accelerate the procedure.

Limitations of this approach include needing a custom-made adapter for intracardiac signals to precordial leads V1–V6, limited unipolar signals (six), and high dependency on reference triggering, which can be distorted by pacing artefacts. Precordial leads of surface ECG are sacrificed. The highest matching score of only 75% might reflect (1) greater sensitivity of IC signal morphology to catheter stability than ECG morphology (optimal score 95%+) and (2) a large area of captured atrial tissue causing deviation from the IC pattern of AT. Some points had to be reinspected manually if the automatic trigger was set inappropriately because of IC pattern fluctuations. These technical and algorithmic issues should be thoroughly evaluated and addressed while developing a dedicated APM module for the mapping system.

Conclusion

Our case demonstrates the high differentiation accuracy of APM of nonsustained AT, using automated intracardiac pattern matching to create a matching score map directly. This approach might be helpful when precise activation mapping is not applicable.

Acknowledgments

We thank Natalie Abraham for her support in developing the pattern-matching setup and Fabian Moser's help in preparing the case.

Funding Sources: None.

Disclosures: The authors have no conflicts of interest to disclose.

Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrcr.2024.07.022.

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