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Contact and Non-Contact Electroanatomic Mapping in Electrophysiology

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ABSTRACT

This brief review focuses on the two available electro-anatomical mapping systems, currently employed for guiding catheter ablation of diverse cardiac arrhythmias, representing two distinct non-fluoroscopic, contact and non-contact, approaches which offer 3D re-conctruction of electroanatomic maps by tracking intracardiac catheters. Mapping systems are now being merged with images from computed tomography or magnetic resonance imaging to produce an accurate anatomic and electrical map of the heart to guide catheter ablation procedures.

INTRODUCTION

During the last decades interventional electrophysiologists achieved remarkable advances in the diagnosis and treatment of cardiac arrhythmias. Single catheter endocardial recordings enabled us to obtain further insight into the pathophysiological mechanisms underlying most of the common arrhythmias. Endocardial electrograms combined with the valuable information derived from the surface electrocardiogram have been proved able not only to delineate diagnosis but also to guide interventional treatment. Radiofrequency catheter ablation procedures altered entirely the management and clinical course of the majority of clinical arrhythmias providing the possibility of definitive therapy and cure with acceptable cost-effectiveness and complication risks.

However, despite these advances, there have been challenges for interventional electrophysiologists that tempered their enthusiasm and limited their ability to provide effective treatment. Some of the cases where experienced operators and existing technology often failed to provide safe and effective treatment are:

- Complex arrhythmias, e.g. ventricular tachycardias in the setting of ischemic cardiomyopathy and multiple myocardial areas of fixed or physiologic block
- Deformed anatomy due to congenital or acquired anomalies
- History of complicated cardiac surgery procedures including cardiac transplantation.

From the early days of invasive electrophysiology the aforementioned considerations had addressed the issue of developing three-dimensional electroanatomic mapping systems. Improved understanding and localization of arrhythmias, accurate definition of cardiac anatomy that vary significantly among patients and visualization of the ablation catheter in the three-dimensional electroanatomic model represent the fundamental features that electrophysiologists would expect from such a mapping system. In addition, the reconstructed anatomical and activation sequence models should be adequately presented to the physicians. Saying that, we should remember that physicians are trained to think and act in two dimensions. Even experienced electrophysiologists tend to work in multiple two-dimensional levels rather that working in the real three-dimensional heart. Thus, exploitation of information presented in the three-dimensions is an additional challenge that electrophysiologists face especially when they begin to work with three-dimensional electroanatomic systems.

THE TWO MAPPING SYSTEMS

A number of software tools, like the clipping tool of the CARTO EP Contact Navigation System (Biosense Webster, Inc., Diamond Bar, CA) and the transparency tool of the ENSITE Non-contact Mapping system (Endocardial Solutions, Inc, Minnesota, MN, U.S.A.) have been developed aiming to facilitate the ability of the system users to understand the living anatomy of the heart providing internal (endoscopic) and external views of the chamber in question including the relative position of the catheter. These two mapping systems are not the only electroanatomic systems that have been developed. However, this brief review will focus on these two systems not only because at the moment they are widely available, but mainly because they represent two distinct approaches, which are the contact and the non-contact technique of electroanatomic mapping.

The first step of working with three-dimensional electroanatomic systems is to create an accurate anatomical model. The creation of the anatomic model of a cardiac chamber is heavily operator-depended, meaning that improper selection of points by the operators may result in an untrustworthy model. Misleading anatomy often results in diagnostic pitfalls by omitting crucial parts of the arrhythmia circuit or the arrhythmia foci. A minimum of 50 points are needed by both contact (Carto) and non-contact (Ensite) three-dimensional electroanatomic systems to create the anatomy of a chamber of the heart, but 100 points are usually appropriate. Although technologically advanced, the three-dimensional electroanatomic systems are obviously limited by the data (points where the catheter has been positioned) that operators provide. Consequently, if the operators fail to position the catheter in the correct anatomical areas the whole procedure is often jeopardized. Moreover, the accuracy of the three-dimensional anatomy can be compromised by uncontrolled factors such as the extreme breathing movements, tension of the mapping catheter towards the myocardial wall and movement of the reference catheter.

At the current stage of evolution, the electroanatomic systems are as good as the operators can be and although fascinating, the three-dimensional electroanatomic models are only stereoscopic computer-based reconstructions of the information that has been provided to the systems by the operators. Furthermore, there are many factors that in practice make the whole procedure of creating an anatomical model more demanding that is generally believed. These factors include the catheter-induced stretching of the myocardial wall, uncontrolled breathing movements, displacement of the reference catheter or the catheter mesh (Ensite), small but electrophysiologically important unmapped anatomical structures and over-interpolation between points acquired from complex structures, which often result in a smooth but inaccurate electroanatomic model.

INCORPORATION OF THREE-DIMENSIONAL ANATOMY INTO THE ELECTROANATOMIC MODELS

In an effort to make the electroanatomic models more accurate and less operator-dependent, the industry has developed software capable to achieve registration of electroanatomic mapping details onto the exact surface of the computed tomography (CT) or magnetic resonance (MR) anatomy. The CartoMerge system, developed for the Carto XP contact-mapping platform is already commercially available in Europe, while the EnSite Verismo, which has been developed for the noncontact-mapping Ensite platform is commercially available only in the U.S.A. Although the advantages of such a holistic eletroanatomic approach are of profound importance, especially in complex cases, the advantages of these systems remains to be proved in clinical practice. In addition, both CartoMerge and EnSite Verismo demand CT or MR images of superior detail and quality. In the real world this means that the use of these systems result in even more increased cost and limited availability of the recently developed advanced electroanatomic technologies. Furthermore, the huge amount of data that result from the processing of the anatomy images and from the registration of the mapping details on the true anatomy surface may slow down the procedure. Due to compatibility issues the computing power of the electroanatomic systems are not expected to follow the remarkable advances in computing power that have been widely available to personal computer users. In addition, the manufacturers tend to prefer the Wintel platform in their latest releases of software and hardware. This choice has obvious benefits regarding costs and compatibility, but it also has worrying downsides regarding mostly the stability of the working software. To our experience, the previous versions of Ensite, which were not based on Intel processors, were more stable but less flexible especially with regard to compatibility with other pieces of hardware. Similarly, the Carto XP software has the virtue of Windows-based simplicity and thus, the users find it extremely friendly and easy to handle. However, although the next editions are expected to be improved, the software tends to react really slowly in demanding situations.

The majority of ablation procedures preformed during the last decade concerned ablation of atrioventricular nodal reentry tachycardias (AVNRT) and accessory pathway-mediated tachycardias. In these arrhythmias, the potential contribution of electroanatomic mapping can be considered limited. Thus, based on current cost-effectiveness criteria, it is doubtful whether advanced electroanatomic mapping could significantly improve the outcome of these procedures. However, the use of shadow catheters, a valuable tool of the NavX system which allows to mark the relative position of the catheter in all places where the His endocardial electrogram can be recorded, can increase the safety of AVNRT ablation by eliminating the possibility of complete atrioventricular block. Notably, this complication still hampers the enthusiasm of electrophysiologiststs when ablating this relatively benign and easy to treat arrhythmia. Furthermore, the ChronoCath tool permits review of earliest activation on all catheters by providing color-coded timing information on the contact electrodes. This tool may facilitate the localization of the earliest activation sequence in cases of complex Wolff-Parkinson-White (WPW) cases, including existence of multiple pathways and/or of deformed anatomy. Similarly, both the Carto and the Ensite system have been proved to be quite useful to guide ablation in complex cases.

Among others, Dr Gurevitz and coworkers have shown that use of electroanatomic systems in 68 patients after failure of conventional ablation resulted in successful ablation in 79% of the cases. Surely, reduced cost and increased availability are expected to increase the clinical value of advanced electroanatomic mapping in the aforementioned arrhythmias whereby the use of these systems is limited today.

COMPARISON BETWEEN CONTACT AND NON-CONTACT ELECTROANATOMIC MAPPING

Electroanatomic mapping has been proved to be quite useful in arrhythmias of complex pathophysiological substrate and in poorly tolerated arrhythmias. The paradigm of complex and dynamic pathophysiological substrate is of course the case of ventricular tachyarrhythmias in patients with ischemic cardiomyopathy. Although, both contact and non-contact electroanatomic mapping can be used to facilitate ablation of ventricular tachycardias, the non-contact mapping has the potential advantage to be applicable in cases where the arrhythmia cannot be tolerated or in cases where the clinical arrhythmia is not reproducible during the electrophysiology study (Table 1, Fig. 1-2). Finally, the dynamic changes of the arrhythmogenic substrate induced by radiofrequency ablation can be continuously evaluated by the operator. This advantage is of clinical importance, given the unexpected changes of the complex arrhythmogenic substrate, which may occur during the ablation of ventricular tachycardias, especially in the setting of ischemic cardiomyopathy. In this setting, it is not uncommon that different forms of ventricular arrhythmias may appear after the clinical arrhythmia has been successfully

TABLE 1. Current applications of electro-anatomical mapping systems

Cardiac arrhythmia	Mapping system
AVNRT	not necessary / ?NavX system
AP-related	not necessary/ ? NavX system
Atrial tachycardia	contact/non-contact mapping
Nonsustained	non-contact mapping
Atrial flutter	contact/non-contact mapping
Atrial fibrillation	contact mapping
Ventricular tachycardia	contact/non-contact mapping
RVOT VT/ LIVT	not necessary/only for difficult cases (nonsustained/ induced with difficulty or erratically)
CAD/DCM	contact/non-contact mapping
Nonsustained/unstable	non-contact mapping
Sustained/stable	contact/non-contact mapping

AP= accessory pathway; AVNRT= atrioventricuar nodal reentry tachycardia; CAD= coronary artery disease; DCM= dilated cardiomyopathy; LIVT= left idiopathic ventricular tachycardia; RVOT= right ventricular outflow tract; VT= ventricular tachycardia

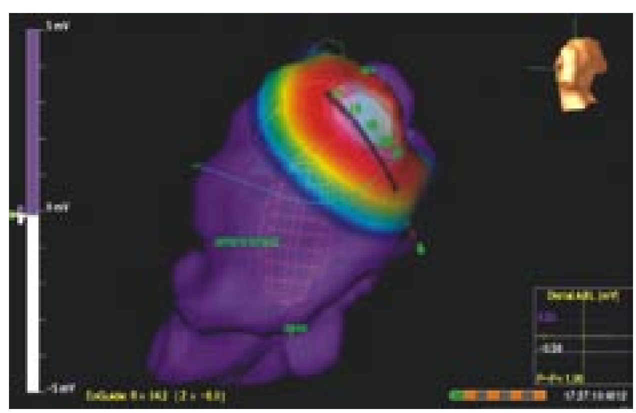

FIGURE 1. Identification of a slowly conducting area at the posterolateral wall of the left ventricle, which represented a critical isthmus site of the arrhythmia. Following application of radiofrequency ablation at the predefined area (black line), the leading edge of depolarization failed to penetrate the slowly conducting zone and the clinical arrhythmia was no longer inducible. The patient suffered from repetitive episodes of sustained monomorphic ventricular tachycardia (110 to 130 bpm) despite optimal drug treatment. The electroanatomic mapping was performed using the noncontact method (ENSITE, Endocardial Solutions, Inc), which allowed monitoring of the dynamic changes of the electrophysiological substrate throughout the procedure.

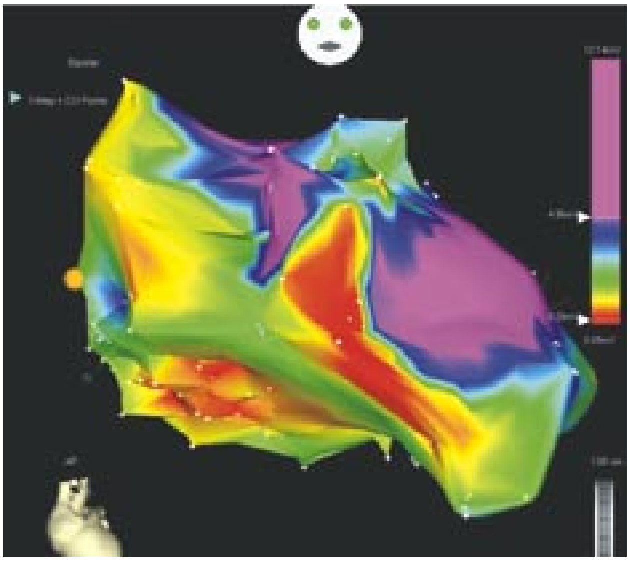

FIGURE 2. Three-dimensional electroanatomic voltage map of the left ventricle of a patient suffering from sustained monomorphic idiopathic ventricular tachycardia, conducted using contact electroanatomic mapping (CARTO, Biosense Webster, Inc.). The voltage map, presented here, clearly shows the septal and anteroseptal areas of the left ventricle, where the radiofrequency lesions had been delivered during the previous ablation session (red colored areas at the map).

ablated. Continuous monitoring of the virtual electrograms and of the propagation map, afforded by the non-contact mapping during sinus rhythm and during ventricular arrhythmias, may help the operators to effectively create a curative strategy. Conversely, in the case of contact electroanatomic mapping, a complete remapping should be performed after the relapse of an arrhythmia because the previous electroanatomic map is no longer valid if radiofrequency ablation lesions had been applied. This is time consuming and in some cases it can be proved simply not feasible. Mapping only the area of interest can be another strategy, but frankly, defining the area of interest can be misleading. On the other hand, based on existing technology, the Ensite balloon catheter is expensive and occupies a large space in the cavity of interest. In particular it is consisted of a 64-electrode mesh, mounted on the outside surface of a 18 × 40 mm balloon. After appropriate positioning in the cavity of interest, this balloon should not be moved, thereafter. The balloon itself often represents an obstacle to the manipulation of the ablation catheter. These practical difficulties are augmented in the case of small cavities like the left ventricle in the case of ventricular hypertrophy and like the right ventricular outflow tract. For the same reasons, non-contact mapping has been underused for the ablation of atrial fibrillation. Manipulation of the ablation catheter around the pulmonary veins can be more easily and accurately performed using contact mapping techniques and that explains why the Carto and the NavX contact mapping systems are mainly used to accomplish circumferential pulmonary veins isolation.

Future directions

The currently available electroanatomic mapping systems should not be considered as expensive fancy toys in the hands of electrophysiologists. They have already drastically changed treatment of certain arrhythmias, like ventricular tachycardias, atrial fibrillation and complex supraventricular tachycardias. However, the available state-of-the-art mapping systems provide only a glimpse in the rapidly evolving field of electrophysiology. Indeed, single catheter endocardial recordings provided the fundamental knowledge to understand the pathophysiology of arrhythmogenesis. However, only advanced electroanatomic mapping may enable us to obtain further insight into the pathophysiology of complex arrhythmias, and most importantly to effectively and safely cure these arrhythmias, incorporating electrical mapping into the living, individualized anatomy of our patients.

The recently developed Niobe system (Niobe, Stereotaxis, Inc) is a magnetic navigation system that allows remote-controlled navigation of an ablation catheter. In conjunction with a motor drive unit, this system was recently used successfully to perform completely remote-controlled mapping and ablation in patients with AVNRT. This system, in combination with capabilities afforded by the latest three-dimensional anatomy-based electroanatomic mapping may give us a vague idea of the advances we are entitled to expect in the early future. Apart from their current capabilities to improve our practice in the electrophysiology laboratory, working with electroanatomic mapping should be also considered as a necessary step in the process of familiarization with the rapidly evolving field of cardiac electrophysiology. In this context, three-dimension electroanatomic mapping is indeed indispensable.

REFERENCES

1. Jackman W, Friday K, Scherlag B, et al. Direct endocardial recording from an accessory atrioventricular pathway: Localization of the site of block, effect of antiarrhythmic drugs, and attempt at nonsurgical ablation. *Circulation* 1983; 68:906.
2. Wellens H, Durrer D, Lie K. Observation on mechanism of ventricular tachycardia in man. *Circulation* 1976; 54:237.
3. Josephson M, Horowitz L, Spielman S, et al. Comparison of endocardial catheter mapping with intra-operative mapping of ventricular tachycardia. *Circulation* 1980; 61:395-404.
4. Cooke PA, Wilbur DJ. Radiofrequency catheter ablation of atrioventricular nodal reentry tachycardia utilizing nonfluoroscopic electroanatomical mapping. *Pacing Clin Electrophysiol* 1998; 21:1802-9.
5. Biosense Webster, Inc. What is a CARTO EP navigation procedure? 2000a. Accessed May 13, 2005. Available at URL ad-

dress: Http://www.Jnjgateway.Com/home.Jhtml?Page=viewcontent&contentid=edea000100010430&loc=useng.
6. Schilling RJ, et al. A non contact catheter for simultaneous endocardial mapping in the human left ventricle: Comparison of contact and reconstructed electrograms during sinus rhythm. *Circulation* 1998; 98: 887-898.
7. Schilling R, Peters N, Davies D: Feasibility of a noncontact catheter for endocardial mapping of human ventricular tachycardias. *Circulation* 1999; 99:2543-2552.
8. Sporton S, Earley M, Nathan A, Schilling R. Electroanatomic versus fluoroscopic mapping for catheter ablation procedures: a prospective randomized study. *J Cardiovasc Electrophysiol* 2004; 15:310-315.
9. Packer DL. Three-dimensional mapping in interventional electrophysiology: techniques and technology. *J Cardiovasc Electrophysiol* 2005; 16:1110-1116.
10. Gurevitz O, Glikson M, Asirvatham S, et al. Use of advanced mapping systems to guide ablation in complex cases. *PACE* 2005; 28:316-323.
11. Lai LP, Lin JL, Lin JM, et al. Use of double-potential barrier to identify functional isthmus at the cavotricuspid isthmus for facilitating catheter ablation of isthmus-dependent atrial flutter. *J Cardiovasc Electrophysiol* 2004; 15:396-401.
12. Verma A, Marrouche N, Schweikert R, et al. Relationship between successful ablation sites and the scar border zone defined by substrate mapping for ventricular tachycardia post-myocardial infarction. *J Cardiovasc Electrophysiol* 2005; 16: 465-471.
13. Ernst S, Ouyang F, Linder C, et al. Initial experience with remote catheter ablation using a novel magnetic navigation system magnetic remote catheter ablation. *Circulation* 2004; 109:1472-1475.
14. Ector J, De Buck S, Adams J, Dymarkowski S, Bogaert J, Maes F, Heidbuchel H. Cardiac three-dimensional magnetic resonance imaging and fluoroscopy merging: a new approach for electroanatomic mapping to assist catheter ablation. *Circulation* 2005; 112:3769-76
15. Friedman PA. Novel mapping techniques for cardiac electrophysiology. *Heart* 2002; 87:575-582.