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ACVD-1109; No. of Pages 9
ARTICLE IN PRESS

Archives of Cardiovascular Disease (2018) xxx, xxx—xxx

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REVIEW

Three-dimensional mapping in the electrophysiological laboratory

Cartographie tridimensionnelle en salle de rythmologie

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Received 2 February 2018; received in revised form 25 March 2018; accepted 27 March 2018

KEYWORDS
Three-dimensional electroanatomical system;
Mapping;
Activation;
Navigation;
Ablation

Summary Investigation and catheter ablation of cardiac arrhythmias are currently still based on optimal knowledge of arrhythmia mechanisms in relation to the cardiac anatomy involved, in order to target their crucial components. Currently, most complex arrhythmias are investigated using three-dimensional electroanatomical navigation systems, because these are felt to optimally integrate both the anatomical and electrophysiological features of a given arrhythmia in a given patient. In this article, we review the technical background of available three-dimensional electroanatomical navigation systems, and their potential use in complex ablations.

MOTS CLÉS
Radio fréquence ;
Ablation ;
Cartographie ;
Système 3D ;
Arythmies

Résumé L'exploration et l'ablation des arythmies cardiaques est basée sur une connaissance optimale du mécanisme de l'arythmie en relation avec l'anatomie concernée, de manière à cibler les composants critiques de celles ci. Actuellement, la plupart des arythmies complexes sont explorées avec des systèmes de navigation électro-anatomique en 3 dimensions (3D), car ceux-ci sont censés intégrer de manière optimale les éléments à la fois anatomiques et électro-physiologiques d'une arythmie donnée chez un patient donné. Dans cet article, sont

Abbreviations: 3D, three-dimensional.

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https://doi.org/10.1016/j.acvd.2018.03.013
1875-2136/

Please cite this article in press as: Maury P, et al. Three-dimensional mapping in the electrophysiological laboratory. Arch Cardiovasc Dis (2018), https://doi.org/10.1016/j.acvd.2018.03.013

rappelés les bases techniques des système 3D actuellement disponibles et les principes de leur utilisation potentielle dans les ablations complexes.

Background and technical aspects

Regular tachycardia may be mapped in different ways. Conventional mapping uses fluoroscopy and standard electrophysiological techniques, and aims at delineating a re-entry circuit or the location of a tachycardia focus. Conventional mapping is the combination of ''activation mapping'', comparing activation on a roving catheter with a set of references catheters, and ''pace mapping'' or ''entrainment mapping''. Conventional mapping, however, requires significant fluoroscopy exposure and skill, and can be tremendously difficult in some cases. Moreover, it is impossible to ensure navigation to a predefined site or that any endocardial or epicardial area has been investigated.

Three-dimensional (3D) electroanatomical mapping systems were first proposed in the 1990s, allowing new exciting investigations of regular atrial and ventricular tachycardia, the ablation of which has increased dramatically in recent years. 3D electroanatomical navigation mapping systems can display the position of catheters in real time on a computer screen, and reconstruct the detailed 3D surface anatomy of a given cardiac chamber, while tagging this reconstructed endocardial or epicardial surface geometry—appearing as a shell in the virtual 3D space—with local electrophysiological information, such as activation time (i.e. the timing of local activation), unipolar or bipolar voltage amplitude (i.e. the presence of normal healthy tissues or scars) and the presence of fractionated complex electrocardiograms or late potentials, in case of atrial fibrillation or ventricular tachycardia.

The initial 3D electroanatomical mapping systems were: CARTO® [1—3] (Biosense Webster Inc., Irvine, CA, USA; currently Johnson & Johnson, New Brunswick, NJ, USA); RPM™ [1,2] (Cardiac Pathway, Sunnyvale, CA, USA; then Boston Scientific, Marlborough, MA, USA), based on ultrasound with dedicated catheters; LocaLisa™ [1,2,4] (Medtronic Inc., Minneapolis, MN, USA), using standard catheters, based on an electrical field; Electroview™ (Bard Electrophysiology, Lowell, MA, USA) [2], using simple electrophysiological data annotation on generic included models of cardiac chambers; and the Basket™ catheter (Boston Scientific), equipped with a very limited 3D mapping system [2]. Currently however, only three major systems are still on the market and widely used by the medical community: CARTO®, EnSite™ NavX™ (St. Jude Medical, St. Paul, MN, USA; now Abbott, Abbott Park, IL, USA) and RHYTHMIA™ (Boston Scientific), although more novel systems with special abilities have recently been commercialized (see below).

The CARTO® system

In this system, first proposed in 1996 by Biosense Webster (currently Johnson & Johnson), magnetic fields are used for electroanatomical navigation and geometry reconstruction [3]. Triangulation is performed by the system using three different ultralow magnetic fields (0.05 to 0.2 gauss; 5×10^{-5} to 5×10^{-6} Tesla), making it possible to permanently measure the distance of the catheter with regard to each of three magnetic generators located beneath the operating table, thus allowing localization of the catheter tip in space (Fig. 1; reproduced with permission from [5]). Moreover, catheter tip orientation is displayed (roll, pitch and yaw rotations in the three planes). An external reference patch is positioned on the patient's back for the detection of possible unintentional patient movements (which may render any navigation incorrect).

Dedicated manufactured catheters are needed for building maps in this system, with magnetic sensors at their tip (in the form of three miniaturized coils). Current versions of the CARTO® system also include the possibility to visualize other non-dedicated catheters (non-magnetic), using impedance-based navigation with six skin patches, similar to the NavX™ system (see below), although without the possibility to use them for building geometry or tagging local information on maps. Moreover, hybrid localization of magnetic catheters (using both magnetic and impedance monitoring) is currently used to correct the bias of each technology. In this system, the intracardiac catheter is optional, and only serves as a reference for timing, when needed, but is not mandatory for geometry certification.

As with other systems, the 3D geometry of the whole cardiac chamber is then reconstructed by dragging the catheter along the endocardial/epicardial surface, with or without collection of electrical information at each site. Activation times at each recorded point of the map are compared with a reference time (intracardiac on the reference catheter or surface electrocardiogram), and are then colour coded from the beginning to the end of a predefined ''window of interest'' (from red to violet, through yellow, green and blue), so revealing the circuit of re-entry or focal sources of activation. The maximal amplitude of the potentials inside the window of interest serve for building voltage maps (see below). Examples are shown in Fig. 2.

Again, as with other systems, there is the possibility to merge computed tomography scans or magnetic resonance imaging 3D reconstructions of the segmented cardiac chamber of interest with the map created with the mapping