A novel approach to visualizing an underlying atrial arrhythmogenic substrate with high-density and high-resolution mapping during extrastimulation

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Introduction

Pulmonary vein isolation (PVI) has been established as an effective treatment for atrial fibrillation (AF), yet a certain number of patients still experience recurrence with PVI alone. Beyond the PVI, various techniques such as linear ablation, complex fractionated atrial electrogram ablation, and low-voltage-area ablation have been explored; however, none of these methods has been definitively established, and their efficacy remains a topic of debate.[1] It is well documented that atrial premature contractions can serve as a trigger for the onset of AF.[2] When conduction with a short coupling interval occurs, it is hypothesized that the conduction velocity and unidirectional block can be affected, potentially leading to arrhythmogenesis. Recent technological advancements have facilitated the swift acquisition of high-density, high-resolution electroanatomical maps. In this report, we present 2 cases in which we were able to elucidate the arrhythmogenic substrate by concurrently creating maps during extrastimulation in addition to conventional mapping and evaluating the differences between them.

KEY TEACHING POINTS

- High-density, high-resolution electroanatomical mapping during extrastimulation can reveal hidden arrhythmogenic substrates undetectable with conventional mapping.
- Simultaneous creation of S1 (basic cycle) and S2 (extrastimulus) maps allows for detailed comparison and identification of arrhythmogenic substrates. In the presented cases, S2 maps revealed abnormal electrical activity not visible on S1 maps.
- Combining ripple map evaluations with S2 maps can enhance the accuracy of identifying arrhythmogenic substrates and improve ablation outcomes.

Case report

Case 1

A 56-year-old male patient was referred for catheter ablation of recurrent AF. This patient had undergone PVI with cryoballoon ablation 3 years previously. After confirmation of the completion of PVI, a substrate map was created using an OCTARAY 3-3-3 catheter and CARTO 3 system (Biosense Webster, Diamond Bar, CA). A high-density electroanatomical map during high right atrium pacing was created. The effective refractory period of the high right atrium was confirmed to be 260 ms. Therefore, a map acquired at a basic cycle of 600 ms (S1 map) and a map during an extrastimulus set at 280 ms (effective refractory period + 20 ms) (S2 map) were simultaneously acquired using the Parallel Mapping Module (CARTO 3 system with V7 software; Biosense Webster). In the S1 map, there were no low-voltage areas or abnormal electrograms; however, in the S2 map abnormal electrograms were recorded on the posterior wall of the left atrium (Figure 1A). Similar findings were observed in the ripple map, with residual excitation on the posterior wall of the left atrium only in the S2 map (Supplemental Video 1). There was no significant difference between the S1 and S2 voltage maps (Figure 1B).

Considering the possibility of an arrhythmogenic substrate on the posterior wall, the OCTARAY catheter was placed on the posterior wall and a bolus of isoproterenol (16 μg) was administered. Initiation of AF was observed on the posterior wall, where abnormal potentials were observed (Figure 1C). Posterior wall isolation was performed, and a subsequent repeat induction test showed no occurrence of

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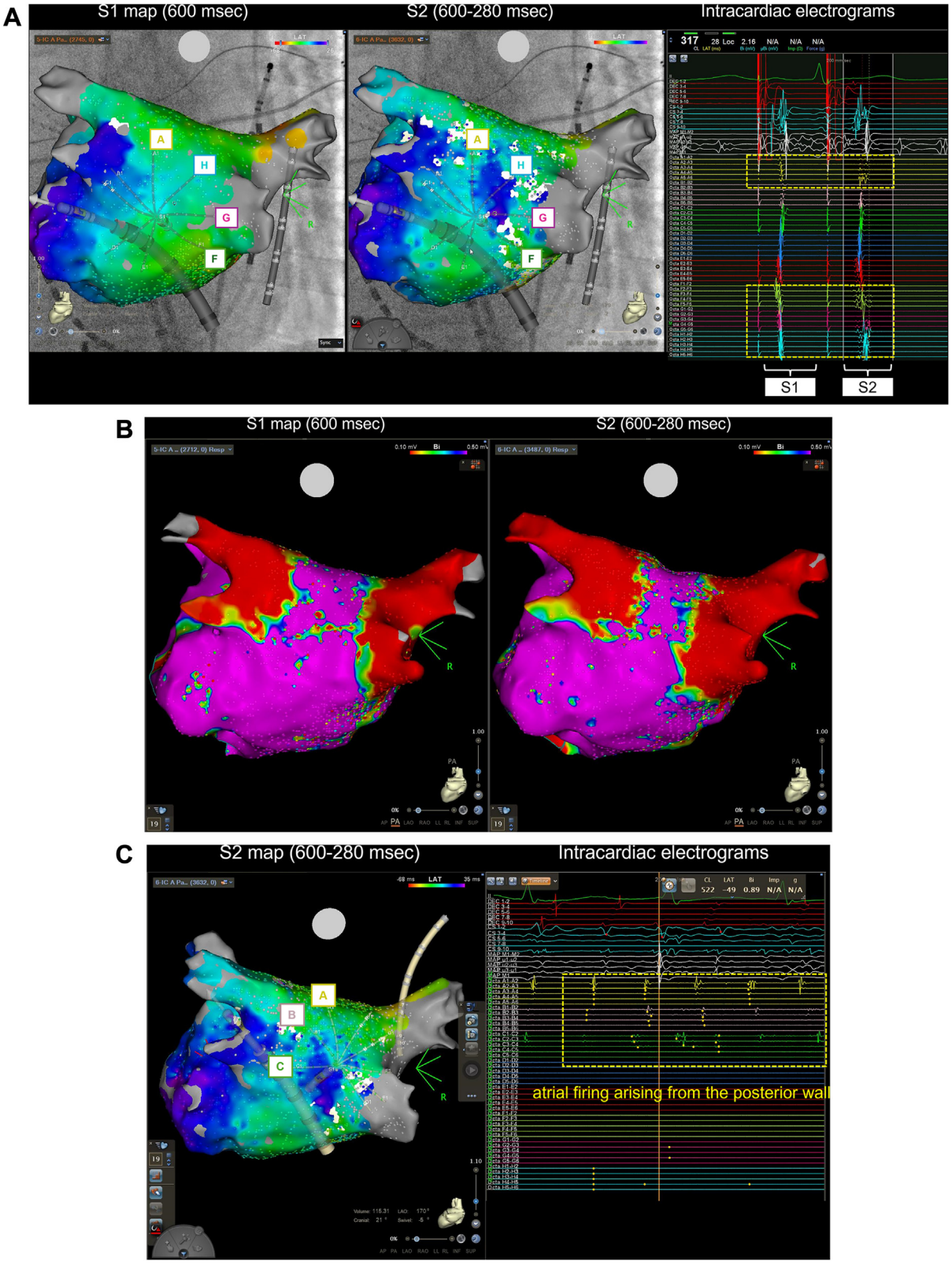

Figure 1 **A:** Local activation time (LAT) maps acquired with 2 different coupling intervals on the left atrial posterior wall. Two LAT maps (left: S1 [600 ms], center: S2 [600–280 ms]) obtained simultaneously using the Parallel Mapping Module (Biosense Webster, Diamond Bar, CA) based on the intracardiac electrograms shown on the right side. Splines A, F, G, and H recorded during S1 recorded normal sharp potentials, while during S2 they recorded fragmented abnormal potentials. **B:** Voltage maps acquired with 2 different coupling intervals on the left atrial posterior wall. The width of the healthy region between the bilateral pulmonary vein isolation lines appeared slightly narrower in the S2 map. Still, there were no obvious low-voltage areas on the posterior wall. Other areas also exhibited healthy voltage in both maps. **C:** Intracardiac electrograms of atrial firing arising from the posterior wall of the left atrium. Atrial fibrillation arose from atrial firing following the administration of isoproterenol with the OCTARAY catheter (Biosense Webster) placed at the site where abnormal potentials had been recorded on the S2 map.

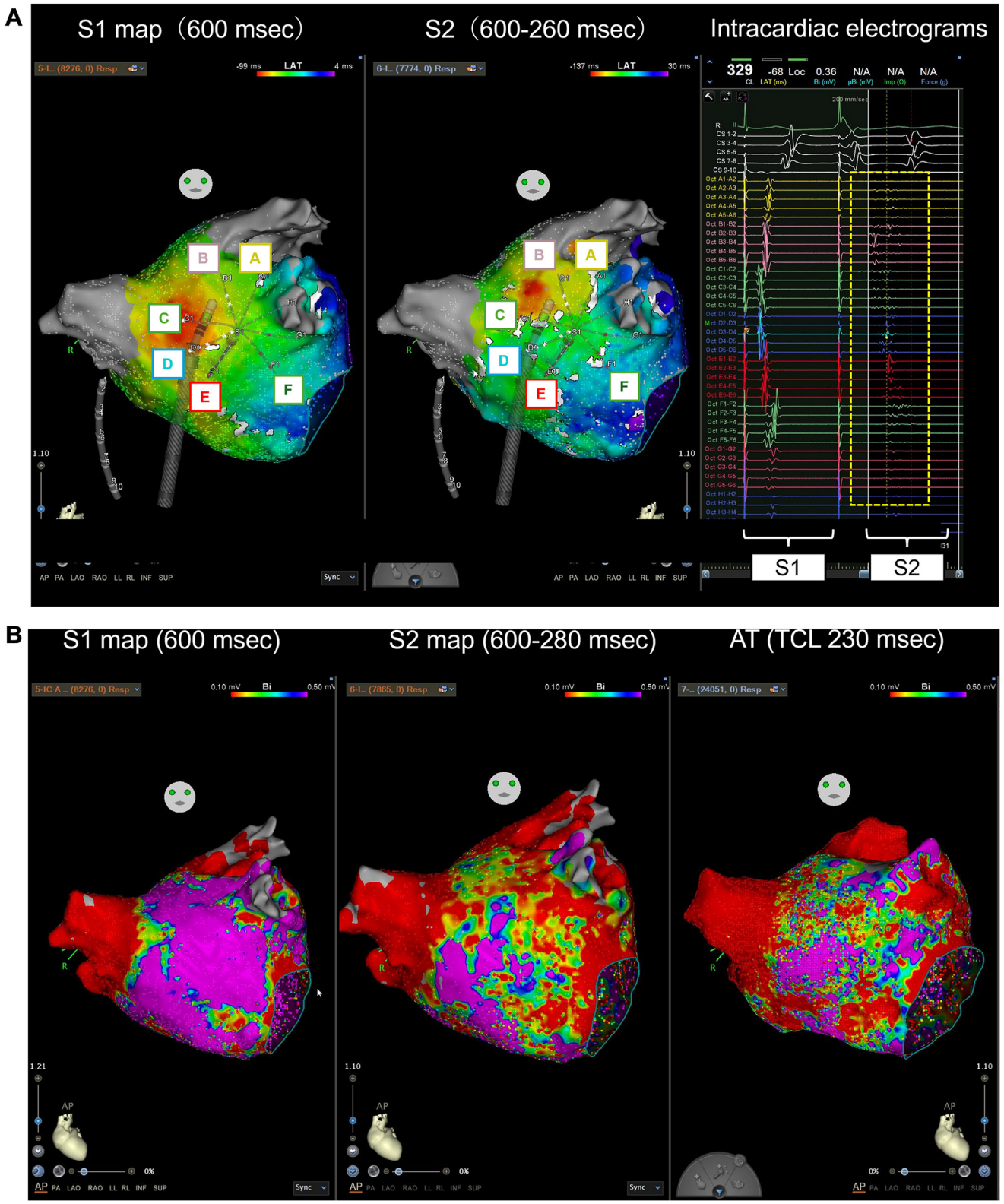

Figure 2 **A:** Local activation time (LAT) maps acquired with 2 different coupling intervals on the left atrial anterior wall. Two LAT maps (left: S1 [600 ms]), center: S2 [600–260 ms]) obtained simultaneously using the Parallel Mapping Module (Biosense Webster, Diamond Bar, CA) based on the intracardiac electrograms are shown on the right side. Splines A–F recorded during S1 recorded normal sharp potentials, while during S2 they recorded widespread fragmented abnormal potentials. **B:** Three voltage maps during pacing or atrial tachycardia. Although there were no obvious low-voltage areas of <0.5 mV in the S1 map, the S2 map revealed widespread low-voltage areas on the left anterior wall and around the left appendage. The voltage map acquired during atrial tachycardia (tachycardia cycle length 230 ms) was similar to the S2 map.

AF. The patient has progressed without any recurrence without postoperative antiarrhythmic drugs.

Case 2

A 71-year-old male was referred for catheter ablation of persistent AF. After completing the PVI, as in case 1, 2 high-density maps (S1 map at a basic cycle of 600 ms and S2 map during an extrastimulus at 260 ms) were acquired using an OCTARAY 3-3-3 catheter. Although there were no obvious abnormal electrograms on the S1 map, the S2 map revealed a widespread low-voltage area of less than 0.5 mV, mainly on the left anterior wall and around the left appendage (Figure 2A). On the left anterior wall area, fractionated potentials with prolonged excitation time were observed, and conduction delay was observed (Figure 2B).

Electrophysiological studies provoked atrial tachycardia (AT) with a tachycardia cycle of 230 ms, and mapping of this AT was performed. The voltage map during AT was very similar to the S2 map, and the site of the conduction delay of the AT corresponded to the site of the conduction delay observed on the S2 map (Figure 2A and Supplemental Video 2). Based on the S2 map and the map during the AT, we considered that the arrhythmogenic substrate was widely distributed, and we completed the procedure by performing linear ablation of the left anterior wall and roof of the left atrium, including the site where the AT was terminated. The patient has also progressed without any recurrence without any postoperative antiarrhythmic drugs.

Discussion

In the present case report, we experienced 2 cases in which mapping during extrastimulus pacing could reveal a hidden arrhythmogenic substrate. To our knowledge, this is the first case report to have visualized an arrhythmogenic substrate identified by high-density, high-resolution mapping during extrastimulation that was related to the occurrence of AF and AT.

In case 1, we suspected an association with non–pulmonary vein foci, and in case 2, we considered an association with a reentrant tachycardia, suggesting the possibility of identifying various arrhythmic substrates by evaluating the map during extrastimulation. First, there were some possible explanations for the occurrence of the S2 map and non–pulmonary vein foci. In damaged atrial myocardium, gap junctions are reduced, leading to delayed electrical conduction. The refractory period in the damaged atrial myocardium becomes heterogeneous, allowing abnormal electrical activities to persist. Based on that background, an association between abnormal atrial electrograms and repetitive atrial firing has been demonstrated.[3,4] We considered that the creation of a high-density, high-resolution S2 map could reveal the locations where atrial firing could occur. Second, regarding the relationship between the S2 map and the substrate location of the reentrant arrhythmias, it has been noted that in abnormal myocardium, the voltage decreases during extrastimulation, and the refractory period could be heterogeneous, facilitating unidirectional block.[5–7]

Another possible explanation for the complex electrograms during extrastimulation could be anatomical factors, such as the overlapping formation of muscle fibers in various orientations, including the septopulmonary bundle and the septoatrial bundle.[8]

Because these mechanisms are often considered to overlap with each other, we suggested that the abnormal potentials visualized by the S2 map could have represented complex arrhythmogenic substrates.

In these cases, we simultaneously created S1 and S2 maps using the Parallel Mapping Module. That allowed us to evaluate the differences between the S1 and S2 maps. We also considered that the ripple map was a very useful tool to visualize the location where the excitation duration was prolonged. There are several reports that ripple map evaluations can help uncover therapeutic targets for AF,[9–11] and we suggest that its accuracy could be improved by using S2 maps in combination with the ripple map.

We believed that this maneuver was a functional substrate mapping; in other words, unlike complex fractionated atrial electrogram mapping, voltage maps, etc, it was an attempt to illustrate the areas that were likely to have actually participated in the arrhythmia and not just areas of abnormal electrograms. In fact, 2 different arrhythmogenic substrates (reentrant arrhythmias and focal firing) were revealed in the S2 map in each of these 2 cases; however, further investigation needs to be performed on whether or not this technique is useful independent of other methods. In addition, further investigation is required to validate our findings and to prospectively evaluate the effectiveness of ablation targeting the arrhythmogenic substrate visualized in the S2 map.

Conclusion

High-density, high-resolution mapping during extrastimulation allows the detection of potential arrhythmogenic substrates.

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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.2024.07.018.

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