Electroanatomical mapping for visualization of atrial activation in patients with incisional atrial tachycardias

C. Reithmann, E. Hoffmann, U. Dorwarth, T. Remp and G. Steinbeck
Medizinische Klinik I, Klinikum Großhadern, Universität München, München, Germany

Aims Incisional atrial tachycardias in patients following surgery for congenital heart disease are based on complex structural abnormalities in these hearts. The aim of this study was to evaluate the use of the electroanatomical mapping system, CARTO, in consecutive patients with different forms of incisional atrial tachycardia.

Methods and Results The electroanatomical mapping system combines electrophysiological and spatial information and allows visualization of atrial activation in a three-dimensional anatomical reconstruction of the atria. Electroanatomical mapping of right atrial activation was performed in 10 patients after surgery for congenital heart disease, surgery for Wolff–Parkinson–White syndrome, or heart transplantation presenting with 13 incisional atrial tachycardias. The three-dimensional mapping allowed a rapid distinction between focal (n=3) and reentrant mechanisms (n=10) and visualization of the activation wavefronts along anatomical and surgically created barriers. Electroanatomical activation maps (mean right atrial activation time 213±107 ms) were constructed with 89±60 catheter positions during an average mapping time of 48±33 min.

Reentrant tachycardias propagating through the tricuspid annulus–vena cava inferior isthmus (n=6) or along periatrial loops (n=4) were identified in eight patients. Ectopic atrial foci near surgical scars could be localized in three patients. Catheter ablation by creation of a lesion in a critical isthmus of conduction or by targeting the arrhythmogenic focus eliminated 11 of 13 incisional atrial tachycardias.

Conclusion Visualization of atrial activation in a three-dimensional reconstruction of the right atrium using the electroanatomical mapping system CARTO facilitates understanding of the mechanism and defines the reentrant circuits of incisional atrial tachycardias. This new method may improve the success rate of electrophysiologically guided and anatomically guided catheter ablation of incisional atrial tachycardias.

Key Words: Atrial tachycardia, electroanatomical mapping, catheter ablation, congenital heart disease.

Introduction

Incisional atrial tachycardia is common during follow-up in patients after surgery for congenital heart disease, and antiarrhythmic drugs are frequently ineffective. Radiofrequency catheter ablation may also be applicable for incisional atrial arrhythmias, but due to the complex structural abnormalities in these hearts, successful ablation represents a considerable challenge[1,2]. The non-fluoroscopic electroanatomical mapping system CARTO is a novel endocardial mapping system which combines electrophysiological and spatial information. Three-dimensional electroanatomical mapping with the CARTO system allows detailed reconstruction of the chamber geometry. With this new mapping technique, the possibility of accurate positioning of the catheter tip has been demonstrated in experimental and clinical studies[3,4]. In addition, the system has been shown to be able to guide the application of radiofrequency energy in a highly accurate and reproducible manner[5].

The mapping system has been reported to facilitate ablation of typical atrial flutter by precise marking of the anatomical boundaries of the reentrant circuit and locating defects in the ablation line[6,7]. In patients with ectopic atrial tachycardias, the sites of arrhythmia origin could be precisely identified with the use of the
The system allowed accurate renavigation to the site of earliest activation, thereby guiding successful ablation of the foci[8–12]. Recently, we have described electroanatomical mapping of a complex atrial tachycardia in a patient after heart transplantation[13].

The aim of this study was to investigate the feasibility and usefulness of electroanatomical mapping in consecutive patients with different forms of incisional atrial tachycardia as a guide for catheter ablation.

**Methods**

**Patients**

The study population consisted of nine consecutive adult patients (seven women and two men, mean age 44 ± 10 years) and one 9-year-old child who underwent electrophysiological study and catheter ablation for symptomatic supraventricular tachycardia. Patients were included if they had undergone previous corrective surgery for congenital heart disease, surgery for Wolff–Parkinson–White syndrome 1985 or heart transplantation[13].

The aim of this study was to investigate the feasibility and usefulness of electroanatomical mapping in consecutive patients with different forms of incisional atrial tachycardia as a guide for catheter ablation.

The study population consisted of nine consecutive adult patients (seven women and two men, mean age 44 ± 10 years) and one 9-year-old child who underwent electrophysiological study and catheter ablation for symptomatic supraventricular tachycardia. Patients were included if they had undergone previous corrective surgery for congenital heart disease, surgery for Wolff–Parkinson–White syndrome or heart transplantation. The patients had a history of tachycardias of 7–5 years and had been treated ineffectively with 3–7 · 1–2 antiarrhythmic drugs. Patient characteristics are given in Table 1.

**Electrophysiological study**

Written informed consent was obtained from all patients. The 'conventional' electrophysiological study was performed in the fasting state after discontinuation of all antiarrhythmic drugs for at least five half-lives.

**Electroanatomical mapping**

The electroanatomical mapping system CARTO has been described in detail previously[13–15]. In brief, the CARTO system. The system allowed accurate renavigation to the site of earliest activation, thereby guiding successful ablation of the foci[8–12]. Recently, we have described electroanatomical mapping of a complex atrial tachycardia in a patient after heart transplantation[13].

The aim of this study was to investigate the feasibility and usefulness of electroanatomical mapping in consecutive patients with different forms of incisional atrial tachycardia as a guide for catheter ablation.

**Methods**

**Patients**

The study population consisted of nine consecutive adult patients (seven women and two men, mean age 44 ± 10 years) and one 9-year-old child who underwent electrophysiological study and catheter ablation for symptomatic supraventricular tachycardia. Patients were included if they had undergone previous corrective surgery for congenital heart disease, surgery for Wolff–Parkinson–White syndrome or heart transplantation[13].

The aim of this study was to investigate the feasibility and usefulness of electroanatomical mapping in consecutive patients with different forms of incisional atrial tachycardia as a guide for catheter ablation.

The study population consisted of nine consecutive adult patients (seven women and two men, mean age 44 ± 10 years) and one 9-year-old child who underwent electrophysiological study and catheter ablation for symptomatic supraventricular tachycardia. Patients were included if they had undergone previous corrective surgery for congenital heart disease, surgery for Wolff–Parkinson–White syndrome or heart transplantation. The patients had a history of tachycardias of 7–5 years and had been treated ineffectively with 3–7 · 1–2 antiarrhythmic drugs. Patient characteristics are given in Table 1.

**Electrophysiological study**

Written informed consent was obtained from all patients. The 'conventional' electrophysiological study was performed in the fasting state after discontinuation of all antiarrhythmic drugs for at least five half-lives.

**Electroanatomical mapping**

The electroanatomical mapping system CARTO has been described in detail previously[13–15]. In brief, the
Circuit.

The mechanism of the incisinal atrial tachycardias was studied using the electroanatomical mapping system: in 10 of the 13 atrial tachycardias, a continuous progression of colours (from red to purple) around the right atrium with close proximity of ‘earliest’ and ‘latest’ local activation, suggested the presence of a right atrial macro-reentrant tachycardia (Fig. 1, left). In these cases,
right atrial activation time \((256 \pm 78 \text{ ms})\) was in a similar range to tachycardia cycle length \((355 \pm 132 \text{ ms})\). The electroanatomical maps of three atrial tachycardias demonstrated radial spreading of activation, from the earliest local activation site (red) in all directions, representing the focal origin of the atrial tachycardia (Fig. 1, right). In these patients, right atrial activation time \((59 \pm 31 \text{ ms})\) was markedly shorter than tachycardia cycle length \((487 \pm 31 \text{ ms})\).

Only part of the reentrant circuit of two incisional reentrant atrial tachycardias (tachycardia cycle length 530 and 550 ms) could be mapped in a patient who had undergone atriotomy in order to conduct a Rastelli operation for transposition of the great arteries (right atrial activation times 344 and 228 ms). Surgically related scars, such as atriotomy scars in the lateral right atrium or atrial septal defect closure, were marked in grey within the three-dimensional electroanatomical maps. A propagation map of right atrial activation was superimposed on the anatomical reconstruction of the right atrium. Thus, the electroanatomical propagation map facilitated visualization of the reentrant circuit of the incisional atrial tachycardias in relation to the surgical scars. There were no complications during or after the procedure.

**Incisional atrial tachycardias propagating through the cavo-tricuspid isthmus**

Entrainment mapping was attempted in all patients with incisional reentrant atrial tachycardias. The cycle lengths and mechanisms of the atrial tachycardias and
the corresponding ablation sites are given in Table 1. The tricuspid annulus–vena cava inferior isthmus was identified by entrainment stimulation as a critical zone of the reentry in four patients after atrial septal defect closure, in one patient with prior operation for transposition of the great arteries and in one patient after prior surgery for Wolff–Parkinson–White syndrome (right-sided accessory pathway). Cavotricuspid isthmus ablation eliminated isthmus-dependent atrial reentrant tachycardias in these six patients.

Incisional atrial tachycardias along a periatriotomy loop

In four patients, a periatriotomy loop in the lateral right atrium was identified as the reentrant circuit. Electroanatomical mapping revealed clockwise single loop reentry around a right atrial lateral scar in a 9-year-old child after orthotopic heart transplantation (Fig. 2(a)). The three-dimensional propagation map allowed estimation and visualization of the conduction velocities along the periatriotomy loop (Fig. 2(b)). A zone of slow conduction was found (from about 11 o’clock to 5 o’clock) on this periatriotomy loop (Fig. 2(c)). Entrainment with concealed fusion and criteria consistent with a site critical to the tachycardia could be demonstrated at the upper border of the atriotomy scar (Fig. 2(d)). The tachycardia could be eliminated by two radiofrequency energy applications at this site.

In three other patients presenting with periatriotomy loop atrial reentrant tachycardias, the electroanatomical mapping system was used to guide the creation of linear lesions between the inferior border of the atriotomy scar and the inferior vena cava by marking these barriers within the three-dimensional map (Fig. 3). In these three patients, the atrial tachycardia along the periatriotomy
loop was no longer inducible after creation of the linear lesions.

In a 30-year-old patient after surgery for transposition of the great arteries, a periatriotomy loop atrial tachycardia (cycle length 550 ms) occurred after the initial ablation of a cavotricuspid isthmus–dependent atrial reentrant tachycardia (cycle length 530 ms). Following creation of a linear lesion between the inferior border of the atriotomy scar and the inferior vena cava, the tachycardia changed to a shorter cycle length (450 ms). This new non-sustained arrhythmia was not ablated due to the prolonged procedural time and uncertainty of its clinical relevance.

Incisional focal atrial tachycardias

The area of earliest atrial activation, as determined by electroanatomical mapping, was the target of catheter ablation in three patients with incisional focal atrial tachycardias. In a 36-year-old woman with prior atrial septal defect closure, the atrial focus was localized in the septal area and could be successfully ablated using the CARTO system (Fig. 1, right). In a 30-year-old woman with Ebstein anomaly and prior surgery for a right posterolateral accessory pathway, an ectopic focus could be successfully ablated in the posterolateral right atrium in close proximity to a large surgical scar. A permanent focal atrial tachycardia at the border of a septal patch was found in a 49-year-old patient with prior atrial septal defect closure. As the arrhythmogenic focus could not be eliminated by radiofrequency catheter ablation, His bundle ablation and pacemaker implantation had to be performed to achieve appropriate control of ventricular rate.

Follow-up

During a follow-up of 18 ± 13 months, incisional atrial tachycardias reoccurred in two patients with incomplete
Figure 2 (a) Electroanatomical mapping of an incisional atrial tachycardia in a 9-year-old child after orthotopic heart transplantation. The map of the right atrium is shown in a RAO projection. Continuous progression of colours from red to purple in a clockwise direction demonstrates the presence of a periatriotomy loop atrial tachycardia. The surgically created scar (no atrial signals or signals of very low amplitude) was coloured grey. Atrial activation time (415 ms) was similar to the atrial tachycardia cycle length (460 ms). (b) Propagation mapping of the atrial tachycardia. Analysis of the conduction velocities along the reentrant circuit suggested the presence of a slow conduction zone (from about 11 o’clock to 5 o’clock) on this clockwise periatriotomy loop. (c) Intra-cardiac recordings and schematic representation of the incisional atrial tachycardia. Surface ECG leads III, V2 and V3 are shown simultaneously with intracardiac recordings from the mapping catheter (MAP), from the high septal right atrium (RA sept) and from the low posteroseptal right atrium near the coronary sinus ostium (CS os prox and CS os dist) (right). Recording from the MAP catheter, located at the upper border of the atriotomy scar, revealed a low-amplitude double potential (arrows). Schematic representation of the clockwise periatriotomy loop is on the left. The assumption was made that the slow conduction area was critical to the tachycardia circuit. (d) Entrainment with concealed fusion and criteria consistent with a site critical to the atrial tachycardia could be demonstrated at the upper border of the atriotomy scar. Post pacing interval (PPI) is equal to tachycardia cycle length (TCL). Stimulus-P (S-P) interval was 250 ms, consistent with an entrance site of the critical zone. Application of radiofrequency energy (25 W) terminated the atrial tachycardia after few seconds. The patient was free of tachycardias at the 4 month follow-up. PCL, pacing cycle length.
Cavotricuspid isthmus block. Both atrial tachycardias could be successfully reablated with the creation of a complete bidirectional isthmus conduction block. One patient (pt. 3) had to be treated during follow-up with sotalol for paroxysmal atrial fibrillation occurring after successful cavotricuspid isthmus ablation and ablation of a periatriomy loop atrial tachycardia. The patient, with surgically corrected transposition of the great arteries, had to be treated with propafenone and beta-blocker as the result of pre-existing ventricular tachycardia, and during a follow-up of 3 months no atrial arrhythmias were documented.

Discussion

The present study demonstrates the clinical experience with the electroanatomical mapping system CARTO in a consecutive series of 10 patients with 13 incisional atrial tachycardias. The CARTO system allowed rapid distinction between a focal origin and an intra-atrial reentrant mechanism and facilitated understanding of the reentrant circuits in relation to surgical scars. In three patients with incisional focal atrial tachycardias, the earliest atrial activation could be precisely identified in a three-dimensional reconstruction of the right atrium and targeted using the same mapping and ablation catheter. In the case of 10 incisional atrial reentrant tachycardias, electroanatomical (propagation) mapping allowed rapid visualization of the activation wavefront and, thus, facilitated the identification of appropriate sites for entrainment mapping and successful catheter ablation.

Similar results have recently been reported by Hebe et al. who investigated the use of the CARTO system in seven patients with a total of 13 incisional reentrant atrial tachycardias. The authors were able to successfully ablate 12 of the 13 atrial tachycardias and suggested that
Electroanatomical mapping aids understanding of and success in catheter ablation of such tachycardias. Based on the case of a patient with a double inlet left ventricle and transposition of the great arteries, Dorostkar et al.\[19\] have described electroanatomical mapping as a systematic approach to postoperative intra-atrial reentrant tachycardia. Using electroanatomical mapping, Shah et al.\[20\] have recently characterized the reentrant circuit of five patients with dual-loop intra-atrial reentrant tachycardias after surgical atrial septal defect closure. These atrial tachycardias had a counterclockwise loop around the tricuspid valve and a clockwise loop around the lateral atriotomy scar.

**Electrophysiologically guided vs anatomically guided ablation**

Entrainment techniques are of central importance to define critical components of incisional reentrant atrial tachycardias\[1-3\]. However, this technique may be difficult in patients with incisional atrial tachycardia due to low-amplitude or absent atrial potentials in the area of surgical incisions. Entrainment stimulation can also transform the tachycardia or induce atrial fibrillation in complex anatomy after surgery for congenital heart disease\[6-9\]. Anatomically guided catheter ablation may be another effective technique for the management of incisional reentrant atrial tachycardia\[21\]. Electroanatomical mapping provides a useful new technology for both electrophysiologically guided and anatomically guided mapping and ablation of complex incisional atrial tachycardia. Analysis of the propagation map may allow the identification of areas of slow conduction and, thus, help to find appropriate sites for entrainment stimulation and catheter ablation. Visualization of surgical scars and anatomical barriers within a three-dimensional electroanatomical map facilitates the creation of linear lesions to transsect a narrow isthmus of conduction tissue.

**Targets for catheter ablation**

The majority of incisional atrial tachycardias after atrial septal defect closure has been reported to propagate through the tricuspid annulus–vena cava inferior isthmus\[22,23\]. In these patients, the mechanism of the tachycardia and appropriate ablation sites can usually be defined by conventional entrainment techniques. However, in more complex atrial tachycardias, such as periatriotomy loop atrial tachycardias, electroanatomical mapping helps to develop a strategy for lesion deployment for each patient. Incisional focal atrial tachycardias may originate from sites in close proximity to surgically created lesions. Precise localization of the focal arrhythmogenic origin and successful ablation using the CARTO system has been reported by several authors\[5-12\].

**Limitations**

One limitation of the use of the electroanatomical mapping system in patients after surgery for congenital heart disease is the prolongation of the procedural time which may be a clinically relevant problem in these patients. Electroanatomical mapping may be difficult or even impossible in patients with non-sustained atrial tachycardia. In these cases of short-lived atrial tachycardias, three-dimensional mapping systems based on a single beat analysis such as the multielectrode basket catheter or the non-contact mapping system may be an alternative to electroanatomical mapping technology. The small number of patients is a limitation of this study. Further studies are needed to evaluate the usefulness of electroanatomical mapping for different forms of incisional atrial tachycardia.

**Conclusions**

Electroanatomical mapping is a safe and feasible method for visualization of atrial activation in patients with complex incisional atrial tachycardia. The technique is appropriate for focal and reentrant incisional atrial tachycardia. This new non-fluoroscopic method facilitates electrophysiologically guided and anatomically guided catheter ablation of incisional reentrant atrial tachycardia.

**References**


