Original Article

Modern Electrophysiology Mapping Techniques

Raymond W. Sy[a,*], Aravinda Thiagalingam[b] and Martin K. Stiles[c]

[a] *Royal Prince Alfred Hospital, Concord Repatriation General Hospital, University of Sydney, Australia*
[b] *Westmead Hospital, University of Sydney, Australia*
[c] *Waikato Hospital and The University of Auckland, New Zealand*

Abstract: **Three-dimensional electroanatomical mapping (EAM) techniques have been developed to assist with the treatment of complex arrhythmias in the electrophysiology laboratory. The most common techniques are contact and non-contact EAM, which have been demonstrated to reduce fluoroscopic exposure and procedural duration. Accuracy has been further enhanced by the integration of these techniques with imaging modalities such as magnetic resonance imaging, computed tomography and real-time ultrasound. In addition, EAM utilising high-density surface electrocardiograms in conjunction with cardiac imaging is being explored as a non-invasive technique for mapping complex arrhythmias. This review will summarise the most recent developments in three-dimensional arrhythmia mapping.**

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Introduction

Cardiac mapping refers to the process of integrating electrocardiographic information within a spatial–temporal framework, with the aims of defining the mechanism and propagation of arrhythmias, and identifying suitable targets for curative ablation. In its broadest sense, cardiac mapping covers the use of surface electrocardiograms as well as intracardiac electrograms (EGMs).

Conventional catheter mapping, based on fluoroscopy and intracardiac EGMs, has facilitated our understanding and curative treatment of many arrhythmias including typical atrial flutter, atrioventricular reentrant tachycardia, atrioventricular nodal reentrant tachycardia and idiopathic ventricular tachycardia. However, the role of conventional mapping is more limited for tackling complex arrhythmias that lack characteristic electrocardiographic patterns and/or involve unfamiliar anatomical locations. Such complex arrhythmias include atypical atrial flutters, some focal atrial tachycardias, atrial fibrillation, most ventricular tachycardias, and arrhythmias associated with congenital heart disease.

Adjunctive three-dimensional electroanatomical mapping (EAM) techniques have been developed to assist with mapping and ablation of complex arrhythmias. These techniques have been rapidly adopted into electrophysiology laboratories and the most commonly used techniques include contact EAM using the CARTO system (Biosense Webster Inc., Diamond Bar, California, USA) and Ensite NavX system (St. Jude Medical Inc., St. Paul, Minnesota, USA), and non-contact EAM using the Ensite array system (St. Jude Medical Inc., St. Paul, Minnesota, USA). Moreover, it is now possible to integrate these techniques with imaging modalities such as magnetic resonance imaging (MRI), computed tomography (CT) and real-time ultrasound. In addition, electroanatomical mapping utilising high-density surface electrocardiograms in correlation with cardiac imaging is being explored as a non-invasive technique for mapping complex arrhythmias. This review will summarise the most recent developments in three-dimensional arrhythmia mapping.

Contact Electroanatomical Mapping

Contact EAM refers to the integration of spatial data and temporal electrical data collected by catheters in contact with either the endocardial or epicardial surface of the heart. The end result is the creation of a three-dimensional geometric map of the chamber of interest, colour-coded with relevant electrophysiological information. Typically, colour maps are used to depict electrical voltage, or electrical activation of an arrhythmia within a cardiac chamber. Cardiac mapping can also be used to catalogue and display additional information. For example, anatomical sites of interest (e.g. location at which tachycardia is terminated with catheter manipulation), critical electrical

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Abbreviations: CFAE, complex fractionated atrial electrograms; CT, computed tomography; EAM, electroanatomical mapping; ECG, electrocardiogram; ECGI, Electrocardiographic Imaging; EGM, electrogram; NICE, Non-invasive Imaging of Cardiac Electrophysiology; PPI, post-pacing interval; MRI, magnetic resonance imaging; TCL, tachycardia cycle length.

* Corresponding author at: Department of Cardiology, Royal Prince Alfred Hospital, Missenden Rd, Camperdown, NSW 2050, Australia. Tel.: +61 2 9515 8063; fax: +61 2 9550 6262.
E-mail address: raymond.sy01@gmail.com (R.W. Sy).

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data (e.g. His bundle EGM, "fractionated EGMs") and ablation sites may also be tagged. Perhaps of most importance, catheters are displayed within the geometric map allowing catheters to be manoeuvred without fluoroscopy. Although validation studies have demonstrated that contact EAM techniques may reduce fluoroscopic exposure, radiation dose and procedural duration for the mapping of many complex arrhythmias, these perceived advantages are counterbalanced by the increased cost and additional time required for preparation [1–3]. Finally, the benefits of using a contact EAM system to map complex arrhythmias are contingent upon the precise collection and accurate interpretation of data. At present, the two most commonly used contact EAM systems are the CARTO and Ensite NavX systems, each with their own advantages and limitations. An ultrasound-based mapping system (Real-time Position Management System, Boston Scientific, Natick, MA, USA) was previously marketed but is not readily available.

CARTO Electroanatomical Mapping System

The CARTO system primarily utilises an ultra-low magnetic field (5×10^{-6} to 5×10^{-5} T) to localise the position of the mapping catheter in space [4]. Magnetic fields are emitted by three separate coils in a locator pad beneath the patient. The strength of the magnetic field emitted by each coil is detected by location sensors embedded in the tip of a dedicated (NaviSTAR) mapping catheter. The distance between the catheter tip and each coil is inversely proportional to the magnetic field strength detected from that coil. Therefore, the position of the catheter tip can be triangulated in space relative to an external reference patch affixed on the patient's back (Fig. 1). There are three location sensors in the catheter tip that are positioned orthogonally to each other, thus allowing the orientation of the catheter tip to be determined in terms of roll, yaw and pitch.

The mapping catheter is moved along the surface of a chamber, simultaneously recording local electrical information and spatial data to generate a three-dimensional depiction of the chamber with electrical information colour-coded and superimposed on the anatomy. Both unipolar and bipolar EGMs can be archived for each spatial location. Movement of the patient relative to the coils is continuously monitored by the system and the operator is alerted to the need for repositioning if the system detects relative motion beyond a set threshold. Compensation for respiratory motion can be achieved by visually selecting points during the same phase of respiration or by automatically gating the collected geometric data against the respiratory cycle.

Advantages of the CARTO system include accurate representation of chamber geometry and the simultaneous collection of electrical and anatomical data. Specifically, in vivo validation studies have reported that the location of a catheter can be determined with a high degree of accuracy using the CARTO system with mean distance error <1 mm [4]. The main limitations are the requirement for the use of a dedicated proprietary mapping catheter, and until recently, the inability to record or display the location of diagnostic or reference catheters. The most recent version (CARTO-3, Biosense Webster Inc., Diamond Bar, California, USA) now allows the position of non-proprietary diagnostic catheters to be displayed. For each specific magnetic location in space, the CARTO-3 system registers the corresponding "electrical current pattern" emitted by the magnetic sensor-equipped mapping catheter. The position of conventional catheters can then be determined based on the detection of the current pattern emitted from each intracardiac electrode on the diagnostic catheter. However, it is still not possible to process electrical information from these catheters for display on the virtual geometry.

Ensite NavX Electroanatomical Mapping System

The Ensite NavX EAM system is functionally very similar to the CARTO EAM but utilises electrical fields to determine catheter location rather than magnetic sensors within the catheter tip [1]. The NavX system consists of three pairs of surface electrodes that are orientated in orthogonal axes [5]. A 5.7 kHz current is applied between each of these pairs in sequence and the potential recorded at any electrode within the field is proportional to the distance of the electrode from the patches allowing the location of electrodes to be determined in three dimensions. The principles of electrical location of catheters are fundamentally the same as an older system which is no longer commercially available (LocaLisa Intracardiac Navigation System, Medtronic Inc., Minneapolis, Minnesota, USA) [6]. When constructing an electroanatomical map, the location of all mobile electrodes (e.g. ablation catheters or mapping catheters) is defined in relation to a fixed reference electrode which is usually a catheter within the coronary sinus.

A key advantage of the NavX system is that virtually any electrode can be located using the EAM system (i.e. a specialised sensor at the catheter tip is not required) and a large number of electrodes can be located and visualised within the map simultaneously (i.e. multiple electrodes on multiple catheters). This allows the operator to determine the location of diagnostic catheters (such as circular catheters used to map pulmonary veins) at the same time as the ablation catheter. Electrical information from multiple electrodes can be displayed on the map which facilitates the rapid acquisition of many points; this may be critical for short-lived arrhythmias. Additionally the operator has access to ablation catheters from a wide variety of manufacturers and utilising a wide variety of energy sources (e.g. cryoablation catheters can be used with the NavX system). The NavX system has even been used to locate the Brockenbrough needle used for transseptal punctures [7]. The NavX system is also less sensitive to patient movement during a procedure as the catheter location is referenced to patches on the skin and to another electrode within the heart (i.e. these references will move with the patient) and not to an external sensor.

The NavX system has the disadvantage of only being able to determine the position of any electrode (i.e. *X*,