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

Running title: Ueda et al.; Magnetic-Navigated Ablation in Malformed Hearts

Akiko Ueda, MD¹; Irina Suman-Horduna, MD, MSc²; Lilian Mantziari, MD, MSc²; Marko Gujic, MD²; Procolo Marchese, MD²; Siew Yen Ho, PhD¹; Sonya V. Babu-Narayan, MB, BS, BSc, MRCP, PhD²,³; Sabine Ernst, MD, PhD, FESC²,³

¹Cardiac Morphology Unit, Dept of Pediatrics, ²Dept of Cardiology, Royal Brompton Hospital; ³NIHR Cardiovascular Biomedical Research Unit, Royal Brompton and National Heart & Lung Institute, Imperial College London, London, United Kingdom

Correspondence:
Sabine Ernst, MD, PhD, FESC
Consultant Cardiologist / Electrophysiologist
Reader in Cardiology, National Heart and Lung Institute
Imperial College, Royal Brompton & Harefield Hospital
Sydney Street
London, SW3 6NP, United Kingdom
Tel: +44 20 7351 8612
Fax: +44 20 7351 8131
E-mail: s.ernst@rbht.nhs.uk

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Abstract

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

Methods and Results - One-hundred-and-fifty-four SVT ablation procedures (228 SVTs) using a 3D-electroanatomic mapping system (EMS) in 116 ACHD patients (mean age 41, 76 male) were classified into three groups; Group A; manual mapping/ablation (n=60 procedures), Group B; RMN-guided mapping/ablation with normal femoral vein access (49), and Group C; RMN-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/or 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 4.2min, p<0.001) despite the longer procedure duration (median 253min, p<0.001). SVTs free rates were 80.4%, 82.4% and 75.8% (p=0.787) during a mean 20months follow-up period.

Conclusions - The combination of RMN, 3D-image integration and EMS facilitated safe and feasible ablation with very low fluoroscopy exposure even in patients with complex anomalies.

Key words: ablation, mapping, supraventricular tachycardia, congenital heart disease
Introduction

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

Three-dimensional (3D) electroanatomic mapping system (EMS) has been employed widely following reports of its role in producing favourable outcome in congenital heart disease-associated SVT ablation\textsuperscript{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 ACHD patients\textsuperscript{7-9}. The main advantages of the RMN, often used in conjunction with 3D-image integration, namely catheter manoeuvrability, stability and precise delineation of the extra- and intracardiac anatomy can now be offered in particular situations such as patients with limited access and mapping difficulty\textsuperscript{10}.

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

 Although there are some reports on catheter ablation in ACHD patients using RMS 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 the RMN to ACHD patients through reviewing our experiences of SVT ablation in ACHD patients using 3D-EMS.

 Methods

 Study design

 Consecutive SVT ablation procedures (154) using 3D-EMS in 116 ACHD patients (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. 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 three 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.

Pre ablation 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 magnetic resonance imaging, a free breathing, diaphragm navigated balanced steady-state free precession (bSSFP) sequence with 3D reconstruction was performed to image the whole heart.

All pre-acquired 3D imaging DICOM data was 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).

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/or internal jugular vein(s) (7Fr or 8Fr sheaths). One or more catheters (quadripolar non-steerable and / or multipolar steerable, Biosense, Webster, Brussels, Belgium) were positioned in accessible chambers, His-bundle area, the coronary sinus or total
cavopulmonary connection (TCPC) for the timing reference and pacing. Decapolar-ring catheter(s) (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 due to interruption of the inferior vena cava (IVC), the timing reference catheter was placed in the (hemi-) azygos 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 ventricle(s) to the atria (group C only).

Electrophysiologic study and ablation

Sequential electroanatomical mapping (CARTO XP RMT and CARTO 3 RMT, both Biosense Webster) was carried out 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, US). When the RMN was selected, mapping was performed using the magnetic navigation system (Niobe II, Sterotaxis Inc., St. Louis, US) in conjunction with the cardio drive system. A detailed description of this system has been published previously.\textsuperscript{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 re-entrant tachycardia, depending on the isthmus between the anatomical right atrioventricular valve and the IVC or hepatic veins confluence. Focal atrial tachycardia was atrial tachycardia originating from a small discrete region with centrifugal activation. We defined intra-atrial tachycardia as a macro re-entrant atrial rhythm involving scar tissue, suture lines or prosthetic materials. Atrioventricular nodal re-entrant tachycardia, atrioventricular reciprocating tachycardia and AF were diagnosed by conventional electrophysiological manoeuvres.

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

After elimination of the index SVT, programmed stimulation with up to two extra stimuli and burst pacing was repeated from at least 2 different atrial sites and further mapping and ablation was carried out 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 ACHD care group. All patients had 12-leads electrocardiograms and Holter recordings routinely during follow-up and also an additional electrocardiogram 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 standard
deviation and non-normally distributed variables were expressed as median and range.

Comparisons between three groups were assessed by the two-tailed multiple t-test with
Bonferroni correction following one-way ANOVA or by the Mann-Whitney test with
Bonferroni correction following Kruskal-Wallis test according to variable distribution. Post hoc
comparisons were performed only when the overall one-way ANOVA / Kruskal-Wallis test
indicated statistically significant differences. Comparison in categorical data was assessed by
the Chi-square 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, USA).

Results

General characteristics

In 116 ACHD patients, 154 SVT ablation using 3D-EMS were 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 guidelines (Figure 1, Table 1). Three groups comprised different complexity of CHDs (p<0.001). Whilst one third of the patients in group A were categorized as simple CHD, less than 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 TCPC operation using a lateral tunnel. Whilst the number of repaired ASD was almost similar to that of non-repaired ASD in group A and B, all ASD patients (8.9%) in group C were status post repair 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 three groups in gender (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 significantly greater number of target SVTs per each procedure (p=0.032, Table 1). Likewise, in group C, there was a trend towards 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 to group A and B (p<0.001) in 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 more than 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 had a femoral arterio-venous fistula required thrombin injection and a second 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 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 intraabdominal 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 in order to access the pulmonary venous atrium in atrial switch patients (Figure 3A, B), the surgically excluded atrium in Fontan patients or the native atrium in TCPC patients (Figure 3C-E).

In 4 ASD patients with large closure devices (Amplatzer 28 – 40mm, average 34.0mm) presenting with AF, the decision was taken to use a retrograde access since 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-atrial tachycardia was seen directly after ablation of pulmonary veins or continuous fractionated atrial electrogram ablation which prompted further linear ablation\textsuperscript{15}. 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 (SVC) associated with left atrial isomerism. As the rest of systemic venous return in this patient was channeled to the atrium through the hemiazygos vein via the persistent left SVC, the ablation catheter was inserted from the femoral vein and then advanced through the hemiazygos vein via the left SVC to the atria.

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

There were no significant differences in acute outcome and procedure parameters in both accesses (a trans-aortic retrograde access and a superior venous access). Post-procedural 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, 20.3±12.3 months in group A, B and C, respectively) in 127 procedures (94%) regardless of initial success, excluding cases with less than 3 months follow-up after the last ablation.

Thirteen patients had palliative or corrective surgery after the last ablation and four patients died more than one year after the ablation unrelated to arrhythmia.

**Discussion**

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

**Different complexities of ACHD**

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 ACHD-associated SVT ablation. In a recent report by Yap et al, 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 mid-term were achieved similarly in all three ACHD 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 utilizing RMN.

**Difficulties in ACHD ablation and the role of remote magnetic navigation**

There are numerous factors which make catheter mapping and ablation in some ACHD patients challenging such as the degree of atrioventricular regurgitation or a post-surgical position of the coronary sinus and not all problematic factors can be readily solved by the RMN. However, to our minds, the RMN helped surmount three major hurdles seen in complex ACHD patients, namely, limited access to the target chamber, extensive atrial enlargement and extensive wall thickness.

Limited access is the consequence of complex intra-/extracardiac anomaly and/or presence of intra-atrial baffles or artificial materials. We selected a retrograde aortic access and/or superior retrograde venous access for group C patients in our study. Both techniques themselves are commonly used in various interventional catheter manoeuvres and readily achieved with manual catheters. In the setting of SVT ablation in ACHD patients, 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 ACHD 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 ACHD patients\textsuperscript{20}, can be difficult to
distinguish from intra-atrial tachycardia 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
freely reach any site inside an enlarged chamber is essential for creating a precise map that then
leads to a successful ablation. In our series of patients, the 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 in order to deliver enough radiofrequency energy to achieve transmural ablation lesions. Again, good catheter reach and contact are vital in creating a complete lesion.

The 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 pre-procedural analysis of the image information enabled us to outline a careful procedure plan including the best and alternative catheter access options. In addition, using the realtime 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 fully oriented with regards 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 patients with interrupted IVC.

A trans-baffle approach is an alternative technique of accessing the separated atrium in
post atrial switch patients or TCPC patients\textsuperscript{19,21}. Although the reported cases stated shorter procedure times of 110–120 minutes, longer fluoroscopy times of 11.7–18.0 minutes were necessary.

A percutaneous transhepatic approach enables operators to introduce catheters to the systemic venous chamber in the setting of IVC interruption\textsuperscript{22}. Although the reported complication rate is less than 5\%, this technique sometimes can lead to serious intra and/or extrathoracic injury such as pneumothorax, intra-abdominal hemorrhage and liver abscess. Additionally, this report showed similar procedure times (230–330 min) as compared to 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 since 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\textsuperscript{23}. While transseptal puncture through the native septum was achieved in 90\% of the cases under the guidance of intracardiac echocardiography, four patients (10\%) required direct puncture through the device due to its large diameter. No major complication or device malfunction was reported, but procedure time and fluoroscopy time was 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 pre-procedural 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 conducted at a single centre 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. Whilst RMN use appears safe and to have beneficial effects on radiation exposure, with good mid-term results, its precise added value requires further study. Learning curve of the operator might affect the procedure outcomes. Additionally, mid-term outcomes in patients with multiple procedures could be affected by the cumulative effect of the previous procedures and therefore might be overestimated. As the underlying diagnoses varied widely even within one group, anatomical complexity is heterogeneous. We hope that future prospective and possibly multi-centre studies in more homogeneous groups will provide further insights to select the optimal mapping and ablation technique for the individual patient.
Conclusions

In ACHD patients, 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 utilizing the RMN in conjunction with 3D image integration and EMS.

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Conflict of Interest Disclosures: Sabine Ernst is a consultant to Biosense Webster and Stereotaxis, Inc.

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### Table 1 Procedure parameters

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>53</td>
<td>40</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>No. of procedure</td>
<td>60</td>
<td>49</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Complexity n(%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple</td>
<td>22 (36.7)</td>
<td>12 (24.5)</td>
<td>4 (8.9)</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>35 (58.3)</td>
<td>12 (24.5)</td>
<td>1 (2.2)</td>
<td>P &lt; 0.001*†‡</td>
</tr>
<tr>
<td>Great complexity</td>
<td>3 (5.0)</td>
<td>25 (51.0)</td>
<td>40 (88.9)</td>
<td></td>
</tr>
<tr>
<td>No. of target SVTs</td>
<td>1 (1 – 3)</td>
<td>1 (1 – 5)</td>
<td>1 (1 – 5)</td>
<td>P = 0.032*</td>
</tr>
<tr>
<td>Image integration (%)</td>
<td>66.7</td>
<td>75.5</td>
<td>97.8</td>
<td>P = 0.001†‡</td>
</tr>
<tr>
<td>No. of diagnostic catheters</td>
<td>2 (1 - 4)</td>
<td>2 (1 – 4)</td>
<td>2 (1 – 3)</td>
<td>p &lt; 0.001†‡</td>
</tr>
<tr>
<td>Irrigated-tip catheter (%)</td>
<td>93.3</td>
<td>97.9</td>
<td>91.1</td>
<td>P = 0.54</td>
</tr>
<tr>
<td>Bidirectional ablation catheter (%)</td>
<td>17.1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Total procedure time (min)</td>
<td>171.0</td>
<td>196.0</td>
<td>252.5</td>
<td>p &lt; 0.001†‡</td>
</tr>
<tr>
<td>(60.0 - 435.0)</td>
<td>(59.0 - 528.0)</td>
<td>(36.0 - 485.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluoroscopy time (min)</td>
<td>7.9 (1.0 - 39.1)</td>
<td>6.1 (0.3 - 44.6)</td>
<td>4.2 (0.6 - 15.5)</td>
<td>p &lt; 0.001†‡</td>
</tr>
<tr>
<td>Dosage (cGym2)</td>
<td>1920.6 ± 2482.5</td>
<td>838.7 ± 1021.0</td>
<td>770.3 ± 2265.8</td>
<td>P = 0.008*†</td>
</tr>
<tr>
<td>No. of RF applications</td>
<td>18 (3 – 61)</td>
<td>18 (1- 75)</td>
<td>26 (5 – 94)</td>
<td>p = 0.119</td>
</tr>
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<td>RF time (sec)</td>
<td>1864.0± 1405.3</td>
<td>1887.6 ± 1998.1</td>
<td>1974.7 ± 1193.6</td>
<td>P = 0.943</td>
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<tr>
<td>Acute success (%)</td>
<td>91.5</td>
<td>83.7</td>
<td>82.2</td>
<td>P = 0.370</td>
</tr>
</tbody>
</table>

Data was expressed as mean ± standard deviation or median (range).

*indicates a significant difference between group A and B, †group B and C, ‡group C and A. NA indicates not available; RF, radiofrequency energy; SVT, supraventricular tachycardia.
Table 2 Details of difficult access group (group C)

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Target SVT</th>
<th>Target chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrograde aortic access</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 ASD post device closure</td>
<td>AF</td>
<td>LA</td>
</tr>
<tr>
<td>3 Glenn with interrupted IVC</td>
<td>c-AFL,</td>
<td>RA or common atria</td>
</tr>
<tr>
<td></td>
<td>IART, Focal AT, AVNRT</td>
<td></td>
</tr>
<tr>
<td>4 Fontan</td>
<td>c-AFL, IART</td>
<td>native and excluded RA</td>
</tr>
<tr>
<td>12 TCPC</td>
<td>c-AFL, IART</td>
<td>TCPC and native RA</td>
</tr>
<tr>
<td></td>
<td>Focal AT, AVNRT</td>
<td></td>
</tr>
<tr>
<td>19 TGA (Mustard/Senning)</td>
<td>c-AFL, IART</td>
<td>PVA and SVA</td>
</tr>
<tr>
<td></td>
<td>Focal AT, AVNRT</td>
<td></td>
</tr>
<tr>
<td>Venous superior access</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Ebstein, blocked femoral veins</td>
<td>AVRT</td>
<td>RA</td>
</tr>
<tr>
<td>1 LA isomerism, ASD, interrupted IVC, absent rt. SVC</td>
<td>IART, Focal AT</td>
<td>RA</td>
</tr>
<tr>
<td>Both</td>
<td>1 LA isomerism, AVSD</td>
<td>AF, IART RA, LA</td>
</tr>
</tbody>
</table>

AF indicates atrial fibrillation; ASD, atrial septal defect; AT, atrial tachycardia; AVSD, atrioventricular septal defect; AVNRT, atrioventricular nodal re-entrant tachycardia; AVRT, atrioventricular reciprocating tachycardia; c-AFL, common atrial flutter; Ebstein, Ebstein anomaly; c-AFL, common atrial flutter; IVC, inferior vena cava; LA, left atrium; PVA, pulmonary venous chamber; RA, right atrium; SVA, systemic venous chamber; SVC, superior vena cava; TCPC, total cavo-pulmonary connection.
Figure Legends:

Figure 1 Defect diagnoses / repairs in three groups. ASD indicates atrial septal defect (including post surgical or device closure); Ebstein, Ebstein anomaly (including tricuspid valve replacement or plasty); TCPC, total cavo-pulmonary connection; TOF, tetralogy of Fallot (post surgical repair); Valve, post valve replacement or plasty (except for Ebstein anomaly); VSD, ventricular septal defect (including post surgical or device closure);

Figure 2 Type of supraventricular tachycardia in three groups. AF indicates atrial fibrillation; AVNRT, atrioventricular nodal re-entrant tachycardia; AVRT, atrioventricular reciprocating tachycardia; c-AFL, common type atrial flutter; Focal, focal atrial tachycardia; IART, intra-atrial macroreentrant tachycardia.

Figure 3 Representative catheter positions in fluoroscopic images in group C. (A), (B) Retrograde access via the aorta to the pulmonary venous atrium in a patient with Mustard operation. Reference catheter was introduced in the systemic venous atrium from the femoral vein. (C), (D) Retrograde access via the aorta to the excluded RA for inferior-isthmus ablation in a TCPC patient. Reference catheter was positioned in the lateral tunnel. (E) Retrograde access via the aorta to the excluded right atrium for slow pathway ablation in a patient with total cavo-pulmonary connection (TCPC). Reference catheter was positioned in the lateral tunnel. (F) Superior venous access in a patient with Ebstein’s anomaly. Both ablation catheter
and diagnostic catheter (His-right ventricle) were introduced from the left subclavian vein to the right atrium. ABL indicates mapping and ablation catheter; LAO, left anterior oblique view; RA, right atrium; RAO, right anterior oblique view; REF, reference catheter; RV, right ventricle; SVA, systemic venous atrium.

**Figure 4** Catheter positions and three-dimensional image construction in a patient with post-surgical repair of atrioventricular septal defect. (A) (B) Three-dimensional (3D) image construction in AP and PA views. (C) Superior venous access via hemiazygos vein, through the left superior vena cava to the right atrium. (D) Retrograde access to the left atrium via the aorta. ABL indicates mapping and ablation catheter; Ao, aorta; LA, left atrium; LSVC, left superior vena cava; LV, left ventricle; PA, pulmonary artery; RA, right atrium; RAO, right anterior oblique view; REF, reference catheter; RV, right ventricle.
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