Novel atrial pace-mapping technique based on dual-chamber electrograms to detect non–pulmonary vein foci

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Introduction

Although pulmonary vein (PV) isolation is a well-established therapy for atrial fibrillation (AF), >20% of patients experience recurrence of AF.[1] Several studies have reported the importance of non-PV foci in triggering AF.[2,3] If non-PV foci are successfully detected and eliminated, the AF recurrence rate following catheter ablation (CA) could be low. However, in some cases, non-PV foci are difficult to identify and eliminate, especially in cases where only 1 ectopic beat initiates AF or because non-PV foci cannot be reproducibly induced even with dedicated induction.[4] In ventricular arrhythmia, an automated pace-mapping system (PASO™ Module; Biosense Webster, Diamond Bar, CA) allows direct comparison between paced QRS morphology and the QRS wave of acquired ventricular arrhythmia during ablation.[5,6]

Conversely, atrial pace mapping is not commonly used for atrial arrhythmias because the P-wave morphology on surface 12-lead electrocardiogram is a dull signal with a low amplitude compared with the QRS wave.[7]

The Intracardiac Pattern-Matching (ICPM) software (CARTO 3; Biosense Webster) automatically identifies changes in unipolar signals recorded by the reference catheter and assigns each pattern to its respective map without operator intervention.[8] We developed a novel atrial pace-mapping technique called Intracardiac Pace Match Scoring (iPASO) using dual-chamber electrograms (EGMs) as a reference that reflects the matching score calculated by the ICPM software on the local activation time (LAT) map. Herein, we present 2 patients with non-PV foci detected using a novel atrial pace-mapping technique.

KEYWORDS Catheter ablation; Atrial fibrillation; Non–pulmonary vein foci; Atrial pace mapping; Mapping technique; Automated technique

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KEY TEACHING POINTS

- Treatment of non–pulmonary vein foci is crucial for the treatment of atrial fibrillation; however, atrial fibrillations that developed from a single trigger beat are difficult to map and cannot be treated.
- Although the pace-mapping software is useful for ventricular arrhythmias, there is no optimal pace-mapping method for atrial arrhythmias.
- Dual-chamber intracardiac electrograms as a reference enable us to conduct precise pace mapping in the atria and search for even a single trigger beat.

Case report

Case 1

The patient was a 77-year-old woman who was referred to our hospital with palpitation caused by paroxysmal AF. On admission, her electrocardiogram showed a sinus rhythm at a rate of 62 beats per minute, and echocardiography showed a reduced ejection fraction of 40% with mild left atrial enlargement. Under general anesthesia, the first CA session was performed using an open-irrigated contact force–sensing catheter (ThermoCool SmartTouch ST-SF; Biosense Webster) with an electroanatomical mapping system (CARTO 3, Biosense Webster). A 6F 20-pole electrode catheter (BeeAT; Japan Lifeline, Tokyo, Japan) was inserted through the right jugular vein into the coronary sinus (CS) as a reference to obtain dual-chamber EGMs from the CS and right atrium (RA). After circumferential PV isolation, AF was induced by a single ectopic beat using bolus injection of isoproterenol (Figure 1A). However, the AF spontaneously resolved.

We performed a novel atrial pace-mapping technique (iPASO) to identify the earliest activation site of the non-PV trigger. The iPASO technique is performed as follows

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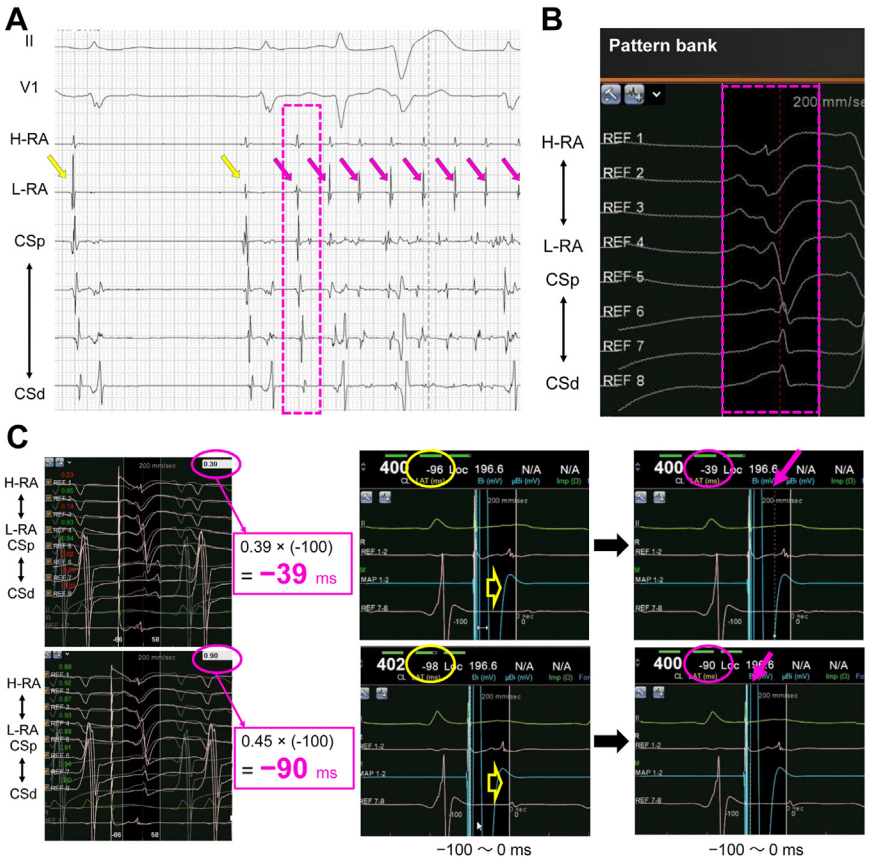

Figure 1 **A:** Intracardiac recordings showing sinus rhythm (*yellow arrow*) and atrial fibrillation initiation from a non–pulmonary vein trigger (*pink arrow*). **B:** Reference signals of trigger premature atrial complex recorded from the coronary sinus (CS) and right atrium (RA). **C:** Representative examples of the iPASO (Intracardiac Pace Match Scoring) technique. The upper panels show the pace match score of the paced signals and reference electrograms of 0.39.

(Supplemental Video 1): (1) Dual-chamber EGMs of the trigger beat on the ICPM module were recorded as a reference (Figure 1B). (2) A new LAT map was created with window of interest from -100 to 0 ms. (3) Detailed pace mapping was performed at each site using a contact force–sensing catheter with minimal output (monophasic 2–5 V at 0.4 ms) generated by a stimulator (SEC-5104; Nihon Kohden, Tokyo, Japan). The pacing cycle length was adjusted to the coupling interval of a trigger beat. Moreover, the matching pattern window of interest was adjusted to escape the stimulus artifact. (4) The average value of the matching score of the paced signals and the reference EGMs were automatically calculated by ICPM software, and the obtained average value was multiplied by (-100 ms). (5) The annotation timing was manually moved to a value equal to the obtained score (Figure 1C). For example, if the matching score was 0.60, the annotation timing was set to -60 ms, and if the matching score was 0.90, the annotation timing was set to -90 ms manually, regardless of the presence of a potential. In summary, the highest score indicates the earliest activation site. Finally, detailed pace mapping was performed at 19 points, and the matching score was acquired from 0.39 (-39 ms) to 0.90 (-90 ms) at the left atrial anterior wall (Figure 2). Pace mapping took 300 seconds. The LAT map indicated a centrifugal activation pattern, and 6 radiofrequency applications were delivered around the earliest activation site. Isoproterenol was administered, and atrial burst pacing was repeated; however, no atrial tachyarrhythmia was observed. The patient remained free from AF/atrial tachycardia (AT) for 6 months after the procedure.

Case 2

The patient was a 52-year-old man with a history of 2 CA procedures for persistent AF who underwent pulmonary isolation, posterior wall isolation, and superior vena cava isolation. However, 1 year after the final treatment, he experienced palpitations caused by AF, and controlling the rate and rhythm despite medications was difficult. Echocardiography revealed a reduced left ventricular ejection fraction of 34% and mild mitral regurgitation with a left atrial dimension of 46.0 mm. The third CA was performed using an open-irrigated contact force–sensing catheter (ThermoCool SmartTouch ST-SF; Biosense Webster) with an electroanatomical mapping system (CARTO 3; Biosense Webster) under general anesthesia. A 6F 20-pole electrode catheter (BeeAT; Japan Lifeline) was inserted through the right jugular vein into the CS as a reference to obtain dual-chamber EGMs from the CS and RA. After confirmation that the 4 PVs, left atrial posterior wall, and superior vena cava were

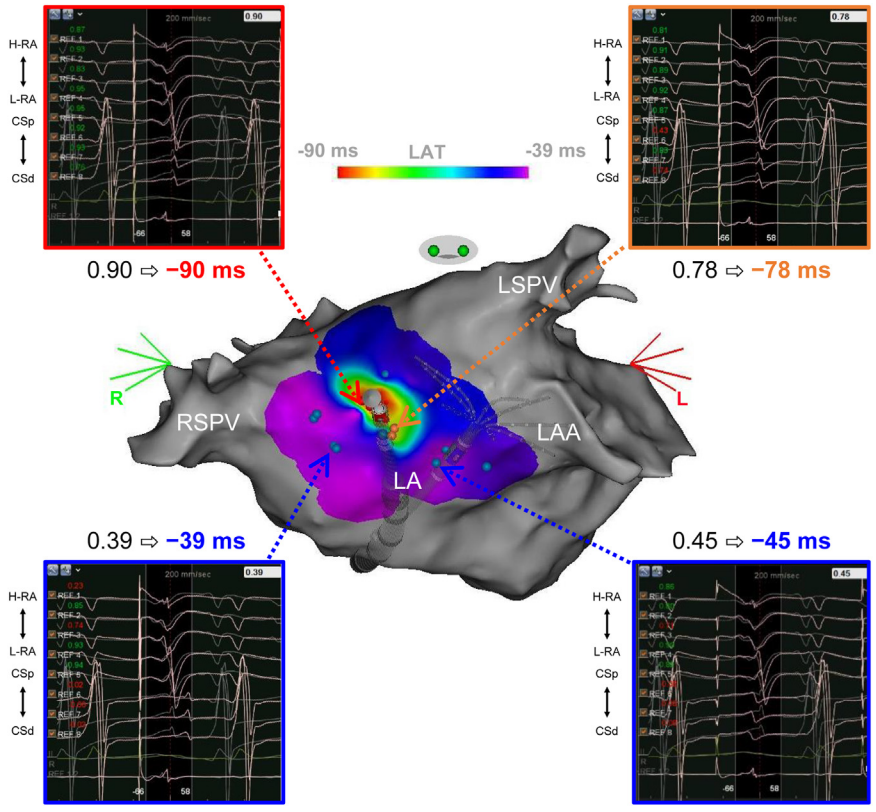

Figure 2 Representative example of an iPASO (Intracardiac Pace Match Scoring) map. The highest matching score is 0.90, calculated as -90 ms, and the scores at the surrounding area are 0.78 (-78 ms, orange), 0.45 (-45 ms, blue), and 0.39 (-39 ms, blue). In other words, the highest score was displayed at the earliest activation site (EAS), similar to a centrifugal pattern with an EAS in the left atrial anterior wall. In this manner, the high and low matching scores obtained from the pace map can be displayed in the mapping, which is useful for determining the origin of the trigger foci.

completely isolated, AF was induced spontaneously after atrial burst pacing with an injection of isoproterenol. The AF was not spontaneously terminated, and external cardioversion was performed at 100 J. As the patient had AF from 1 ectopic beat and reduced ejection fraction, cardioversion might exacerbate heart failure. Therefore, we searched the non-PV trigger site using the iPASO technique. In this case, the highest score was 0.90 (-90 ms) from the inferior tricuspid annulus (6 o'clock direction). Detailed pace mapping was performed around the highest-scoring site. The score obtained for the surrounding area was lower and showed a centrifugal pattern on the iPASO map (Figure 3 and Supplemental Video 2). Finally, pace mapping was performed at 11 points, and the matching score was acquired from 0.15 (-15 ms) to 0.90 (-90 ms). Pace mapping took 213 seconds. Six radiofrequency applications were delivered around the site with the highest matching score. Isoproterenol was administered, and atrial burst pacing was repeated; however, no atrial tachyarrhythmia was observed. The patient had no AF/AT recurrence for 6 months.

Discussion

Despite reports on several mapping procedures for non-PV triggers[9–11] and focal AT, previous studies reported on methods of searching for arrhythmia using a mapping catheter, which has limitations in cases of poor inducibility or AF initiation from a single trigger beat. In ventricular cases, the reference QRS morphology and paced QRS morphology could be compared using the PASO module[5]. However, unlike the QRS morphology, the P wave has small and dull potential; thus, comparing the reference P wave with the paced P-wave morphology is difficult. According to Man and colleagues,[7] the spatial resolution of atrial pace mapping is approximately 17 mm, which is not clinically useful. Hayashi and colleagues[12] also reported that a more detailed mapping is possible by combining the P-wave morphology and bipolar EGM sequences recorded by CS. However, as we reported previously,[11] the single-chamber reference of the CS has some limitations in distinguishing the target site from other arrhythmias, including catheter-induced and fusion beats. Therefore, combining the CS signals with the RA signals from the 2 axes is more accurate than combining the waveforms recorded from the CS alone. Thus, the matching score of the pace mapping obtained by the ICPM module is an automatically calculated value that is considered to have high reproducibility and objectivity without the influence of operator judgment.

The pace mapping–obtained matching scores were evaluated on a scale of 0–1.0. However, there is no way to reflect the matching score in 3-dimensional mapping as in the correlation map obtained by PASO. Therefore, the matching score

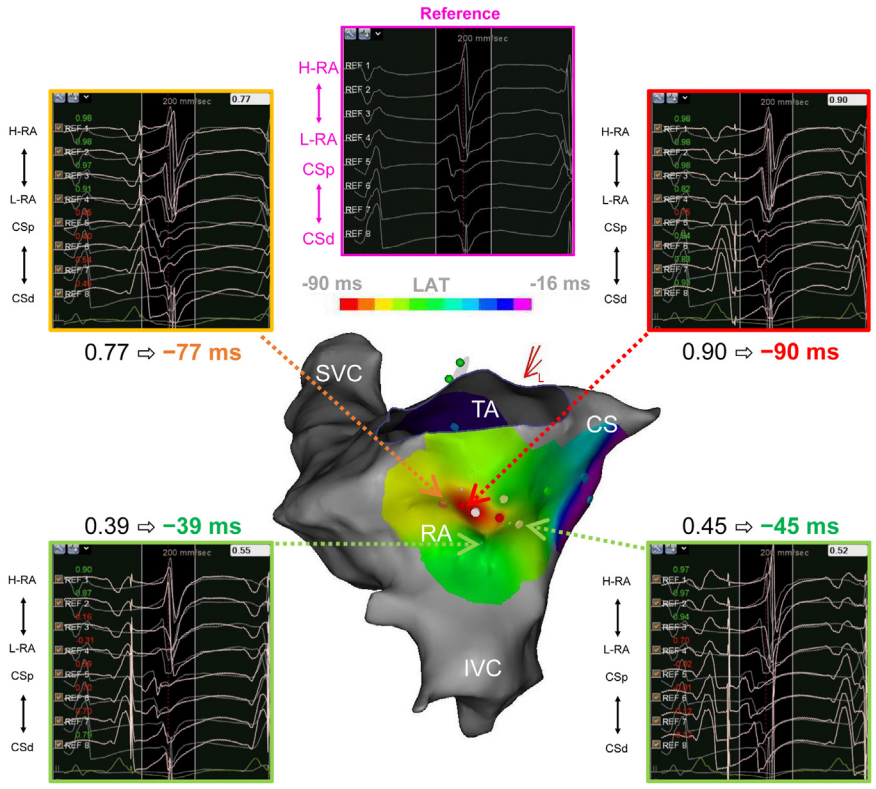

Figure 3 The iPASO (Intracardiac Pace Match Scoring) map of case 2. The earliest activation site of the trigger foci was the coronary sinus proximal region (pink). In this case, the highest score was 0.90 (-90 ms), and the surrounding scores were 0.77 (-77 ms), 0.45 (-45 ms), and 0.39 (-39 ms). A centrifugal pattern with the earliest activation site at the 12 o'clock position of the tricuspid annulus was observed (Figure 2).

can be reflected in the LAT map as the LAT by manually performing timing annotation based on the time obtained by multiplying the obtained matching score by (-100 ms). Although the timing annotation is done manually, it is based on the matching score calculated automatically by the ICPM software, which is weighted and averaged. With the ICPM software, reproducible and objective mapping can be obtained without the operator's experience or intention. The pace match map is similar to a PASO correlation map, where the highest matching area is the earliest activation site from which an image is obtained that propagates in a centrifugal pattern.

However, whether using a 3.5 mm electrode tip ablation catheter or multielectrode mapping catheter is better for pace mapping is unclear. Of course, the size of the electrode tip of the ablation catheter is larger than that of the mapping catheter, which may capture a wider area of the myocardium. However, the contact force helps reproduce the pace and avoids catheter-induced arrhythmia.

These 2 cases presented were non-PV foci of the left atrial anterior wall and CS ostium origin; however, further studies are needed to investigate whether the iPASO technique could identify the origin of other locations, such as the left atrial posterior wall, left atrial appendage, atrial septum, crista terminalis, right atrial appendage, and vein of Marshall. In addition, this atrial pace-mapping technique searches for the earliest activation site of the trigger beat, and the same is considered true when searching for the EAS site of focal AT.

This study has some limitations. First, this is only a case report; a case series would be able to confirm the usefulness of the novel atrial pace-mapping technique. Second, because isoproterenol was administered at the time of induction, the propagation time of intra-atrial excitation may have been affected, which may have caused some degree of dissociation between the morphology of the reference EGMs. Third, the reference EGMs were unipolar signals that fluctuated with respiration compared with bipolar signals. Despite the lack of an absolute optimal cutoff value for the matching score, a higher score should be better, but pacing artifact may affect the score, and a score of 0.80–0.85 should be reasonable. Fourth, the procedure might not be applicable in patients with impaired atrial structure who have very high thresholds for stimulation and unclear atrial potentials because the reference EGMs may have a low voltage. In addition, AF does not necessarily begin with the same beat and may start with different beats in each event. In such a situation, it would be necessary to perform additional mapping and treatment again. Finally, the pace-mapping technique might have limitations with respect to the epicardial origin, including the preferential pathway.

Conclusion

The cases presented herein demonstrated the usefulness of the iPASO technique to detect a non-PV trigger, especially AF with low inducibility and immediate AF reinitiation.

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Appendix

Supplementary Data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrcr.2023.07.014.

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