

REVIEW

Contact and Noncontact Mapping Systems in the Electrophysiology Laboratory

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ABSTRACT

The most important step for the operator to perform a successful radiofrequency ablation procedure for the treatment of cardiac tachyarrhythmias is to accurately identify the origin of and localize the arrhythmia focus and to determine the sequence of electrical activity. Intracardiac mapping techniques came a long distance from single catheter recordings to three dimensional voltage and morphology reconstructing systems. The aim of this review is to summarize the benefits and disadvantages of the existing cardiac mapping systems.

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INTRODUCTION

The most important step for the operator to perform a successful radiofrequency ablation procedure for the treatment of cardiac tachyarrhythmias is to accurately identify the origin of and localize the arrhythmia focus and to determine the sequence of electrical activity. Electrophysiology mapping, which started more than 40 years ago with single-channel recordings with a single catheter, has been transformed into a system in which multiple channels and multiple catheters are employed to make synchronous recordings possible in various anatomical regions of the heart and therefore can now provide more detailed information. Despite the synchronous recording, the fact that anatomical regions cannot be clearly distinguished in the two-dimensional fluoroscopic imaging has made the transition obligatory to systems in which the recordings combined together with the computer program and the activation sequence of the heart are given accurately along with three-dimensional mapping.¹ Furthermore, although the use of a large number of endocardial catheters is beneficial in diagnosis and treatment of many tachyarrhythmias, the regions that recordings are taken and neighborhoods of ablation target points may not be clearly localized visually in various fluoroscopic projections. As the use of fluoroscopy in complex tachyarrhythmias is extended, and exposure to ionizing radiation is prolonged, dire need has emerged to develop different mapping systems to facilitate these procedures.² Among these mapping systems, the multi-electrode basket catheter and electromagnetic mapping systems (CARTO), as well as the traditional endocardial catheter mapping and electroanatomic mapping systems (NavX) (developed from a different version of the initially called Localisa system) have been grouped together as the “contact” mapping systems. In this group it is essential to take electrical recordings from direct contact with the endocardial cavity or

ABBREVIATIONS

AF = atrial fibrillation
 CT = computed tomography
 MEA = multi-electrode array
 MRI = magnetic resonance imaging
 VT = ventricular tachycardia

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the epicardial surface of the heart. The “*noncontact*” mapping system (the Ensite system) is a completely different method, whereby electrogram and myocardial activation sequence is obtained by measuring the voltage difference of depolarization without any contact with the endocardium.

TRADITIONAL MAPPING

This technique is aimed to identify the activation sequence and the point of origin of the arrhythmia with reference to an electrode on the basis of circulating diagnostic catheters within the heart and recording endocardial electrical activity in different cardiac regions. It has been extensively used for diagnosis and treatment of most tachyarrhythmias for many years. Catheter placement for pacing, mapping and ablation are performed under fluoroscopy. During tachycardia, the process of detecting reentry circuits by performing cardiac pacing in certain cardiac regions is known as “entrainment”, and it is one of the basic foundations of this technique along with electrically activated sequence detection.³ The disadvantages of this system, which is the mainstay of more advanced mapping systems used today, are the exposure to ionizing radiation because of the need for fluoroscopy-guidance; the inability to distinguish two-dimensional fluoroscopic images of anatomical regions; the difficulty in assessing the position of the catheter and the irretraceable characteristic of catheter-placed location; the small number of intracardiac electrograms obtained; and its inadequacy in the presence of complex arrhythmias, or multiple arrhythmias at a time, or short-lived and/or unstable arrhythmias.⁴

THE CARTO ELECTROANATOMICAL MAPPING SYSTEM

CARTO (Biosense-Webster Inc., California, United States), defined as an electromagnetical mapping system, detects the precise locations of mapping and ablation catheters in three-dimensional environment by using the principles of electromagnetic field.⁵ Intracardiac electrograms are obtained from a large number of catheters in the cavities of the heart, as well as reference catheters. The system presents a three-dimensional map of certain heart cavities and calculation of the differences between the duration of regional activation and reference activation could be used to obtain color-coded electrophysiological information.⁶ In a simpler way, the system can be summarized as a magnetic emitter device which is placed on the table under the patient in supine position. This device is equipped with three spirals which create ultra-low magnetic field. The reference catheter is, on the other hand, a 7F directed catheter (NAVI-STAR) which has a magnetic sensor and a radiofrequency emitting thermocouple located

on the tip. Three-dimensional placement of the catheter in the cavity of the heart is calculated by the processing program with the aid of information sent by the tip sensor, as it moves, about the distance from magnetic field sources. It accurately detects the magnetic field of the catheter, then sends the data of the location (x, y, and z axis) and orientation (yaw, pitch and roll movements).⁵ Thanks to the intracardiac electrograms from the points that the distal end of the catheter is in contact with, the localization on three-dimensional mapping is finalized through detection of activation duration and color coding. Red color-coded regions indicate the earliest activation; blue and purple latest activation; further, yellow and green indicates the intermediate activation. Although activation artifacts resulting from rapid cardiac stimulation and movement during the tachyarrhythmia could be partially solved by placing the catheter on a relatively constant anatomical region, for changing the position of the patient or respiratory-related artifacts, an additional anatomical reference point has to be used. This reference could be obtained by placing a sensor carrying catheter inserted into the coronary sinus or the right ventricular apex, or an outside patch (REF-STAR, QwikPATCH) could also be used.

Electromagnetical system mapping of atrial flutter has increased procedural success and reduced radiation exposure;^{7,8} similarly, the system has led to increased rate of successful ablation in patients with atrial tachycardia.⁹⁻¹¹ Especially in cases with atypical atrial flutter in congenital heart disease, despite atrial dilatation and complex anatomical structures, clear mapping of insulation barrier limiting tachyarrhythmia circuit has been reported to facilitate the isthmus block.¹² Use of the system for ablation of accessory pathways and atrioventricular reentry has also shown success comparable to traditional methods.^{13,14} Case reports showing the successful use of the system for ventricular arrhythmia ablation are also available. Also, the system has been successfully used in idiopathic left ventricular tachycardia and right ventricular outflow tract tachycardia;¹⁵ it has also been an effective method in patients after surgery for congenital heart disease, and also for ventricular tachycardia ablation.¹⁶ In the treatment of arrhythmias originating from the left and right ventricle due to scar tissue, it was also found successful in creation of linear lesions.¹⁷

Arrhythmogenic right ventricular dysplasia, whereby the right ventricular cardiac myocytes have been replaced by fibrotic tissue or fat, is a progressive disease. In these patients, in order to reduce the risk of sudden cardiac death, the implantable cardioverter-defibrillator should be used. However, as the progressive course of the disease may lead to an increase in the number of device shocks delivered to the patient, the ablation therapy might be considered later in the process. In these patients, there are studies in which the electroanatomic CARTO mapping of the myocardial tissue that is the focus of arrhythmias is employed; mapping and ablation therapy is applied in these patients in a similar manner to the one used

for ablating scar tissue-associated ventricular tachycardia in ischemic patients.^{18, 19} Boulos et al¹⁸ showed that the region mapped with CARTO is well-matched with both the magnetic resonance imaging (MRI) and with echocardiographic evidence showing the arrhythmogenic region. CARTO is also preferred to guide ablation treatment of atrial fibrillation with encircling lesions to isolate the pulmonary veins in the left atrium.²⁰ As with other procedures, in these cases, CARTO diminishes fluoroscopy and shortens the procedure time.

Despite these advantages, there are aspects of the system that need to be further developed:

- The most important disadvantage relates to the need for sequential and point by point data acquiring during mapping; the arrhythmia circuit would be difficult to delineate in arrhythmias without continuity; this process may not be tolerated by the patient for a long time. However, thanks to mapping of low-voltage viable tissues and scar tissues, ablation can be done in sinus rhythm, thus avoiding use of techniques requiring induction of VT which may produce hemodynamic compromise.
- Only one simultaneous rhythm mapping is possible. If an arrhythmia develops during sinus rhythm mapping, all mapping needs to be done all over again from the beginning.
- Mapping takes time as it processes point by point. To solve this problem, the touch points were reduced with a later-produced 26-electrode catheter and two magnetic-sensors Qwikstar. Moreover, with the Qwikmap system, the evaluation of mapping can be done more quickly.
- As mapping and ablation is carried out with a special catheter, it confers additional costs; thus, the total cost of the procedure is increased. Also, bidirectional movement of the catheter is restricted.
- The system does not detect catheters without magnetic sensors.
- Since the mapping evaluates only one cardiac cavity, the site of early activation may not necessarily be the origin of the arrhythmia; however, tachycardia may originate in another cavity which is not included in the mapping. On the other hand, this problem exists in other mapping systems as well.

Recent technological advances gave way to inclusion of three-dimensional computed tomography (CT) and MRI images into the standard system of the CARTO electroanatomic mapping (CARTOSYNC). One step further to this, by combining these images with the CARTO maps, more precise anatomic CARTO maps can be created (CARTOMERGE). It is also possible to include data from intracardiac echocardiography (CARTOSOUND).

To summarize, CARTO has been tested in all heart cavities and for a variety of arrhythmias. CARTO is a system that reduces the need for fluoroscopy, and needs to continue to be developed due to its disadvantages mentioned above.

MAPPING WITH MULTI-ELECTRODE BASKET CATHETER

Placing the helical structure catheter which consists of basket-shaped electrodes in the heart cavity, electrograms are recorded from different locations. The collapsed catheter is introduced within a long sheath. Upon entering a cavity, the sheath is pulled back and the catheter assumes its spiral form. The most commonly used one is the 64-electrode basket catheter (Boston Scientific, California, USA). The number of studies using this method in the literature are limited. It has an advantage especially in short-lasting arrhythmias and multi focal tachycardia, as many simultaneous recordings are gathered from the given cardiac cavity.²¹ Recording just a few beats might be enough to uncover the arrhythmia circuit. In the atrial flutter ablation, it is valuable in determining the isthmus point and slow conduction point.^{22,23}

The limitations of the system are as follows:

- Myocardial contact of the basket catheter within the cavity might not be proper because it may be smaller or bigger for the cavity; and therefore it may not stay stable. Recording and evaluation of electrograms can be difficult.
- As the basket catheter is multi-electrode and therefore requires a multi-channel recording device, such devices should be available in the laboratory.
- Use of ablation and diagnostic catheters along with basket catheter in the same cardiac chamber might be difficult.
- The number of studies with human participants is quite low.
- It is difficult to use the basket catheter in structures such as the left atrial appendage, or the pulmonary veins.
- Electrode contact may be affected by cardiac contractions; as a result, the recordings can be misleading.

NONCONTACT MAPPING

The noncontact multi-electrode mapping system, EnSite 3000 (St. Jude, Minnesota, USA), uses electrograms obtained without direct contact with the endocardium. The system is composed of a 64-electrode 9F multi-electrode array (MEA) catheter mounted on a 7.5 ml balloon; the system also comprises the reference patch electrode, amplifiers and processor unit. MEA catheter filters and records intracavitary far-field potentials at a frequency of 1.2 kHz. Up to 3360 virtual unipolar electrograms are obtained simultaneously from the cavity surrounding the cardiac catheter and thus a three-dimensional map of the cavity can be constructed.²⁴⁻²⁶ The MEA catheter balloon is advanced into the heart cavity within a special sheath and inflated 50/50 percent with isotonic/contrast material. Then, mapping is completed with the construction of a three-dimensional map, and conventional ablation and diagnostic catheters can be used around the balloon. The MEA catheter

determines the location catheters around by spreading low frequency signal of 5.68 kHz. The catheter's sensitivity of determining location of surrounding catheters in 35 mm range is quite high, however sensitivity decreases with distance of 40 mm and above.²⁷⁻²⁹ By scanning the cavity, the system gets 1200 measurement data per second from 3360 electrograms. Therefore, the whole activation map of the cavity could be constructed with a single beat. Thanks to this feature, it could be preferred in arrhythmias associated with hemodynamic compromise, short-lasting arrhythmias or in arrhythmias which are hard to re-induce. As it maps the whole cavity, it could provide invaluable data in situations with more than one arrhythmia, or situations with more than one arrhythmogenic foci and reentry circuits.

EnSite had been tried in ischemic VT ablation, and has been proven useful and successful at all stages from detection of arrhythmogenic foci to guiding ablation.³⁰ When the MEA catheter is inserted into the left atrium, it can successfully detect arrhythmogenic foci outside the pulmonary veins.³¹ In a study,³² it was used in complicated anatomical and post-operative substrates; noncontact mapping was conducted for 11 arrhythmias in 6 patients after Fontan procedure, and linear lesions were produced. However, high recurrence rates draw some attention. In another study it was used to treat atypical right atrial flutter;³³ it was observed that during the 17-month follow-up period, in 13 of 15 patients, arrhythmia was completely eliminated.

Weak points of the system are:

- MEA catheter balloon might make manipulation of the other catheters difficult especially in the atria.³⁴
- As the sensitivity of the MEA catheter is less than 40 mm from the center, when used in dilated hearth cavities, the catheter needs to be repositioned.²⁶
- Potentials taken from remote regions are low-amplitude, and therefore they might be confused with scar tissue.
- Due to use of high-profile balloon, anticoagulation is needed, and this can lead to bleeding complications.
- As in CARTO, this system maps only one cavity and earliest activation does not necessarily mean the origin of arrhythmia. It should always be remembered that arrhythmia might originate in another cavity.

LOCALISA

The Localisa system (Medtronic, Minneapolis, USA) is a three-dimensional mapping system that allows placement of conventional catheters to the heart chambers under fluoroscopic guidance. Catheters are located and placed with the aid of three electric fields (x, y and z planes) produced by administering 30 kHz frequency and 1 mA current from three adhesive skin patch electrodes in orthogonal position. Electrical current applied on thorax passes through the internal organs,

causing voltage drop, which is recorded by the electrodes.³⁵ Thus, the position and the distance of catheters to each other can be calculated. The frequency of the current emitted from the electrodes does not interfere with electrograms; also 1 mA current is harmless to the patient and in accordance with the international safety standards. Placement of the electrodes is as follows; the first electrode is placed on the heart, the second one is placed laterally, the third and the last one are placed posterior to the heart. The posterior electrode is also used as the current collector electrode during radiofrequency ablation. The system has been reported to locate catheters with 2 mm precision.³⁶

It has been shown that the system can be used for ablation of supraventricular tachycardias and reduces exposure to ionizing radiation by 35%.³⁷ In a different study, it was compared with the traditional method in the ablation of atrial flutter.³⁸ It was also documented that mean fluoroscopy time was decreased from 16 minutes to 7 minutes. Particularly, in 9 out of 26 patients total fluoroscopy time throughout the entire procedure took less than 1 minute. This system was also used for the treatment of pulmonary vein isolation for atrial fibrillation, and there were meaningful decreases in radiofrequency application time, total procedure time, and fluoroscopy time.^{39,40,41}

The limitations of the system which needs a special catheter are as follows:

- Artifact formation due to respiration and contractions makes mapping difficult.
- Patching electrodes to areas in close proximity of the surface electrocardiogram electrodes may cause interference.
- As all cardiac formations are not homogenous, all voltage drops in electric field may not be reliable.

ENSITE NAVX

EnSiteNavX (St. Jude, Minnesota, ABD), which was based on Localisa technology, was developed and integrated with the EnSite system. Just like Localisa, it uses three electrode patches to form 3 orthogonal planes (x, y, z); 5 kHz frequency signals emitted from the electrodes form a voltage gradient between electrode pairs of the electrode. Voltage gradients from each of the three planes is calculated and combined, and then three-dimensional position of the catheters is determined. Positions of 64 electrodes and 12 conventional catheters are simultaneously determined up to 90 times per second. Mapping of the current heart chamber could be constructed by circulating one of the catheters in the endocardial cavity.⁴² With help of the information of electrode length and the distance between electrodes, contact location and electrode tip could be modeled and the distance could be calculated from the geometric model. Thanks to the filters, mapping can be continued during ablation. In addition, CT and MR images can be uploaded to the system (NavX Fusion), and automatically

combined with the voltage map.⁴³ After geometric modeling, voltage map and regional activation map can be constructed with point by point consecutive catheter touch. Extracardiac signals are used as fixed reference. Then, the program merges activation map with the geometric model.

There are studies on the use of the EnsiteNavX system in the treatment of atrial fibrillation. An Italian registry, which was recently published,⁴⁴ revealed that in patients who underwent catheter ablation for atrial fibrillation (AF) with the NavX mapping system, one and two year freedom from AF recurrence were 67.4% and 50.0%, respectively. A former study showed similar results for circumferential pulmonary vein isolation done with either Ensite/NavX or Carto mapping.⁴⁵ In another study, AF ablation procedures which were done with the NavX system were compared with the CartoMerge system.⁴⁶ Pulmonary vein isolation, linear ablation or both were used in this trial. There was no significant difference between total procedure time and clinical outcomes.

The NavX mapping system is more reliable than its predecessor LocaLisa and other systems in terms of respiratory artifacts. As in LocaLisa a fixed electrode in the heart (for example, settled into the coronary sinus) could be used as well as a special algorithm that can be useful in reducing the system artifact. In addition to this, an important advantage of the system is that it does not need a special catheter. Another important point is its ability to localize esophagus directly.

Its current limitations include:

- Patient-specific anatomical deformities and scar tissues can be deceptive if filters settings are not adjusted.
- It might be difficult to view the desired endocardial region with catheter tip. With anatomical focus “oversizing”, orientation to the region can be more comfortable with the tip of the catheter. **Table 1** presents a comparison among the mapping systems which are in general use.

CONCLUSION

As technology advances, industry comes up with newer devices, newer programs and newer mapping systems. Initial strategies, like the basket catheter, ceased to exist in relatively short time periods. As the electrophysiology community demands better technology to identify the arrhythmia focus more clearly, to be exposed to lower radiation, and to radically treat electrical disease, the industry has responded with various technological advances by developing quite versatile electro-anatomical mapping systems. These mapping systems facilitate the electrophysiologist's and ablationist's work, and render it possible to treat more complicated cases, like atrial fibrillation and ventricular tachycardia. Importantly, the available systems provide the operator with more options in deciding on the use of the most suitable system for the patient's particular type of tachycardia and arrhythmogenic substrate, which plays a major role in the pursuit of success.

TABLE 1. Comparison of General Characteristics of Electroanatomical Mapping Systems in General Use.

Parameter	CARTO	Ensite NavX	EnSite Array
Simultaneous multiple chamber rendering	+	+	-
Transparent view	-	+	+
Activation time mapping	+	+	+
Voltage mapping	+	+	+
Nonsustained tachycardia mapping	Hardly	Hardly	Best
Hemodynamically unstable tachycardia mapping	Not recommended	Not recommended	Best
Catheter tip-tissue contact visualization	++	+	+
Ablation catheter use	Specific catheter	Any	Any
Spatial accuracy (mm)	1	<1	<1
Temporal accuracy (frame)	0.1 K	1.2 K	1.2 K
Multiple catheter use	Detects only magnetic sensor catheters	Possible	Possible
Scar tissue mapping	+++	+	+
Catheter manipulation	+	+	Array catheter limits ablation catheter manipulation if cardiac cavity is not dilated

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