Unusual Presentations of Cavotricuspid Isthmus-Dependent Right Atrial Flutter Following Robotic Bi-atrial CryoMaze Ablation for Atrial Fibrillation

1WILLIAM R. MADDOX, MD, 2W. RANDOLPH CHITWOOD, JR, MD, 3CRYSTAL B. OGLESBY, RN, BSN and 1ADAM E. BERMAN, MD

1Section of Cardiac Electrophysiology, Division of Cardiology; Medical College of Georgia, Georgia Health Sciences University, Augusta, GA
2East Carolina Heart Institute and Department of Surgery, Brody School of Medicine, East Carolina University, Greenville, NC
3Georgia Health Sciences Health System, Augusta, GA

ABSTRACT. Recent advances in the surgical management of atrial fibrillation (AF) include the creation of bi-atrial ablation lesion sets utilizing cryoablation techniques. These lesions sets may then serve as the substrate for re-entrant atrial tachycardias with unusual electrocardiographic appearances. We report two cases of patients with symptomatic AF and severe mitral valve (MV) regurgitation who underwent robotic MV repair with a concomitant bi-atrial CryoMaze ablation. Both patients subsequently presented with atrial tachycardias with unusual surface electrocardiographic appearances. Each patient underwent invasive electrophysiologic testing at which time cavotricuspid isthmus-dependent right atrial flutter was diagnosed and successfully ablated. Clinicians caring for patients undergoing this complex surgical procedure should be familiar with unusual manifestations of typical atrial flutter following extensive epicardial ablation. These postoperative tachycardias may be amenable to curative catheter ablation.

KEYWORDS. atrial fibrillation, atrial flutter, catheter ablation, MAZE procedure, Surgical ablation, three-dimensional mapping.

Introduction

Atrial fibrillation (AF) is the most common arrhythmia seen in the general population. The prevalence of atrial fibrillation is approximately 1% and this is estimated to increase approximately 2.5 times in the coming decades.1 AF is a major contributor to cardiovascular morbidity and mortality, and is frequently associated with an increased incidence of heart failure and risk of thromboembolic complications.2 The treatment of AF has been a rapidly evolving science. Antiarrhythmic medications have long been considered first-line therapy for the maintenance of sinus rhythm in AF patients. However, long-term efficacy of these agents is often suboptimal.3 Consequently, catheter-based and surgical ablation procedures have been developed representing more definitive treatment of AF.

Surgical approaches to the management of AF

The Cox–Maze III procedure has long been available for the treatment of AF.4 This procedure involves a ‘cut and
sessed a box lesion around all four pulmonary veins, the tricuspid valve. The left atrium was entered via a lesion from the RA appendage to the elevation of sinus to the tip of the RA appendage; and an endocardial perpendicular, transverse lesion from the coronary atrium included an intercaval lesion extending from the coronary sinus to the beginning of atriochamatic and mitral annuloplasty, and subsequently developed an atrial lesion encompassing the entire atrial myocardium, creating barriers to intra-atrial electrical impulse propagation, rendering the atria less likely to initiate and sustain AF. Reports demonstrate a majority (75–95%) of these patients remaining arrhythmia free at mean follow up of 5.7 years. These data are supported in both freestanding AF surgical procedures, and those operations involving concomitant surgical revascularization and/or valvular intervention.

Owing in part to its technical complexity, the Cox–Maze III procedure is not widely performed. Consequently, significant interest has arisen in the development of standalone, beating heart AF surgical procedures featuring rapid creation of permanent atrial ablative lesions. Recently, a minimally invasive technique has been developed producing lesion sets similar to those seen in the Cox–Maze III procedure using cryoablation techniques. Preliminary studies have revealed promising data when assessing for long-term maintenance of sinus rhythm in postoperative follow up. While these results are encouraging, incomplete or healed surgical lesion sets may create atrial substrate favoring the development of scar-mediated macro-re-entrant atrial tachyarrhythmias. We report the presentations and clinical course of two patients who underwent minimally invasive robotic bi-atrial CyroMaze AF ablation procedure with concomitant mitral valve (MV) annuloplasty, and subsequently developed unusual presentations of typical cavitricuspid isthmus (CTI)-dependent right atrial (RA) flutter.

Clinical patient presentations

Case 1

A 58-year-old woman with a history of hypertension was referred to our center for management of medically refractory paroxysmal AF and atrial tachycardia (AT). Her medical history was significant for adriamycin-induced cardiomyopathy, left ventricular ejection fraction (LVEF) of 30–35% with moderate to severe mitral valve regurgitation (MR). She had failed sotalol and amiodarone therapy for control of atrial arrhythmias. She underwent invasive catheter electrophysiologic (EP) testing and several right ATs were successfully targeted and ablated. Owing to her symptomatic valvular heart disease, she was then referred for MV repair and concomitant surgical AF ablation.

Surgical AF ablation involved multiple bi-atrial lesion sets. Lesions were created using a frost probe at -140°C for 2 min (ATS CryoMaze Surgical Ablation System, ATS Medical Inc, Minneapolis, MN). Lesions on her right atrium included an intercaval lesion extending from the superior vena cava (SVC) to the inferior vena cava (IVC); a perpendicular, transverse lesion from the coronary sinus to the tip of the RA appendage; and an endocardial lesion from the RA appendage to the elevation of the tricuspid valve. The left atrium was entered via Sondergaard’s groove. The left atrial (LA) lesions included a box lesion around all four pulmonary veins, a connecting lesion to the level of P3 of the MV, and a lesion in the oblique sinus up to the level of the coronary sinus (Figure 1). The LA appendage was surgically oversewn. MV annuloplasty was completed using a 32-mm band.

The patient had an uneventful postoperative course. Her heart failure was treated medically with improvement of her LVEF to 40–45% and minimal residual MV regurgitation. Six months postoperatively, she presented to the emergency department complaining of heart racing and accompanying dyspnea. An electrocardiogram (ECG) demonstrated evidence of atrial tachycardia with 2:1 conduction with purely positive flutter waves in lead V1 (Figure 2). Adenosine was administered yielding complete atrioventricular nodal (AVN) block with unperturbed underlying atrial tachycardia. ECG analysis during AVN block revealed fractionated flutter waves in the inferior leads, consistent with prolonged atrial activation in the setting of atrial scar (Figure 3). Following initiation of rate control agents, she elected to proceed with repeat invasive catheter EP testing and ablation.

Electrophysiology study

The patient underwent a conventional four-catheter EP study. Catheters were placed in the coronary sinus (CS), His bundle region, right ventricle (RV) and along the crista terminalis (CT). Her baseline rhythm was atrial tachycardia with a cycle length (CL) of 268 ms. Surface ECG analysis of atrial activity revealed discreet atrial flutter waves measuring 174 ms in duration. Three-dimensional (3D) electroanatomic mapping with the CARTO mapping system (Biosense Webster, Diamond Bar, CA) was used to create an activation and bipolar voltage map of tachycardia within the RA. The entire tachycardia cycle length was encompassed within the body of the RA, and voltage mapping revealed a region of dense myopathic scar along the RA free wall consistent with a prior surgical lesion set (Figure 4). Additional scar was noted near the cavitricuspid isthmus and anterior RA. Activation mapping revealed slowed wavefront propagation diffusely through the regions of low voltage. Propagation mapping revealed apparent figure-of-eight re-entry with a critical isthmus on the right atrial free wall (Figure 5). We entrained tachycardia from the RA free wall and the post-pacing interval (PPI)-tachycardia cycle length (TCL) in this region measured 13 ms. Surface flutter wave analysis was confounded owing to their low amplitude; concealed versus manifest fusion was difficult to ascertain. Manual power-controlled radiofrequency ablation (RFA) was performed in this region using a 3.5-mm tip open irrigation catheter (Biosense Webster). RFA in this region failed to terminate tachycardia but did slightly alter the tachycardia cycle length. Reanalysis of propagation mapping revealed activation of the CTI during tachycardia. Entrainment from the CTI revealed a PPI-TCL=20 ms. Again, surface ECG analysis during native tachycardia and overdrive pacing was obscured by the duration of the flutter wave and QRS superimposition. RFA was

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performed along the CTI resulting in termination of tachycardia. A linear lesion set was created yielding bidirectional CTI block upon postablative differential pacing. Isoproterenol infusion was initiated and bidirectional CTI block persisted. With burst pacing, no tachycardia was re-inducible.

Case 2
An 83-year-old man with a history of severe MR and cardiomyopathy was referred for management of symptomatic, medically refractory persistent AF. Amiodarone therapy failed to control his burden of AF. Transesophageal echocardiography demonstrated a flail A2 segment of the anterior leaflet of the MV. The patient was referred for robotic MV repair and concomitant surgical AF ablation. A similar template surgical lesion set was created as described in the previous case (cf. Figure 1). MV repair was accomplished with a 34-mm annuloplasty ring and leaflet repair. His postoperative course was uneventful. However, 2 months after his procedure, he presented complaining of fatigue and dizziness. ECG revealed a very low-amplitude atrial tachycardia with 2:1 conduction. Flutter wave morphology were very low amplitude and demonstrated fragmentation. The patient failed medical therapy with dofetilide and was referred for an invasive catheter EP study and ablation procedure.

Electrophysiology study
The patient underwent a four-catheter EP study with diagnostic catheters positioned in the CS, His bundle region, RV, and along the CT. Baseline rhythm was atrial tachycardia with a TCL=307 ms. Adenosine administration revealed continued tachycardia with AV

Figure 1: Anatomic distribution of lesion set for robotic CryoMaze procedure. 1. Intercaval lesion extending from the superior vena cava to the inferior vena cava; 2. A perpendicular, transverse lesion from the coronary sinus to the tip of the right atrial appendage; 3. A connecting lesion to the level of P3 of the mitral valve; 4. Left atriotomy line at Sondergaard's groove; 5. Epicardial lesion in the oblique sinus up to the level of the coronary sinus; 6. Box lesion around the four pulmonary veins; 7. Endocardial lesion from the right atrial appendage to the elevation of the tricuspid valve; 8. Anterior endocardial lesion; 9. The left atrial appendage was oversown.
nodal block and very broad and fractionated flutter waves (Figure 6). The EnSite NavX™ (St. Jude Medical, Minnetonka, MN) mapping system was used to remotely create an activation and bipolar voltage map of the right atrium using Stereotaxis with an open irrigation catheter (RMT CelsiusThermocool, Biosense Webster). Attempts at entrainment from the RA free wall were successful and revealed apparent concealed fusion, but

Figure 2: Twelve-lead electrocardiogram of presenting tachycardia. Discreet flutter waves are noted in lead V1.

Figure 3: Electrocardiogram rhythm strip recorded during adenosine-induced anterograde atrioventricular nodal block. Note the fractionated flutter wave morphologies.
this was difficult to ascertain as the flutter waves were indiscernible on surface ECG. The PPI–TCL=9 ms from this location. RFA was applied in this territory, but failed to terminate tachycardia. Seeking beat-to-beat propagation analysis, we opted to deploy the EnSite array within the right atrium (RA). A combined non-contact dynamic substrate and propagation map of the RA was created. Activation mapping revealed slow wavefront propagation activation through the CTI. RFA was stereotactically applied along the CTI with the open irrigation catheter resulting in termination of tachycardia. Consolidation lesions were performed yielding bidirectional CTI block rendering the patient non-inducible for recurrent atrial flutter.

**Discussion**

Macro-re-entrant atrial tachycardias may occur following either endocardial or epicardial ablation of AF. The cases described herein represent the first reports of the unusual surface ECG appearance of typical CTI-dependent RA flutter occurring remotely following bi-atrial surgical CryoMaze AF ablation. In both of these
instances, strikingly unusual flutter waves were observed on surface ECG. Additionally, the surface ECG appearance of the flutter waves confounded analysis of ECG criteria for entrainment during invasive EP testing. Propagation mapping may be challenging owing to the extremely low voltages seen within the atria following atrial debulkment during surgical ablation. Additionally, entrainment techniques may yield similar return cycle lengths in a variety of locations. Coupled with difficult to analyze surface ECG flutter wave morphologies during entrainment, the distinction between concealed and manifest fusion may be obfuscated leading to failed initial ablation sites.

Atrial tachyarrhythmias following surgical ablation procedures have been well described. Wazni et al studied 23 patients presenting with atrial tachyarrhythmias after surgical “cut and sew” Maze procedures. Roughly one-third of these patients had recurrent AF. Approximately 20% of these patients also demonstrated inducible focal atrial tachycardias, and 43% demonstrated incisural atrial tachycardias, originating from both the RA and LA. Ishii et al reported a case series of 200 patients who underwent surgical Maze procedure. A total of 86 of the 200 experienced atrial tachyarrhythmias postoperatively. 41% of these patients experienced atrial flutter with most of these events occurring relatively soon following surgery. Chugh et al reported a case series of 15 patients presenting with CTI-dependent atrial flutter following prior LA ablation for AF. In this series, a significant number of CTI-dependent atrial flutters exhibited unusual surface ECG flutter wave morphologies. This was postulated to have been due to extensive debulking of the LA with significant loss of bipolar voltage in the LA. In their series, however, it is unclear how many of these patients underwent RA ablation at the time of LA ablation.

Bi-atrial surgical ablation utilizing cryotherapy has been shown to be effective in the maintenance of sinus rhythm in patients with AF. The ablative lesion sets mimic those of the Cox–Maze procedure but use cryoenergy as the energy source. Intraoperatively, the atria are ablated with the following lesion sets: The LA lesion set consists of en bloc pulmonary vein isolation as a box lesion set, a connecting lesion to the mitral annulus, and a perpendicular mitral isthmus lesion epicardially across the coronary sinus. The RA lesion set includes a free wall intercaval line extending inferiorly from the SVC to the IVC, a lesion perpendicular to this inferiorly, extending below the CTI, and an endocardial lesion extending from the CTI lesion to the tricuspid annulus.

Figure 5: Carto electroanatomic propagation map of the right atrium during tachycardia. Note the apparent figure of eight activation sequence. The wavefront courses through the cavotricuspid isthmus (CTI) as would be expected during this type of re-entry. Return cycle lengths along the right atrial free wall and CTI were fairly similar with difficult to analyze surface flutter waves during entrainment confounding the diagnosis.
These lesion sets result in dense scar formation; however, healed regions of myocardium or incomplete lesions may provide the electroanatomic substrate for scar-mediated re-entrant tachycardias.

For patients presenting after extensive surgical atrial ablation with atrial tachycardias, 3D electroanatomic mapping is indispensable in characterizing underlying tissue properties as well as propagation mapping. In our case series, the tachycardic circuit was determined to be confined to the densely myopathic RA using 3D mapping. Entrainment techniques remain a cornerstone of localizing the critical isthmuses facilitating reentrant circuits. Key characteristics and techniques pertinent to catheter mapping and ablation of these arrhythmias are summarized in Table 1. In both of our patients, entrainment revealed a short PPI-TCL with apparent concealed fusion, but RFA in the region of entrainment failed to terminate tachycardia. Further entrainment mapping revealed the CTI to be the critical isthmus of the reentrant circuit. RFA along the CTI terminated tachycardia rendering it non-inducible.

Conclusions

The bi-atrial robotic CryoMaze procedure may create the electroanatomic substrate for unusual appearing atrial tachycardias. Detailed 3D electroanatomic mapping coupled with traditional tachycardia entrainment

Table 1: Key findings in the catheter mapping and ablation of unusual post-operative right atrial tachycardias

- In the post-surgically ablated atrium, three-dimensional electroanatomic mapping is indispensable for substrate characterization and tachycardia propagation.
- Surface electrocardiogram (ECG) flutter wave morphology may be dramatically altered owing to the presence of dense scar within the atria.
- Determination of concealed versus manifest fusion during tachycardia entrainment may be challenging due to low amplitude surface ECG flutter wave morphologies coupled with broad areas of dense scar.
- A thorough pre-procedural comprehension of the number and location of prior surgical ablation lesion sets is critical to planning and successfully completing endocardial catheter mapping studies.
techniques facilitate successful endocardial catheter ablation of atrial tachycardias presenting late after surgery.

References