Contemporary Outcomes of Supraventricular Tachycardia Ablation in Congenital Heart Disease
A Single-Center Experience in 116 Patients

Akiko Ueda, MD; Irina Suman-Horduna, MD, MSc; Lilian Mantziari, MD, MSc; Marko Gujic, MD; Procolo Marchese, MD; Siew Yen Ho, PhD; Sonya V. Babu-Narayan, MBBS, BSc, MRCP, PhD; Sabine Ernst, MD, PhD, FESC

Background—Remote magnetic navigation–guided ablation with 3-dimensional (3D)-image integration could provide maximum benefit in patients with complex anatomy. We reviewed supraventricular tachycardia (SVT) ablation in adult patients with congenital heart disease to assess the contribution of these technologies.

Methods and Results—One hundred fifty-four SVT ablation procedures (228 SVTs) using a 3D-electroanatomic mapping system in 116 adult patients with congenital heart disease (mean age, 41; 76 male) were classified into 3 groups: Group A, manual mapping/ablation (n=60 procedures); Group B, remote magnetic navigation–guided mapping/ablation with normal femoral vein access (49); and Group C, remote magnetic navigation–guided mapping/ablation with difficult access (45). Group A included simple anomalies with less SVTs. Group B comprised predominantly Fontan patients with more SVTs. Group C included more complex defects, such as intra-atrial baffle or interrupted inferior venous access, in which retrograde aortic and superior venous accesses were used exclusively with more frequent use of image integration (97.8%; P<0.001). Acute success was 91.5%, 83.7%, and 82.2%, respectively (P=0.370). In group C, fluoroscopy time was the shortest (median, 4.2 min; P<0.001) despite the longer procedure duration (median, 253 min; P<0.001). SVTs free rates were 80.4%, 82.4%, and 75.8%, respectively (P=0.787) during a mean 20-months follow-up period.

Conclusions—The combination of remote magnetic navigation, 3D-image integration, and electroanatomic mapping system facilitated safe and feasible ablation with very low fluoroscopy exposure even in patients with complex anomalies. (Circ Arrhythm Electrophysiol. 2013;6:606-613.)

Key Words: ablation © congenital heart disease © mapping © tachycardia, supraventricular

In the growing number of adult patients with congenital heart disease (CHD), supraventricular tachycardia (SVT) is one of the most common sources of morbidity and hospital admission.1-4 Catheter ablation for SVT in this cohort is an important therapeutic option attributable to frequently experienced drug refractoriness and possible hemodynamic deterioration and thrombus formation.

Three-dimensional (3D) electroanatomic mapping system (EMS) has been used widely after reports of its role in producing favorable outcome in CHD-associated SVT ablation.5,6 Currently, further technological advances, such as irrigated catheter system and remote magnetic navigation (RMN) systems, are beginning to provide further solutions for the various remaining problems encountered during electrophysiological studies in adult patients with CHD.7-9

The main advantages of RMN, often used in conjunction with 3D-image integration, namely catheter maneuverability, stability, and precise delineation of the extracardiac and intracardiac anatomy can now be offered in particular situations, such as patients with limited access and mapping difficulty.10

Previous studies have shown that acute and long-term ablation success rates decline with increasing complexity of the underlying anomaly,5,11 which seems self-evident when the whole spectrum of adult CHD is considered. However, the gap in outcome between simple and complex cases could be narrowed by using newer technologies.

Although there are some reports on catheter ablation in adult patients with CHD using RMN with image integration, systematic examination on the role played by these technologies in particularly complex cases is scarce.

The purpose of this study was to assess the contribution of RMN to adult patients with CHD through reviewing our

Received August 3, 2012; accepted May 6, 2013.
From the Cardiac Morphology Unit, Department of Pediatrics (A.U., S.Y.H.), and Department of Cardiology (I.S.-H., L.M., M.G., P.M., S.V.B.-N., S.E.), Royal Brompton Hospital, London, United Kingdom; and NIHR Cardiovascular Biomedical Research Unit, Royal Brompton and National Heart and Lung Institute, Imperial College London, London, United Kingdom (S.V.B.-N., S.E.).
Correspondence to Sabine Ernst, MD, PhD, FESC, Consultant Cardiologist/Electrophysiologist, Reader in Cardiology, National Heart and Lung Institute, Imperial College, Royal Brompton and Harefield Hospital, Sydney St, London, SW3 6NP, United Kingdom. E-mail s.ernst@rbht.nhs.uk
© 2013 American Heart Association, Inc.
Circ Arrhythm Electrophysiol is available at http://circep.ahajournals.org DOI: 10.1161/CIRCEP.113.000415
experiences of SVT ablation in adult patients with CHD using 3D-EMS.

Methods

Study Design
Consecutive SVT ablation procedures (154) using 3D-EMS in 116 adult patients with CHD (mean age at the index procedure, 40.7±15.1 years; 76 male), from October 2007 to April 2012, were reviewed. Some of these cases were reported previously.10,12 Decision on selection of mapping system, catheter, and vascular access was made preoperatively by an experienced electrophysiologist on the basis of availability of equipment and each patient’s condition. Procedures were classified into 3 groups according to the access and mapping technique: (1) 3D-EMS with conventional deflectable mapping/ablation catheter (group A), (2) 3D-EMS with RMN using normal femoral vein access (group B), and (3) 3D-EMS plus RMN in patients with difficult access (group C). Procedure parameters such as duration, fluoroscopy exposure, and complications were assessed. Clinical outcomes were acute procedural success and freedom from SVT during follow-up.

Preablation 3D-Imaging and Image Processing
In the majority of cases, preoperative imaging study was performed by cardiovascular magnetic resonance or cardiac computed tomography for 3D-image integration. For cardiovascular MRI, a free breathing, diaphragm navigated balanced steady-state free precession sequence with 3D reconstruction was performed to image the whole heart. All preacquired 3D imaging DICOM data were processed for 3D reconstructions not only of the heart, but also of major veins and the aorta and used during ablation procedures by integration with the mapping information (POLARIS software, Biosense Webster, Brussels, Belgium).8

Vascular Access
After obtaining written informed consent, all procedures were performed under general anesthesia in the presence of an experienced cardiac anesthetist with continuous invasive arterial blood pressure monitoring.

For placement of diagnostic catheters, vascular access was gained via the femoral, subclavian, and internal jugular veins (7Fr or 8Fr sheaths). One or more catheters (quadrupolar nonsteerable and multipolar steerable, Biosense, Webster, Brussels, Belgium) were positioned in accessible chambers, His-bundle area, the coronary sinus, or total cavopulmonary connection for the timing reference and pacemaker. Decapolar-ring catheters (Lasso, Biosense, Webster) were placed at the ostium of the pulmonary vein(s) in those patients with atrial fibrillation (AF) in whom the access was obtained via a transseptal puncture, through an atrial septal defect (ASD) or via patent foramen ovale.

In situations without direct venous access to the systemic atrial chambers with the exception of hepatic veins attributable to interruption of the inferior vena cava (IVC), the timing reference catheter was placed in the (hemi-) aygous vein to record far-field atrial signals via a femoral vein approach.

The mapping and ablation catheter (Navistar, Navistar DS, Navistar ThermoCool, Navistar RMT DS or Navistar ThermoCool RMT, Biosense Webster, Brussels, Belgium) was introduced via the femoral vein (in group A, B) or via any other accessible vein (in group C). In patients with a target chamber in the systemic circulation, femoral arterial access was obtained, and the catheter was advanced retrogradely via the aorta and the ventricles to the atria (group C only).

Electrophysiological Study and Ablation
Sequential electroanatomic mapping (CARTO XP RMT and CARTO 3 RMT, both Biosense Webster) was performed in all patients during spontaneous or pace-induced SVT. Intracardiac electrograms were recorded on an AXIOM Sensis recording system (Siemens AG, Forchheim, Germany), and all electrogram and mapping information was displayed on the Odyssey platform (Sterotaxis Inc, St, Louis, MO). When RMN was selected, mapping was performed using the magnetic navigation system (Niobe II, Sterotaxis Inc, St, Louis, MO) in conjunction with the cardio drive system. A detailed description of this system has been published previously.13,14 Tachycardia mechanisms were diagnosed based on activation map and conventional electrophysiological study. Common atrial flutter was defined as a single (counter)-clockwise macro reentrant tachycardia, depending on the isothmus between the anatomic right atrioventricular valve and the IVC or hepatic veins confluence. Focal atrial tachycardia (AT) was AT originating from a small discrete region with centrifugal activation. We defined intra-AT as a macroreentrant atrial rhythm involving scar tissue, suture lines, or prosthetic materials. Atrioventricular nodal reentrant tachycardia, atrioventricular reciprocating tachycardia, and AF were diagnosed by conventional electrophysiological maneuvers.

After diagnosis was confirmed, radiofrequency energy was delivered with temperature-control mode with maximum setting at 60° in solid-tip catheters and power-control mode with maximum output at 45 Watts in irrigated-tip catheter with saline flow of 30 mL/min. Point-by-point linear radiofrequency energy applications were performed in cases of intra-AT and common atrial flutter. Conduction block was assessed by using electroanatomic remapping during pacing close to the line of block in the majority of cases. When the target SVT was AF, ipsilateral pulmonary vein isolation and continuous fractionated atrial electrogram ablation were selected.15 Electric isolation of the pulmonary veins was confirmed when ≥2 catheters could be positioned in the left atrium.

After elimination of the index SVT, programmed stimulation with up to 2 extra stimuli and burst pacing was repeated from ≥2 different atrial sites, and further mapping and ablation were performed if another sustained SVT was inducible. Acute success was defined as no inducibility of any SVTs.

Follow-up
All patients were followed up in outpatient clinic after 6 weeks from the discharge and then every 3 to 6 months. They were also seen by the care group for adult CHD. All patients had 12-leads ECGs and Holter recordings routinely during follow-up, and also an additional ECG was acquired if the patients experienced recurrence of symptoms or deteriorations with heart failure.

Statistical Analysis
For purpose of analysis, multiple procedures within the same patient were assumed to be independent. In such cases, only the period after the last procedure was assessed for freedom from arrhythmia.

Normally distributed continuous variables were expressed as mean and SD, and non-normally distributed variables were expressed as median and range. Comparisons between 3 groups were assessed by the general linear model (GLM) or by the Mann–Whitney test with Bonferroni correction after 1-way ANOVA. Mean and median were used if the data were skewed, and non-parametric tests were performed. Comparisons were performed only when the overall 1-way ANOVA/Fisher PLSD test with Bonferroni correction after 1-way ANOVA indicated statistically significant differences.

Comparison in categorical data was assessed by the χ2 test with adjustment when overall result indicated statistically significances. Statistical significance was taken as P<0.05. Statistical analysis was performed with SPSS (Chicago, IL).

Results

General Characteristics
In 116 adult patients with CHD, 154 SVT ablation using 3D-EMS was performed. Thirty patients underwent multiple procedures (2 in 24 patients, 3 in 4 patients, and 4 in 2 patients). Among them, different systems/accesses were used in respective procedures in 10 patients.
Procedure classification was as follows: (1) 3D-EMS with conventional deflectable mapping/ablation catheter (group A 60 procedures in 53 patients), (2) 3D-EMS with RMN in normal femoral vein access (group B 49 procedures in 40 patients), and (3) 3D-EMS with RMN in difficult access (group C 45 procedures in 32 patients).

We classified the complexity of the underlying defect in each group according to the American College of Cardiology/American Heart Association 2008 Guidelines16 (Figure 1; Table 1). Three groups comprised different complexity of CHDs (P<0.001). Whereas one third of the patients in group A were categorized as simple CHD, <10% were of great complexity. Group B was dominated with moderate and great complexity CHDs, such as univentricular physiology after Glen or Fontan (right atrium-pulmonary artery) surgery. Group C had the majority of great complexity CHD, such as atrial switch surgery for complete transposition of the great arteries and univentricular physiology after total cavopulmonary connection operation using a lateral tunnel. Whereas the number of repaired ASDs was almost similar to that of nonrepaired ASDs in group A and B, all patients with ASD (8.9%) in group C were status postrepair with large closure devices. Patients in group C (32.0±12.6 years) were significantly younger than those in group A (46.9±14.2 years) or group B (40.9±14.6 years; P<0.001). There were no significant differences between the 3 groups in sex (male proportion 68.3%, 55.1%, and 57.8%, respectively).

Mapping and Ablation
A total of 228 SVTs were targeted for mapping and ablation. Seventy-four SVTs were targeted in group A, 85 SVTs in group B, and 69 SVTs in group C, respectively. Group B had a significantly greater number of target SVTs per procedure (P=0.032; Table 1). Likewise, in group C, there was a trend toward more target SVTs than in group A, without reaching statistical significance. The type of SVTs in each group is depicted in Figure 2.

Procedural Parameters
Procedural parameters are shown in Table 1. Three-dimensional image integration was used most frequently in group C, followed by group B (P=0.001). Significantly fewer diagnostic catheters were used in group C as compared with groups A and B (P<0.001) consistent with limited vascular access in this group. Irrigated-tip catheters were selected in all cases unless such a catheter was unavailable and, therefore, were used in >90% in all groups. Although patients in group C had the longest total procedure time (median, 252.5 minutes; P<0.001), the fluoroscopy time was shortest (median, 4.2 minutes; P<0.001). Acute success rate in group A tended to be higher than that of other groups, but the differences failed to reach statistical significance.

There were no life-threatening procedural complications. One patient who had a femoral arteriovenous fistula required thrombin injection, and another patient experienced a hemothorax as a consequence of central jugular venous catheter inserted during anesthesia.

Vascular Access in Difficult Access Group C
A total of 45 procedures in 32 patients were included in group C (3D-EMS + RMN with difficult access to the target chamber). The detailed demography of this group is shown in Table 2. The original diagnosis for univentricular physiology was either tricuspid atresia or double-inlet left ventricle or double-outlet right ventricle associated with atrial isomerism. Retrograde aortic access was used in 42 procedures, and superior venous access was used in 2 procedures. The remaining

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**Figure 1.** Defect diagnoses/repairs in 3 groups. ASD indicates atrial septal defect (including postsurgical or device closure); CHD, congenital heart disease; Ebstein, Ebstein anomaly (including tricuspid valve replacement or plasty); TCPC, total cavopulmonary connection; TOF, tetralogy of Fallot (postsurgical repair); Valve, postvalve replacement or plasty (except for Ebstein anomaly); and VSD, ventricular septal defect (including postsurgical or device closure).
1 procedure required both accesses. One patient with interrupted IVC had undergone an electrophysiological study using a transhepatic venous access previously, which resulted in substantial intra-abdominal bleeding requiring emergency blood transfusion.

In most of the patients with retrograde aortic access, tachycardia originated from the chamber not directly accessible from a venous approach. Therefore, a retrograde aortic approach was used to access the pulmonary venous atrium in patients with atrial switch (Figure 3A and 3B), the

Figure 2. Type of supraventricular tachycardia in 3 groups. AF indicates atrial fibrillation; AVNRT, atrioventricular nodal reentrant tachycardia; AVRT, atrioventricular reciprocating tachycardia; c-AFL, common type atrial flutter; Focal, focal atrial tachycardia; and IART, intra-atrial macroreentrant tachycardia.
surgically excluded atrium in Fontan patients or the native atrium in patients with total cavopulmonary connection (Figure 3C–3E).

In 4 patients with ASD with large closure devices (Amplatzer 28–40 mm, average 34.0 mm) presenting with AF, the decision was taken to use a retrograde access because direct puncture was deemed impossible after close examination of the relationship of the device and native septum by transesophageal echocardiography. In these patients, pulmonary vein isolation (using a circumferential mapping catheter) was impossible to be confirmed besides using the ablation catheter itself, but organization into intra-AT was seen directly after ablation of pulmonary veins or continuous fractionated atrial electrogram ablation, which prompted further linear ablation. One of 2 procedures using a superior venous access targeted an atrioventricular reentrant tachycardia in a patient with Ebstein anomaly and bilateral thrombosed femoral veins after previously failed ablation procedures (Figure 3F). The other procedure was in a patient with multiple SVTs who had an interrupted IVC with short hepatic veins draining directly into a right-sided atrium and absent right superior vena cava associated with left atrial isomerism. Because the rest of systemic venous return in this patient was channeled to the atrium through the hemiazygos vein via the persistent left superior vena cava, the ablation catheter was inserted from the femoral vein and then advanced through the hemiazygos vein via the left superior vena cava to the atria.

One patient who also had interrupted IVC required both accesses (venous and retrograde arterial) to reach and subsequently ablate multiple SVTs arising from both atria (Figure 4A–4D).

There were no significant differences in acute outcome and procedure parameters in both accesses (a transaortic retrograde access and a superior venous access). Postprocedural transthoracic echocardiography showed no evidence of aortic valve damage in any patient who required retrograde access.
Follow-up
Arrhythmia-free rates in group A, B, and C were 80.4%, 82.4%, and 75.8% (P=0.787), respectively, during a mean follow-up period of 20.0±12.8 months (24.7±13.1, 16.9±12.8, and 20.3±12.3 months in group A, B, and C, respectively) in 127 procedures (94%), regardless of initial success, excluding cases with <3 months follow-up after the last ablation. Thirteen patients had palliative or corrective surgery after the last ablation, and 4 patients died >1 year after the ablation unrelated to arrhythmia.

Discussion
Our experience of SVT ablation in adult patients with CHD demonstrates that intracardiac and extracardiac anomaly-related access difficulty can be overcome, and that procedures can be performed as safely and successfully as in cases with relatively simple defects. Interestingly, patients experienced lower fluoroscopy exposure when using RMN in combination with 3D-image integration and the EMS even in cases with the most complex anatomy.

Different Complexities of Adult CHD
Complexity of the underlying anatomy varies individually, and not all cases share similar difficulties during interventional procedures, which explains the differences in reported outcomes in adult CHD–associated SVT ablation.5,11 In a recent report by Yap et al,11 acute ablation success in patients after Fontan or Mustard surgery was significantly lower than that of ASD or tetralogy of Fallot. By contrast, in our study, feasible SVT ablation outcomes for both acute and midterm were achieved similarly in all 3 adult CHD groups despite the different degree of complexity of the underlying defects. This might suggest that at least some part of procedural difficulties in group B and C that are absent in group A could be overcome by using RMN.

Difficulties in Adult CHD Ablation and the Role of RMN
There are numerous factors that make catheter mapping and ablation in some adult patients with CHD challenging, such as the degree of atrioventricular regurgitation or a postsurgical position of the coronary sinus, and not all problematic factors can be readily solved by RMN. However, from our perspective RMN helped surmount 3 major hurdles seen in complex adult patients with CHD, namely, limited access to the target chamber, extensive atrial enlargement, and extensive wall thickness.9,10,17–19

Limited access is the consequence of complex intra/extracardiac anomaly and presence of intra-atrial baffles or artificial materials. We selected a retrograde aortic access and superior retrograde venous access for group C patients in our study. Both techniques themselves are commonly used in various interventional catheter maneuvers and readily achieved with manual catheters. In the setting of SVT ablation in adult patients with CHD, however, catheter manipulation after advancing the catheter into the heart, such as when crossing a small ventricular septal defect, aortic or atrioventricular valves, is more difficult than that in normal anatomy. Given
the limited curve radius, retrograde catheter manipulation is technically very difficult when performed with conventional catheters. Steering the magnetic ablation catheter via the distal end allows any given site within a given cardiac chamber to be reached, thereby increasing mapping accuracy.

Giant atria are frequently encountered in the adult CHD population (in particular in Fontan or Ebstein patients) and, in these situations, adequate catheter reach is even more difficult. Especially in the presence of intra-atrial conduction delay associated with large or multiple scar areas or incision lines, the correct diagnosis of the underlying SVT mechanism is not always easy. For instance, focal ATs, which are not uncommon in adult patients with CHD, can be difficult to distinguish from intra-AF when detailed mapping is not achieved (eg, some area of an enlarged chamber is inadvertently omitted). Moreover, the number of diagnostic catheters is also limited as demonstrated in group C, therefore, electroanatomic mapping of entire chambers plays an important role in patients with complex anatomy. Hence, the facility to reach any site freely inside an enlarged chamber is essential for creating a precise map that then leads to a successful ablation. In our series of patients, RMN proved to be invaluable in extensive atrial enlargement with its controllability of the distal magnetic tip.

Extensive wall thickness must be taken into consideration to deliver enough radiofrequency energy to achieve transmural ablation lesions. Again, good catheter reach and contact are vital in creating a complete lesion.

Role of 3D-Image Integration

Furthermore, in our study, 3D-image integration was used more often in patients with more complex defects (group B and C). Detailed preprocedural analysis of the image information enabled us to outline a careful procedure plan, including the best and alternative catheter access options. In addition, using real-time features of both EMS and RMN on 2 simultaneous references fluoroscopic images with real-time depiction of the tip of the ablation catheter enabled the operator to be oriented fully with regard to the location and orientation of the catheter tip during the mapping and ablation process.

In our opinion, the combination of these technologies contributed largely to the excellent ablation outcome in our series with the additional benefit of low fluoroscopy exposure even in the group with complex CHDs.

Previous Reports

Various techniques for catheter access have been reported in patients with intra-atrial baffle, closure device, or in patients with interrupted IVC.

A transbaffle approach is an alternative technique of accessing the separated atrium in patients after atrial switch or in patients with total cavopulmonary connection. Although the reported cases stated shorter procedure times of 110 to 120 minutes, longer fluoroscopy times of 11.7 to 18.0 minutes were necessary.

A percutaneous transhepatic approach enables operators to introduce catheters to the systemic venous chamber in the setting of IVC interruption. Although the reported complication rate is <5%, this technique sometimes can lead to serious intrathoracic and extrathoracic injury, such as pneumothorax, intra-abdominal hemorrhage, and liver abscess. Additionally, this report showed similar procedure times (230–330 min) as compared with our study but much longer fluoroscopy time (15–35 min).

There is an emerging awareness of AF treatment in a growing population of patients with ASD closure devices because it is considered that the AF substrate can progress even after the ASD repair. Recently, transseptal punctures in patients with closure devices have been reported. Although transseptal puncture through the native septum was achieved in 90% of the cases under the guidance of intracardiac echocardiography, 4 patients (10%) required direct puncture through the device because of its large diameter. No major complication or device malfunction was reported, but procedure time and fluoroscopy time were 4.1 hour and 80 minutes, respectively, which was again much longer than our procedures. Potential limitations in catheter mobility or a puncture placed too anteriorly might risk damaging the left atrial anterior wall and aorta. The preprocedural transesophageal echocardiography and information on the rims before device insertion could be important for the optimal selection of access to the left atrium. Although categorized as simple CHD according to the guideline, repaired ASDs sometimes cause difficulties to access the left atrium, regardless of whether the approach is a septal puncture or retrograde access with RMN, meaning that the grading system of CHD is not directly equivalent to procedure complexity in the setting of SVT ablation.

Limitations

This study was performed at a single center in a retrospective manner, and the selection of the mapping system, catheters, and image integration were dependent on the operator’s decision and availability. Treatment assignment was not blinded to CHD complexity in this study. The sample size is small. Although the use of RMN seems safe and to have beneficial effects on radiation exposure, with good midterm results, its precise added value requires further study. Learning curve of the operator might affect the procedure outcomes. Additionally, midterm outcomes in patients with multiple procedures could be affected by the cumulative effect of the previous procedures and, therefore, might be underestimated. Because the underlying diagnoses varied widely even within 1 group, anatomic complexity is heterogeneous. We hope that future prospective and possibly multicenter studies in more homogeneous groups will provide further insights to select the optimal mapping and ablation technique for the individual patient.

Conclusions

In adult patients with CHD, multiple SVTs are frequently seen and target atria are occasionally difficult to access. Difficult intra/extracardiac anomaly-related access can be overcome in complex cases, and procedures can be performed as safely and successfully as in relatively simple cases with even lower fluoroscopy exposure by using RMN in conjunction with 3D-image integration and EMS.
Sources of Funding
This project was supported by the National Institute for Health Research (NIHR) Cardiovascular Biomedical Research Unit of Royal Brompton and Harefield NHS Foundation Trust and Imperial College London. This report is independent research by the NIHR Biomedical Research Unit Funding Scheme.

Disclosures
S. Ernst is a consultant to Biosense Webster and Stereotaxis, Inc. A. Ueda is supported by a fellowship from Fukuda-Denshi and St. Jude Medical. L. Mantziari is supported by grants from the European Heart Rhythm Association and the Hellenic Cardiological Society. S. Babu-Narayan is supported by the British Heart Foundation. The views expressed in this article are those of the author(s) and not necessarily those of the NHS, the NIHR, or the Department of Health.

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CLINICAL PERSPECTIVE
Supraventricular tachyarrhythmias are frequently encountered in young and adult patients late after reparative surgery for congenital heart disease, and are one of the leading causes of adverse outcome in this cohort. Catheter ablation is challenging in the presence of numerous individual hurdles, such as distorted anatomy, wall hypertrophy, enlarged chambers, and limited vascular access. Ablation success rate in more complex congenital heart cases is inferior to those of simpler congenital heart cases. However, a combination of recent technologies, namely electroanatomic mapping, 3-dimensional (3D)-image integration using preprepared image reconstruction and remote magnetic navigation, could contribute to narrowing the gap between ablation success rate in simple versus complex cases. Integration of 3D-images allows electrophysiologists to plan first-line and alternative vascular access to chambers of interest. Magnetic navigation, which can be safely used even in patients with implantable devices, enables electrophysiologists to perform procedures in anatomically encased areas or extensively enlarged chambers. Although these technologies are not necessarily available in all centers as first-line, they should at least be considered as an alternative strategy for patients in whom conventional ablation procedures have failed. In addition, for atrio pulmonary Fontan patients undergoing conversion to total cavopulmonary connection, intraoperative antitachycardiac measures should be considered, because postoperative access to some parts of the heart may be difficult to achieve, at least with conventional means.
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*Circ Arrhythm Electrophysiol*. 2013;6:606-613; originally published online May 17, 2013; doi: 10.1161/CIRCEP.113.000415

*Circulation: Arrhythmia and Electrophysiology* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-3149. Online ISSN: 1941-3084

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