

Atrial Macroreentry in Congenital Heart Disease

Darragh J. Twomey, Prashanthan Sanders and Kurt C. Roberts-Thomson*

Centre for Heart Rhythm Disorders, University of Adelaide and Royal Adelaide Hospital, Adelaide, Australia

Abstract: Macroreentrant atrial tachycardia is a common complication following surgery for congenital heart disease (CHD), and is often highly symptomatic with potentially significant hemodynamic consequences. Medical management is often unsuccessful, requiring the use of invasive procedures. Cavotricuspid isthmus dependent flutter is the most common circuit but atypical circuits also exist, involving sites of surgical intervention or areas of scar related to abnormal hemodynamics. Ablation can be technically challenging, due to complex anatomy, and difficulty with catheter stability. A thorough assessment of the patients status and pre-catheter ablation planning is critical to successfully managing these patients.

Keywords: Congenital heart disease, supraventricular tachycardia, catheter ablation.

INTRODUCTION

Significant congenital heart disease (CHD) occurs in 6 of every 1000 live births [1]. In adulthood, arrhythmias are often problematic in these patients and present significant therapeutic challenges. These patients have distorted anatomy, hemodynamic stress and often hypoxia, and conduction system abnormalities, leading to both brady and tachyarrhythmias. While many forms of atrial tachyarrhythmias have been described, including AV nodal reentry, focal atrial tachycardia [2] focal junctional tachycardia [3] and AF, macroreentry is the most common form of tachyarrhythmia in this group. These arrhythmias are termed 'intra-atrial reentrant tachycardias' (IART) and are due to reentry around an anatomic obstacle, at least 2 centimeters in diameter [4]. In this review we will focus on this arrhythmia in the common forms of CHD.

GENERAL CONSIDERATIONS

IART occurs in all forms of CHD, from atrial septal defect and Tetralogy of Fallot repair, to more complex disease, such as following the Mustard and Senning procedures for transposition of the great arteries and the Fontan procedure in patients with a univentricular circulation due to tricuspid atresia or a double inlet left ventricle. Arrhythmia most often presents in adulthood, years after surgery and more complex anatomical lesions are associated with a higher risk of developing this complication. In conjunction with the precarious haemodynamic status often seen in complex CHD, these arrhythmias are often poorly tolerated, and significant morbidity can occur. It is important to recognize that arrhythmias may represent a change in hemodynamics and should prompt reassessment of the patient's status.

THERAPEUTIC OPTIONS

The options for treatment in patients with IART and CHD include antiarrhythmic medications, catheter ablation, pacing and surgery.

MEDICAL MANAGEMENT

There are few reports of successful medical therapy for IART. Published ablation data often includes details of failed medication, but significant bias exists as these groups are selected for ablation due to drug resistance. In general, the principles for antiarrhythmic therapy are as for other forms of heart disease. Therapeutic regimens used included beta-blockers, calcium channel antagonists, class Ia agents, class III agents and digoxin, administered alone or in combination [5]. One study, prior to the advent of ablation for IART, probed 19 patients and reported successful arrhythmia suppression with class Ia agents (plus beta blockers or digoxin) in 6 patients, with 11 requiring amiodarone and 2 undergoing pacemaker implantation. Beta blockers or calcium channel antagonists alone did not maintain sinus rhythm in any patient [6]. Dofetilide has been used in patients with congenital heart disease and, in a multicenter study, demonstrated initial success rates of 85% with maintenance of sinus rhythm in the long term of 55% [7]. Two patients had torsades de points at high dose and the authors suggest halving the dose in these patients. Amiodarone has been considered the most effective medication, but its side effects limit its use in young patients.

One of the concerns with atrial arrhythmias in this population is the potential risk of thromboembolic complications. Indeed, there is growing evidence to suggest that increased atrial rates alone may be sufficient to confer a thromboembolic risk. A study examining transesophageal echocardiograms in non-anticoagulated patients with congenital heart disease and regular narrow complex tachycardia revealed a high incidence of intra-atrial thrombus (42%), [8] suggesting anticoagulation is generally indicated.

*Address correspondence to this author at the Centre for Heart Rhythm Disorders, Level 5, McEwin Building, Royal Adelaide Hospital, North Terrace, Adelaide, SA 5000, Australia; Tel: +61 8 8222 2723; Fax: +61 8 8222 2722; E-mail: kurt.roberts-thomson@adelaide.edu.au

ABLATION

Adequate medical management of IART is frequently not possible [9] and an invasive strategy is often required. Ablation of the reentry circuits is technically challenging and reported success rates are lower than standard atrial arrhythmias, with increasingly complex CHD associated with lower rates of ablation success. Multiple circuits may exist, which can involve both artificial (suture lines, prosthetic material) and natural (crista, valve annuli and vena cavae) regions of conduction block. Complex anatomy is associated with increasingly complex circuits and the use of electroanatomical mapping systems, potentially in conjunction with pre-procedural MRI or CT assessment of cardiac structure, allows accurate characterization of these circuits and regions of conduction block, and may improve outcomes [10, 11]. The distorted anatomy and complex circuits make the p wave morphology difficult to interpret and thus careful activation and entrainment mapping are critical to determining the mechanism and location of the arrhythmia. These patients have particular issues complicating catheter ablation, particularly with regard to the vascular access and distorted anatomy. In all cases, knowledge of the surgical incisions and operation is important in planning the ablation procedure, and the use of technologies such as Remote Magnetic Mapping may improve catheter stability [12, 13].

PACEMAKER IMPLANTATION

In cases resistant to ablation therapy, pacing may be considered as an alternative therapy, and is often indicated for coexistent sinus node disease. Pacemakers capable of anti-tachycardia pacing have in some series been found to be useful when the arrhythmia demonstrates pace terminability [14], although anatomical variations can offer a significant technical challenge to the implanter. Following pacemaker insertion, medical rate control or catheter ablation of the AV node can provide symptomatic improvement.

SURGICAL INTERVENTION

Rarely has further surgical intervention been advocated as often this is at a greater risk to the individual. However, there are some series that have described successful intervention in highly resistant cases, although this may only be appropriate if further additional surgery is warranted on hemodynamic grounds [15] as operative mortality can be as high as 10% [16].

ATRIAL SEPTAL DEFECTS (ASD)

The incidence of IART can be difficult to estimate as many studies examining its prevalence do not distinguish between IART and other atrial arrhythmias. One early study showed the incidence of atrial flutter to be as high as 18% over a mean of only 2.3 years post ASD repair [17]. Another found all supraventricular tachycardias occurred in only 7% in a cohort of 135 patients over a mean follow up of 15 years [18]. It is recognized that prior to surgery, the dilated right and left atria show electroanatomic remodeling characterized by prolonged refractory periods, conduction slowing and reduced voltage, predisposing to re-entrant arrhythmias [19, 20]. ASD closure, using a transcatheter device or surgically, appears to reduce the incidence of arrhythmia [21-23].

ASD repair usually involves a lateral right atrial incision prior to closure of the defect with direct closure, or the use of a pericardial or Dacron patch.

The most common circuit is cavotricuspid isthmus dependent flutter. In patients who have undergone surgery, reentry around the atriotomy incision is also observed (Fig. 1). Several studies have demonstrated the coexistence of two distinct macro reentrant circuits, or ‘dual-loop’ re-entry [24-26]. One described 5 patients following ASD repair. All had CTI-dependant atrial flutter, with three having additional reentry around the atriotomy scar [24]. Shah *et al.* also reported 5 cases of post ASD repair right atrial flutter present-

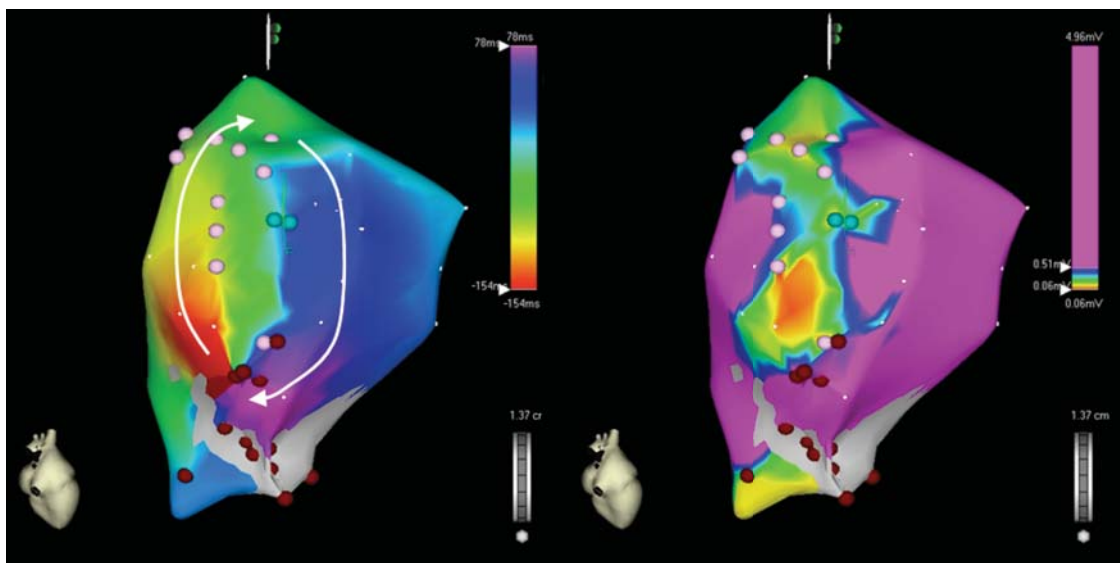


Fig. (1). This figure shows electroanatomic maps of the lateral right atrium in a patient with IART post surgical ASD repair. The left map is an activation map demonstrating a clockwise re-entrant circuit. The right map is a voltage map demonstrating the region of low voltage, colored in red and green, on the lateral wall which corresponds to the atriotomy incision. This incision is the central obstacle around which the tachycardia circuit revolves. Catheter ablation (red dots) between the region of low voltage and the inferior vena cava terminated tachycardia.

ing with an ECG pattern suggestive of typical flutter. Following electroanatomical mapping, it was found that two circuits were present in each patient. After ablation in the CTI, the ECG changed abruptly, predominantly with positive p waves in the inferior leads, but a mean change in cycle length of only 13 milliseconds and no intervening pause. In one patient, the surface ECG was unchanged except for a change in cycle length. The second tachycardia was circuiting the atriotomy scar and a second line of ablation was then required between the atriotomy scar and the IVC, or in one case, the scar and tricuspid annulus [25]. This highlights the importance of monitoring the ECG morphology and activation patterns closely during ablation. In some cases there is a conduction channel traversing the free wall scar that can sustain the free wall tachycardia. Focal ablation at this site can abolish tachycardia. Kalman *et al.*, following the exclusion of cases of typical flutter, examined 9 patients with 10 IARTs. The majority of these were incisional tachycardias on the right atrial free wall but the authors also described a case of reentry around the septal patch. This required ablation between the patch and the tricuspid annulus. Left sided IART is rare, but can occur (Fig. 2).

Snowdon *et al.* recently published techniques for assessing ablation line integrity in right free wall flutter. Atriotomy to IVC lines was assessed by pacing the ablation catheter, placed posterior to the line in the low lateral RA, and recording the timing and activation sequence of electrograms produced by a 20-pole catheter positioned between the scar and the tricuspid valve. Similarly atriotomy to TV lines can be assessed by pacing inferior to the line [27].

Flutter wave morphology can be useful prior to EP assessment. In one study of 16 patients, all patients with typical morphology had an isthmus dependant circuit and no

patient with atypical morphology was found to have only a CTI-dependant arrhythmia [24]. However, a significant proportion of both typical and atypical flutter patterns had more than one circuit, demonstrating the lack of specificity from ECG assessment alone.

TETRALOGY OF FALLOT

In a large cohort of 793 patients, the incidence of atrial flutter or fibrillation over a 10 year period was only 7% [28]. A recent multi-centre study found 11.5% of patients with corrected Tetralogy of Fallot developed IART, although this did include a small number of patients with pulmonary atresia. Analysis of this cohort also found IART was more prevalent in patients with RA enlargement, hypertension and those who had more than one surgical procedure [29]. Roos-Hesselink and colleagues found all patients with atrial arrhythmias to have right atrial and right ventricular enlargement on echocardiography [30].

Surgery for Tetralogy of Fallot involves patch closure of the ventricular septal defect and enlargement of the right ventricular outflow tract. Access has generally been via the right ventricle, which can predispose to ventricular arrhythmias, but a trans-atrial approach is now mainly used [28].

The atrial incision for a Tetralogy of Fallot repair is similar to that used in patients to repair an ASD and therefore the arrhythmias are similar. Nakagawa *et al.* described 3 patients with IART and Tetralogy of Fallot. All had a lower atrial scar or line of double potentials, confluent with the IVC and a more superior, anterior scar. Successful focal ablation was performed between these 2 areas in all cases [31]. Triedman and colleagues found successful sites to be at the inferomedial RA in both patients with Tetralogy of Fallot, with one

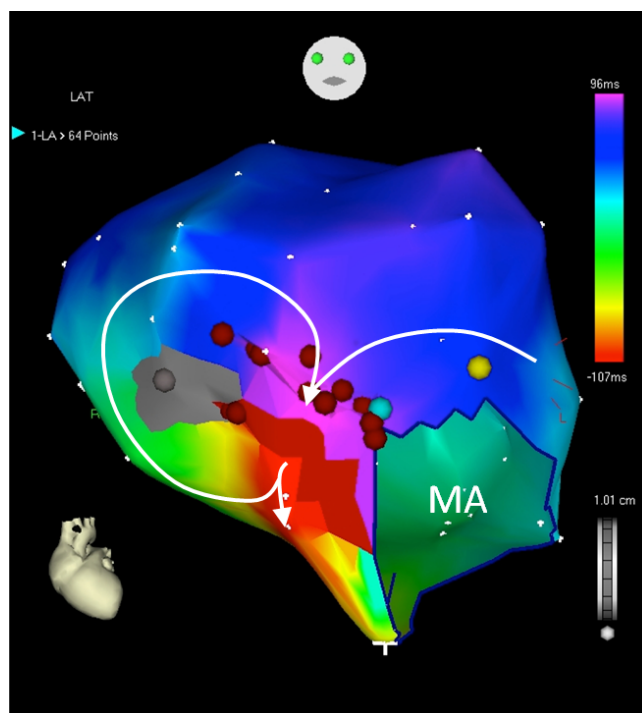


Fig. (2). This figure is an electroanatomic map of the left atrium, in the anterior view, in a patient post ASD repair. This activation map demonstrates the presence of dual loop reentry around the mitral annulus (MA) and the ASD patch (shown in grey). Catheter ablation (red dots) between the patch and the mitral annulus terminated tachycardia.

also requiring ablation at the RA-SVC junction [5]. Another study reported successful ablation in the posterior CTI in 3 patients [32].

EBSTEIN'S ANOMALY

Up to one third of patients with Ebstein's anomaly have an accessory pathway. These are mainly right sided and often multiple and most arrhythmias are related to this. The abnormal tricuspid valve can require surgical repair, along with concomitant congenital lesions, increasing the probability of macroreentrant circuits [33].

Surgical intervention for tricuspid regurgitation or additional lesions predisposes to IART. Right atrial dilatation is common and can promote CTI dependant arrhythmia. Catheter stability can be difficult on the abnormal tricuspid isthmus. In the largest tachyarrhythmia study of this group, comprising 32 patients, there were 5 instances of CTI dependant flutter and 5 of other IARTs, which were found to consist of multiple circuits in two [33].

TRANSPOSITION OF THE GREAT ARTERIES

Transposition of the great arteries is the commonest cause of atrial flutter in the young [9]. The incidence of atrial flutter following Mustard surgery was 25% over a mean follow up period of 3 years in one early study [17]. Another found a 40% incidence of all supraventricular tachycardias, including AF, over a mean of 4.5 years. This study also found a weak association between supraventricular tachyarrhythmia and sudden death [34]. A third included all regular supraventricular tachycardias and found the incidence to be 6, 12 and 17% at 1, 3 and 5 years post-op, with older age of operation, the need for valve replacement and older surgical techniques being associated with a higher risk of SVT [35].

Atrial switch procedures for Transposition of the Great Arteries involve the creation of an intra-atrial baffle to divert deoxygenated systemic venous blood to the mitral valve, left ventricle (LV), pulmonary artery (PA) and pulmonary circulation and oxygenated blood, returning from the lungs, to the

tricuspid valve, right ventricle, (RV) aorta and systemic circulation. The Senning procedure involves creation of the baffle solely from atrial tissue whereas the Mustard procedure uses a single patch made of pericardial tissue or Dacron, following excision of the atrial septum (Fig. 3). Significant anatomical variation can occur. For example, during the Mustard procedure, the coronary sinus is generally kept on the pulmonary venous side, but a suture line can be placed anterior to it, keeping it on the systemic venous side. These variations highlight the need for careful review of operative notes prior to undertaking catheter ablation.

Femoral artery access is often required to allow mapping of the pulmonary venous atrium retrogradely via the aorta. The tortuosity of this route can make catheter manipulation and stability during ablation difficult.

In Mustard patients, the baffle suture line can act as an area of conduction block. Senning patients have more complex surgical anatomy, one study described a number of lines of conduction block in detail: 1) the suture line where the atrial septal flap forms a roof over the pulmonary veins; 2) the edge of the atrial septal remnant; 3) the suture line where the right atrial free wall attaches to the atrial septal remnant to form the roof over the systemic venous tube and 4) the suture line where the rightward most section of the pulmonary venous atrium is attached to the remaining right atrial free wall [2]. 10 circuits were identified in 9 Mustard patients. Of these, 9 involved the isthmus between the tricuspid annulus and IVC but successful ablation was only possible in 6. In all cases, only the medial isthmus could be accessed from the systemic venous side, the lateral isthmus was always found on the pulmonary venous side, requiring femoral arterial access, negotiation through the right ventricle, and prolapse of the ablation catheter across the tricuspid valve into the pulmonary venous atrium. In a study of 14 Mustard and Senning circuits, Collins and colleagues showed the valve annulus-IVC isthmus to be the successful ablation site in 8, with 6 of these requiring retrograde access to the pulmonary venous aspect of the baffle. The remaining 6 circuits were ablated in the lateral RA wall [36]. One study of 4 pa-

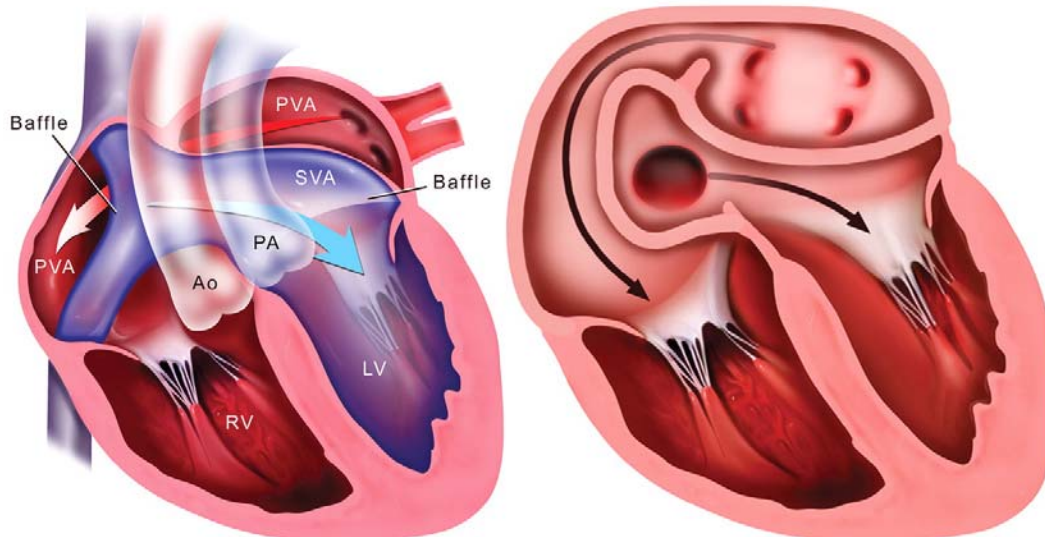


Fig. (3). This figure shows the surgical conduits created by the Senning procedure, with a cut-away illustration on the right. (Reproduced with permission – Gaca AM *et al.* Radiology. 2008; 247:617-631).

tients with 5 IARTs outside the CTI, demonstrated the site of successful ablation to be between the baffle and coronary sinus in 2, the baffle and tricuspid annulus in 1, the atriotomy and tricuspid annulus in 1 and the low posterior systemic venous atrium in 1 [37]. Chan *et al.* described successful ablation locations in 3 Mustard patients, all of which were in the systemic venous atrium, 2 at the coronary sinus ostium, and one in the low atrium [32]. In contrast, the study by Yap *et al.* demonstrated that only 29% of IARTs were CTI-dependant in post-Mustard patients and that successful RFA was significantly less likely, when compared with other CHD [10].

UNIVENTRICULAR CIRCULATION

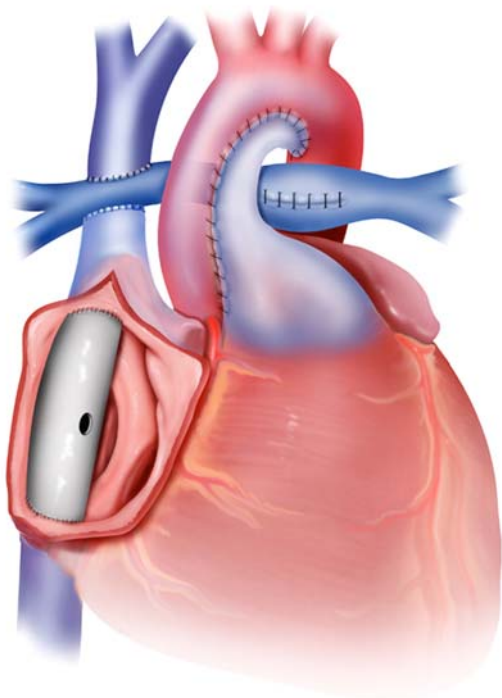
Patients having undergone the Fontan procedure have a high incidence of atrial arrhythmias. In one study it occurred in 22% of patients [38], in another the incidence was 6% at 1 year and 17% at 5 years [35]. Takahashi *et al.* studied patients undergoing Fontan conversion surgery and found IART in 25%, even prior to surgery [39].

Patients with univentricular circulation usually undergo the Fontan procedure in two stages. The first, also known as the bidirectional Glenn procedure, connects the superior vena cava to the right pulmonary artery. The inferior vena cava is connected to the pulmonary artery during the second stage, also known as Fontan completion. Variations of the procedure occur, the classic Fontan connected the right atrium to the PA via a conduit; a widely used modification of this anastomosed the RA directly to the PA. More recently, an internal or external conduit has been used to connect the IVC to the PA, to create a total cavopulmonary

connection [40]. (Fig. 4). The highly complex anatomy and surgical intervention predisposes to significant atrial scarring.

The Fontan circulation is often associated with circuits that are neither perivalvular nor incisional, as shown in a study by Nakagawa and colleagues [31]. The scarring can be variable and thus the circuits also show a degree of variability between individuals (Fig. 5). Despite this, focal ablation of channels between areas of block successfully terminated arrhythmias in 5 of these patients. Several studies have highlighted the complexity of ablation in Fontan patients. One described 4 patients; two were successfully ablated by connecting the Fontan circuit and the TA in one and the atriotomy in the other. Successful ablation was not possible in the remaining two cases [37]. Another described both successful and unsuccessful sites in 6 patients. Two of these were successful at the SVC junction, one at the Fontan anastomosis, and one connected the anastomosis and the SVC. Three of these patients had further arrhythmic circuits; attempted ablation in the inferior RA was unsuccessful in all cases. One patient had a circuit which could not be ablated in the inferomedial RA and the final patient had 5 distinct circuits, all of which were successfully ablated [5]. Mandapati *et al.* studied 37 IART circuits in 22 Fontan patients and found all to be CTI dependant, with twelve revolving around the IVC, and the remainder being periannular [41]. A large study, including 40 patients, showed 53% of successful ablation sites were at the lateral RA, with 21% on the anterior wall, and only 15% involved the cavotricuspid isthmus [36]. In a large series of patients with CHD and IART, Yap *et al.* determined that patients with Fontan palliation were significantly more likely to

Panel A)



Panel B)

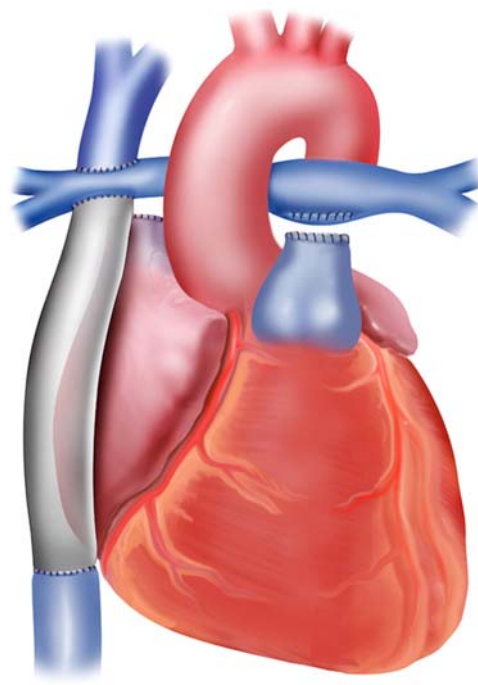


Fig. (4). This figure illustrates (A) the fenestrated Fontan lateral tunnel and (B) Fontan extracardiac conduit. (Reproduced with permission – Gaca AM *et al.* Radiology 2008; 247: 617-31).

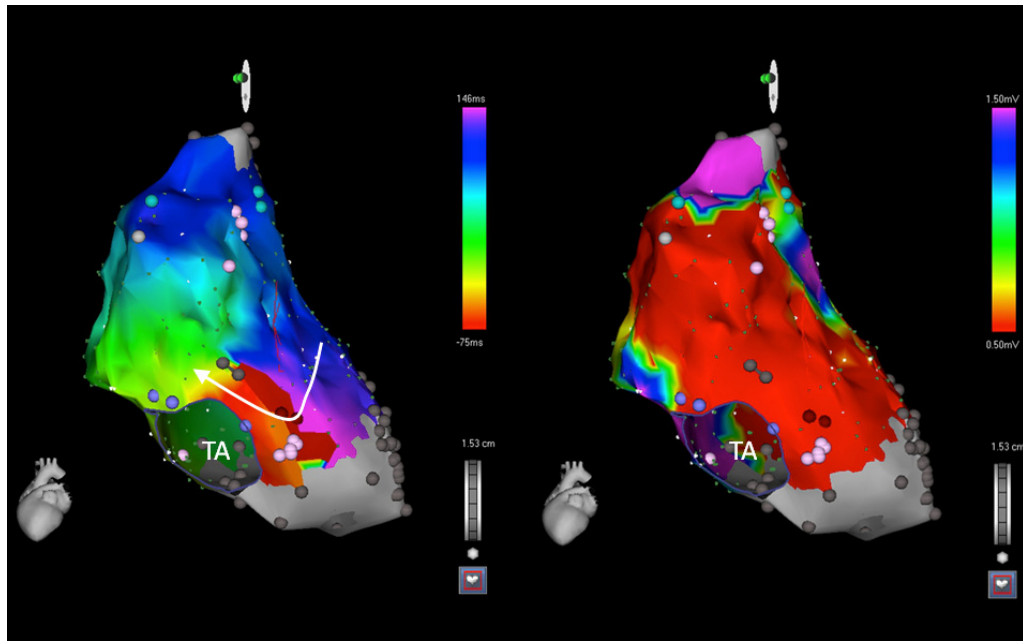


Fig. (5). This figure shows electroanatomic maps in a patient with IART post Fontan. The right voltage map demonstrates the large region of low voltage, shown in red, in this chamber. The left activation map demonstrates activation through the region of low voltage in the posteroseptal aspect of the right atrium. Catheter ablation (red dots) at this site terminated tachycardia. TA = tricuspid annulus.

have a non-CTI circuit (79%) when compared with other CHD patients (51%).

OUTCOMES

In the largest published series, the overall acute success rate in 193 ablation procedures was 63%, ranging from 43% in post-Mustard patients, to 76% in those post ASD closure (Fig. 6) [10]. Despite 79% of those successfully ablated remaining free of arrhythmia at 6 months, at 4 years this had dropped to 49%, with Fontan patients showing a marked reduction in success rate, of only 15%. At repeat study, the

site of successful ablation was different to the original site in 62%. The strongest predictor of recurrence was a previous Fontan operation (HR 2.18) along with increasing age. Triedman *et al.* reported the efficacy of RFA in 55 cases of IART and found recurrence was most likely to occur with 6 months of the procedure. 40% of patients were free of arrhythmia at 3 years [42]. In a later study, the predictors of a favorable outcome were determined by logistic regression and found to be the use of modern technology (electro-anatomical mapping and irrigated ablation catheters), non-Fontan physiology and fewer IART circuits [11].

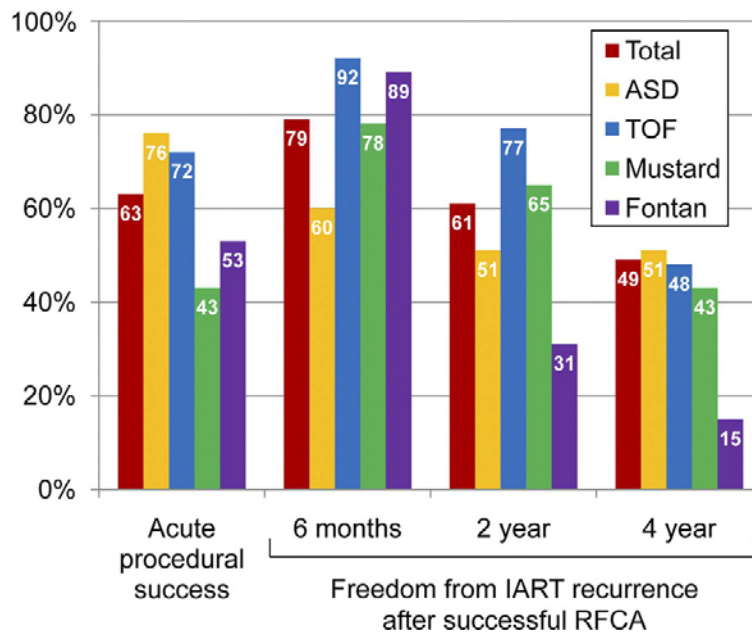


Fig. (6). This graph shows the acute and long term procedural success rates in different groups of surgically corrected CHD. (Reproduced with permission – Yap *et al.* J Am Coll Cardiol 2010; 56: 1589-96).

CONCLUSION

IART in patients with surgically corrected congenital heart disease is uncommon in clinical practice but is prevalent in this small group of patients. Medical management is often unsuccessful, requiring the use of invasive procedures. Cavotricuspid isthmus dependent flutter is the most common arrhythmia but the existence of multiple circuits is common. In patients with increasingly complex anatomy, the presence of complex circuits at other sites becomes more frequent and success rates are lower. A thorough assessment of the patient's status and pre-catheter ablation planning is critical.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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