

Non-Fluoroscopic Electroanatomical Mapping (CARTO System) in the Ablation of Atrial Tachycardias

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Introduction and objectives. The recent introduction of navigation systems has made substantial improvements in cardiac electrophysiological mapping. We present our experience with non-fluoroscopic electroanatomical mapping in patients with atrial tachycardias.

Patients and method. We studied 24 consecutive patients with atrial tachycardias (10 of whom had undergone previous radiofrequency ablation which failed). In all patients we performed electroanatomical mapping of the atria with the CARTO system, which combines electrophysiological and spatial information and allows visualization of atrial activation in a three-dimensional anatomical reconstruction of the atrial cavity. Mapping was performed during tachycardia (22 patients) or in sinus rhythm (2 patients), using a left atrial approach in 12 patients. Cooled-tip ablation was performed in 3 patients.

Results. Three-dimensional mapping distinguished clearly and rapidly between reentrant (9 patients) and focal mechanisms (15 patients). Radiofrequency catheter ablation was aimed at the critical isthmus of conduction (voltage maps) in patients with macroreentrant tachycardias. For focal tachycardias the catheter was re-navigated within the target area (activation maps) to the earliest focus of ectopic impulses. Acute success was obtained in 19 patients (79.2%), with early recurrence in 2 of them. Fluoroscopy time was 60 (21 min).

Conclusions. Visualization of atrial activation in a three-dimensional reconstruction of the atria with the CARTO electroanatomical mapping system facilitated the integration of electrophysiological and anatomical information in patients with atrial tachycardias. This technique is potentially helpful in ensuring successful treatment of the substrate of tachycardia in this selected group of patients.

Key words: Atrium. Tachycardia. Catheter ablation. Mapping.

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La cartografía electroanatómica no fluoroscópica (sistema CARTO) en la ablación de las taquicardias auriculares

Introducción y objetivos. La introducción de los sistemas navegadores ha supuesto un cambio sustancial en la cartografía electrofisiológica cardíaca. Presentamos nuestra experiencia con el uso de la cartografía electroanatómica no fluoroscópica en pacientes con taquicardias auriculares.

Pacientes y método. Se incluye a 24 pacientes consecutivos con taquicardias auriculares (10 de ellos con intentos previos de ablación fallidos). En todos los casos se realizó una cartografía auricular electroanatómica mediante el sistema CARTO, que combina información electrofisiológica y espacial y permite la visualización de la activación atrial en una reconstrucción anatómica tridimensional de la aurícula. La cartografía se realizó durante taquicardia (22 pacientes) o en ritmo sinusal (2 pacientes), con abordaje en la aurícula izquierda en 12 pacientes. La ablación se efectuó con un catéter de punta irrigada en 3 pacientes.

Resultados. La cartografía tridimensional permitió una clara y rápida distinción entre un mecanismo macrorreentrante (9 pacientes) y un origen focal (15 pacientes). Las aplicaciones de radiofrecuencia se dirigieron hacia el istmo crítico de conducción identificado en las macrorreentradas mediante mapas de voltaje de auriculogramas o hacia el área de mayor precocidad ectópica focal en los mapas de activación. El tratamiento se realizó con éxito en 19 pacientes (79,2%) y se produjo una recurrencia precoz en 2 de ellos. El tiempo de fluoroscopia fue de 60 ± 21 min.

Conclusiones. La cartografía electroanatómica con sistema CARTO permitió la visualización tridimensional de la activación auricular, evitando el esfuerzo de integración electrofisiológico y anatómico en estos pacientes con taquicardias auriculares. El apoyo iconográfico que supone podría facilitar el éxito de la ablación con radiofrecuencia en este seleccionado grupo de pacientes.

Palabras clave: Aurícula. Taquicardia. Ablación con catéter. Mapeo.

ABBREVIATIONS

RF: radiofrequency.
AT: atrial tachycardia.

INTRODUCTION

Radiofrequency (RF) ablation is a well established therapeutic option for patients with atrial tachycardia (AT) refractory to pharmacological treatment.¹ The optimal ablation site varies from patient to patient, therefore accurate electrophysiological mapping is particularly important. Mapping has usually been performed with fluoroscopy in combination with analysis of electrograms, but fluoroscopic spatial resolution is often limited, even with biplanar techniques, and requires exposure to ionizing radiation. Moreover, endocardial surfaces do not show up with fluoroscopy and the catheter tip cannot be located exactly but only approximately relative to adjacent structures.

In recent years, non-fluoroscopic electroanatomical techniques with a special electrocatheter have been developed to overcome these drawbacks. The so-called CARTO system (Biosense Ltd., Israel)²⁻¹² uses a mapping catheter with a localization sensor in its tip to automatically and simultaneously acquire an electrogram and determine its three-dimensional coordinates. This information is transferred to the mapping system, which generates a color-coded three-dimensional electroanatomical map of the heart chamber with relevant electrophysiological information in real time. The objective of the present study is to report our experience with the use of this navigation and mapping system in the ablation of AT in a selected group of consecutive patients.

PATIENTS AND METHODS

From January 2000 to December 2002, 24 patients with AT who underwent ablation procedures in our laboratory (eight men and 16 women; mean age, 39.3 ± 22.5 years) were studied. Table 1 summarizes their main clinical characteristics. It should be noted that these patients had been refractory to a mean of 2.2 ± 1.5 antiarrhythmic drugs. Ten of these patients had undergone previous unsuccessful ablation procedures (range, 1-4 procedures) and 7 patients had undergone more than one previous ablation procedure. At least one of the previous procedures had been performed with the support of the CARTO system in three of these 10 patients. We describe the results corresponding to the most recent study in each patient. In patients with atrial macroreentrant tachycardias, the most recent procedure targeted the

TABLE 1. Clinical Characteristics of the Patients*

Patient	Age, Years/ Sex	Previous Ablations	Associated Heart Disease	Clinical Presentation
1	24/M	2	No	Incessant
2	23/F	No	No	Repetitive
3	37/F	2	No	Paroxysmal
4	25/F	1	No	Paroxysmal
5	73/F	No	IHD (1 vessel); LVH	Paroxysmal
6	13/F	Typical flutter	Fontan for single ventricle	Incessant
7	42/M	Typical flutter	AS ostium secundum	Incessant
8	14/M	2	Tachycardiomyopathy	Incessant
9	40/F	No	No	Incessant
10	30/M	No	No	Repetitive
11	47/F	No	AS ostium secundum; Ebstein	Incessant
12	23/M	3	No	Incessant
13	9/F	1	AS ostium secundum; TAPVD	Incessant
14	70/F	2	No	Repetitive
15	43/F	4	No	Incessant
16	12/F	No	Tachycardiomyopathy	Incessant
17	45/M	1	No	Paroxysmal
18	21/F	No	No	Paroxysmal
19	77/M	No	No	Paroxysmal
20	58/F	No	No	Paroxysmal
21	19/F	No	Fontan in single ventricle	Paroxysmal
22	77/F	No	Mitral prolapse; severe MR	Incessant
23	78/M	2	No	Incessant
24	42/F	No	Rheumatic mitral valve disease	Incessant

*IHD indicates ischemic heart disease; AS, atrial shunt; TAPVD, total anomalous pulmonary venous drainage; LVH, left ventricular hypertrophy; MR, mitral regurgitation; M, male; F, woman.

recurrence or persistence of the same tachycardia, as defined by its electrocardiographic pattern. Seven patients had other documented prior arrhythmias: typical atrial flutter (2 patients), sinus node dysfunction (2 patients), Wolff-Parkinson-White syndrome (1 patient) and prior atrial fibrillation (2 patients). One of the patients with atrial fibrillation showed isolated episodes of paroxysmal atrial fibrillation. The other patient developed tachycardia during mitral surgery after RF application to treat her underlying chronic atrial fibrillation. Follow-up, which was by outpatient visits or telephone contact, lasted 17 ± 13 months (range, 1-36 months).

Electrophysiological Study

Following informed consent, each patient underwent an electrophysiological study in fasting conditions. Administration of any drug had been discontinued for a period of at least five half-lives. The right femoral vein was punctured to allow the

introduction of conventional multipolar catheters into the high right atrium, the His bundle area and, occasionally, the coronary sinus and the apex of the right ventricle. Clinical tachycardias were induced by programmed atrial stimulation with extrastimuli and/or atrial pacing at different set frequencies if the tachycardia was not incessant. Isoproterenol was infused if necessary. Standard criteria were applied for diagnosis of AT as focal or reentrant.^{13,14}

Patients with focal AT underwent a preliminary study to determine whether the arrhythmia originated in the left or right atrium by measuring activation with respect to an atrial reference electrogram or the P wave in the surface electrocardiogram. Patients with macroreentrant AT were studied initially for a fractionated electrogram and then underwent entrainment mapping to help localize the reentrant circuit.^{15,16} Mapping was performed during tachycardia (22 patients) or in sinus rhythm (2 patients). If left atrial mapping was required, access was via transseptal puncture with Brockenbrough needles and Mullin sheaths (9 patients) or a patent foramen ovale (3 patients). The intracardiac signals were filtered between 30 and 500 Hz and displayed simultaneously with 4-6 electrocardiographic leads at recording speeds between 100 and 200 mm/s on a 12-channel polygraph (Midas, Hellige Biomedical, Freiburg, Germany).

Electroanatomical Cartography

The characteristics and operation of this navigation system have been described in detail previously.^{2-4,6} The system can determine the position of the catheter with a resolution of less than 1 mm, both in *in vivo* and *in vitro* studies.^{3,4} A reference electrogram was selected to define the fiducial point (maximum value of the reference signal). The fiducial point defined the activation time at the mapping catheter with respect to the acquired points for generation of the three-dimensional map. The time window of interest was centered on the fiducial point for acquisition of the local activation signal in the mapping channel. The width of the window was set to 20 ms less than the tachycardia cycle time. A right atrial or coronary sinus electrogram was used for reference. Each mapping point was added to the chamber map if it met the preset spatial (<2 mm) and temporal (<2 ms) stability criteria. For focal AT, an activation map was generated that identified the regions of earliest activity with respect to the reference electrogram (Figures 1 and 2). A high density map was then generated around these regions that included analysis of bipolar and unipolar electrograms. The maximum orthogonal size of these regions between the points with earliest activity (± 5 ms) was determined (Figures 1 and 2). When the map was complete, RF

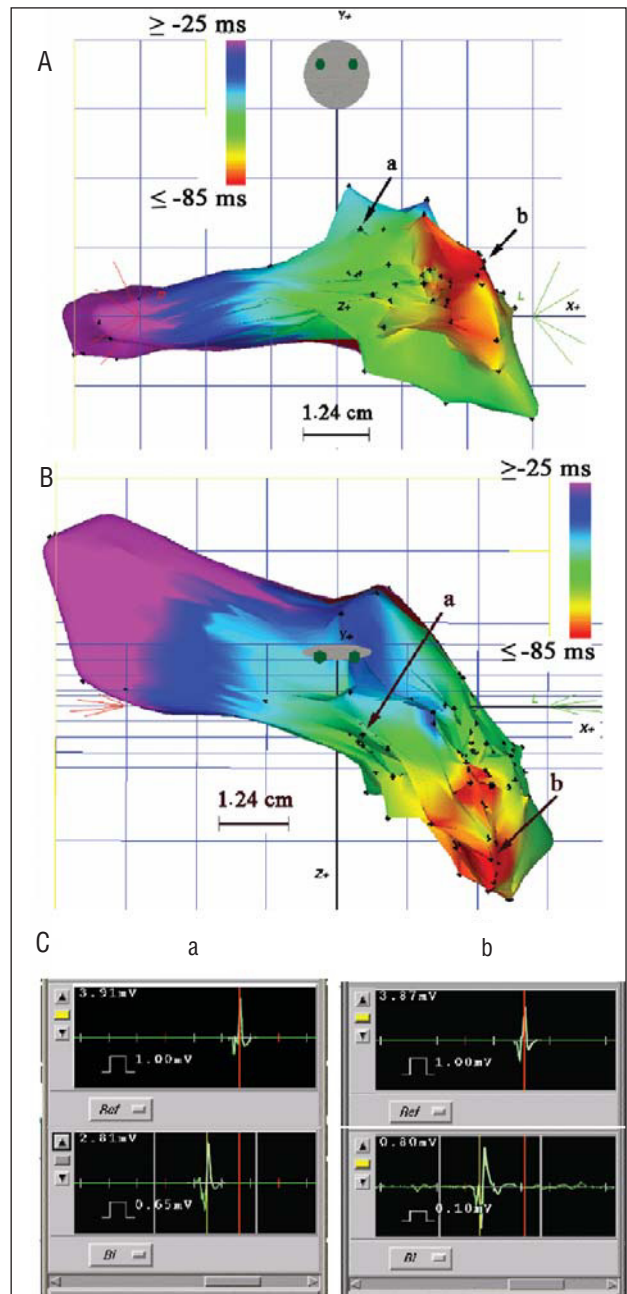


Figure 1. Electroanatomical activation map of the roof of the left atrium and its auricle during automatic focal atrial tachycardia originating from the upper and mediobasal left atrial auricle. A and B: slightly posterior oblique anteroposterior and cranial projection, respectively, of the same map. Note the progressive change to red as the mapping points are activated earlier with respect to the broad start of activation. C: bipolar electrograms corresponding to points a (further from the focus) and b (earliest activity) with respect to the fiducial or reference electrogram (in right atrium). The grey bars mark the window of interest. Activation occurred at -58 ms at point a compared to -94 ms at point b.

applications targeted the points of earliest activity. For reentrant AT, we always attempted to identify scar regions (endocardial points with bipolar signals of

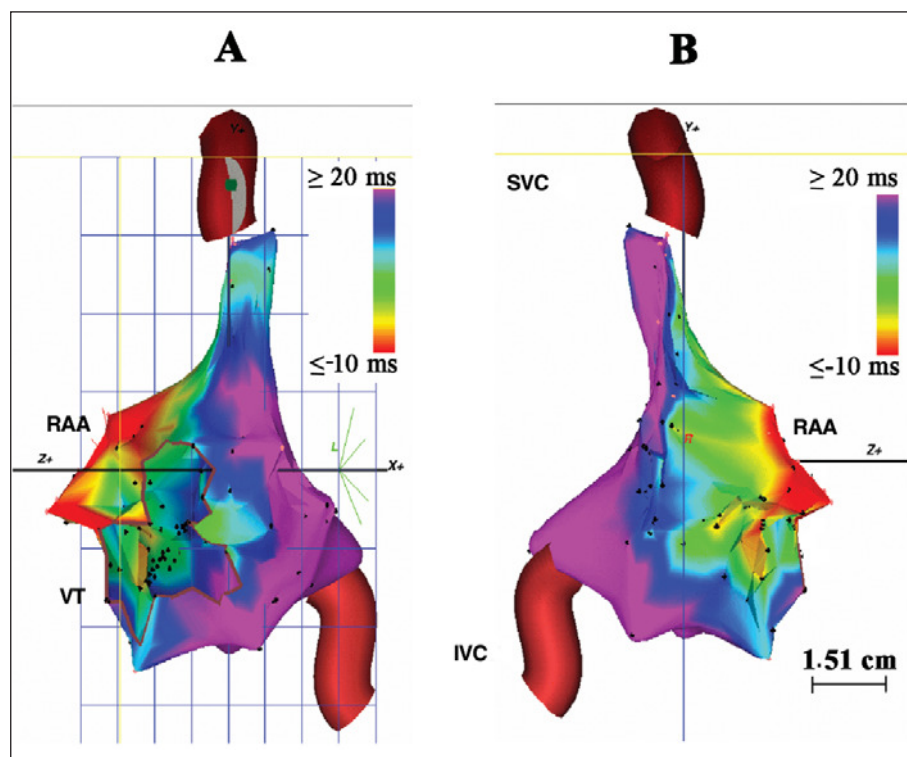


Figure 2. Electroanatomical activation map during incessant tachycardia originating from the base of the right auricle. Red indicates early activity with respect to the fiducial electrogram of the lateral face of the right atrium by means of a catheter with active fixation. A and B: left anterior oblique (45°) and right side projections of chamber map, respectively. After four radiofrequency applications, which resulted in transitory slowing or suppression of ectopy, definitive elimination was finally achieved (patient 16). RAA indicates right atrial auricle; IVC, inferior vena cava; SVC, superior vena cava; TV, tricuspid valve

approximately 0.1 mV)^{8,17} by generating a voltage map of the chamber to locate anatomic isthmuses to be targeted by RF applications (Figures 3 and 4). Voltage mapping was performed in sinus rhythm in 2 patients with incisional AT that could not be reproducibly induced for long periods, with a window of interest of 100 ms either side of the reference sinus atrial electrogram. A Navistar catheter (7 Fr, Cordis Webster) was used in 21 patients, with a 4 mm tip (19 patients) or 8 mm tip (2 patients). We used an open-circuit cool-tip catheter in the three remaining patients (Navistar-Thermocool, Cordis Webster, 8 Fr; 3.5 mm distal electrode) after some previous unsuccessful ablation attempts (Figure 1). The RF applications were performed with a conventional source (Stockert EP-shuttle) in temperature and power control mode (setpoints: 60 °C and 50 W). The procedure was successful if the tachycardia disappeared after ablation and did not recur. Quantitative data were expressed as mean±SD. Means were compared with the Mann-Whitney U test. Statistical significance was set at $P<.05$.

RESULTS

Localization of Tachycardia Substrates by Electroanatomical Mapping

A mean of 137 ± 75 mapping points were recorded with the CARTO system (range, 50-237 points). Atrial tachycardia was focal in 15 patients. The nine

remaining patients showed reentrant behavior, which was incisional in five of these patients. The focal tachycardias were left-atrial in nine patients (Figure 1), right-atrial in three patients (Figure 2) and septal in the 3 remaining patients (Table 2). 3 left macroreentrant tachycardias (Figure 3) and a patient with reentry by the low *crista terminalis* were reported. All 5 incisional reentrant tachycardias were right-sided (Figure 4). The fluoroscopic examination time was 60 ± 21 min (range, 30-95 min).

Results of the Radiofrequency Ablation

The ablation procedures were successful in 19 (79.2%) patients overall. Ten of these were patients with focal tachycardias (66.7%) and 9 were patients with atrial macroreentrant tachycardias. The mean number of RF applications was 12.6 ± 11.2 (range, 1-49). In 1 patient (patient 1) with a DDDR pacemaker for an associated sinus node dysfunction, atrioventricular block occurred immediately after right medial septal ablation. Surgical ablation was chosen in 2 of the unsuccessful ablation procedures in patients with ectopic tachycardias. One of these patients underwent removal of the apex of the left auricle, which permanently eliminated AT (Figure 1). Epicardial ablation with RF in the other patient with an extensive node near to the anterior tricuspid ring was also ineffective. During follow-up, recurrence of ectopic AT was observed one month after the procedure. Likewise, a recurrence was also reported

Figure 3. Anterior right oblique projection of a voltage map of bipolar electrograms in the left atrium of a patient with a macroentry by the mitral annulus, identified by entrainment mapping from the proximal, medial and distal coronary sinus. Grey and red indicate endocardial scar regions (bipolar voltage <0.0 mV). An anatomic isthmus was identified between the superior mitral annulus and scar regions. Radiofrequency (red points) was applied that eliminated the tachyarrhythmia. B: anterior right oblique projection of activation map; the dark red band defines the meeting point of earliest (in red) and most delayed (in violet) activation times of the aforementioned macroentry; LAA indicates left atrial auricle; MV, mitral valve; RSPV, superior right pulmonary vein; LSPV, superior left pulmonary vein.

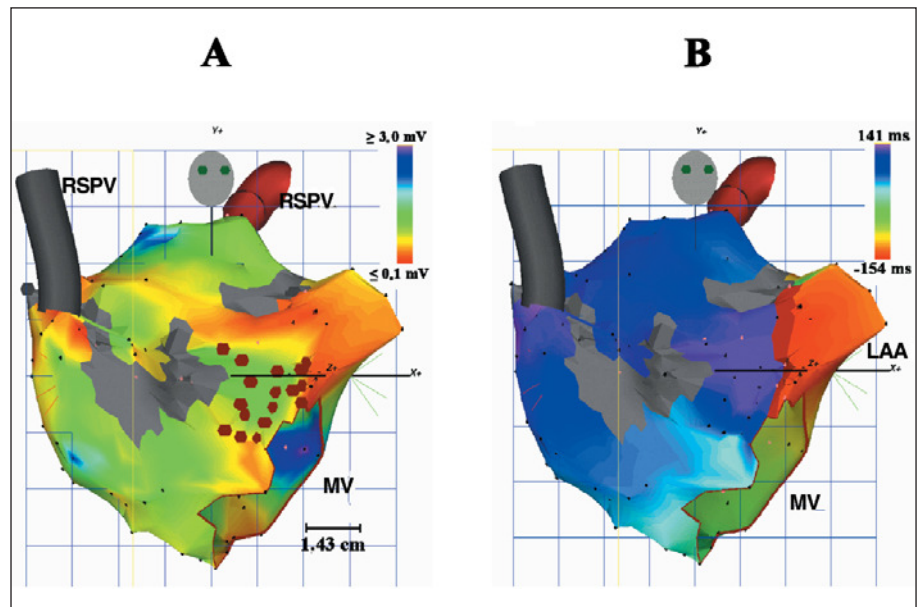


TABLE 2. Electrophysiological Characteristics of the Patients*

Patient	Type of Tachycardia	Cycle Duration, ms	Substrate Site	Mapping Points	RF Applications	Catheter
1	Focal	310	Right septal	117	10	Navistar, 4 mm
2	Focal	360	Superior mitral annulus	67	3	Navistar, 4 mm
3	Focal	290	Left inferior paraseptal	133	7	Navistar, 4 mm
4	Focal	500	Upper face of LAA	70	8	Navistar, 4 mm
5	Focal	310	Left superior paraseptal	197	8	Navistar, 4 mm
6	Reentrant	340	Right anterior	210	4	Navistar, 4 mm
7	Reentrant	280	Right anterior	179	6	Navistar, 4 mm
8	Focal	360	Anterior atrial face of tricuspid annulus	101	20	Navistar-Thermocool, 3.5 mm
9	Reentrant	330	Reentry by mitral annulus	153	20	Navistar, 4 mm
10	Focal	300	Left posterior	82	7	Navistar, 4 mm
11	Reentrant	360	Right anterior	111	11	Navistar, 4 mm
12	Focal	250	Upper face of distal LAA	155	18	Navistar-Thermocool, 3.5 mm
13	Reentrant	260	Right anterior	137	6	Navistar, 4 mm
14	Focal	300	Posterosuperior face of LV (near to LSPV)	286	30	Navistar, 4 mm
15	Focal	500	Posterosuperior face of LV (near to LSPV)	73	19	Navistar-Thermocool 3.5 mm
16	Focal	270	Base of right auricle	154	4	Navistar, 4 mm
17	Focal	480	Superoanterior atrial face of tricuspid annulus	60	10	Navistar, 8 mm
18	Focal	400	Posterosuperior LA (between LAA and LSPV ostium)	50	1	Navistar, 4 mm
19	Reentrant	350	Low Crista terminalis	115	11	Navistar, 4 mm
20	Focal	280	Adjacent to RSPV: ostium	121	27	Navistar, 4 mm
21	Reentrant	313	Anteroinferior RA	209	17	Navistar, 8 mm
22	Focal	370	Posteroinferior face of RA	76	1	Navistar, 4mm
23	Reentrant	440	Posterior face of LA	90	13	Navistar, 4 mm
24	Reentrant	280	Reentry by mitral annulus	327	44	Navistar, 4 mm

*RA indicates right atrium; LA, left atrium; LAA, left atrial auricle; LSPV, left superior pulmonary vein; RSPV, right superior pulmonary vein; RF, radiofrequency.

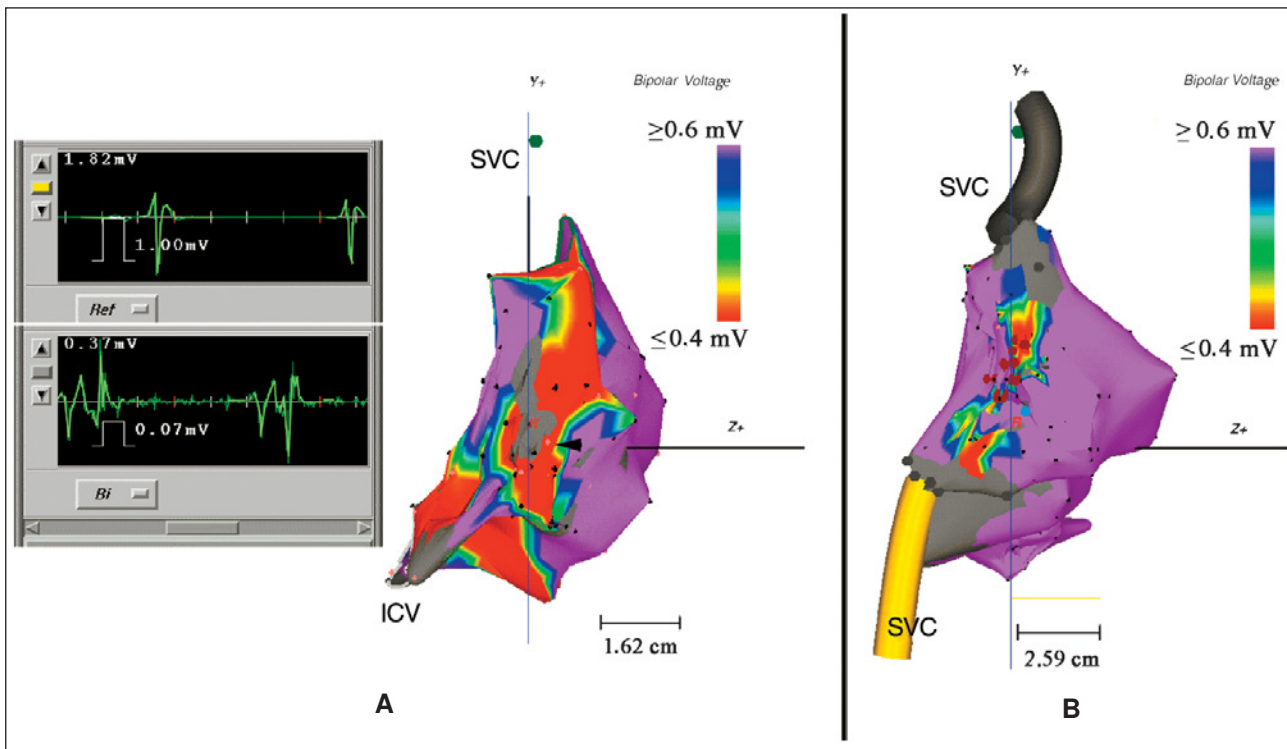


Figure 4. Right atrial lateral right projection of voltage maps of bipolar electrograms of a patient with post-incisional atrial tachycardia. Grey indicates scarred endocardial surfaces, whereas red indicates regions with voltages ≤ 0.4 mV. A. The map was constructed during tachycardia. An endocardial isthmus was identified (arrow) where radiofrequency applications were made that interrupted the tachycardia. Left: fractionated electrograms along the red area (lower panel) with respect to the reference electrogram (upper panel). B. Voltage map constructed during sinus rhythm. Red dots indicate radiofrequency applications at the isthmus located in the right atrial postero lateral free-wall. IVC, inferior vena cava; SVC: superior vena cava.

one and a half months after ablation in a patient with reentrant tachycardia. A further 2 patients had chronic atrial fibrillation.

A tendency to a more extensive area of early activation (± 5 ms) of the atrial focus was observed when tachycardia persisted after ablation. The estimated focal area in the five patients with unsuccessful ablation of focal AT was 392 ± 210 mm² versus 240 ± 148 mm² in cases that were successful ($P=0.083$), whereas the width of the anatomic isthmus in the ablated reentrant tachycardias ranged from 5.2 to 21.3 mm.

DISCUSSION

The success rate in our selected series of patients with AT is almost 80%. Recently, the Spanish Registry of Catheter Ablation reported a success rate of 73.1% for procedures performed during 2001.¹⁸ More striking is our 100% success rate for macroreentrant tachycardias, compared to 46% in the aforementioned Registry and 66% in the large population of Friedman et al.¹⁹ We might therefore be surprised by the excellent success rate for ablation of 87% cited by Ouyang et al.¹¹ in a broad population of patients with

left macroreentrant tachycardias, compared to 21% reported in the Spanish Registry.¹⁸ Of course our patient population is clearly selected, that is, 42% of patients had previously undergone an unsuccessful ablation procedure and tachycardias were located in the left atrium in 54.2% of patients, unlike numerous other previous populations with a clear predominance of right AT.^{18,20} Nevertheless, the substrate site has not been clearly shown to influence the success of the ablation procedure.^{18,20} This may be because left-sided tachycardias are underrepresented in previous studies. In some populations though, right-sided location was the only significant predictor of successful ablation of focal tachycardias.²¹ Four of our 5 failures during the procedure were located in or near the septum, or in the left auricle. Our only failure for right atrial tachycardia was located in ridged areas of the wall, close to the base of the auricle.²⁰ In our patients, ectopic tachycardias tended to have a larger area of early activity refractory to ablation. This may be due to more diffuse or less concentrated focal areas or to a narrow grouping of multiple foci. Alternatively, we may not be mapping the area close to the ectopic focus particularly if this is located epicardially, or the focus may overlie a fast atrial circuit. We cannot rule out

that the larger area of early activity is due to technical limitations and suboptimal activation mapping. In any case, we related the extent of early activity with the need to perform multiple RF applications to completely eliminate the node.

The CARTO System in Atrial Tachycardias

The active nodes of ectopic AT may lie anywhere on either side of the atrial septum. A three-dimensional mapping system seems the ideal choice for such cases because the imaging defines the atrial endocardial surface well and provides relevant electrical information to identify areas with early activity. The navigation system clearly reduced the effort required by the operator to integrate electrophysiological and anatomical information in studies that may have become prolonged. The CARTO system was particularly useful in patients with reentrant AT because the voltage maps provided a graphic display of the anatomic isthmus between scar regions or between a scar region and anatomical boundaries. The endocardial tracts where the applications were performed could therefore be identified.¹⁰ Entrainment mapping, when possible, was extremely useful for assessment of whether these isthmuses were implicated in sustaining reentry. It has been suggested that the high rate of recurrence of tachycardias in patients with right incisional macroreentry could be because not all reentry circuits have been identified. This task would be facilitated by electroanatomical mapping.¹⁰ A randomized study in parallel with conventional mapping would be hard to perform because this is an uncommon condition, therefore evidence of its usefulness must be gathered from observational experience. Nevertheless, retrospective analyses from a single center show that electroanatomical mapping was a positive long-term predictor of success in ablation of reentrant intraatrial circuits.¹⁹ Moreover, more than half the 10 patients who had undergone previous procedures were referred from other centers. We therefore do not know the details of these procedures, such as the number of RF applications. Indirect evidence that the navigation system is more effective would have been provided if more RF applications had been made in the previous procedures than in the last attempt with the navigation system. However, seven of these 10 patients underwent more than one previous unsuccessful ablation attempt so the cumulative number of applications is probably high.

Apart from the high cost of the procedure, use of this navigation system is time consuming but does not reduce examination time, at least in non-routine cases.^{10,19} Moreover, the examination time might actually increase because it takes time to learn to use the system effectively.¹⁹ The procedure times could be

shortened by using fewer mapping points to define the arrhythmogenic node rather than the whole chamber,¹² or by subsequent developments in the system.

CONCLUSIONS

Electroanatomical mapping with the CARTO system displays right and left atrial activation in three dimensions, which reduced the effort needed to integrate electrophysiological and anatomic information in our patient population with AT. The objective and design of the study are purely descriptive and do not provide firm conclusions about the usefulness of the system. The display afforded by the navigation system could facilitate RF ablation in this selected patient group. The results from this study were promising and the procedure was successfully performed in almost 80% of the patients.

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