Electrophysiology

Narrowing of the Superior Vena Cava–Right Atrium Junction During Radiofrequency Catheter Ablation for Inappropriate Sinus Tachycardia: Analysis With Intracardiac Echocardiography

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OBJECTIVES
The study explored the potential for tissue swelling and venous occlusion during radiofrequency (RF) catheter ablation procedures using intracardiac echocardiography (ICE).

BACKGROUND
Transient superior vena cava occlusion has been reported following catheter ablation procedures for inappropriate sinus tachycardia (IST). Presumably, venous occlusion could occur owing to thrombus formation or tissue swelling with resultant narrowing of the superior vena cava–right atrial (SVC-RA) junction.

METHODS
Intracardiac echocardiography (9 MHz) was used to guide ablation catheter position and for continuous monitoring during RF application in 13 ablation procedures in 10 patients with IST. The SVC-RA junction was measured prior to and following ablation. Successful ablation was marked by abrupt reduction in the sinus rate and a change to a superiorly directed p-wave axis.

RESULTS
Eleven of 13 procedures were successful, requiring 29 ± 20 RF lesions. Prior to the delivery of RF lesions, the SVC-RA junction measured 16.4 ± 2.9 mm. With RF delivery, local and circumferential swelling was observed, causing progressive reduction in the diameter of the SVC-RA junction to 12.6 ± 3.3 mm (24% reduction, p = 0.0001). A reduction in SVC-RA orifice diameter of ≥30% compared to baseline was observed in five patients.

CONCLUSIONS
The delivery of multiple RF ablation lesions, often necessary for cure of IST, can cause considerable atrial swelling and resultant narrowing of the SVC-RA junction. Smaller venous structures, such as the coronary sinus and the pulmonary veins, may be expected to be more vulnerable to this complication. Thus, ICE imaging may be helpful in preventing excessive tissue swelling leading to venous occlusion during catheter ablation procedures. (J Am Coll Cardiol 1999;33:1667–70) © 1999 by the American College of Cardiology

Intracardiac echocardiography (ICE) is an emerging technology with considerable promise for assisting interventional electrophysiology procedures. Investigators to date have focused attention on the use of ICE to improve procedural efficacy, either by providing better anatomic characterization of the electrophysiologic substrate or to monitor electrode–tissue contact (1–8). Little information is available on the use of ICE to monitor and/or prevent the development of complications during catheter ablation. Transient superior vena cava (SVC) occlusion has been reported following catheter ablation for inappropriate sinus tachycardia (IST) (3). Presumably, venous occlusion could occur on the basis of radiofrequency (RF) lesion-induced tissue swelling and/or development of thrombus. Smaller-diameter venous structures, such as the coronary sinus and the pulmonary veins, may be expected to be subject to even greater risk of occlusion with ablation procedures performed in adjacent tissue (9).

To determine whether RF lesion-induced tissue swelling is a plausible mechanism for venous occlusion and to assess whether ICE might be useful in monitoring this potential complication, we measured the effect of RF lesion delivery on the orifice size of the SVC–right atrial (SVC-RA) junction in patients undergoing ablation for IST.

METHODS

Patient population. Ten patients referred for catheter ablation of IST performed under ICE guidance were included in the study (May 1996 to January 1998). All patients had paroxysmal palpitations, and five had a history...
of syncope. All patients failed drug therapy including beta-adrenergic blocking agents (n = 10), antiarrhythmic agents (n = 8) and calcium antagonists (n = 5) before ablation attempts. Previous His bundle ablation and attempts at sinus node modification had been performed before referral to our institution in two and three patients, respectively. The mean age was 28 ± 7 years and nine of the patients were women. Before electrophysiologic study, all patients had ambulatory monitor tracings demonstrating paroxysmal supraventricular tachycardias, which corresponded to symptomatic episodes. Noninvasive sinus node function testing, including exercise testing, response to graded doses of isoproterenol and intrinsic heart rate under autonomic blockade (10,11), was performed in all patients and demonstrated either abnormalities in resting rate and/or inappropriate response to catecholamine infusion or exercise. A total of 13 ablation procedures were performed in the 10 patients, with repeat procedures required for initial failure (n = 2) or recurrent symptoms following an initially successful ablation (n = 1).

Electrophysiologic study and ablation. Informed consent was obtained from all patients before the procedure. Patients were studied in the postabsorptive state under conditions of conscious sedation obtained by intravenous infusion of midazolam and short-acting narcotic. Catheters were inserted through the femoral and left basilic veins and positioned under fluoroscopic and ICE guidance to the high right atrium, atrioventricular junction and right ventricular apex. A steerable thermistor-equipped catheter with either a 4- or 8-mm tip electrode was used for mapping and ablation (EP Technologies, San Jose, California); the 8-mm tip was used preferentially to facilitate visualization with ICE imaging. Surface leads and intracardiac electrograms filtered from 30 Hz to 250 Hz were displayed and recorded using a digital amplifier/recorder system. Episodes of IST, if not present spontaneously, were induced with graded infusion of isoproterenol. Although the mapping and ablation procedure was primarily anatomically based, electrophysiologic mapping of the earliest atrial activation during episodes of IST was performed for confirmation of the appropriateness of ablation site targets using one or more of the following techniques: 1) sequential multisite mapping using the ablation catheter; 2) multisite simultaneous mapping using a multipolar “crista” catheter (Webster Laboratories, Baldwin Park, California), or 3) nonfluoroscopic, electroanatomic mapping for right atrial activation (CARTO™, Biosense Ltd., Israel).

Radiofrequency energy was delivered in a unipolar fashion to areas of the superior lateral crista terminalis, demonstrating earliest activation during sinus tachycardia. High output pacing (10 mA, 2 ms pulse width) was performed at all prospective RF target sites to ensure that diaphragmatic stimulation did not occur, indicating the potential for RF-induced damage to the phrenic nerve. The RF power was adjusted to achieve a tip temperature of 50 to 55° and/or a specified impedance drop from baseline (measured at 5-W output, 10-ohm drop with a 4-mm tip electrode and 5 ohms with an 8-mm tip), and applied for 120 s. Procedural success was defined by the following: 1) an abrupt decrease (≥30 bpm) in sinus rate during RF lesion delivery; 2) the sudden appearance of superiorly directed p-wave morphology (negative p wave in lead III); and 3) the persistence of these features despite infusion of isoproterenol (up to 4 mcg/min) for at least 30 min following the delivery of the final RF lesion.

ICE imaging and data acquisition. Intracardiac echocardiography was performed using a 9-MHz rotating ultrasound transducer, mounted at the distal end of a 9F, 110-cm catheter (Boston Scientific Co., Watertown, Massachusetts). Images were acquired using a Sonos Intravascular Imaging System (Hewlett-Packard, Andover, Massachusetts). The transducer provides circular images at a rate of up to 30 frames/s. The maximal radial imaging depth is up to 10 cm and the maximal axial resolution approximately 0.2 to 0.3 mm. The imaging catheter was advanced to the high right atrium via a femoral venous approach using an 11F Mullins sheath. Right atrial imaging planes are cross-sectional views 10° oblique (posterior-superior and anterior-inferior) of the SVC-IVC axis (Fig. 1). The view used for IST ablation was at the level of the SVC-RA junction, which demonstrates the superior crista terminalis (Fig. 1). The SVC-RA junction was defined by the confluence of the SVC, right atrium and right atrial appendage. In this imaging plane, the superior medial crista terminalis is demonstrated just lateral to the ascending aorta and just anterior to the right pulmonary artery. In this same view, the superior lateral crista terminalis can also be demonstrated, at the orifice of the right atrial appendage (Fig. 1). The SVC-RA orifice was measured in end-systole as the distance between the superior medial and superior lateral crista terminalis. In addition, ICE imaging was used continuously throughout the procedure to guide ablation catheter placement and assess electrode-tissue contact.

The orifice diameter of the SVC-RA junction was measured prior to and following RF lesion delivery. Data analysis was performed in a retrospective fashion. The SVC-RA junction measurements were performed on identical views pre- and postablation; in addition to the specificity of the anatomic landmarks, control measurements of the SVC lumen pre- and postablation were compared to
ensure that identical views were compared. Intraobserver variability with repeated measurements was \(4\%\). The primary variable used for analysis was the percentage reduction of the SVC-RA orifice \([(\text{pre-post})/\text{pre-measurement}]\) caused by the delivery of RF lesions.

**Statistical analysis.** Data are presented as mean values \(\pm\) SD. Comparison of SVC-RA orifice size before and following RF lesions was performed using the paired Student \(t\) test.

**RESULTS**

Acute procedural success, defined by abrupt slowing of the sinus rate and transition to a superiorly directed p-wave morphology in lead III, was achieved in 11 of 13 procedures and required a mean of 29 \(\pm\) 20 RF applications (range 5 to 69). No procedural complications were observed. One patient required pacemaker implantation following complete sinus node ablation.

Before the delivery of RF lesions, the orifice of the SVC-RA junction measured 16.4 \(\pm\) 2.9 mm (Table 1). The RF energy delivery caused tissue swelling at the site of catheter contact as well as circumferential swelling around the SVC-RA junction with resultant decrease in the diameter of the SVC-RA junction orifice. In general, tissue swelling in the SVC-RA junction increased with time during the procedure and with the delivery of sequential lesions; the reduction in orifice diameter did not correlate with the number of lesions delivered, however. Following the last RF lesion delivered, the orifice measured 12.6 \(\pm\) 3.3 mm (24\% reduction, \(p = 0.0001\); Fig. 1). A reduction in SVC-RA orifice diameter of \(\geq30\%\) compared with baseline was observed in five patients.

Superior vena cava occlusion and clinical signs of SVC syndrome were not observed. Small adherent thrombi were identified within crater lesions in four patients, but did not contribute significantly to SVC-RA isthmus reduction. Recovery of tissue swelling within the SVC-RA junction was not observed during ICE monitoring for 30 min following the delivery of the final RF lesion. In the three patients who required repeat procedures (range: one to eight months between procedures), no evidence of persistent tissue swelling at the SVC-RA junction was observed (SVC-RA junction 17.0 \(\pm\) 3.0 mm and 16.3 \(\pm\) 1.5 mm prior to first and second procedures, respectively; \(p = \text{NS}\)).

**DISCUSSION**

Delivery of multiple RF lesions, often required for cure of IST, causes significant tissue swelling at the SVC-RA junction, an area that serves as the inlet to the right atrium. This swelling is most marked at the site of RF delivery but also occurs throughout the entire circumference of the SVC-RA junction, presumably through spread of interstitial edema through the contiguous tissue space. Some degree of tissue swelling is essential for therapeutic lesion delivery \((5,12,13)\); extensive swelling can prevent adequate catheter contact with the crista terminalis and may produce critical narrowing at venous ostia. This tissue swelling and resultant narrowing of the SVC-RA junction persists throughout the time span of the ablation procedure, but appears to resolve within weeks to months. Animal studies have demonstrated that right atrial tissue thickening follow-

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**Table 1.** Patient Characteristics, SVC-RA Orifice Measurements and Ablation Outcome

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<th>Patient</th>
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**Figure 1.** Narrowing of the SVC-RA junction with RF delivery. The ICE images are 10° oblique cross-sectional views oriented such that the ultrasound transducer is in the center of the image, posterior and superior structures are at the top of the image, anterior and inferior structures at the bottom and right-sided (lateral) structures to the viewer’s right. The arrows refer to the SVC-RA junction at the level of the superior lateral crista terminalis. In the left frame, the SVC-RA junction is shown at baseline (arrows). After RF delivery to the lateral crista terminalis (right frame), circumferential tissue swelling was noted, with a 40% reduction in the SVC-RA junction. The open arrowhead demonstrates a crater at RF lesion site. Ao, aorta; c, catheter; RPA, right pulmonary artery; RAA, right atrial appendage; SVC, superior vena cava.
ing radiofrequency application increases with time and persists for at least 150 min (13). Although SVC occlusion was not observed, the characteristics of the tissue swelling at the SCV-RA junction observed in this study support the conclusion that RF-induced tissue swelling is a plausible mechanism for this complication.

The enthusiasm for catheter ablation techniques is justifiable, given the low incidence of adverse events and the high efficacy in many arrhythmia syndromes (7,14–17). Nonetheless, as catheter ablation techniques are being applied in the hope of curing more challenging arrhythmias, a careful ongoing assessment of the risk/benefit balance is essential. The possibility of significant procedural morbidity, including damage to contiguous vascular structures such as the aorta and coronary arteries, has been suggested (18–21). The occurrence of SVC occlusion as well as pulmonary venous occlusion leading to the development of pulmonary hypertension (9) underscores the potential for clinically important complications of RF-induced tissue swelling. The ICE imaging using currently available technology allows for continuous monitoring of intracardiac and contiguous vascular structures and may prove helpful in the avoidance of adverse effects of RF-induced tissue swelling.

Although the current study, with its retrospective design, does not present data on the use of ICE to avoid adverse events, it does demonstrate the feasibility of the technique in monitoring the SVC-RA junction during ablation of IST. Further investigation will be required to determine the efficacy of ICE imaging in preventing procedural complications related to tissue swelling.

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REFERENCES