Single-loop incisional atrial tachycardia encircling the entire right atrium: Where is the critical isthmus?

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**Introduction**

Identifying a critical isthmus is important when trying to ablate macroreentrant tachycardias. A critical isthmus, which typically demonstrates a slow conduction and reduced amplitude, allows the reentrant wavefront to circulate without encountering any refractory tissue along the way. The majority of the incisional atrial tachycardias (ATs) have a macroreentrant mechanism, and the entrainment pacing is an essential tool to confirm the participation of specific areas in the circuit and to identify a suitable isthmus area for ablation. However, in this case of incisional AT, entrainment with concealed fusion, which identified “isthmus” with the conventional electrophysiological maneuvers, was observed throughout the circuit. A long single-loop reentrant circuit encircling the entire right atrium produced the phenomenon, and there were no low-voltage fractionated potentials within the circuit. These findings made us reconsider the definition of “isthmus” in this kind of enclosed reentrant tachycardia.

**Case report**

A 61-year-old man who underwent a mitral valve surgery via the superior transseptal approach was referred for catheter ablation to treat a sustained AT (AT1) and paroxysmal atrial fibrillation. Typical flutter wave was observed on the surface electrocardiogram with a rapid ventricular rate during AT1 (138 beats per minute) (Supplementary Figure 1). Although hemodynamically stable, the patient had mild heart failure symptoms such as exertional dyspnea and cough. On admission, the chest radiograph exhibited a small pleural effusion. The plasma brain natriuretic peptide level was 214 pg/mL. The echocardiographic data revealed normal valve function but slightly impaired left ventricular function (ie, left ventricular ejection fraction of 48% with diffuse hypokinetic motion without wall thinning).

After informed consent was obtained, multipolar electrode catheters were inserted into the femoral vein and positioned in the great cardiac vein and left atrium via a transseptal approach. Subsequently, heparin was administered to achieve an activated clotting time of 250–300 seconds. Electroanatomical mapping was performed using the CARTO3 mapping system (Biosense Webster, Diamond Bar, CA). To obtain sufficient waiting time and ensure the lesion durability, we first performed the extensive encircling pulmonary vein isolation using an irrigated-tip catheter with its radiofrequency energy of 30–40 W (ThermoCool ST SF; Biosense Webster). Following the pulmonary vein isolation for the paroxysmal atrial fibrillation and identification of the sustained AT1 as a common type of atrial flutter, catheter ablation of the cavotricuspid isthmus was performed, during which the tachycardia cycle length (TCL) abruptly increased from 263 ms to 340 ms and AT1 shifted to another AT (AT2) (Figure 1B).

Because AT2 did not terminate even after completion of the linear ablation of the cavotricuspid isthmus, we subsequently performed entrainment pacing during the shifted AT (AT2). The postpacing interval (PPI) after entrainment at the cavotricuspid isthmus was 33 ms (>30 ms).

**KEY TEACHING POINTS**

- Surgical incisions and anatomical barriers can create a complex long atrial tachycardia circuit without apparent low-voltage areas on its course.
- Concealed fusion with a postpacing interval equal to the tachycardia cycle length, which is typically seen in an isthmus, can be observed at multiple sites in a complex scar-mediated atrial tachycardia.
- The role of concealed entrainment as a guide for catheter ablation is limited in atrial tachycardia. Electroanatomical mapping systems help determine the complex circuit and potential ablation target.
Conversely, concealed entrainment with a PPI almost equal to the TCL was observed at multiple sites within the right atrium (Figures 1 and 2, and Supplementary Figure 2). In addition, the stimulus-to-reference electrogram intervals were almost equal to the pacing-to-reference electrogram intervals at those sites. Activation mapping using a multielectrode mapping catheter (PentaRay; Biosense Webster) identified AT2 as a single-loop macroreentrant AT encircling the right atrium.
the entire right atrium. Voltage mapping during AT2 identified discrete low-voltage areas possibly associated with the previous surgery. In particular, the right lateral and septal linear low-voltage areas reflected incisions created during the right atriotomy and the transseptal approach, respectively. A small scar caused by a cannulation was found proximal to the superior vena cava. The wavefront of AT2 progressed via a maze-like circuit created by conduction block lines within the incisions and anatomical barriers including the tricuspid valve, crista terminalis, superior vena cava, and inferior vena cava (Figure 2 and Supplementary Video). Although there seemed to be multiple narrow isthmi throughout the circuit, we attempted to identify the slow conduction area using the Coherent activation mapping included with CARTO3 version 7. By increasing the conduction velocity threshold, slow conduction areas represented by thicker conduction velocity vectors were first highlighted between the right lateral incisional scar and upper portion of the inferior vena cava (Figure 3). The distance between them was 11.9 mm, which was shorter than the other alternative lines (eg, distance between the inferior portion of the lateral incision and inferior vena cava = 21.8 mm). After confirming the absence of phrenic nerve capture by pacing, we created a conduction block line by linear ablation between them, which resulted in the termination of AT2. The bipolar electrograms at the successful ablation site were fractionated but revealed a relatively short duration with a preserved amplitude (>0.5 mV) (Figure 3). During a 1-year follow-up, the patient remained arrhythmia free, and the heart failure symptoms as well as cardiac function significantly improved thereafter.

Discussion

A right atrial incision after cardiac surgery predisposes patients to complex macroreentrant ATs by creating temporal and spatial excitable gaps. In this rare case of a single-
loop incisional AT encircling the entire right atrium, the spatial excitable gap (length of the circuit that is excitable at a given time) created by incisions and anatomical obstacles may be an important contributor to the maintenance of this macroreentrant tachycardia. On the other hand, the contribution of the slow conduction to the temporal excitable gap (time during the cycle length that the circuit is excitable) was seemingly relatively small. There were no slow conduction areas (defined as <0.3 m/s) with low voltage and prolonged fractionated potentials throughout the circuit. Similar to typical atrial flutter, the long length of the reentrant circuit might provide a sufficient spatial excitable gap within the circuit, and the wavefront deceleration would not necessarily be needed in this kind of single-loop reentrant AT.

A notable point in this case was the findings from the entrainment pacing after the cavotricuspid isthmus ablation. In the present study, concealed entrainment with a PPI matching the TCL was obtained at multiple sites within the right atrium. Although subsequent three-dimensional mapping revealed the single-loop reentrant circuit, the findings of the concealed entrainment did not provide a clue where to ablate within the circuit. In contrast to the ventricle, the atrium is predisposed to developing maze-like obstacles due to its complex anatomy, thin walled structures, and vulnerability to a hemodynamic pressure. Especially in patients who underwent catheter ablation or open heart surgery, as in this case, the multiple obstacles may limit the direction of the wavefront propagation, resulting in a reduced diagnostic accuracy of the concealed entrainment for identifying the critical isthmus.

This limitation of the entrainment approach for identifying an isthmus highlights the importance of using electroanatomical mapping systems for a complex AT. Advancements in the 3-dimensional mapping systems and automated annotation algorithms have permitted us to create high-resolution maps with an adequate point density. Of importance, we need to acknowledge that the critical areas of arrhythmogenesis mostly occur in diseased tissue where the voltage is attenuated, and handling the low voltages and complex electrograms is still a challenge when creating a precise electroanatomical map. In this case, we obtained clear boundaries between the scar and healthy myocardium using the CARTO3 mapping system, but the results might have been different using a more high-density and high-resolution mapping system (Rhythmia; Boston Scientific, Cambridge, MA). In addition, the precise recognition of the local electrograms with the Rhythmia platform would delineate a more detailed AT circuit. Conversely, though the resolution may be limited, the CARTO3 Ripple mapping algorithm, which aligns all of the recorded electrograms from each point, can display all information about the complex fractionated electrograms without mis-annotation of the local activation time. In addition, the recently developed Coherent mapping algorithm can manage these complex electrograms considering the global pattern of activation, and it enabled us to visually identify areas of conduction slowing or block. In this case, the

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anatomically shortest site between obstacles and relatively slow conduction site overlapped with each other, and we created conduction block there, considering the potential arrhythmogenesis of the slow conduction areas and unlikelihood of occurrence of any complications. When using the 3-dimensional mapping system in complex ATs, the operators should recognize how the low-voltage and complex fractionated electrograms are handled with each platform.

Conclusion
Concealed fusion with a PPI equal to the TCL, which is typically seen in an isthmus, can be observed at multiple sites throughout the circuit in an enclosed single-loop macroreentrant AT. A recent advancement in the electroanatomical mapping systems has helped not only to delineate background obstacles and complex tachycardia circuits but also to visualize potential critical slow conduction zones in patients with macroreentrant AT. This case reminded us that a site where concealed entrainment is seen is not always consistent with an anatomically narrow site and slow conduction site in complex macroreentrant ATs. Where on the circuit you should ablate requires an integrated assessment referring to the circuit width, conduction velocity, and anatomical safety.

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Appendix
Supplementary data
Supplementary data associated with this article can be found in the online version at https://10.1016/j.hrcr.2020.12.003.

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