A CASE FOR EDUCATION

Cavotricuspid isthmus ablation for atrial flutter: Anatomic challenges and troubleshooting

Georgios Christopoulos, MD, Konstantinos C. Siontis, MD, Ugur Kucuk, MD, Samuel J. Asirvatham, MD, FHRS

From the Department of Cardiovascular Medicine, Mayo Clinic, Rochester, Minnesota.

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. 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. 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

KEYWORDS Ablation; Anatomy; Atrial flutter; Bidirectional block; Cavotricuspid isthmus
(Heart Rhythm Case Reports 2020;6:115–120)

Address reprint requests and correspondence: Dr Samuel J. Asirvatham, Division of Cardiovascular Diseases, Mayo Clinic College of Medicine, 200 First St SW, Rochester, MN 55905. E-mail address: asirvatham.samuel@mayo.edu.

Test your knowledge!
Take an interactive quiz related to this article: https://www.heartrhythmcasereports.com/content/quiz_archive
imaging, right atrial angiography, or cardiac computed tomodraphy. 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.

### 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. Prominent pectinate muscles can be recognized by ICE, by the presence of large atrial potentials, or by the catheter movement on

| 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                             |
| Prominent Eustachian ridge         | - Use of an irrigated ablation catheter                                          |
|                                    | - 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.
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. 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. 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. In these patients, ablation on the ridge itself may be necessary. ICE did not demonstrate a prominent Eustachian ridge in the present case.
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. 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. 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
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. 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. 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).

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.

References
1. Cabrera JA, Sanchez-Quintana D, Farre J, Rubio JM, Ho SY. The inferior right atrial isthmus: further architectural insights for current and coming ablation technologies. J Cardiovasc Electrophysiol 2005;16:402–408.
2. Asirvatham SJ. Correlative anatomy and electrophysiology for the interventional electrophysiologist: right atrial flutter. J Cardiovasc Electrophysiol 2009;20:113–122.
3. Gami AS, Edwards WD, Lachman N, et al. Electrophysiologic anatomy of typical atrial flutter: the posterior boundary and causes for difficulty with ablation. J Cardiovasc Electrophysiol 2010;21:144–149.
4. Nakagawa H, Lazara R, Khastgir T, et al. Role of the tricuspid annulus and the eustachian valve/ridge on atrial flutter: Relevance to catheter ablation of the septal isthmus and a new technique for rapid identification of ablation success. Circulation 1996;94:407–424.
5. McKay T, Thomas L. Prominent crista terminalis and Eustachian ridge in the right atrium: Two dimensional (2D) and three dimensional (3D) imaging. Eur J Echocardiogr 2007;8:288–291.
6. Fuller IA, Wood MA. Intramural coronary vasculature prevents transmural radiofrequency lesion formation: implications for linear ablation. Circulation 2003;107:1797–1803.
7. Perez JJ, Gonzalez-Suarez A, Berjano E. Numerical analysis of thermal impact of intramyocardial capillary blood flow during radiofrequency cardiac ablation. Int J Hyperthermia 2018;34:243–249.
8. Stavrakis S, Jackman WM, Nakagawa H, et al. Risk of coronary artery injury with radiofrequency ablation and cryoablation of epicardial posteroseptal accessory pathways within the coronary venous system. Circ Arrhythm Electrophysiol 2014;7:113–119.
9. Bertram H, Bokenkamp R, Peuster M, Hausdorf G, Paul T. Coronary artery stenosis after radiofrequency catheter ablation of accessory atrioventricular pathways in children with Ebstein’s malformation. Circulation 2001;103:538–543.
10. Kella DK, Yasin OZ, Isath AM, et al. Radiofrequency ablation of the cavotricuspid isthmus for management of atrial flutter in patients with congenital heart disease after tricuspid valve surgery: A single-center experience. Heart Rhythm 2019;16:1621–1628.
11. von Ludinghausen M. The venous drainage of the human myocardium. Adv Anat Embryol Cell Biol 2003;168:I-VIII, 1–I-VIII, 104.
12. Cendrowska-Pinkosz M. The variability of the small cardiac vein in the adult human heart. Folia Morphol (Warsz) 2004;63:159–162.