Initial experience with catheter ablation of tachycardias using a three-dimensional real-time position management and mapping system

Üçboyutlu gerçek zamanlı pozisyon yönetim haritalama sistemiyle taşikardilerin kateter ablasyonunda ilk deneyimlerimiz

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Objectives: Three-dimensional real-time position management system (RPM) uses an ultrasound technique to display real-time movements of catheters, to construct anatomy of heart chambers, and to obtain activation/voltage mapping. This study presented our initial experience with the RPM system used for the ablation of supraventricular or ventricular tachycardias.

Study design: Ten patients (9 males, 1 female; mean age 30 years; range 20 to 75 years) underwent electrophysiologic studies and radiofrequency ablation using the RPM mapping system for the treatment of arrhythmias. Seven patients had accessory pathways, one patient had a slow pathway, and two patients had ventricular arrhythmias.

Results: RPM-guided radiofrequency ablation was successful in six patients (60%). Failure of ablation was attributed to the RPM system in two patients, due to catheter instability and difficulties in steering to ablate the left lateral accessory pathways, and to the localization and characteristics of arrhythmias in two patients. The mean operation time was 146±45 min (range 60 to 180 min), with a mean fluoroscopy time of 43±22 min. No complications occurred during or after the procedure.

Conclusion: The RPM system provides satisfactory anatomical construction of heart chambers, marking of anatomic and electrophysiologic spots, three–dimensional real-time positioning of the catheters and activation/voltage mapping. It can be used to guide radiofrequency ablation of atrial and ventricular arrhythmias.

Key words: Arrhythmia/surgery; catheter ablation/methods; echocardiography, three-dimensional; image processing, computer-assisted; tachycardia, ventricular/surgery.

Amaç: Üçboyutlu gerçek zamanlı pozisyon yönetim sistemi (RPM), kateterlerin gerçek zamanlı hareketini göstermek, kalp boşluklarının anatomisini çıkartmak ve aktivasyon/voltaj haritalama için ses dalgası yayılımını kullanan bir sistemdir. Bu çalışmada süpraventriküler veya ventriküler taşikardilerin ablasyonunda bu teknikle ilgili ilk deneyimlerimiz sunuldu.

Çalışma planı: Çalışmaya aritmi nedeniyle elektrofizyolojik çalışma ve RPM haritalama sistemiyle radyofrekans (RF) ablasyonu uygulanan 10 hasta (9 erkek, 1 kadın; ort. yaş 30; dağılım 20-75) alındı. Yedi hastada aksesuvar yol, bir hastada yavaş yol, iki hastada ventriküler aritmi vardı.

Bulgular: RPM sistemi kılavuzluğunda yapılan radyofrekans ablasyonu altı hastada (%60) başarılı oldu. Başarısız sonuç, iki hastada, sol lateral aksesuvar yol kateterinin sabit olmaması ve manipülasyonundaki zorluk nedeniyle RPM sistemine bağlandı; iki hastada ise başarısızlık aritminin kendi özelliğinden ve yerleşiminden kaynaklandı. Ameliyat süresi ortalaması 146±45 dk (dağılım 60-180 dk), ortalama skopi süresi 43±22 dk idi. İşlem sırasında veya sonrasında komplikasyon izlenmedi.

Sonuç: RPM sistemi kalp boşluklarının anatomisini çıkarabilmekte, anatomik ve elektrofizyolojik noktaları işaretleyebilmekte, kateterlerin üçboyutlu ve gerçek zamanlı olarak takibini ve aktivasyon/voltaj haritalama yapabilmektedir. Bu sistem aritmilerin radyofrekans ile ablasyonunda yol gösterici olarak kullanılabilir.

Anahtar sözcükler: Aritmi/cerrahi; katater ablasyonu/yöntem; ekokardiyografi, üçboyutlu; görüntü işleme, bilgisayar destekli; taşikardi, ventriküler/cerrahi.

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Radiofrequency catheter ablation has become the treatment of choice for a wide spectrum of arrhythmias. Conventionally, fluoroscopy is used to track catheter position. X-ray is known to cause deterministic (skin injury, hair loss, and cataract) as well as stochastic (malignancy) side effects.[1] New treatment modalities have expanded the use of ablation in the treatment of arrhythmias, thus necessitating prolonged use of fluoroscopy. New navigation and mapping techniques have been introduced to the field of electrophysiology, providing more accurate, sensitive, and user-friendly interfaces. One of the pioneers of these new mapping systems, the CARTO system (Biosense-Webster, Diamond Bar, CA, USA), uses magnetic field. Another system, NavX™ (Version 5.0, St. Jude Medical Systems & Endocardial Solutions Inc., St. Paul, MN, USA) uses radiofrequency signals to navigate the position of the catheters. A new three-dimensional mapping system, Real-time Position Management (RPM) System (EP Technologies, Boston Scientific, San Jose, CA, USA) has recently become available, with an ultrasound transducer embedded in the catheter shaft.

In our department, the RPM system has been primarily set up for radiofrequency ablation of atrial fibrillation. Here, we report our initial experience with the RPM system used mainly for the ablation of supraventricular or ventricular tachycardias. These cases represent the initial learning curve of our electrophysiology staff, as well.

PATIENTS AND METHODS

Real-time Position Management System. The system is based on an ultrasound technique. It uses two reference catheters [a decapolar coronary sinus (CS) catheter and a quadripolar right ventricle (RV) catheter] and one mapping (roving) ablation catheter. The CS reference catheter contains nine 1-mm ring electrodes and one 2-mm tip electrode, whereas the RV reference and ablation catheters contain three 1-mm ring electrodes and one 4-mm tip electrode. The reference and ablation catheters are equipped with four and three ultrasound transmitters/receivers, respectively. Ultrasound pulses generated at a frequency of 558.5 kHz by the transducers of the reference and ablation catheters are received. The time interval from the transmission to reception is the mainstay in calculation of the distance between the transducers. Data are transferred to the mapping computer and a 3-D reference frame is established. Triangulation is used to track the position of additional transducers, to define the location of the catheter(s) within the reference frame, providing a real-time display of the catheters' position and a reconstruction of a three-dimensional anatomy of the heart chambers. Since the dimensional and structural characteristics of the catheter are known, a real-time 3-D graphic representation of the catheters, including the position of the electrodes and the transducer is possible (Figures 1 to 6). A more detailed description was published previously.[2,3]

The system is capable of simultaneously processing seven position management catheters. Signals are sampled at 3 kHz per channel with a resolution of 14 bits. Electrograms and catheter positions are stored on hard disk. The original position of the reference catheters can be displayed on the real-time window as a green line, allowing repositioning of displaced reference catheters. The frame rate of the real-time imaging is once per cardiac cycle for the catheter itself. The little ball of the ablation catheter tip is refreshed 15 times per second.

Patients. Ten patients (9 males, 1 female; mean age 30 years; range 20 to 75 years) underwent electrophysiologic studies and radiofrequency ablation using the RPM mapping system for the treatment of supraventricular or ventricular tachycardia. Demographic and clinical characteristics of the patients are presented in Table 1. All the patients gave consent before the study.

Electrophysiologic studies. All the patients were brought to the cardiac electrophysiologic laboratory in a non-sedated and fasting state. They were given appropriate conscious sedation. In all the patients, two reference catheters and one mapping/ablation catheter were introduced percutaneously using the internal jugular, subclavian and/or femoral approach. The decapolar reference catheter was positioned

Table 1. Demographic and clinical characteristics of the patients

	n	%	Mean±SD
Male/female (n)	9/1		
Age (years)			30±18
Height (cm)			173±9
Weight (kg)			74±13
Symptomatology			
Palpitation	8	80	
Atypical chest pain	5	50	
Shortness of breath	5	50	
Duration of symptoms (years)			10±15
Syncope	2	20	
Documented tachycardia	3	30	

Table 2. Electrophysiologic variables

	n	%	Mean±SD
Induced-tachycardia cycle length (ms)			321±29
Number of radiofrequency applications			9±9
Maximum °C reached			60±4
Mean °C reached			56±5
Total duration of radiofrequency (sec)			392±263
Fluoroscopic time (min)			43±22
Duration of the electrophysiologic study (min)			146±45
Supraventricular tachycardia induction	5	50	
Radiofrequency application	9	90	
System success	6	60	
Overall success	8	80	

either in the CS or in the right atrium mostly along the crista terminalis. The quadripolar reference catheter was positioned in the right ventricular apex or anteroseptal region. For ablation, a 7-F, 4-mm tip bidirectional steerable RPM catheter (Boston Scientific) was used. The remaining part of the electrophysiologic study included programmed electrical stimulation, induction protocols, and diagnostic maneuvers as in the conventional approach.[4] No efforts were made to reduce fluoroscopy time during the RPM ablation procedures. The navigation system was used whenever possible at the operators' discretion. In the presence of a patent foramen ovale, the patient was heparinized as in the condition when the ablation catheter is introduced to the left chambers.

Values of selected variables were summarized by standard descriptive statistics and expressed as mean±standard deviation.

RESULTS

Radiofrequency ablation was successful in six patients (60%). Procedural parameters are listed in Table 2. The mean operation time was 146±45 min (range 60 to 180 min). In five patients, the CS catheter was introduced via the right internal jugular vein. In four patients, the position of the CS catheter along the crista terminalis was satisfactory for mapping and navigation. At the end of the electrophysiologic study, the catheters were removed, hemostasis was achieved, and all the patients were discharged in good condition. Characteristics of the cases together with success rates are listed in Table 3, and illustration of some cases are presented in Figures 1 to 6.

DISCUSSION

The RPM system provided successful ablation in 60% of the patients. In two patients, failure of abla-

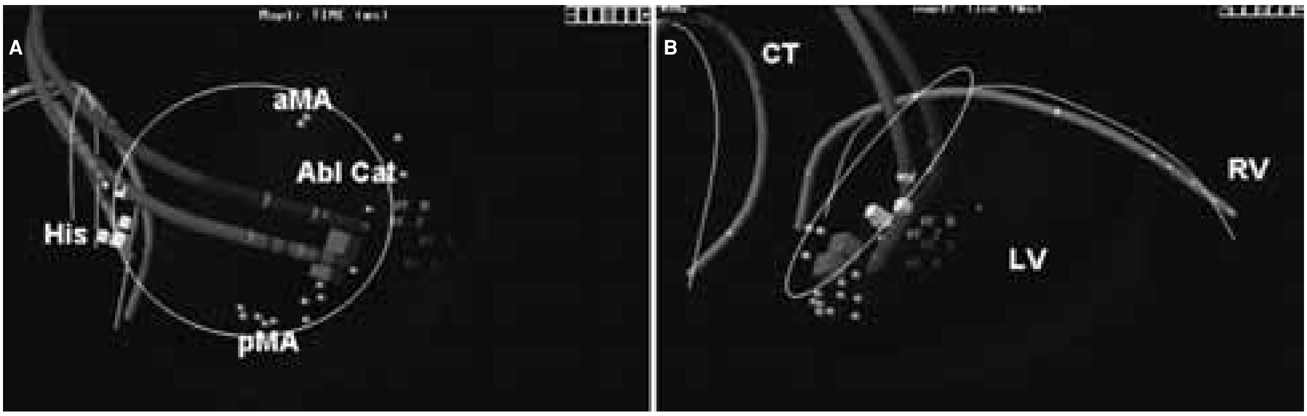

Figure 1. Position of the catheters and anatomic landmarks in Case 2 with left posterolateral accessory pathway in **(A)** left and **(B)** right anterior oblique positions. Bundle of His was marked with yellow cubes. White ring represents the mitral annulus and small green cubes are the markers pointing where the tip of the roving catheter recorded equal AV electrocardiograms. Big blue cubes represent unsuccessful radiofrequency application sites, while small green cubes tagged with RF 7 and RF 8 represent the success sites. Orientation of the ablation catheters at unsuccessful and successful sites was depicted as red and gray in color, respectively. The distance between the tips of the successful and unsuccessful application spots was 4.5 mm. Green lines are the original position of the reference catheters. Abl Cat: Ablation catheter; aMA: Anterior mitral annulus; pMA: Posterior mitral annulus; CT: Crista terminalis; RV: Right ventricular RPM catheter.

Table 3. Characteristics of arrhythmias and the procedures

Case	Gender/age	Type of arrhythmia	Tachycardia cycle length (ms)	Localization of CS reference catheter	RPM success	Overall procedure success
1	M/26	LL concealed pathway/AVRT	288	Crista terminalis	0	1
2	M/21	LPL AP/AVRT	-	Crista terminalis	1	1
3	F/45	LPL AP/AVRT	322	Coronary sinus	1	1
4	M/22	LL AP/AVRT	293	Coronary sinus	0	1
5	M/36	RMS AP/AVRT	-	Coronary sinus	1	1
6	M/20	RPS AP/AVRT	336	Crista terminalis	1	1
7	M/20	RPL AP/AVRT	320	Coronary sinus	1	1
8	M/75	AVNRT	-	Coronary sinus	1	1
9	M/22	VT/frequent PVC	-	Coronary sinus	0	0
10	M/20	VT/frequent PVC	-	Posterior right atrium	0	0

RPM: Real-time position management; AP: Accessory pathway; LL: Left lateral; LPL: Left posterolateral; RMS: Right midseptal; RPS: Right posteroseptal; RPL: Right posterolateral; AVNRT: Atrioventricular nodal re-entrant tachycardia; PVC: Premature ventricular contraction; VT: Ventricular tachycardia; AVRT: Atrioventricular re-entrant tachycardia.

tion was inherent to the arrhythmia itself, making the overall success of the system 80%. This result was secondary to insufficient catheter manipulation for the ablation of targets located at the left lateral mitral annulus. Based on the operator’s experience, the system provided a good anatomical construction of heart chambers including the CS, marking of anatomic and electrophysiologic spots, real-time navigation of the catheters, and the activation maps.

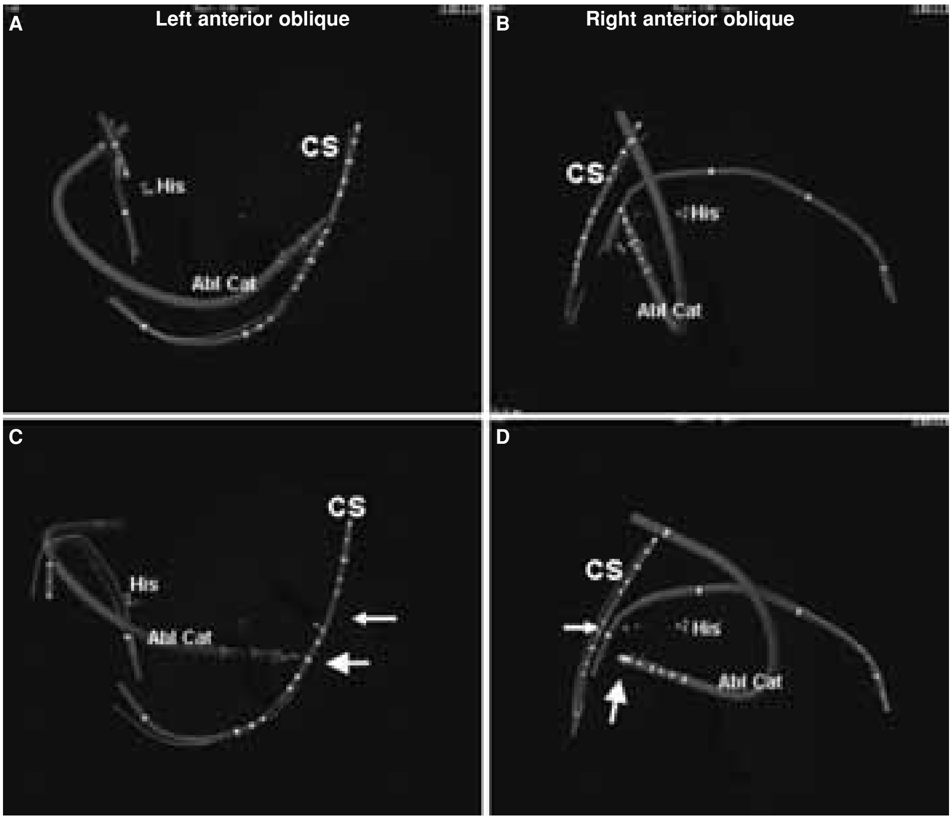

Figure 2. The orientation of the catheters during **(A, B)** unsuccessful and **(C, D)** successful radiofrequency applications in Case 3 with a left posterolateral preexcitation. The initial radiofrequency application was more lateral (narrow arrow) than the successful one (wide arrow). The success site was 5 mm posteroseptal to the first radiofrequency site. CS: Coronary sinus; Abl Cat: Ablation catheter.

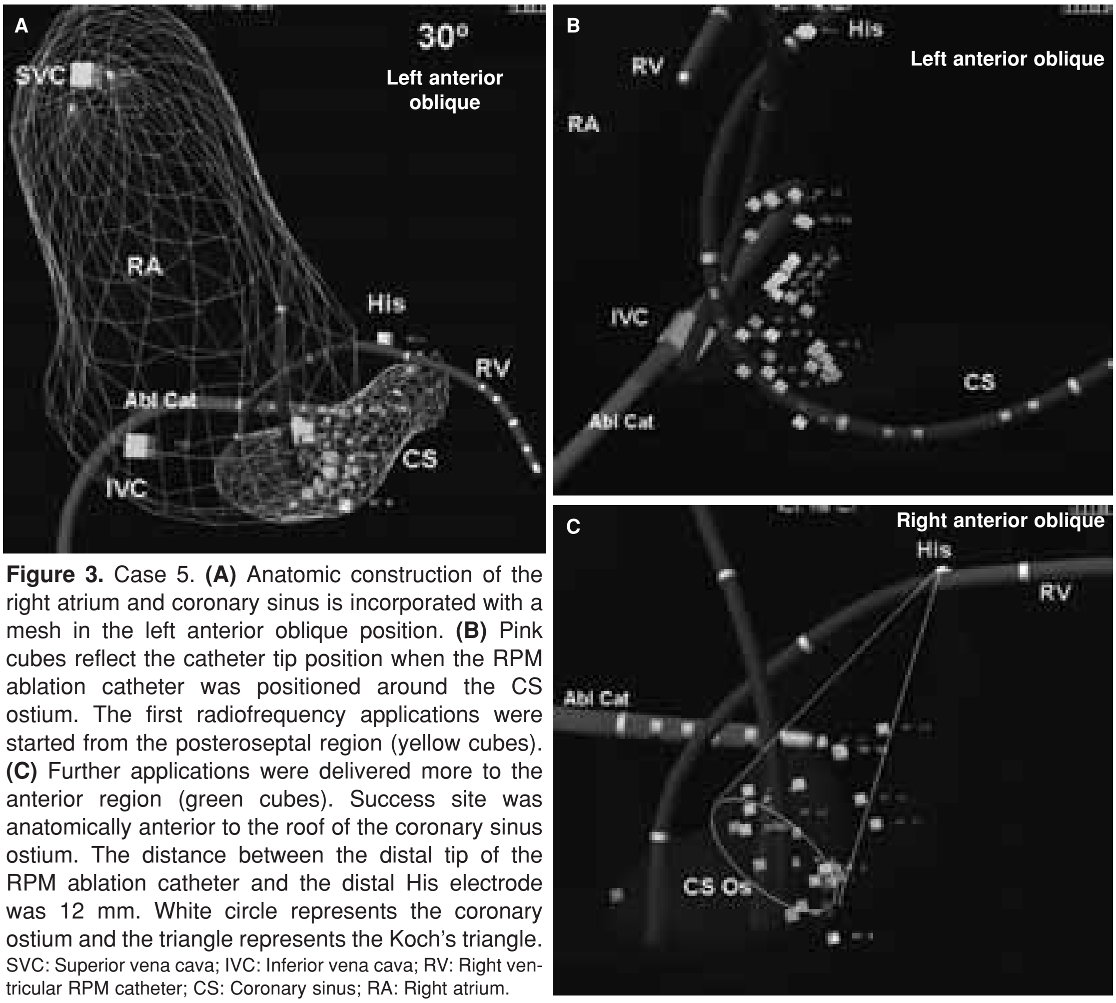

Figure 3. Case 5. **(A)** Anatomic construction of the right atrium and coronary sinus is incorporated with a mesh in the left anterior oblique position. **(B)** Pink cubes reflect the catheter tip position when the RPM ablation catheter was positioned around the CS ostium. The first radiofrequency applications were started from the posteroseptal region (yellow cubes). **(C)** Further applications were delivered more to the anterior region (green cubes). Success site was anatomically anterior to the roof of the coronary sinus ostium. The distance between the distal tip of the RPM ablation catheter and the distal His electrode was 12 mm. White circle represents the coronary ostium and the triangle represents the Koch's triangle. SVC: Superior vena cava; IVC: Inferior vena cava; RV: Right ventricular RPM catheter; CS: Coronary sinus; RA: Right atrium.

Failure of the RPM system to ablate the arrhythmia source should be described in detail to evaluate the system. In Case 1, ablation failed due to insufficient handling of the catheter for accessory pathways at the left lateral localization, mainly because of lack of experience on the part of the operator with the RPM ablation catheter in that particular localization. However, for septally localized targets, relatively stiff and long shaft increased the stability of the RPM ablation catheter and made the procedure undemanding. In case 5, successful application was due to catheter stability provided by the long sheath from the femoral vein. In case 9, no radiofrequency was delivered at all because premature ventricular contractions were not frequent enough to chase and ablate. In such cases, noncontact mapping, the EnSite NavX system (Endocardial Solutions, St. Paul, MN, USA) would be the only option, which uses three pairs of skin patches placed in orthogonal planes. A 5-kHz electrical signal is applied alternately across each pair of patches to create a voltage gradient along the axis between them. Three-dimensional position of each catheter electrode can be calculated using the sensed voltages on all three axes. By moving any of the catheters to trace the endocardial contors of the chamber of interest, a three-dimensional model of the geometry of that chamber can be reconstructed. Ablation sites can be marked either as projections on the reconstructed endocardium or as independent three-dimensional spheres. The non-contact mapping technology is based on a multielectrode array which consists of an 8-ml ellipsoid balloon surrounded by a braid of 64 electrically insulated wires, each with a small break in insulation, leading to unipolar electrodes. The far-field electrograms detected by the array are enhanced and resolved mathematically. An inverse solution to the Laplace's equation and the boundary element method predict a signal at a remote point. Thus,

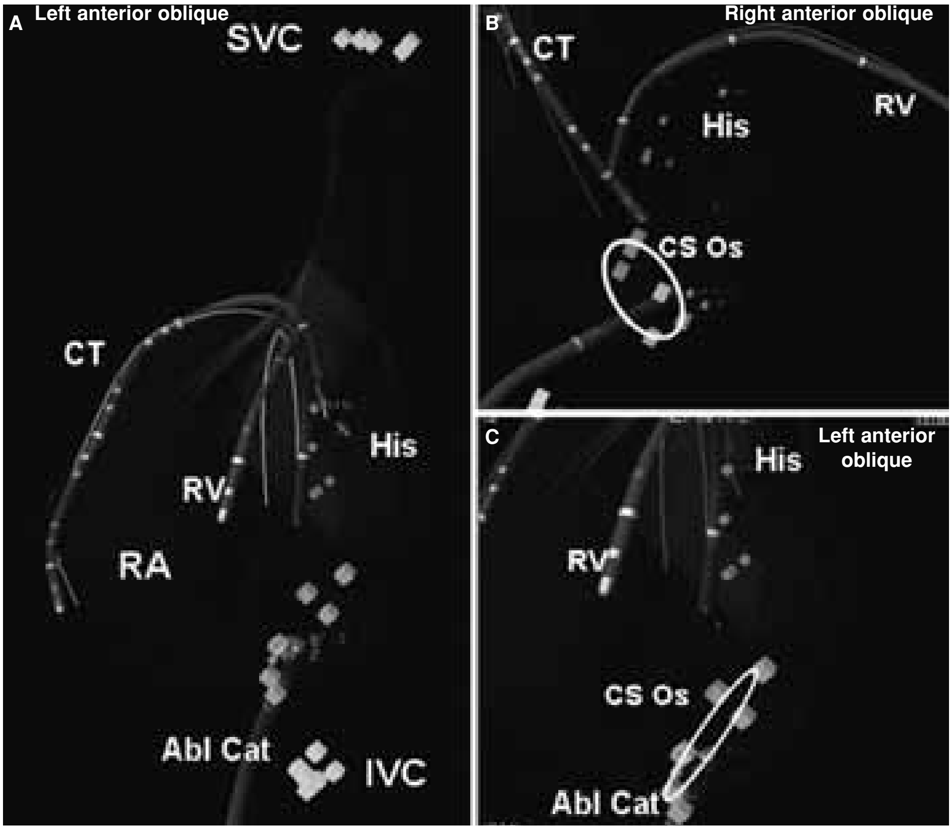

Figure 4. (A) A left anterior oblique view showing the position of the catheters and their relation to other cardiac structures in Case 6 with a right posteroseptal accessory pathway. The anatomy of the right atrium was constructed. The RPM coronary sinus (CS) reference catheter was placed through the crista terminalis (CT) via the right femoral vein. The RPM ablation catheter was at the postreoseptal region. Orange cubes position the distal electrode of the roving catheter when the catheter is at the CS orifice and the white ring represents the CS ostium (CS Os). His is marked with pink cubes. Successful ablation site (RF 3) is presented in **(B)** right and **(C)** left anterior oblique views. SVC: Superior vena cava; IVC: Inferior vena cava; RV: Right ventricular RPM catheter; RA: Right atrium.

only one target beat will be enough to map once it is recorded. In brief, the CARTO system uses electromagnetic real-time technology to determine the location and orientation of a 7-F steerable catheter. By the induction of a low magnetic field (1026-1025 T) and by the use of a reference catheter placed on the patient's back, a precise catheter tip location can be determined.

Activation mapping depends on the isochrones and point map of the earliest activation signal from the reference point. This partly depends on the operator, since synchronization to the activation potential is not uniformly accurate and requires manual editing. The RPM system allows the operator to handle manual editing for fine-tuning and localize the discrete point. In case 10, the origin of premature ventricular contraction was close to the His region and partial success of the procedure was inherent to the arrhythmia origin itself. This was the only case in which the effectiveness of activation mapping was demonstrated. In such a case, only cryoablation would be useful, since it provides cryomapping before applying permanent cryoablation. The electrophysiologic effects of cryoapplication at -30 °C or above for brief periods are completely reversible once cryoapplication is halted and the tissue is allowed to rewarm. Failure of ablation in cases 9 and 10 cannot solely be attributed to the RPM system as in cases 1 and 4, in which the features of the RPM catheter were the main reason for ablation failure. Thus, the actual rate of failure of the RPM system was 20%.

The RPM system also indicates the catheter position during mapping and allows catheter manipulation. The images of the catheter position at any time as a ghost catheter makes it easy to orient the catheters to a previous position. Additionally, anatomic construction, activation,

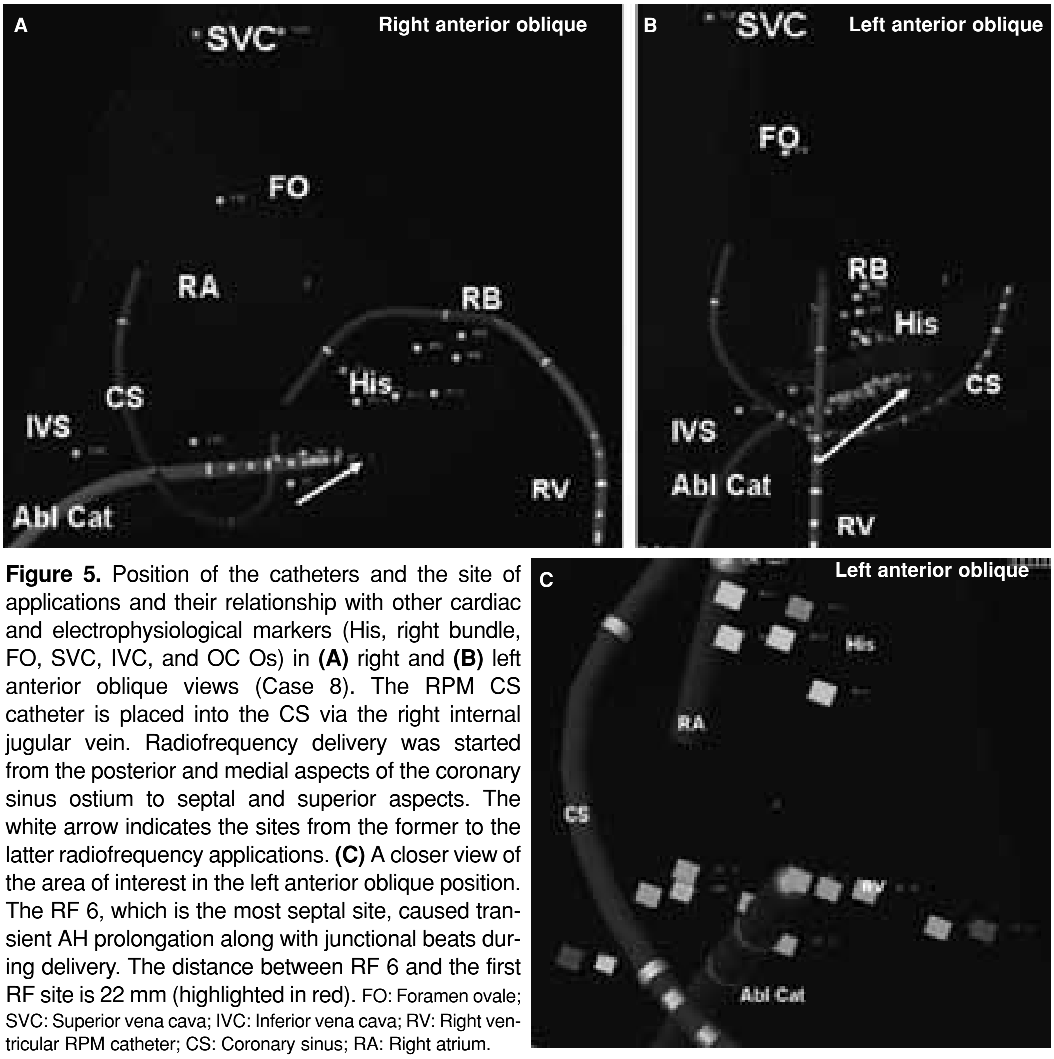

Figure 5. Position of the catheters and the site of applications and their relationship with other cardiac and electrophysiological markers (His, right bundle, FO, SVC, IVC, and OC Os) in **(A)** right and **(B)** left anterior oblique views (Case 8). The RPM CS catheter is placed into the CS via the right internal jugular vein. Radiofrequency delivery was started from the posterior and medial aspects of the coronary sinus ostium to septal and superior aspects. The white arrow indicates the sites from the former to the latter radiofrequency applications. **(C)** A closer view of the area of interest in the left anterior oblique position. The RF 6, which is the most septal site, caused transient AH prolongation along with junctional beats during delivery. The distance between RF 6 and the first RF site is 22 mm (highlighted in red). FO: Foramen ovale; SVC: Superior vena cava; IVC: Inferior vena cava; RV: Right ventricular RPM catheter; CS: Coronary sinus; RA: Right atrium.

and voltage mapping can be performed simultaneously.

The catheters in the RPM system can be reused to reduce the cost of the procedure within the limitations of hospital policy, medical ethics, patients' consent, and legitimacy. The lumen-free EP catheters were reused in the USA until 2000, and are currently used in developing countries, but this practice has aroused controversy regarding virion infections.

The RPM system significantly reduces the fluoroscopic time as with other electroanatomic mapping systems.[5] However, it was not short in our patients because concentration was given on the system rather than making efforts to reduce fluoroscopy time, and because the patients represented the first cases in the learning curve. A similar learning curve with the RPM system has been described in atrial flutter ablation, with a reduction in fluoroscopic exposure in time.[5]

Being only a presentation of our initial experience with the RPM system, this study does not reflect the effectiveness of the activation and voltage mapping. Further procedures with the RPM system in patients with atrial fibrillation, incisional arrhythmias, and complex re-entrant tachycardias are needed for a more comprehensive evaluation of the activation and voltage mapping characteristics of the system. Prospective randomized studies will allow to define the effectiveness of the RPM mapping system not only for tachycardias, but also for the ablation of complex arrhythmias. A recent study by Zeppenfeld et al.[6] demonstrated the feasibility of the RPM mapping system in substrate ablation of left ventricular ischemic tachycardias.

In conclusion, the RPM system has merits and demerits. Among its advantages are *(i)* incorporation of activation times to the anatomic model to provide electroanatomic mapping along with volt-

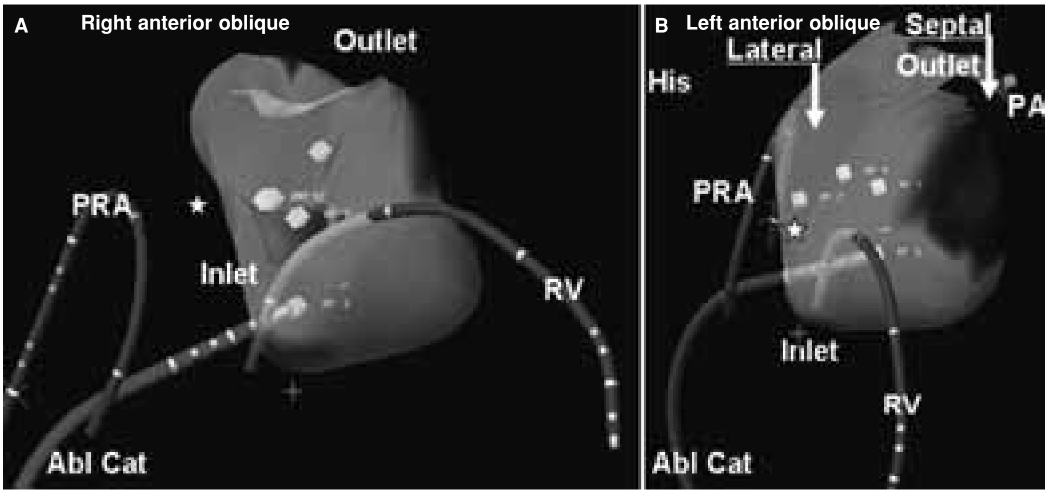

Figure 6. Isochrone activation mapping draws the sequence of activation within the RVOT with the red color showing the earliest and violet the latest activation in **(A)** right and **(B)** left anterior oblique views (Case 10). Red star indicates the first ventricular activation in the inlet of RV around the His region. Another relatively early site is also detected above the His (white star) in the inlet of RV. Application of RF3 caused right bundle branch block which actually abolished frequent premature beats. PRA: Posterior right atrium.

age mapping; *(ii)* real-time display of all catheters and storage of the positions; *(iii)* easy catheter repositioning in case the reference catheter is displaced; *(iv)* minimal influence of the body, cardiac, or respiratory motion on the reference field; *(v)* better stiffness of the catheter shaft for ablation of slow pathways and septal accessory pathways. Its disadvantages include *(i)* the need for at least three predefined catheters for each electrophysiological study, *(ii)* few catheter options for ablation, and *(iii)* a relatively stiff distal part and relatively limited steerability of the ablation catheter for left lateral accessory pathways. A significant learning curve exists and our initial experience with this new mapping system is fairly satisfactory. Its effectiveness needs to be evaluated in a wide range of patients.

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