Conduction Recovery After Electrical Isolation of Superior Vena Cava
– Prevalence and Electrophysiological Properties –

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Background: Superior vena cava (SVC) is an infrequent yet an important source of atrial fibrillation (AF). The data on SVC reconnection are limited.

Methods and Results: Following pulmonary vein (PV) antrum isolation for AF, SVC isolation was systemically performed under angiographic and mapping guidance using 4-mm non-irrigated tip catheter. SVC reconnection could be evaluated in 76 consecutive patients (65±9 years, 59 male) who underwent repeat AF ablation after 16±16 months. SVC was isolated at the 1st, 2nd, 3rd and 4th AF ablation procedure in 63, 7, 5 and 1 patient by 7.3±3.1 radiofrequency applications. SVC reconnection was observed in 56 patients (74%). In the majority, the conduction gap was located at the anterolateral SVC-right atrium (RA) junction. After re-isolation of SVC, 2/7 patients (29%) had reconnection at the following procedure. Among 63 patients who underwent PV and SVC isolation at the initial procedure, the prevalence of reconnection for PV and that for SVC were similar (53/63, 84% vs. 46/63, 73%; P=0.129). Dissociated activity, however, was more frequently observed in the PVs than in the SVC (47/63, 73% vs. 10/63, 16%; P<0.0001). During the procedure, AF initiation from a thoracic vein was identified in 19/63 patients (30%).

Conclusions: SVC reconnection is common after 1 or more previous isolation procedures undertaken for AF ablation. Its prevalence is similar to that of PV reconnection. The location of the conduction gap varies widely but is most frequently found at the anterolateral SVC-RA junction. (Circ J 2013; 77: 352–358)

Key Words: Atrial fibrillation; Catheter ablation; Isolation; Reconnection; Superior vena cava
Mapping and Ablation Protocol
All anti-arrhythmic drugs were discontinued for at least 5 half-lives prior to the procedure. All patients were effectively anticoagulated for >1 month before the procedure. Transesophageal echocardiography was performed to exclude atrial thrombi. Cardiac enhanced computed tomography was performed to evaluate cardiac anatomy. The surface electrocardiogram (ECG) and bipolar intracardiac electrograms were continuously monitored and stored on a computer-based digital recording system (LabSystem PRO, Bard Electrophysiology, Lowell, MA, USA). The bipolar electrograms were filtered from 30 to 500 Hz. A 7-Fr 14-pole 2-site mapping catheter (Irvine Biomedical, Irvine, CA, USA) was inserted through the right jugular vein and positioned in the coronary sinus (CS) for pacing, recording and internal AF cardioversion. Electrophysiological assessment was performed under mild sedation with pentazocine and hydroxyzine pamoate.

Ablation Procedure
The ablation was performed according to the strategy described previously. In brief, after a trans-septal puncture, 2 long

Table. Clinical Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>n (% ) or mean± SD</th>
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<tbody>
<tr>
<td>n</td>
<td>76</td>
</tr>
<tr>
<td>Age (years)</td>
<td>64.6±8.5</td>
</tr>
<tr>
<td>Male</td>
<td>59 (77.6)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>36 (47.4)</td>
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<tr>
<td>Structural heart disease</td>
<td>6 (7.9)</td>
</tr>
<tr>
<td>Type of AF</td>
<td></td>
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<tr>
<td>Paroxysmal</td>
<td>50 (65.8)</td>
</tr>
<tr>
<td>Persistent</td>
<td>11 (14.5)</td>
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<tr>
<td>Long-standing persistent</td>
<td>15 (19.7)</td>
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<tr>
<td>LAD (mm)</td>
<td>44.4±6.5</td>
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<tr>
<td>LVEF (%)</td>
<td>65.0±9.9</td>
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AF, atrial fibrillation; LAD, left atrial diameter; LVEF, left ventricular ejection fraction.

Figure 1. A circular mapping catheter was placed in the superior vena cava (SVC). SVC isolation was performed during pacing from high right atrium (HRA) to separate SVC potential from right atrium (RA) potential. (A) SVC potential was delayed by point-by-point radiofrequency (RF) application at the RA-SVC junction (from left to right panels), until (B) the SVC was isolated from the RA. CS, coronary sinus.
sheaths (SL0, AF Division, St. Jude Medical, Minneapolis, MN, USA) were introduced into both superior PVs. Pulmonary venography during ventricular pacing and contrast esophagography were performed to obtain the relative locations of the PV ostia vis-à-vis esophagus. A total of 100 IU/kg body weight of heparin was given following the trans-septal puncture, and heparinized saline was additionally infused to maintain the activated clotting time at 250–350 s. Two circular mapping catheters (Lasso, Biosense Webster, Diamond Bar, CA, USA) were placed in the superior and inferior PVs, and the left- and right-sided ipsilateral PVs were circumferentially and extensively ablated under 3-D mapping system guidance (CARTO3, Biosense Webster). Posteriorly, ablation was performed anatomically in the left atrium (LA), approximately 1–3 cm from the PV ostia. Anteriorly, ablation was performed on the edge of the left PVs guided by earliest PV potential. The endpoint was the bidirectional conduction block between LA and PVs. RF current was delivered point by point with a 3.5-mm externally irrigated-tip quadripolar ablation catheter (Thermocool; Biosense Webster) with power up to 35 W, target temperature ≤38°C and irrigation rate 30 ml/min. The power was limited to 20 W on the posterior wall close to the esophagus.

In patients with persistent AF, LA substrate ablation was performed after PVAI, targeting fractionated or continuous electrical activity during AF. The endpoint of ablation was transformation of complex fractionated atrial electrograms into discrete electrograms locally or termination of AF. The patient was classified as cardioverted if sinus rhythm could not be restored by catheter ablation. PVAI was reassertained in sinus rhythm.

SVC Isolation
SVC isolation was performed systematically during pacing from right high atrium (RA) in all patients if the SVC potentials were recorded. The circular mapping catheter was placed at the level of the lower border of the pulmonary artery above the SVC-RA junction guided by SVC angiography. During sinus rhythm, the SVC potentials were fused with the local RA signals, necessitating ablation during high RA pacing. RF energy was delivered point by point for 30 s each using a 4-mm tip non-irrigated catheter in temperature-controlled mode with maximum temperature set at 50°C and maximum power at 35 W. Before RF delivery, high output pacing (10 mA) was performed at every site and if diaphragmatic stimulation was observed, ablation was avoided locally to prevent phrenic nerve injury. The endpoint of ablation was to eliminate all SVC potentials on the mapping catheter (Figure 1).

Follow-up
Patients underwent continuous, in-hospital ECG monitoring for 3 days following the procedure. The first outpatient clinic visit was 3 weeks after the ablation procedure. Subsequent follow-up visits consisted of clinical interview, ECG, and 24-h Holter monitoring every 3 months at the cardiology clinic. No antiarrhythmic drugs were prescribed after the 3 month blanking period. Patients with palpitations were encouraged to use an event recorder. Recurrence was defined according to the patient’s symptoms, and/or if arrhythmia lasting >30 s was documented. A repeat procedure was strongly recommended for the patients with documented recurrent atrial tachyarrhythmia.

Statistical Analysis
Continuous variables are expressed as mean±SD or median and interquartile range (IQR), depending on the normality of distribution. Continuous and categorical variables were compared using Student’s t-test and chi-square test, respectively. P<0.05 indicates statistical significance.

Results
Clinical Characteristics
The pre-procedural clinical and echocardiographic character-
The characteristics are listed in Table. Three patients had cardiomyopathy (dilated in 2 and hypertrophic in 1), 2 had coronary artery disease and 1 had valvular heart disease. In total, structural heart disease was present in 676 patients (7.9%). Successful PVAI was achieved in all patients at the initial procedure and all patients underwent repeat ablation for recurrent atrial tachyarrhythmias (AF in 51 patients [67.1%], atrial tachycardia in 18 [23.7%], both AF and atrial tachycardia in 2 [2.6%], common flutter in 2 [2.6%] and frequent symptomatic premature atrial contractions in 3 [4.0%]).
SVC Electrical Isolation
Successful SVC isolation was achieved in 63 patients (82.9%) at the initial, 7 (9.2%) at the second, 5 (6.6%) at the third, and in 1 (1.3%) at the fourth ablation procedure. Mean SVC diameter was 21.8±4.0 mm on SVC angiography. The average number of RF applications for SVC isolation was 7.3±3.1. Following the SVC isolation, 16 patients (21.1%) had dissociated activity in SVC (Figure 2). Among those with a regular ectopic SVC rhythm, the average cycle length was 2,800±2,040 ms (median, 2,000 ms; IQR, 1,400–3,800 ms). In 3 patients (2.8%), AF originated spontaneously (without any provocation) from the SVC during the procedure (Figure 3). Right phrenic nerve palsy was observed in 4 patients (5.3%) during the procedure, but it recovered within 1 month in all.

SVC Reconnection at Repeat Procedure
At a mean of 16.2±15.6 months after SVC isolation, SVC reconnection was evaluated during the repeat procedure. SVC reconnection was observed in 56 patients (73.7%). There were no significant differences in the number of RF applications (7.8±3.2 vs. 6.3±2.8, P=0.079) and the diameter of SVC (22.2 mm vs. 20.6 mm, P=0.14) between the patients with and without reconnection, respectively. The various locations of conduction gap are shown in Figure 4A. In the majority of patients, the conduction gap was located at the anterolateral part of the SVC-RA junction. In patients with conduction gap, the average conduction delay from the onset of P wave to the earliest SVC potential recorded on the circular mapping catheter was 48±23 ms in sinus rhythm. It was significantly prolonged to 86±25 ms from the pacing spike during high RA pacing (P<0.0001; Figures 5A,B). The conduction gap was successfully closed by an average of 4.2±2.9 RF applications in all (Figure 5C) except 2 patients. In these 2 patients, we abandoned re-isolation of the SVC due to phrenic nerve capture at high pacing output.

Among 56 patients who underwent SVC re-isolation, 7

Figure 5. Electrical reconnection between the right atrium (RA) and superior vena cava (SVC) was observed at repeat session in (A) sinus rhythm and (B) during pacing from the high RA (HRA). (C) The conduction gap was closed by radiofrequency application. CS, coronary sinus.
(12.5%) underwent a third ablation procedure 14.6±10.1 months after the second procedure. In 2/7 patients (28.5%), SVC reconnection was observed again and the conduction gap was closed by RF applications.

**Comparison With Electrical PV Isolation**

We compared the electrophysiological characteristics of SVC and PVs in 63 patients who underwent successful PVAI and SVC isolation at the initial procedure. Following PVAI, 46 patients (73.0%) had dissociated activity in at least 1 PV, which was significantly more frequent than that in the SVC (10 patients, 15.9%; *P*<0.0001). Among the dissociated PVs with a regular ectopic rhythm, the average cycle length was 2,590±1,370 ms (median, 2,400 ms; IQR, 1,350–3,550 ms). Dissociated activity was seen in 37 left (58.7%) and 30 right (47.6%) PVs (*P*=0.211). Twenty-one patients (33.3%) had dissociated activity in both right and left PVs, while 17 (27.0%) did not have any electrical activity in the PVs. The cycle length remained steady or increased over the recording period in most cases. During the procedure, AF initiation from a thoracic vein was identified in 19/63 patients (30.2%). These were the left superior PV, the left inferior PV, the left common PV, the right superior PV, the right inferior PV and the SVC in 10, 5, 2, 11, 2 and 3 patients, respectively.

At a mean of 12.9±13.6 months after the initial procedure, PV reconnection was observed in 53/63 patients (84.2%) and SVC reconnection in 46/63 patients (73.0%; *P*=0.129). The distribution of PV conduction gap location is shown in Figure 4B. All conduction gaps were successfully closed by RF application.

Among 7 patients who underwent a third procedure, PV reconnection was observed in 2/7 patients (28.5%), similar to the incidence of SVC reconnection. One patient had both SVC and PV reconnection. One patient had reconnection of the right superior PV, and the other had that of the right superior and inferior PVs. All reconnections were closed by RF application.

**Discussion**

**Major Findings**

To our knowledge, this is the first study with detailed characterization of electrical reconnection of SVC in the context of AF ablation. The findings are as follows. First, electrical reconnection of the SVC is as frequently observed as the reconnection of PV after initial and subsequent isolation procedures. Second, conduction gap location can be widely distributed but in the majority it is located at the anterolateral part of the SVC-RA junction. Third, dissociated activity is less frequently observed in the SVC than in the PVs. Fourth, like PV reconnection, SVC reconnection can recur even after elimination of the conduction gap.

**SVC: Trigger and Driver of AF**

The SVC has been described as one of the most common sources of non-PV triggers. Embryologically, SVC originates from the sinus venosus, which has arrhythmogenic properties. On histology the atrial myocardial sleeves extend into the SVC for up to 2–5 cm. Because the embryological sinus precursor encompasses all the pacemaker sites, myocardial sleeves in the SVC harbor ectopic pacing cells that can depolarize by means of accelerated automaticity, providing the substrate for atrial arrhythmias.

Arruda et al reported a 12% incidence of SVC triggers in a cohort of 190 AF patients. Lin et al demonstrated that most of these SVC triggers would have been missed without the use of provocation. Higuchi et al noted long myocardial sleeves measuring >30 mm and large SVC potentials with amplitude >1.0 mV in patients in whom AF was triggered from the SVC. Based on these data, a randomized prospective study elegantly demonstrated that empirical SVC isolation in addition to PVAI improves the outcome of AF ablation in patients with paroxysmal AF.

**SVC-RA Electrical Connection**

Yeh et al reported that the SVC-RA connection is most commonly located at the septum and that the myocardial sleeve at the posterior wall is thinner than elsewhere in the canine SVC. A human autopsy study of the SVC-RA junction showed that myocardial sleeves extended from the RA into 38/50 SVCs. Moreover, the RA-SVC myocardial connection was more commonly discontinuous than circumferential with a mean thickness of 1.2±1.0 mm and mean length of 13.7±13.9 mm. Lin et al showed that all of 7 patients who underwent 3-D mapping of SVC had less myocardial tissue in the posterior SVC wall.

Goya et al reported breakthroughs between the SVC and RA in 16 patients. They were located in the anterior aspect of the RA-SVC junction in 3, laterally in 4, posteriorly in 10, and septally in 6 patients. In the present study the most likely location of SVC reconnection was the anterolateral SVC-RA junction. It might be explained partly by the fact that the site where the phrenic nerve was captured by high output pacing during the procedure and/or the sinus node was located, was targeted more gently. Considering the anatomical proximity of the SVC and right superior PV, RF applications on the anterior part of the PV antrum might have some impact on the result.

**Comparison With PV Reconnection**

It is well known that AF recurrences after AF ablation are very often associated with reconnections between the LA and PVs. Cheema et al noted recurrence of PV conduction in >90% of patients 1 h after initial electrical isolation. Cappato et al found that late conduction recurrence across acutely disconnected RF lesions delivered at the ostia of the multiple PVs is common in patients undergoing catheter ablation of AF. Recently, Kowalski et al nicely demonstrated that PVs showing electrical reconnection after catheter-based antral ablation are frequently found to have anatomic gaps or non-transmural lesions at the sites of catheter ablation, and that return of PV conduction after catheter-based isolation procedures is assumed to be due to failure to create permanent contiguous transmural lesions in at least part of the ablation line, on histology. In the present study, the prevalence of SVC reconnection was similar to that of PV reconnection, and the PV conduction gap location was widely distributed circumferentially around the PV antrum.

**Dissociated Thoracic Vein Activity**

Previous experimental studies have noted ectopic pacemaker activity within the PVs. These spontaneous trigger activities might originate from the PV antrum or inside the PV and are responsible for the dissociated PV electrical activity observed after the PVAI. In prior reports, dissociated activity was observed in 9–90% of the PVs after PV isolation. Chen et al described SVC cardiomyocytes and their electrophysiological characteristics. In the present study dissociated SVC activity could be observed after SVC isolation, but much less frequently than PV activity after PV isolation. The smaller isolated muscular sleeve and lower automaticity in the SVC than in the PV might explain this result.
Study Limitations
While the present study gives important insights into the activity of the SVC following isolation during AF ablation, it has some limitations. First, this study included patients who underwent repeat procedure; therefore there is no information on patients without recurrent atrial tachyarrhythmias. The previous studies, however, which evaluated electrical PV reconnection, also included the same limitation. Second, SVC isolation was performed using non-irrigated tip catheter in a temperature-controlled fashion, which is different from PVAI. Third, SVC-triggered AF was identified in only a small number of patients, mostly because aggressive provocation had not been undertaken.

Conclusion
SVC electrical reconnection is a common finding and its prevalence is similar to that of PV electrical reconnection in patients undergoing repeat AF ablation for recurrent atrial tachyarrhythmias. Although the location of the conduction gap can vary widely, it is located at the anterolateral SVC–RA junction in the majority of cases. SVC reconnection may recur even after successful re-isolation at the previous procedure.

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Disclosures
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References