Ablation of atrial tachycardias after correction of complex congenital heart diseases: utility of intracardiac echocardiography

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Aims
Our goal was to analyse the utility of intracardiac echocardiography (ICE) for navigation and ablation of atrial tachycardias (ATs) after surgical correction of congenital heart disease (CHD).

Methods and results
Catheter ablation of ATs was performed in seven patients (one woman, mean age 21 ± 6 years) after correction of complex CHD: d-transposition of the great arteries (Mustard procedure in two patients, Senning procedure in two patients) and univentricular circulation (total cavopulmonary connection in two patients, atriopulmonary connection in one patient). The ablation was guided by a combination of electroanatomical mapping (CARTO, Biosense-Webster) and ICE (Acuson, Siemens). Intracardiac echocardiography was used during mapping to identify relevant anatomical structures and monitor tissue contact and for guidance of atrial baffle puncture. Biatrial mapping was necessary in six of seven patients and atrial baffle puncture in three. The clinical AT was abolished in all patients. No complications were noted. During follow-up of 23 ± 13 months, two patients (28%) had arrhythmia recurrence. One patient developed atrial fibrillation, and recurrent AT in the other patient was controlled by re-ablation.

Conclusion
Despite complicated cardiac anatomy, catheter ablation of AT after complex CHD can be performed safely and with a high success rate. Intracardiac echocardiography facilitates mapping, identification of relevant cardiac structures, and could be used for safe guidance of transbaffle puncture.

Keywords
Catheter ablation • Intracardiac ultrasound • Congenital heart diseases

Introduction
Atrial tachycardias (ATs) often occur late after surgical correction of congenital heart diseases (CHDs).1–3 Electroanatomic mapping has been successfully used to delineate the complex 3D anatomy of cardiac chambers and evaluate arrhythmia mechanism. However, access to ablation targets for radiofrequency ablation in patients after correction of complex CHD may be limited by variant anatomy and by surgically created obstacles such as baffles or prostheses.1 This makes mapping and catheter ablation a very challenging procedure. The aim of our report is to analyse the utility of intracardiac echocardiography (ICE) in guiding these procedures.

Methods
Patient population
The study group included seven patients (one female, mean age 21 ± 6 years) with regular ATs after correction of complex CHD who underwent catheter ablation in our institution between 2004 and 2007 (Table 1). Index surgical procedure included atrial switch for d-transposition of the great arteries in four patients (Mustard procedure in two and Senning procedure in another two), total cavopulmonary connection (TCPC) in two patients, and atriopulmonary connection in one patient. All patients had documented ATs on ECG prior to the ablation procedure.
Mapping and ablation

The patients underwent an electrophysiological study after discontinuation of antiarrhythmic drugs. The procedure was performed under local anaesthesia in all but one patient. A 7F quadripolar electrode catheter positioned in the left appendage or an 8F bipolar active fixation lead (Tendril 100 cm, St. Jude Medical, St Paul, MN, USA) screwed into the right atrium were used as time reference for electroanatomical mapping (CARTO XP, Biosense Webster, Diamond Bar, CA, USA). An 8F, saline-irrigated tip ablation catheter (Navistar Thermocoool, Biosense Webster) was used for mapping and subsequent ablation. Simultaneous recordings of atrial electrograms (filtered at 50–500 Hz) and 12-lead surface ECG were digitally stored (Prucka Cardiolab, GE Medical Systems, Milwaukee, WI, USA).

A 10F, phased-array ultrasound tipped catheter that consists of a 64-element multiple frequency transducer (5–10 MHz) (AcuNav, Acuson—Siemens, Mountain View, CA, USA) was inserted into the right atrium or systemic atrium via the left femoral vein in six patients and via the right subclavian vein in one patient with a closure of the inferior vena cava. The ICE catheter was connected to the ultrasound system (Sequoia) of the same manufacturer. Intracardiac echocardiography was used to delineate the complex atrial anatomy and to assist transbaffle puncture whenever needed. A conventional Brockenbrough needle and a supporting sheath (SR 0) (Daig, Minnetonka, MN, USA) were used for this purpose. When the atrium of pulmonary veins was cannulated, heparin was administered in order to maintain the ACT level of 300 s.

In patients with sinus rhythm, an electroanatomical map of the atria was first created in order to delineate anatomy. Intracardiac echocardiography was used during the mapping to visualize and annotate all relevant structures (e.g. annuli, appendage, suture lines). All mapping points with a local activation signal distinguishable from noise were taken into account, rather than using a distinct voltage cut-off value to define a scar. Moreover, when low-voltage signals from the mapping catheter were recorded, ICE was used to ascertain good tissue contact and then, pacing capture at 10 mA was used to distinguish dense scar from viable tissue. Following the map creation, programmed electrical stimulation was performed to induce clinical arrhythmia.

During arrhythmia, an activation map was constructed in order to characterize the activation sequence. Entrainment mapping was performed only after completing the high-density activation map in order to prevent termination and/or change in the morphology of the mapped tachycardia. Radiofrequency energy was applied to transect the critical isthmus of the circuit and/or to destroy arrhythmia focus. Radiofrequency current was delivered for maximum of 90 s, with a maximum power set at 40 W and the maximum temperature at 43°C using an EP-Shuttle generator (Stockert, Biosense Webster). Saline flow rate was set at 15–20 mL/min. When linear ablation lesions were designed (i.e. cavotricuspid isthmus line), ICE was used to rule out the presence of ridges and excavations within the target area and, if present, to verify a good catheter—tissue contact and stability. In case of re-entrant circuits, re-mapping during atrial pacing was employed to verify block across the deployed ablation line after termination of AT.

The patients were discharged from the hospital after the procedure without antiarrhythmic drugs treatment. Antiaggregation or anticoagulation therapy was initiated according to the level of the expected risk of thrombo-embolism.

Results

Clinical AT in all four patients after atrial correction of d-transposition of the great arteries was isthmus-dependent atrial...
In order to gain access to the portion of isthmus located within the pulmonary venous atrium, a transbaffle puncture was used in three patients and a pre-existing communication was employed in the remaining one patient. Intracardiac echocardiography proved to be very useful in guiding this part of the procedure and allowed safe transbaffle crossing even in one patient with closure of the inferior vena cava in whom the puncture had to be performed through the right jugular vein (Figure 1). In all four patients, conduction block across both portions of the cavotricuspid isthmus was achieved and confirmed by electroanatomical mapping (Figure 2).

In one patient with TCPC, two intra-atrial re-entrant tachycardias were inducible, which circulated around the central scar within the intra-atrial tunnel. The common atrium was reached using a retrograde approach and critical isthmuses were transsected by catheter ablation and connected to the nearest anatomical barriers. The other TCPC patient presented with two ATs that were focal and originated from different foci within the common atrium. In this case, the access into the atrium was achieved through pre-existing fenestration and navigated by ICE (Figure 3A and B).

The patient after atrio-pulmonary connection (Fontan procedure) presented with four different inducible intra-atrial re-entrant tachycardias originating mostly from the right atrial free wall, and repeated procedures were needed to abolish all arrhythmias. Besides the lateral wall, catheter ablation across the ridge between the superior vena cava and pulmonary anastomosis was necessary to prevent arrhythmia recurrences (Figure 3C).

In total, biatrial mapping was necessary in six of seven patients (86%) and atrial baffle puncture in three of six patients (50%). Intracardiac echocardiography proved useful in delineation of cardiac anatomy in all cases and in guidance of transbaffle access whenever performed. Inducible ATs were abolished in all patients. Mean procedural and fluoroscopic times were 278 ± 78 and 20 ± 15 min, respectively. No complications were observed. An implantable cardioverter-defibrillator was inserted after the ablation procedure in one patient with a previous history of cardiac arrest and low ejection fraction of the systemic right ventricle.

During follow-up of 23 ± 13 months, two patients (28%) had arrhythmia recurrence. One patient after atrial correction of transposition of great arteries had repeated episodes of atrial fibrillation, which were successfully suppressed by a combination of amiodarone and dual chamber pacemaker implant. In patient after atrio-pulmonary correction, two re-ablations were required to control IART recurrences.

**Discussion**

This study presents initial experience with a combination of electroanatomical mapping and ICE to navigate catheter ablation of ATs after surgical correction of complex CHD. It describes the ICE guidance for transbaffle puncture to obtain biatrial access.

**Value of 3D mapping**

Electroanatomic mapping (CARTO)5,6 or non-contact mapping system (EnSite)7,8 has been recently reported to describe arrhythmia mechanism and to facilitate catheter ablation of ATs after CHD. However, the complexity of mapping and ablation varies according to the type of CHD and its surgical correction. Compared with patients after simple atriotomy (e.g. in patients after surgical repair of atrial septal defect) in whom the re-entry circuit is located mostly in the right atrium,9 the spectrum of ATs in patients after correction of complex CHD is much broader. Re-entrant circuits may be confined in both atria and/or ATs could be focal in
Figure 2. Patient after Mustard correction of d-transposition of the great arteries. (A and B) Position of the ablation catheter on the cavitricuspid isthmus from both sides of the intra-atrial baffle (A, in systemic venous atrium; B, in pulmonary venous atrium). (C) Electroanatomical map of both atria in the left anterior oblique view after creation of ablation lines during pacing in the low systemic venous atrium. Activation times are colour-coded (red as the earliest, violet as the latest). Note the late activation (violet colour) in the low lateral right atrium that documents the presence of block across the isthmus. IVC, inferior vena cava; MA, mitral annulus; SVC, superior vena cava; TA, tricuspid annulus.

Figure 3. An example of the Fontan circulation. (A) Doppler colour-coded flow within the fenestration in the intra-atrial tunnel in a patient after total cavopulmonary connection. Intracardiac echocardiography was used to navigate the catheter into the fenestration. (B) The mapping catheter introduced through the communication from the channel into the common atrium. (C) Intracardiac echocardiography image of the right atrium in a patient after atrioipulmonary connection. The mapping catheter is positioned on the ridge between the superior vena cava and pulmonary anastomosis. Ablation across this ridge terminated the clinical re-entrant tachycardia. Note the close relation to the right coronary artery (arrow). LA, left atrium; PA, pulmonary artery; RA, right atrium; SVC, superior vena cava; TA, tricuspid annulus.
origin. This was confirmed in our series where electroanatomical mapping described the mechanism of all ATs correctly.

**ICE-guided biatrial access**

The most common re-entry circuit in patients after atrial correction of d-transposition of the great arteries is re-entry around the tricuspid annulus or the inferior vena cava.\(^{10,11}\) In order to achieve complete conduction block across the isthmus, mapping and linear ablation in both atria are necessary in most cases.\(^ {10,11}\) Although the pulmonary venous atrium can be reached via the retrograde approach (i.e. through the aorta and right ventricle), it is usually difficult to obtain good catheter stability on the isthmus. In addition, mechanical prosthesis in tricuspid position may prevent retrograde access. In our series, we described approach to the pulmonary venous atria using transbaffle puncture guided by ICE. In our experience, ICE provides direct monitoring and selection of a suitable site for the puncture. One of our cases documents that the transbaffle puncture can be safely performed even via the superior vena cava. In addition, ICE can be used for early detection of potential complications, e.g. pericardial effusion.

Similarly, access from the venous tunnel to the atrium may be required in patients with TCPC. We clearly documented that ICE could be used for detection and localization of the pre-existing communication and navigation of the mapping catheter through the canal. Theoretically, it could also be used for guidance of puncture of a tunnel wall, although this procedure was not necessary in our series. As an alternative, access to the atrium has been described in patients with extra-atrial tunnel using direct percutaneous transthoracic approach.\(^ {12}\)

**Delineation of anatomy**

Exact delineation of individual anatomy is crucial for the characterization of intra-atrial re-entrant circuits and localization of anatomical obstacles for impulse propagation. Addition of ICE to the CARTO system facilitated the mapping of the atria and allowed easy identification of anatomical landmarks (i.e. left atrial appendage, pulmonary veins, etc.) and correlation of local electrograms to specific anatomical structures (i.e. suture lines, atretic tricuspid valve, etc.). Moreover, when linear lesions are designed, conduction gaps within the lines are usually associated with variable anatomy and difficult access to the relevant cardiac structures on the endocardial surface (ridges or excavations).\(^ {13}\) In such case, ICE enabled visualization of these sites and helped to monitor tissue contact. Complete block across the line was achieved in all patients.

Besides ICE, integration of images from computer tomography with electroanatomical maps (CARTO Merge™) has been proposed for depiction of the complex anatomy.\(^ {14,15}\) However, merged reconstruction represents only virtual image, and its quality is highly dependent on the segmentation and registration accuracy. In our experience, ICE provides an advantage over image integration as it enables real-time imaging.

**Study limitation**

The relatively small number of patients limits observations made by this study. However, only patients with complex CHD were selected in whom ICE is expected to provide the greatest benefit. Secondly, the use of ICE is associated with additional costs, and no data are available which prove that ICE decreases the duration of the procedure, fluoroscopic time, and/or affects the success rate.

**Conclusions**

Ablation of ATs in patients after surgical correction of complex CHD could be performed successfully and safely despite complicated anatomy and difficult access to the relevant cardiac chamber. Addition of ICE to electroanatomical mapping for such procedures is useful for navigation of catheter position, monitoring tissue contact, identification of relevant anatomical structures, guidance of the transbaffle puncture, or localization of interatrial communication and for early detection of potential complications.

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**References**

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