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Review article

Advanced ablation strategies for management of post-surgical atrial arrhythmias

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ABSTRACT
Post-surgical arrhythmias include a wide range of arrhythmias occurring late after cardiac surgery and represent a complex substrate for catheter ablation either because of extended scar and remodeling or because of limited access to the area of interest. Novel image integration and ablation tools have made the catheter ablation in this population both feasible and successful. We review a structured approach to catheter ablation of post-surgical atrial arrhythmias in various patient cohorts including the most common congenital heart defects.

Keywords: catheter ablation, remote magnetic navigation, congenital heart disease, atrial tachycardia

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INTRODUCTION

Cardiac arrhythmias are frequently encountered after cardiac surgery and can occur in the immediate post-surgical period or later, months or even years after surgery. In the postoperative period, arrhythmias may complicate the patient's course and prolong the stay in the intensive care unit.[1,2] Late after surgery, cardiac arrhythmias are believed to stem mainly from the unavoidable scars left behind (e.g. after an atriotomy or even by the cannulation sites for the cardiopulmonary bypass).[3–5] However, progression of the structural heart disease, pressure increase and dilation can lead to pronounced fibrosis, which in itself can promote both focal and/or re-entrant arrhythmia.[6] Regardless of the mechanism, the presence of frequently recurrent or sustained arrhythmias is related to reduced quality of life, risk of tachycardiomyopathy, high thromboembolic risk and eventually reduced survival.[7–9]

Catheter ablation of post-surgical atrial arrhythmias is nowadays feasible and successful with the use of advanced 3D image integration and ablation tools. We review different post-surgical situations and describe management options by catheter ablation as an alternative to long-term antiarrhythmic therapy.

PREPARATION OF THE ABLATION PROCEDURE

Detailed knowledge of individual anatomy

Understanding the individual anatomy is the cornerstone of a successful ablation procedure. Information on the dimensions of the cardiac chambers, the spatial relationship between different cardiac structures, or the presence of a patent foramen ovale are some examples of necessary information that could facilitate the procedure. Furthermore, in patients with congenital heart disease a detailed revision of the specific anatomy of each individual is a prerequisite for a successful ablation. Not infrequently, patients with congenital defects have limited accessibility to cardiac cavities due to complex intra-/extracardiac anomaly and/or presence of intra-atrial baffles or artificial materials. However, with detailed knowledge of the anatomy and the use of advanced tools these obstacles can be overcome and procedures can be performed as safely and successfully as rather simpler cases with even lower fluoroscopy exposure.[10]

Review of surgical procedure note

While understanding the underlying anatomy is a prerequisite to insertion and navigation of the catheters, knowing the location and extent of surgical incisions and suture placement is of paramount importance in order to unveil the arrhythmia origin. Review of the surgical operation reports is necessary to understand the exact procedure performed in each individual and obtain information about the technique used (e.g. on/off pump, canulation sites, location of patches etc).

ADVANCED TECHNIQUES

3D image reconstruction

In order to understand the individual 3D anatomy, we recommend to perform a cardiac magnetic resonance (CMR) scan, or alternatively a computed tomography (CT) scan when a CMR is contraindicated. For CMR imaging, a free breathing, diaphragm navigated, balanced steady-state free precession sequence allows for a non-contrast whole heart image without exposure to radiation. All pre-acquired 3D imaging DICOM data are processed for 3D reconstructions of the heart, major vessels and the aorta and used during ablation procedures by integration with the mapping information (POLARIS software, Biosense Webster, Brussels, Belgium) (Figure 1).

3D electroanatomical mapping

The 3D electroanatomical mapping system (CARTO XP or CARTO 3 RMT, Brussels, Belgium) is used: a) to localize the catheters without the need to x-ray; b) to calculate 3D reconstructions of electrical activation sequences (activation maps) and of local signal amplitude (voltage maps): c) to display in 3D the anatomy of a heart chamber using sequential localization of the catheter.[11] The 3D electroanatomical maps are superimposed or merged on the reconstructed 3D surfaces of each cardiac structure derived from CT of CMR scans (Figure 2).

Remote magnetic navigation

The remote magnetic navigation system uses two permanent magnets placed on both sides of the patient, which create a magnetic field that navigates the catheter inside the patient's chest. The direction

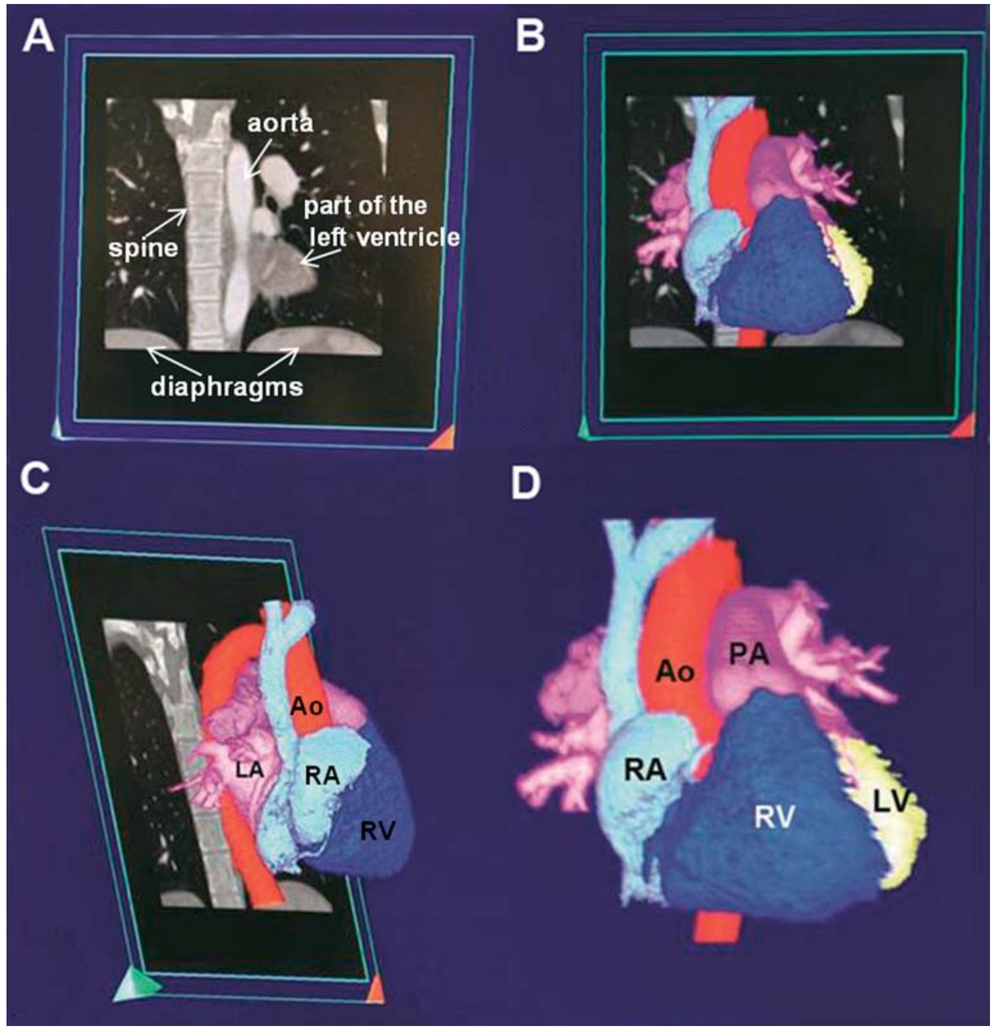

Figure 1. Three-dimensional segmentation of the cardiac surfaces using a computed tomography (CT) scan of the heart. A, CT anteroposterior view; B, 3D cardiac anatomy is reconstructed using the acquired images; C, right anterior oblique view of the same scan to appreciate 3D; D, final 3D model used for merging with the 3D electroanatomical system during ablation.

of the magnetic field and thus the movement and deflection of the catheter is manipulated remotely by the operator via a computer located in the control room.[12,13] This system allows for fine movements and enhances the anatomical reach of the catheter tip into difficult to access sites (Figure 3). Contrary to conventional catheters, the magnetic catheter is steered from the tip; and due to the very soft shaft of the body of the catheter, any position can be reached even when multiple turns have been taken already (Figures 2, 3 and 6). These are encountered rather commonly in surgically repaired congenital heart disease patients.[14] In addition, remote magnetic navigation allows reaching and successfully ablating endocardial sites of arrhythmias even when the vascular access to the heart is restricted.[10,15,16]

REVIEW OF VARIOUS PATIENT COHORTS

Incisional atrial tachycardia

The presence of intra-atrial scars, consequence of previous atriotomy incisions, adds a significant risk of late atrial tachycardia occurrence. Scar-related arrhythmias are encountered most commonly after surgical repair of atrial septal defects but can complicate the course of any patient who underwent a surgical atriotomy for any other reason (Figure 4).[5] Before the advent of catheter ablation, surgical ablation of accessory pathways was employed in some centres to treat the Wolf-Parkinson-White syndrome. Not uncommonly, patients can present with a different arrhythmia, usually macroreentrant, years after the surgery.[17]

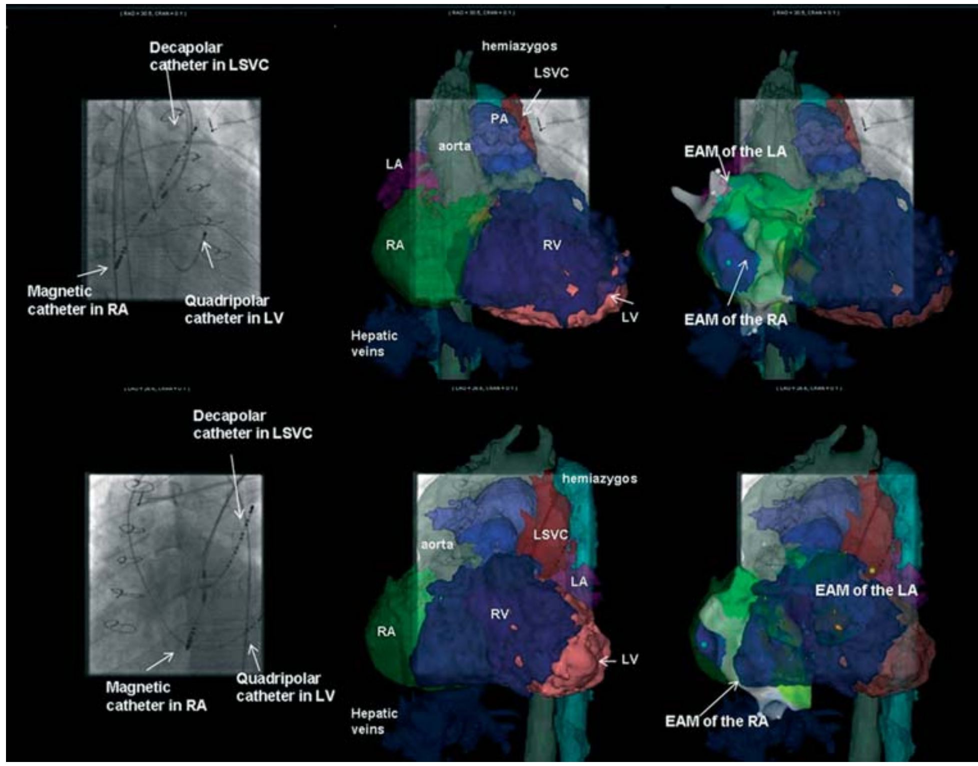

Figure 2. **Image on image technique. Fluoroscopic images of the heart and catheters in right anterior oblique (RAO) and left anterior oblique (LAO) views (left panel); Superimposition of 3D reconstructed surfaces of the cardiac cavities and vessels on the fluoroscopic image (middle panel); Electroanatomical maps of the cavities of interest on top of the 3D reconstructed surfaces (right panel). RA, right atrium; LSVC, left superior vena cava; LA, left atrium; PA, pulmonary artery; RV, right ventricle; LV, left ventricle; EAM, electroanatomical map.**

Particular care is mandated not to damage some adjacent structures to the ablation site, such as the sinus node or the right phrenic nerve. To avoid extensive radiofrequency ablations close to these areas, during the electrophysiological study pacing manoeuvres need to be performed in order to identify the trajectory of the phrenic nerve. The sinus node area can be found at the upper end of the crista terminalis, which usually presents as a ridge and displays double potentials (ref Figure 4).

Atrial tachycardia after intraoperative maze surgery

The maze procedure was introduced in 1987 for the surgical treatment of atrial fibrillation. The concept of this technique is to interrupt as many potential macro-reentrant circuits as possible within the atria in order to prevent reentry or fibrillation. The operation included pulmonary vein isolation and multiple incisions placed in both the right and the left atrium.[18] There is a great variability in the design and number of incisions employed by different surgeons over the years and even though the maze procedure was relatively successful in controlling atrial fibrillation in some patients, an overall risk of recurrence or development of scar-related atrial tachycardia as high as 43% was reported.[19,20] The spectrum of atrial tachyarrythmias post maze surgery is wide and includes most commonly recurrent atrial fibrillation (35%) due to reconnection of the pulmonary veins, as well as re-entrant atrial tachycardias (right or left atrial incisional flutter) or focal atrial tachycardias (Figure 5).[21]

SUPRAVENTRICULAR TACHYCARDIAS AFTER SURGICAL REPAIR OF CONGENITAL HEART DISEASE

Atrial fibrillation after repair of atrial septal defect

Atrial septal defects (ASDs) are the most common congenital malformations in the adult population. Not infrequently, a patient's course is complicated by atrial flutter or atrial fibrillation both of which

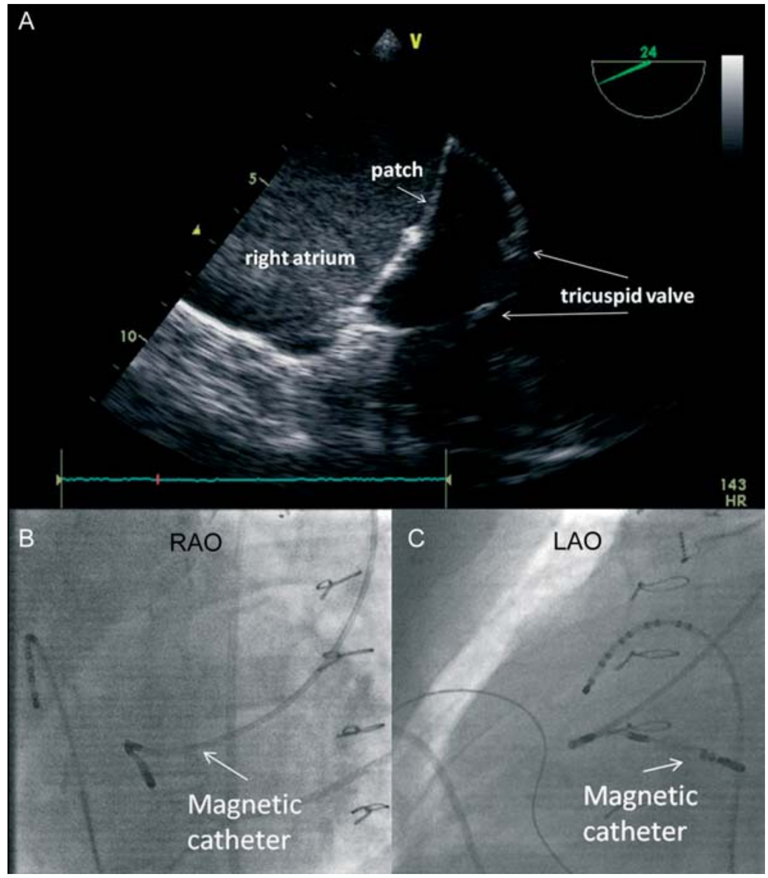

Figure 3. **An example of difficult anatomical reach. A patient with double inlet and double outlet right ventricle presented with atrial tachycardia. He had a patch over the right atrioventricular valve (A). The magnetic catheter is advanced retrogradely via the aorta to the left ventricle and via a large ventricular septal defect to the right ventricle and subsequently to the right atrium below the patch (B and C). Ablation at this site terminated the tachycardia. Access to this area was not possible antegradely.**

affect the quality of life and increase morbidity and mortality due to the increased risk of stroke.[22] Even after surgical or percutaneous closure of the ASD atrial fibrillation remains the most frequent arrhythmia and its prevalence relates to the age at the time of the repair and the pulmonary pressure.[3,5,22,23]

Radiofrequency catheter ablation of atrial fibrillation after surgical or percutaneous closure of the ASD is challenging, because it often requires transeptal punctures through the patch or the closure device or through the adjacent native septum. There are some data showing that this is feasible, safe, and effective in patients with ASD closure devices.[24] However, when the device is large and transseptal access is impossible through the native septum, a direct transseptal puncture of the device requires longer time.[25]

Magnetic navigation can offer an alternative solution for the ablation of atrial fibrillation in patients after closure of an ASD. The magnetic catheter is advanced retrogradely via the aorta advanced to the left atrium, and pulmonary vein isolation can be safely and effectively performed (Figure 6).[26]

Tachycardias after atrial switch (Mustard/Senning) operation

Between the early 1960s and mid-1980s, the Mustard and Senning operations represented the major surgical palliative procedures to redirect the atrial inflow to the opposite atrioventricular valve in children with dextro-transposition of the great arteries.[27,28] These operations involved re-routing of the venous return towards the opposite ventricle by creating intra-atrial baffles made of either an artificial material in the Mustard variant or pericardium in the Senning form. The surgical correction also

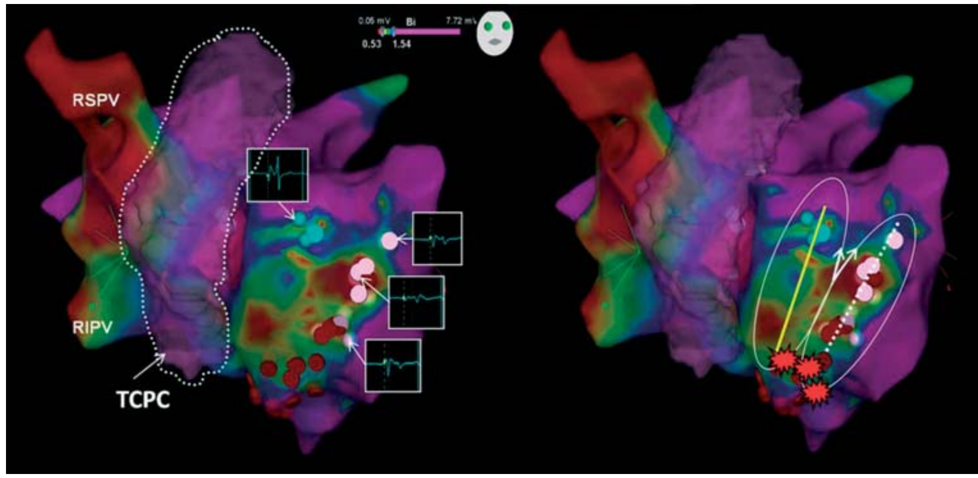

Figure 4. This is a patient with a history of tricuspid atresia and total cavo-pulmonary connection (TCPC). Figure presents the electroanatomical map of his right and left atrium. The map was created using a magnetic catheter that was retrogradely advanced via the aorta to the left ventricle, left atrium and finally right atrium through an atrial septal defect. Depiction of voltage amplitude during a sequentially acquired sinus rhythm map: Red color depicts very low bipolar voltage amplitude (<0.05 mV) and purple depicts normal voltage amplitude (>1.5 mV) of healthy myocardium. The right atrium presented a large area of scar (shown as the area delineated by the blue color). In the area of previous atriotomy (dotted line) in parallel to the atrioventricular grove double potentials were recorded (white dots). The yellow line represents the crista terminalis with double potentials recorded (turquoise dots). Right panel shows a potential macro re-entrant circuit that can form around the lines of block. Radiofrequency ablation (red dots) was delivered to close the gap between the lines of block and the inferior vena cava in order to stop the macro re-entrant circuit. TCPC, total cavopulmonary connection; RSPV, right superior pulmonary vein; RIPV, right inferior pulmonary vein.

involved longitudinal splitting of the subtricuspid isthmus and atrial septectomy. Long-term follow up of 132 patients after a Senning operation revealed a good long term survival up to 88% in 20 years. However, the probability of maintaining permanent sinus rhythm was 55% and 44% in 10 and 20 years respectively.[8]

The most common types of supraventricular arrhythmias in patients with Mustard or Senning intracardiac baffles are represented by macrorentrant tachycardias in relationship with the previous atriotomy scars or sites of placement of the suture lines for intracardiac baffles.

The most frequently encountered form of macrorentry is a macro-circuit turning around the tricuspid valve.[29,30] The cavotricuspid isthmus is parted by the baffle placement within the atria, which leads to separation of the caval and tricuspid annular aspects of the isthmus on the systemic and pulmonary venous sides of the circulation. Termination of the tachycardia during radiofrequency ablation is usually achieved from the neopulmonary venous side, although completion of the isthmus block might require radiofrequency energy delivery from both sides of the circulation.

Another common circuit is usually identified along the lateral right atrial wall, which is located in the neopulmonary venous atrium after a Mustard or Senning surgery. This circuit is likely created by the right atriotomy and/or fibrosis along the crista terminalis. Possible target isthmuses for ablation are between the atriotomy and anterior tricuspid annulus, or the inferior or superior limbs of the baffle.[31]

Focal atrial tachycardias, in relationship with the suture lines, are not uncommon.[31] The tachycardias can arise from both systemic and pulmonary atria, and are likely to be induced during the electrophysiological procedures after the index tachycardia – most frequently a cavotricuspid dependant or incisional macroreentry – has been successfully ablated.

The access to the morphologically right atrium in these patients can be achieved by a transbaffle puncture or a retrograde approach. In our series of 9 patients,[32] who underwent a total of 13 ablation procedures, the retrograde approach with remote magnetic navigation was used to facilitate the access and perform a complete mapping of the pulmonary venous atrium. Twenty-two different atrial tachycardias were mapped and ablated, 21 originating from the pulmonary venous atrium and 1 originating from the systemic venous atrium. Ten out of 13 procedures were successful in

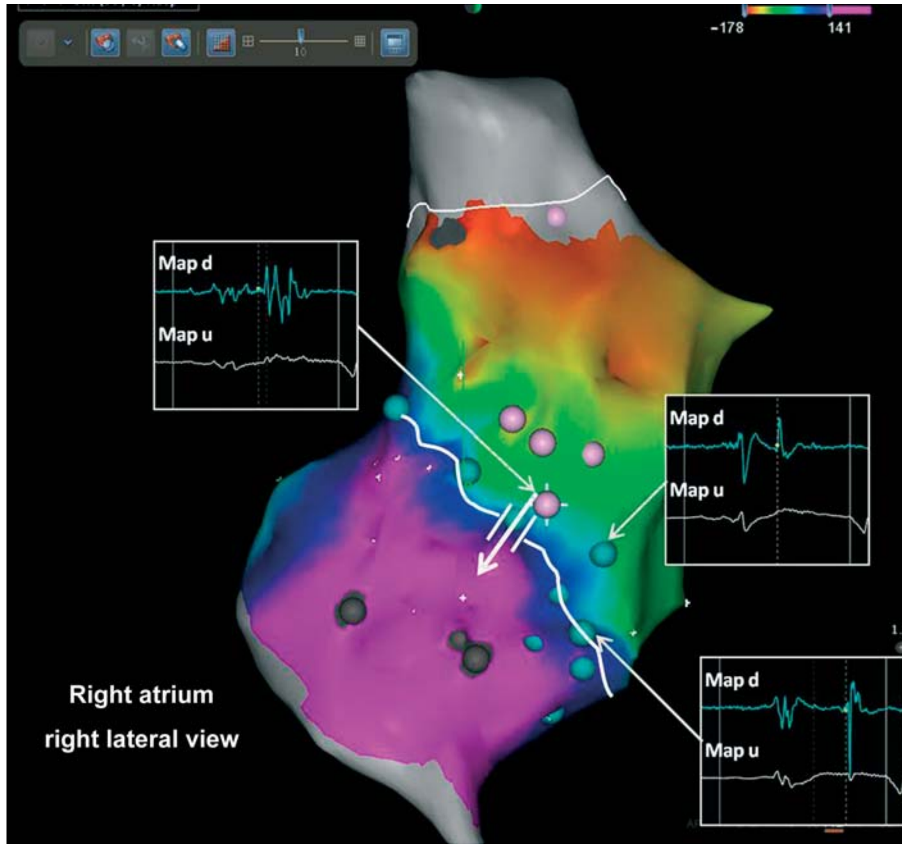

Figure 5. **Right atrial tachycardia in a patient late after tricuspid annuloplasty and maze surgery for atrial fibrillation. This patient presented with an atrial tachycardia with P wave morphology very similar to sinus P waves, which was mapped and successfully terminated after isolation of the superior vena cava (white line). Subsequently, a second macro-reentrant atrial tachycardia was induced with its critical isthmus represented by a gap in a previous surgically created line of block in the free right atrial wall. Closure of this gap by radiofrequency ablation successfully terminated the tachycardia.**

eliminating all atrial tachycardias and 8 out of 9 patients were in sinus rhythm after a median follow up of 201 days.[32]

Atrial tachycardia after Fontan procedure or total cavopulmonary connection (TCPC) conversion

The Fontan procedure is performed in paediatric patients with a single functional ventricle either due to valvular defects (tricuspid atresia, pulmonary atresia), or due to hypoplastic right or left ventricle. The procedure involves connection of the right atrium to the pulmonary arteries in order to support the pulmonary circulation bypassing the morphologically right ventricle.[33,34] Total cavopulmonary connection (TCPC) conversion is a surgery that tunnels the inferior and superior vena cava to the pulmonary artery in order to support the lung flow.[35] Supraventricular arrhythmias after TCPC conversion are thought to occur less frequently than after the classic Fontan repair.[36] However even with extracardiac conduits, the incidence of supraventricular tachyarrhytmias remains as high as 9% compared to 13% in lateral tunnel TCPC patients at 1 year follow up.[37]

In the presence of a TCPC connection, the access to the remainder of the right atrium is no longer possible by a transvenous approach, unless a transbaffle puncture is performed. In our recent series,[32] we demonstrated that an exclusively retrograde arterial approach using remotely navigated magnetic catheters and 3D image integration is a feasible and safe alternative with high chances of success and very low fluoroscopy exposure. In 3 patients the critical part of the re-entrant circuit was the isthmus between the right atrioventricular annulus and the scar at the posterior wall of the remaining part of the right atrium.

In one case with right atrial isomerism and twin AV nodes, an AV nodal-to-AV nodal re-entrant tachycardia was reproducibly inducible and successfully ablated at the inferior AV node.[32]

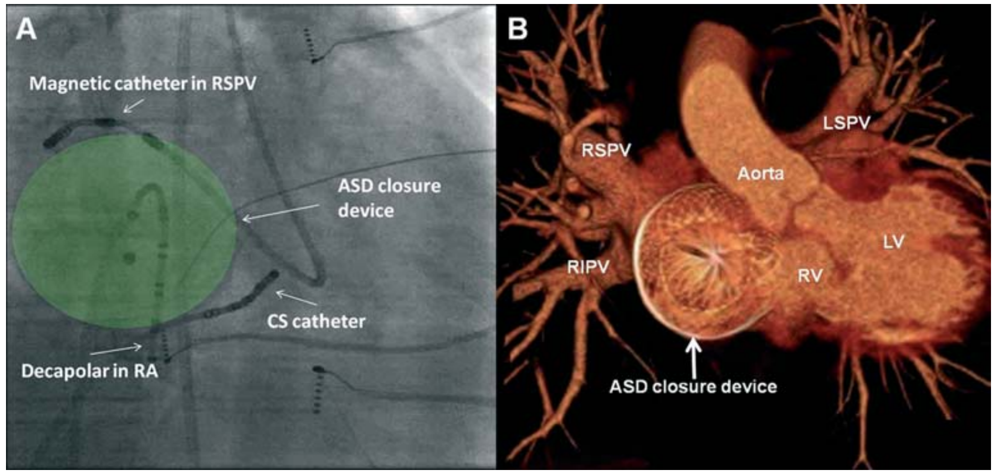

Figure 6. A patient with a large ASD closure device (40 mm) presented for atrial fibrillation ablation. A: Right anterior oblique view with the magnetic catheter in the right superior pulmonary vein (RSPV). The magnetic catheter was advanced retrogradely via the aorta to the left atrium. B: The closure device as depicted in a computed tomography scan of the patient. Note the significantly large size of the device leaving no adjacent septum to allow a transeptal puncture. ASD, atrial septal defect; CS, coronary sinus; RA, right atrium; RSPV, right superior pulmonary vein; RIPV, right inferior pulmonary vein; LSPV, left superior pulmonary vein; RV, right ventricle; LV, left ventricle.

CONCLUSIONS

A structured approach to post-surgical arrhythmias ablation involves review of the anatomy and surgical report, three-dimensional reconstruction of the cardiac endocardial surfaces from CT or CMR scans and three dimensional electroanatomical mapping. Remote magnetic navigation is a novel technology that is particularly able to assist at navigating the ablation catheter to any sites, especially when previous surgeries have made direct access impossible. The advances in imaging and ablation tools have offered a solution to the ablation of the most complex post-surgical arrhythmias even to patients with complex congenital heart defects and multiple surgical operations.

Competing interests

Sabine Ernst is a consultant in Biosense Webster and Stereotaxis Inc.

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