A CASE FOR EDUCATION

Cavotricuspid isthmus ablation for atrial flutter: Anatomic challenges and troubleshooting

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Introduction

In patients with cavotricuspid isthmus (CTI)-dependent atrial flutter, ablation along the CTI is often a routine and straightforward procedure. However, certain aspects of the regional anatomy can pose technical challenges such that bidirectional block across the CTI can be difficult to achieve.[1] Using a case example, we review common challenges with CTI ablation, discuss the important anatomic considerations that are relevant to procedural difficulty, and present approaches to troubleshooting.

Case report

A 68-year-old man with history of treated hypertension and hyperlipidemia presented with episodic palpitations and shortness of breath. He was diagnosed with atrial flutter and underwent electrical cardioversion but his arrhythmia recurred. He was unable to tolerate medications; therefore an electrophysiologic study and ablation was recommended. Entrainment maneuvers were consistent with CTI-dependent, counterclockwise atrial flutter. A 3.5-millimeter open irrigated tip radiofrequency (RF) ablation catheter (THERMOCOOL, Biosense Webster, Irvine, CA) was used. Ablation along the CTI terminated the flutter. Bidirectional block established at the end of the procedure. However, 6 months later the patient presented again with episodic palpitations and recurrent arrhythmia. Electrocardiogram showed the same pattern of typical atrial flutter (Figure 1).

A repeat electrophysiologic study was performed. The patient was brought to the electrophysiology laboratory in atrial flutter. Diagnostic catheters were positioned in the high right atrium, annular right atrium across the CTI, coronary sinus, and right ventricle. An intracardiac echocardiography catheter (ICE; ACUNAV, Siemens, Mountain View, CA) was inserted through the right femoral vein (Figure 2). The right atrial electrograms demonstrated high-to-low activation, and the coronary sinus electrograms demonstrated proximal-to-distal activation. Entrainment maneuvers confirmed the atrial flutter to be CTI-dependent. Using an open-irrigated 3.5-mm-tip RF ablation catheter (THERMOCOOL, Biosense Webster) through a Swartz Braided SL1 guiding introducer sheath (St Jude Medical, Saint Paul, MN), ablation along the CTI was performed at a power of 30 W with titration guided by impedance and temperature monitoring. We used a power-controlled setting with a maximum temperature setting of 40°C and a flow rate of 17 mL/min. Contact force sensing was not used. The tachycardia terminated with ablation, but achievement of bidirectional block across the CTI ablation line was challenging.

Below, we discuss common anatomic variants that can interfere with CTI ablation and their applicability in our case (Table 1).

Discussion

Prominent sub-Eustachian pouch

The sub-Eustachian pouch (pouch of Keith) is a physiologic depression of the CTI just anterior to the Eustachian ridge and laterally to the Thebesian valve at the orifice of the coronary sinus. In some individuals this pouch can be prominent, particularly near the septum. A deep sub-Eustachian pouch may cause difficulty with CTI ablation because of poor blood flow, resulting in rapid temperature and impedance rise, possible coagulum formation, and inadequate lesion formation, while concomitantly increasing the risk of perforation.[2] In addition, the pouch can generate difficulty in maintaining sufficient catheter–tissue contact while withdrawing the catheter from the tricuspid annulus to the inferior vena cava (IVC) if one assumes a planar CTI. The presence of the pouch can be recognized by the atypical movement of the catheter tip fluoroscopically and it is readily recognizable by ICE

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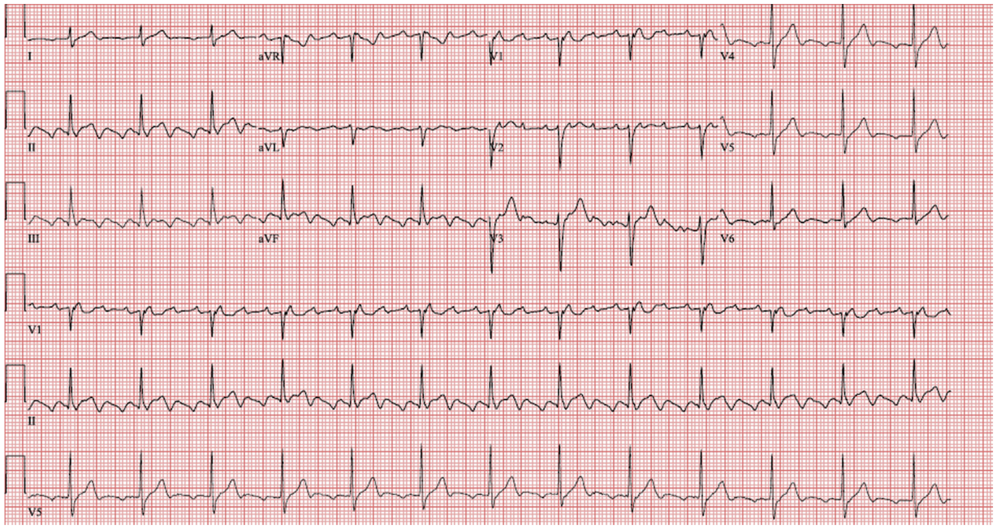


Figure 1 Patient's electrocardiogram revealing typical atrial flutter.

imaging, right atrial angiography, or cardiac computed tomography. Both the limited blood flow and poor catheter contact within the pouch can result in difficulty or inability to achieve bidirectional CTI block.

When the electrophysiologist is aware of the presence of a prominent sub-Eustachian pouch, the ablation approach can be modified by positioning the catheter more laterally in order to avoid the pouch (Figure 3). In cases where this is not possible (catheter stability, increased thickness of atrial tissue), ablation within the pouch with cautious energy titration using irrigated catheters can be attempted to prevent sudden rises in impedance, tissue vaporization, and steam pop. Use of contact force–sensing ablation catheters may be considered. When these approaches are ineffective or not feasible, electrical isolation of the pouch with an encircling ablation lesion anchored to the IVC and tricuspid annulus can be performed. In our case, ICE imaging did not demonstrate a prominent sub-Eustachian pouch.

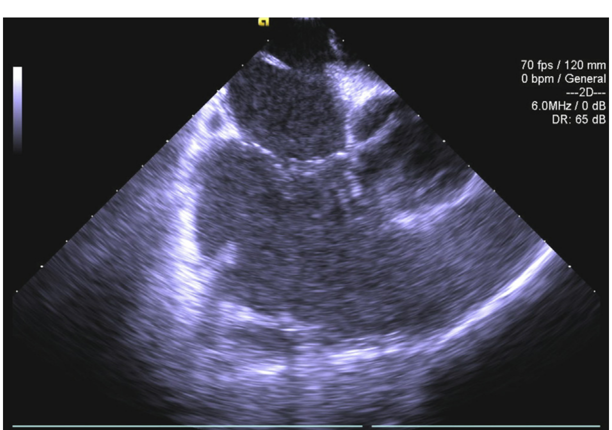


Figure 2 Intracardiac echocardiography from the redo cavotricuspid isthmus ablation procedure.

Prominent pectinate muscles

Prominent pectinate muscles can extend from the crista terminalis into the CTI and can pose a challenge in successful CTI ablation. Reasons for the difficulty include increased thickness of the atrial tissue, catheter instability while moving the catheter along a less smooth CTI, and wedging of the catheter between 2 pectinate muscles, resulting in impedance rise and inadequate power delivery.[2,3] Prominent pectinate muscles can be recognized by ICE, by the presence of large atrial potentials, or by the catheter movement on

Table 1 Common anatomic challenges of cavotricuspid isthmus ablation and suggested troubleshooting

Anatomic challenge	Troubleshooting
Prominent sub-Eustachian pouch	• Ablation line more laterally than usual position • Use of an irrigated ablation catheter and/or contact force–sensing catheters • Ablation power uptitration • Circular ablation to isolate the pouch and anchoring to the IVC and tricuspid annulus
Prominent pectinate muscles	• Ablation line more medially than usual position • Use of an irrigated ablation catheter
Prominent Eustachian ridge	• Use of guiding sheath • Arching the ablation catheter to prevent contact with the Eustachian ridge
RCA or SCV acting causing "heat sink"	• Ablation line more laterally away from the SCV • Ablation power uptitration • Temporary obstruction of SCV ostium with a catheter or angioplasty balloon • Epicardial CTI ablation via SCV

CTI = cavotricuspid isthmus; IVC = inferior vena cava; RCA = right coronary artery; SCV = small cardiac vein.

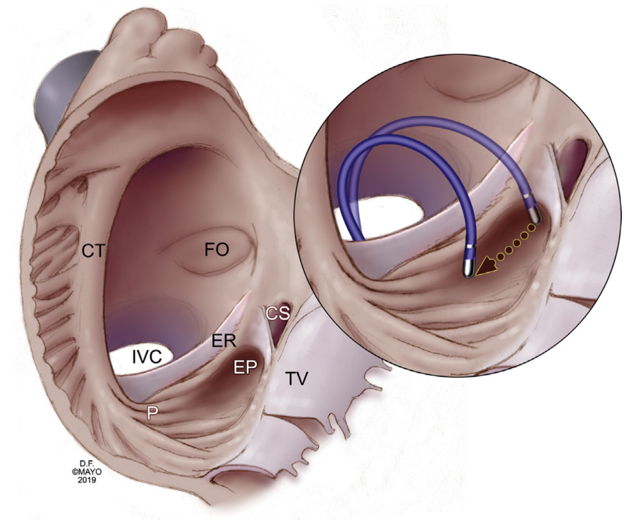


Figure 3 In patients with a prominent sub-Eustachian pouch, the catheter can be positioned more laterally to allow better tissue contact and avoid rapid temperature and impedance rises. CS = coronary sinus; CT = crista terminalis; EP = Eustachian pouch; ER = Eustachian ridge; FO = foramen ovale; IVC = inferior vena cava; P = pectinate muscles; TV = tricuspid valve.

fluoroscopy. If the problem is recognized, the ablation line can be performed more medially toward the septum where the pectinates are less prominent (Figure 4). Alternatively, use of an irrigated catheter can be considered to allow higher energy delivery to create transmural lesions across the CTI. The ICE image from our case does not indicate the presence of prominent pectinate muscles.

Prominent Eustachian ridge

The Eustachian ridge divides the CTI into an anterior sub-Eustachian portion between the Eustachian ridge and the tricuspid annulus, and a more posterior portion leading from the ridge to the anterior border of the IVC.[4] When prominent, a Eustachian ridge may act as a fulcrum that reverses the torque transmitted to the ablation catheter, making catheter manipulation along the CTI difficult.[2,3] This can be detected either by identifying a paradoxical catheter response to clockwise/counterclockwise torque, or by ICE. Using a guiding sheath over the Eustachian ridge often overcomes the problem (Figure 5). It may also be helpful to alter the catheter orientation (ie, creating a loop with the ablation catheter using maximum flexion over the Eustachian ridge). In addition, the presence of myocardial fibers within the Eustachian ridge in some patients may allow conduction through the ridge and therefore ablation only between the tricuspid valve and the Eustachian ridge may not be adequate.[3–5] In these patients, ablation on the ridge itself may be necessary. ICE did not demonstrate a prominent Eustachian ridge in the present case.

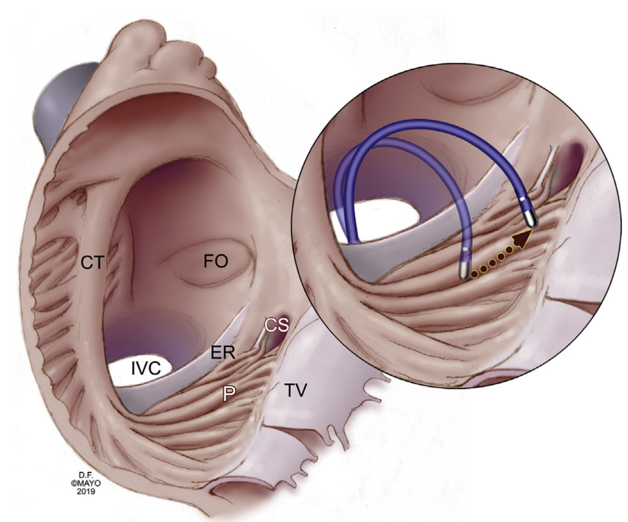


Figure 4 In patients with prominent pectinate muscles ablation can be preferably performed more medially to avoid the pectinates. See Figure 3 for abbreviations.

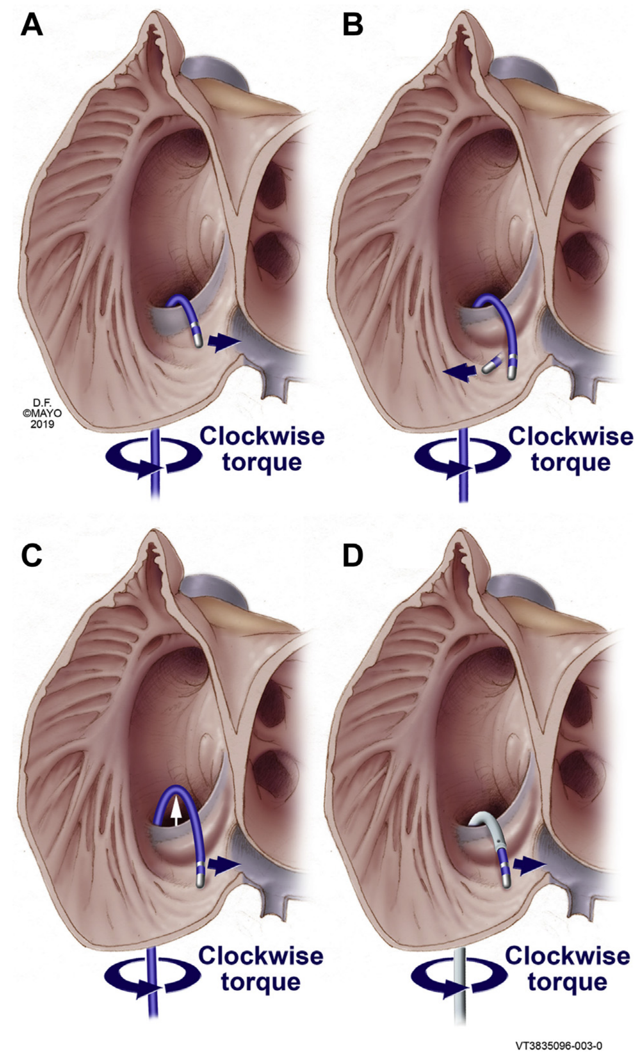


Figure 5 **A:** Normal anatomy. **B:** Prominent Eustachian ridge can act as a fulcrum that results in paradoxical lateral movement of the ablation catheter with clockwise torque. **C:** Arching the catheter over the Eustachian ridge can enable free clockwise or counterclockwise rotation while maintaining contact of the catheter tip with the isthmus. **D:** Using a guiding sheath over the Eustachian ridge can provide catheter support off of the Eustachian ridge so that clockwise rotation results in catheter movement toward the septum.

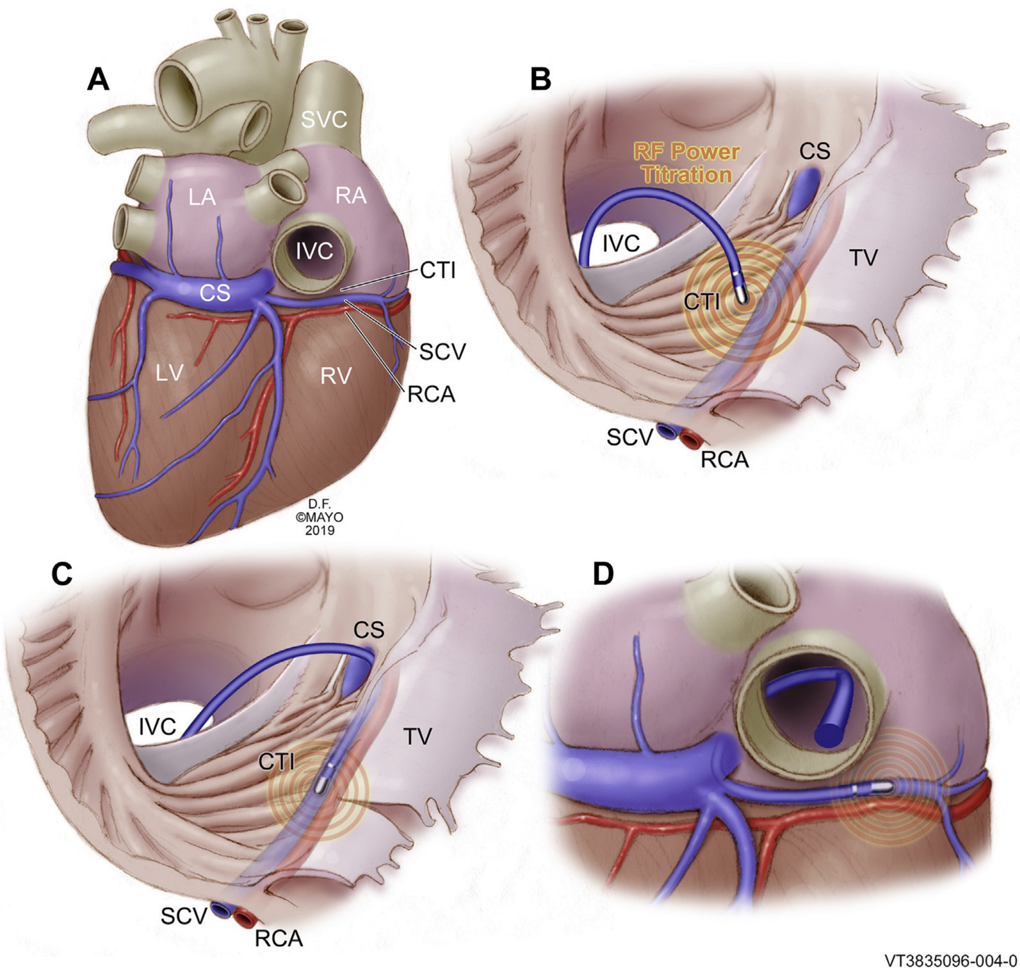


Figure 6 **A:** The right coronary artery (RCA) and the small cardiac vein (SCV) run on the epicardial aspect of the cavotricuspid isthmus (CTI) and can cause a "heat sink" effect when ablating the CTI. **B:** The problem can be addressed by ablation power uptitration guided by temperature and impedance monitoring. **C, D:** Alternatively, epicardial ablation of the CTI can be performed by advancing the ablation catheter into the SCV. CS = coronary sinus; IVC = inferior vena cava; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle; SVC = superior vena cava.

"Heat sink" effect due to coronary vessel

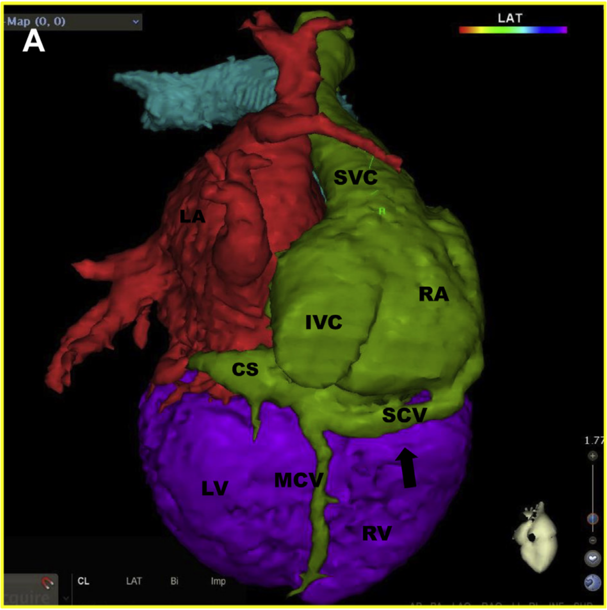
Intravascular blood flow in proximity to the tissue where RF energy is applied may result in convective heat loss and ineffective lesion formation. Direct energy deposition occurs within only 0.5–0.8 mm of the catheter electrode surface. The remainder of the RF lesion forms from conductive heating of adjacent myocardial tissue.[6] If heat transfer is counteracted by another mechanism, such as by removal of heat by flowing blood, then the RF lesion may be smaller than anticipated.[7] This phenomenon has been commonly referred to as "heat sink." It can be observed during ablation of atrial or ventricular tissue, particularly in the vicinity of intramural coronary arteries.

In the case of CTI ablation, the distal right coronary artery (RCA) and small cardiac vein (SCV) run on the epicardial aspect of the CTI and may cause a "heat sink" effect. This may be suspected when a prominent RCA or SCV is visualized by ICE. This was indeed the reason for difficulty in lesion formation and achievement of bidirectional block in our case. Note that a prominent SCV is present in Figure 2. ICE can be helpful in distinguishing the SCV from the RCA because the SCV is typically a thin-walled structure. ICE Doppler imaging can also be utilized to distinguish the 2 vessels, but this can be difficult owing to the relatively small size of both vessels.

The following approaches can be employed to address this problem:

(1) CTI ablation with uptitration of power guided by impedance and temperature monitoring, as performed in our case, can counteract the "heat sink" effect. For CTI ablation with irrigated catheters, we typically titrate power between 25 and 40 W with maximum temperature setting 40°C and irrigation flow 17–30 mL/min, aiming at an impedance drop of 5–10 ohms per ablation lesion.

(2) A more lateral ablation line can be performed that increases the distance from the medial portion of the SCV where the vessel has a large caliber. This approach was also used in our case. A lateral ablation line was carried from the tricuspid annulus to the IVC and bidirectional block was demonstrated with pacing maneuvers medially and laterally to the ablation line. It should be noted that a lateral ablation line will not be effective if the "heat sink" phenomenon is due to a prominent



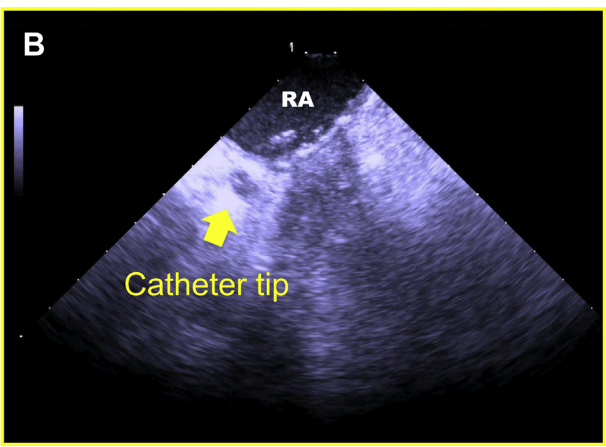


Figure 7 **A:** Preprocedure cardiac computed tomography identified the small cardiac vein (*black arrow*) in a patient with tricuspid annuloplasty ring and cavotricuspid isthmus (CTI)-dependent atrial flutter. **B:** Intracardiac echocardiography (ICE) imaging shows the tip of the ablation catheter in the small cardiac vein (*yellow arrow*). Ablation in the small cardiac vein (SCV) was necessary for CTI block since a portion of the CTI tissue was inaccessible from the endocardium owing to the presence of the annuloplasty ring. MCV = middle cardiac vein. Reproduced with permission from Kella and colleagues.[10]

RCA, as the caliber of the vessel is in fact larger more laterally on the tricuspid annulus.

(3) Placement of a catheter in the ostium of the SCV to temporarily obstruct venous blood flow and reduce the "heat sink" effect can be considered.

(4) Advancement of the ablation catheter into the SCV for ablation in the epicardial aspect of the CTI for creation of a transmural lesion can be considered in refractory cases (Figure 6). SCV anatomy can be variable and can impact ablation feasibility (see below). To cannulate the SCV, the ablation catheter should be placed just ventricular to the coronary sinus ostium at the level of the tricuspid valve and sharp clockwise torque should be applied to move the catheter tip into the coronary sinus. Then, the catheter is curved rightward and posteriorly to avoid cannulation of the middle cardiac vein. After the curve is applied, the catheter is simultaneously torqued clockwise and pulled back slowly, releasing the curve, which allows cannulation of the SCV.

Recommended ablation settings include an initial power of 5 W and slowly uptitrating to 20 W with a maximum temperature setting of 40°C and a flow rate of 17 mL/min. Temperature and impedance rises can limit the ability to deliver sufficient power in the SCV, and these should be monitored closely. Prior to ablating in the SCV, a coronary arteriogram should be performed to document a safe distance of the ablation catheter from the RCA. A definite recommendation for a safe distance between the SCV and the RCA cannot be made. However, safe distance considerations when ablating within the SCV should not differ significantly from ablation in other coronary venous structures where some of the above distance cut-offs have been derived from. A prior study of ablation of epicardial accessory pathways in the posteroseptal region reported that coronary injury happened in 50% of cases when RF was performed within 2 mm from the artery.[8] A distance of >5 mm between the RF ablation site and a coronary artery is generally associated with low risk of arterial injury, even though it should be noted that collateral injury at a distance >5 mm cannot be ruled out when high-power ablation is performed. RCA thermal injury can be of particular concern in pediatric patients even with endocardial ablation, such as in patients with Ebstein anomaly.[9] Ablation via the SCV may also be necessary in patients with prior tricuspid valve replacement or repair with an annuloplasty ring. In such patients, a portion of the endocardial CTI may be inaccessible owing to the presence of the prosthetic material in a more atrial position (Figure 7).[10]

Color flow Doppler ultrasound can be useful to distinguish SCV flow from arterial flow from the RCA and define the spatial relationship of the vessels to the CTI. It should be noted that the SCV may be very small or absent in many patients, therefore not allowing cannulation with a standard ablation catheter. A prior study demonstrated that the SCV was absent in 31% of cases, smaller (<1 mm) in diameter in 40%, and larger caliber (≥1 mm) in 29%.[11] Furthermore, the SCV may drain into the middle cardiac vein in a minority of patients (12% in a prior autopsy study),[12] in which case cannulation may be challenging or not feasible.

Other considerations

Several additional factors can contribute to inadequate CTI ablation. The following parameters should be considered:

(1) Inadequate power titration is a common reason of incomplete CTI block. Short (5-second) bursts of ablation with high power can be efficacious when using 4-mm-tip or irrigated-tip catheters.

(2) Tissue edema from initial inadequate ablation lesions can hamper subsequent successful ablation lesions in the same locations during the same procedure.

(3) Adenosine may help unmask dormant conduction across the CTI and can also be used in such cases.
(4) Extending postablation waiting periods may be valuable when there is concern for dormant conduction.

Conclusion

Several anatomic variations of the CTI can make energy delivery challenging and predispose to acute procedural failure and recurrence of atrial flutter. The recognition of these variations, primarily with the use of intraprocedural ICE, is critical in developing effective and safe troubleshooting approaches. In particular, the "heat sink" effect due to blood flow in prominent coronary vessels should be recognized as a potential cause of difficult CTI ablation in some patients. This problem can be addressed successfully using several different approaches described in this report.

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