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# Superior Vena Cava Isolation In Ablation Of Atrial Fibrillation

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**Abstract**

Superior vena cava (SVC) is one of the most important non-pulmonary vein (PV) origins of atrial fibrillation (AF). SVC isolation (SVCI) is effective especially in patients with paroxysmal AF from SVC origin. It should be carefully performed because of potential complications such as phrenic nerve paralysis, SVC stenosis, and sinus node injury. There are two major different approaches to treat SVC focus in the ablation of AF. The conventional approach is to perform SVCI only if AF from the SVC origin is actually recognized using pacing maneuvers and/or isoproterenol infusions. Another approach is the empiric SVCI in addition to PV isolation in all cases. The rate of AF freedom one year after initial AF ablation by empiric SVCI was almost same as the conventional method (85-90% AF freedom). Additionally, the conventional method has also a good result even 5 years after ablation (73.3% AF freedom). Because of the excellent result in the conventional approach and possible complications after the SVCI, the empiric SVCI + PVI in all AF cases is still controversial . Patients with a long SVC myocardial sleeve are possible candidates for empiric SVCI in addition to PVI.

## Introduction

Catheter ablation has emerged as a promising new technique in the treatment for atrial fibrillation (AF), which potentially cure AF radically and emancipate peoplepatients from bothersome antiarrhythmic drug treatments. The cornerstone procedure of AF ablation is the electrical isolation of pulmonary veins (PVs) from left atrium (LA) by ablating PV antrum region in the LA since ectopic beats initiating AF mostly originate from PVs.[1] Ectopic beats which initiate AF also arise from non-PV foci; superior vena cava (SVC), LA posterior wall, crista terminalis, coronary sinus ostium, ligament of Marshall, and interatrial septum.[2] Approximately 26-28% of AF patients have non-PV foci, although it differs according to clinical studies.[2, 3] Of these sites, the SVC is considered to be the most common source of ectopies which harbors 26-30% of non-PV foci.[3-5] The SVC often becomes an important target during AF ablation.[6, 7] In this review, we describe the method and the indication of SVC isolation together with the mechanism of SVC arrhythmogenicity.

## Embryogenesis And Arrhythmogenicity Of SVC And PV

Right anterior cardinal vein is incorporated into the primitive right atrium to form a future SVC together with the right sinus horn. Right sinus horn form the sinus venosus in the right atrium of the embryo which becomes a smooth part called the sinus venarum in the adult heart, also known as the venarum sinus, which is separated from the rest of the right atrium by a ridge of fibres called the crista terminalis. The sinus venosus also forms the SA (Sino Atrial) node and the coronary sinus which contain cells of the cardiac conduction system.

PVs grow from the LA as the following process; a primitive vein sprouts out of the LA, which bifurcates twice to make four PVs that grow toward developing lungs. A plexus of veins is formed from lungs and will meet with the developing PVs out of the LA to establish a connection. As the LA develops, the common PV is progressively incorporated into the LA wall until all four PVs enter the posterior wall of the LA separately. The incorporated PVs form the smooth posterior wall of the LA, whereas the trabeculated portion of the LA comes to occupy a more anterior part of the LA.

There are remnants of cardiac conduction system (pacemaker cell) in SVC and PVs, as in crista terminalis or coronary sinus which are often targets for atrial tachycardia. Since these remnants in SVC and PVs can become arrhythmogenic foci triggering AF,[8-10] treating AF triggers from SVC as well as from PVs is important in catheter ablation of AF.

## Histological Findings Of Myocardial Extension In SVC

The postmortem study of Kholová et al. using 25 human autopsied hearts, the myocardial extension from RA (Right Atrium) to SVC was recognized in 19/25 SVCs (76%) and SVC-RA myocardial connection was discontinuous in most cases and circumferential in few cases, with the mean thickness of 1.2±1.0 mm and a mean length of 13.7±13.9 mm (maximum, up to 47 mm).[11] Heterogeneous fiber arrangements and degenerative changes of myocardium with penetrating fibrous tissue are often recognized in SVC myocardium , which could potentially form a substrates for heterogeneity of electrical coupling and an arrhythmogenicity.[11, 12]

## Mechanism Of Arrhythmogenicity In SVC

The true mechanism of the arrhythmogenicity in the SVC is still unclear. However, several studies are demonstrating possible

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None

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mechanisms of its arrhythmogenicity.

### SVC As An Initiator Of AF

Sicouri et al.[13] demonstrated in their study using canine SVC preparations that the late phase 3 early afterdepolarization (EAD) and the delayed afterdepolarization (DAD)-mediated extrasystoles as well as the abnormal automaticity may serve as triggers of AF, which were also observed in PV preparations. SVC-aorta ganglionated plexi (GP) is located in the medial SVC and aortic root, superior to the right pulmonary artery. SVC-aorta GP serves as a relay station between extrinsic and intrinsic cardiac autonomic nervous systems.[14] High-frequency stimulation of the SVC-aorta GP or acetylcholine injection to SVC-aorta GP can induce a significant shortening of the effective refractory period and subsequent AF originating from the SVC. These effects can be eliminated after the ablation of SVC-aorta GP.[15] These findings suggest that the SVC-aorta GP plays an important role in the initiation of AF from the SVC, especially in vagal AF.

### SVC As A Perpetuator Of AF

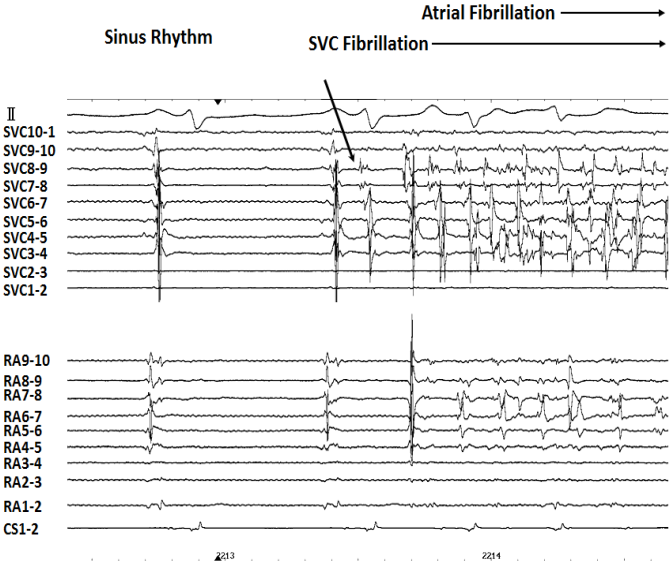
In the study of Higuchi et al. using a fluoroscopy and a 3D electro-anatomical mapping, myocardial extensions in the SVC of patients with SVC-related AF were significantly longer than those of patients without SVC-related AF (34.7±4.4 mm, vs. 16.5±11.4 mm, P<.0001). Some patients without SVC-related AF did not have any myocardial extensions in the SVC.[7] In a subset of SVC-related AF patients, the SVC fibrillation with passive conduction to right atrium (RA) is observed after initiation of AF from the SVC. SVC sometimes plays a role as a perpetuator of AF.[16] Figure 1 shows an example of SVC-related AF patient with these findings. A certain amount of myocardial sleeve is essential in a SVC in order to serve as a substrate of AF, not only as an initiator of AF. Figure 2 shows the 3D electro-anatomical mapping which shows the myocardial extension in the SVC of a patient with a SVC-related AF. Note that the myocardial extension is recognized until 41.8 mm above the SVC-RA junction.

## Induction Of SVC-Related AF

The basic maneuver to induce ectopic beats is following; (1) AF induction is attempted by high-frequency pacing from catheters placed in the RA, the coronary sinus, or PVs with intravenous infusion of isoproterenol (0.5-2μg/min/kg) as necessary. (2) AF is cardioverted into sinus rhythm. (3) Ectopic beats triggering AF can be recognized after cardioversion. Interestingly, in the study of Lin et al., only 2 patients had spontaneous SVC-AF. Eleven patients needed isoproterenol infusion with pacing-triggered ectopic beats to induce SVC-AF, and 15 patients had SVC-AF after electrical cardioversion of AF. It means only 7% of these foci were observed spontaneously during the procedure.[2] This finding was also reported in the experimental dog model, in which autonomic influences promoted spontaneous automaticity and triggered activity in SVC sleeves.[13] Thus, isoproterenol infusion, pacing maneuver, and cardioversion are often needed to recognize SVC triggers.

## Procedure Of SVC Isolation

Formerly, the arrhythmogenic focus inside of the SVC was carefully examined under the guidance of a multipolar catheter or a basket catheter placed in the SVC in the similar way performed in PVs, and focal ablation at arrhythmogenic foci in the SVC was performed.[6, 17] The arrhythmogenic focus inside the SVC is located relatively far from the SVC-RA junction (Lin et al. 25.3±9.7mm, 29±19.9mm,[2] Tsai et al. 19±9.7mm,[6] Higuchi et al. 25.4mm, 32.2mm[7]). However, since arrhythmogenic foci can be multiple and SVC also has the role of maintaining AF same as PVs, the recent standard method is the electrical isolation of SVC (SVCI). SVCI can be obtained by ablating about 5-10mm above the SVC-RA junction with the guidance of 3D electro anatomical mapping and a circular mapping catheter placed near the SVC-RA junction. The SVC-RA junction should be defined "electrically" since the sinus node is located near the SVC-RA junction. The SVC-RA junction can be defined by the presence of merged SVC and local RA potential recorded from a circular mapping catheter. Note the difference of electrical and anatomical SVC-RA junction (Figure 3A). If you place the circular mapping catheter about 5-10mm above the SVC-RA junction, you can recognize sharp SVC potentials and far-field small RA potentials (Figure 3B). The ideal SVCI line is just below the circular mapping catheter at that level. Usually SVCI can be achieved by ablating



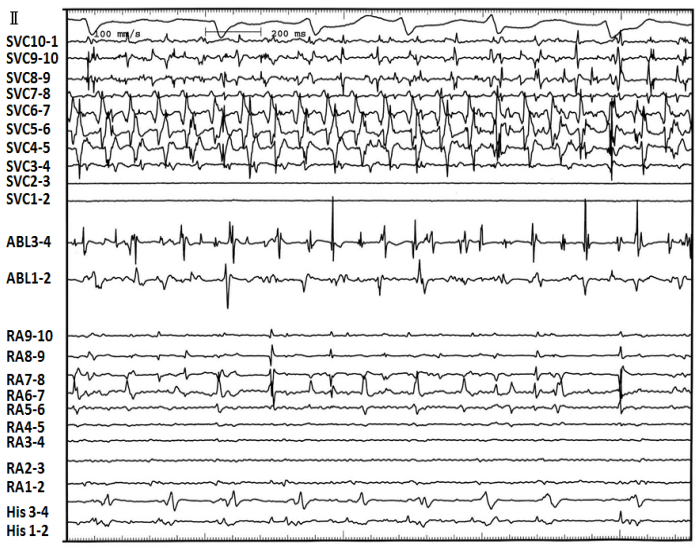




**Figure 1:** These figures show a case of AF initiated from the SVC. Ectopic beats initiated the SVC fibrillation, and then AF started (A). Note the SVC fibrillation (tachycardia cycle length was 80-100ms) with passive conductions to RA (B). SVC was an initiator and also a perpetuator of this AF

SVC = superior vena cava, RA = right atrium, CS = coronary sinus, ABL = ablation, AF = atrial fibrillation

the earliest activation of SVC potential during sinus rhythm in a point-by-point fashion using 3D electro anatomical mapping, not by circumferential ablation.[18] The RF energy is usually applied from 20W and can be raised up to 30W if necessary in order to avoid complications.

## Possible Complications Of SVCI

Several complications have been reported in the SVC focal ablation and also in the SVCI.

### SVC Stenosis

SVC stenosis is sometimes recognized after RF application in the SVC. Callans et al. reported the SVC narrowing after multiple RF applications at the SVC-RA junction in patients with inappropriate sinus tachycardia. In this study, local and circumferential swelling of the SVC was observed, causing a progressive reduction in the SVC-RA junction by 24%.[19] The experimental study using mongrel dogs demonstrated variable (mild to severe) SVC narrowing after a conventional (4mm tip, 60$^0$C, 60 sec) RF application (6-7 times) in the SVC both acutely and gradually.[20] There is also a case report that resulted in severe stenosis of the SVC after RF ablations to obtain the SVCI using an irrigated-tip catheter (25W, 10 times, 278 sec, totally).[21] In order to reduce the risk of PV stenosis and treat ectopies from PV ostia, extensive PV isolation (PVI) at PV antrum area is the standard method recently. However, since the sinus node is located near the SVC-RA junction, SVCI should be performed "inside" the SVC. That is the greatest difference from the PVI.

### Sinus Node Injury

Sinus node injury is also a possible complication, which usually occurs if RF ablations are applied below the SVC-RA junction. The SVC-RA junction should be determined carefully before RF applications and the ablation line to create SVCI is about 5-10mm above the SVC-RA junction.[22] RF applications should be ceased immediately if the acceleration of sinus rhythm is observed, which indicates damages to the sinus node. Akoum et al. utilized late gadolinium enhancement MRI for detecting a pre-existing sinus node dysfunction by evaluating structural remodeling in the RA.[23] This modality can be used before performing SVCI for detecting patients with a pre-existing sinus node dysfunction, who may have a more potential risk of sinus node injury after ablations near the SVC-RA junction. Performing MRI prior to ablation may also help us understand the anatomy of RA and SVC of each patient.

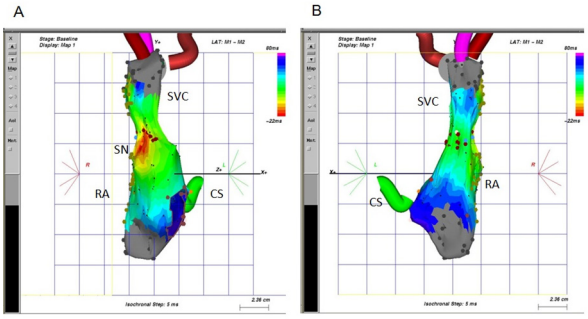



**Figure 2:** This figure shows the 3D electro-anatomic mapping of the SVC and the RA in a SVC-related AF patient (A: Left anterior oblique view, B: right anterior oblique view). The earliest activation site is the sinus node since the activation map was obtained during sinus rhythm. Red dots indicate radiofrequency application sites. The SVC myocardial extension was recognized until 41.8 mm above the SVC–RA junction

SVC = superior vena cava, RA = right atrium, CS = coronary sinus, SN = sinus node

### Right Phrenic Nerve Injury

Right phrenic nerve injury is the most frequently recognized complication. The right phrenic nerve is close to the SVC superiorly and adjacent to the lateral border of the entrance of the inferior vena cava to the right atrium inferiorly. While the right phrenic nerve is immediately adjacent to the anterolateral wall of the SVC, it veers posteriorly as it approaches the SVC-RA junction. The damage to the phrenic nerve occurs usually during RF applications on the posterolateral aspect of the SVC, and it causes a right side diaphragm paralysis. Even if the right phrenic nerve paralysis mostly recovers within one year,[24] confirming not to capture the right phrenic nerve by a pacing maneuver should be performed before applying RF ablations to avoid damages to the nerve. Additionally, the movement of right diaphragm should be checked periodically using a fluoroscopy to detect the nerve damage as soon as possible.

## Indication Of SVCI And Its Result

### Performing SVCI Only If SVC Trigger Is Recognized

This is the standard strategy that has been performed. Chang et al. reported the long-term outcome of ablation therapy in 68 patients with AF from SVC origins which were induced using isoproterenol infusions and cardioversions.[17] In this study, the rate of AF freedom was 85.3% at 1 year, 78.7% at 2 years, and 73.3% at 5 years after the initial ablation procedure. Additionally, patients with pure SVC-initiating AF presented a better outcome than those with coexisting PV triggers. They also found that the 5 year result after segmental SVCI was same as circumferential SVCI, which means segmental point-by-point ablation is enough for obtaining the electrical isolation of SVC from RA.

### Prophylactic SVCI In Addition To PVI

This method has been recently proposed, in which SVCI is prophylactically performed in addition to PVI for all cases of AF. A randomized control study in which patients were assigned into empiric SVCI + PVI group or PVI only group shows an interesting result.[25] In this study, 16% of patients in empiric SVCI + PVI group could not accomplish SVCI because of the risk of phrenic nerve injury or the absence of SVC sleeve. Their one-year success rate after an initial ablation procedure with PVI and PVI+SVCI was following; 77% vs. 90% in paroxysmal AF (P = 0.04), 74% vs. 80% (P = 0.52) in persistent AF, and 69% vs. 67% in permanent AF. Empiric SVCI in addition to PVI has improved the outcome of AF ablation solely in patients manifesting paroxysmal AF, not in persistent or permanent AF. On the other hand, the result of a nother randomized prospective study comparing PVI only and empiric PVI+SVCI for patients with paroxysmal AF was different.[26] In this study, they did not find statistical significance between these two strategies regarding the success rate one year after initial AF ablation (PVI = 81%, PVI+SVCI = 86%; P = 0.75).

### Implication From Two Different Methods

The success rate of AF ablation at one year after initial ablation by empiric PVI+SVCI (Corrado et al.; 90%, Wang et al.; 86%) seems to be almost same as the conventional method in which performing SVCI is performed only for patients who have triggers in the SVC (Chang et al.; 85.3%). Additionally, the conventional method has also a good result even 5 years after ablation, which was 73.3%. It seems not to be necessary to isolate all SVCs prophylactically to reduce AF recurrences. We may have to spend enough time to induce

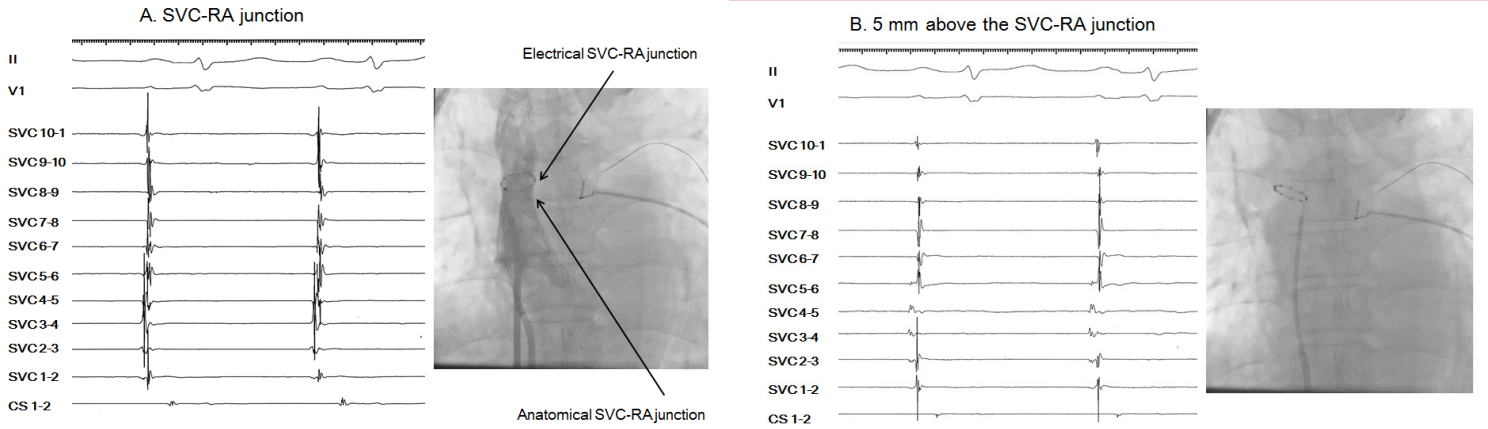



**Figure 3:** **Local electrograms at the electrical SVC-RA junction (A). You can see sharp RA potentials at SVC 3-4, SVC 4-5. Note the difference of location at electrical and anatomical SVC-RA junction. SVC electrograms 5 mm above the SVC-RA junction (B). Sharp SVC potentials and far-field small RA potentials can be recognized**

SVC-related AF using isoproterenol infusion, pacing maneuver, and cardioversion. Additionally, the effect of SVCI in patients with persistent or permanent AF seems to be limited. The fact that the SVC-related AF often occurs in a vagal paroxysmal AF supports this finding.[5]

### Possible Indication Of Empiric SVCI

In the study of Higuchi et al.[7] as mentioned above, a relatively long SVC myocardial extension is necessary for SVC to become a perpetuator of AF. In addition, the ectopic focus of SVC is relatively far from the SVC-RA junction.[2, 6, 7] They concluded that patients with SVC which is over 30 mm length had significant SVC-related AF episodes. The length of SVC myocardial extension over 30 mm identified SVC-related AF with 100% sensitivity and 94% specificity. Although further studies to investigate the effect of empiric SVCI using this indication is needed, this study proposes a possible indication of empiric SVCI only in patients with a long SVC myocardial extension without investigating ectopic foci, especially in paroxysmal AF patients.

## SVC Isolation In Patients With Anomalous PV Drainage

Partial anomalous pulmonary venous return (PAPVR) has a prevalence of 0.5% in the general population.[27] Anomalous pulmonary vein drains into the pulmonary circulation via the SVC, azygos, innominate veins, inferior vena cava, coronary sinus or RA creating a pulmonary-to-systemic shunt. Patients may be asymptomatic if the shunt is small. AF can occur in patients with asymptomatic PAPVR and SVC isolation is needed in case with PV drainage via the SVC in order to eliminate PV firings which may be misunderstood as SVC firings.

## Conclusion:

Because of the proximity of SVC-aorta GP to the SVC and the extension of myocardium in the SVC from the RA, SVC frequently becomes an important source of ectopic beats initiating AF. The procedure of SVCI is different from PVI in that SVCI should be performed 5-10 mm "inside" the SVC from the SVC-RA junction to avoid sinus node injury, whereas PVI should be performed at the PV antrum which is about 10 mm "outside" the PV from the LA-PV junction. Therefore, there should be an enough myocardial extension in the SVC to accomplish SVCI safely and SVC should not be "prophylactically" isolated in all patients, who may have just a tiny SVC myocardial extension. Performing SVCI only if SVC triggers are recognized after isoproterenol infusions, pacing maneuvers, and cardioversion seems to be reasonable in order to avoid unnecessary ablations and complications. Empiric SVCI in patients with a long SVC myocardial extension can be another strategy.

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