Frontiers in Noninvasive Cardiac Mapping

Rotors in Atrial Fibrillation-Body Surface Frequency-Phase Mapping

Felipe Atienza, MD[a], Andreu M. Climent, PhD[a], María S. Guillem, PhD[b], Omer Berenfeld, PhD, FHRS[c,*]

KEYWORDS

• Atrial fibrillation • Body surface mapping • Rotors • Dominant frequency • Fourier transform • Phase mapping

KEY POINTS

- Atrial fibrillation (AF) maintenance in experiments and certain groups of patients depends on localized reentrant sources with fibrillatory conduction to the remainder of the atria.
- AF can be eliminated by directly ablating AF-driving sources or "rotors" that exhibit high-frequency, periodic activity.
- The RADAR-AF randomized clinical trial demonstrated that in paroxysmal AF patients, selective ablation of highest frequency sites responsible for AF maintenance is as effective as circumferential pulmonary vein isolation, and decreased ablation risks.
- Body surface potential map (BSPM) dominant frequency estimation allows the global identification of high-frequency sources driving AF before and during the electrophysiology laboratory procedure for ablation.
- Phase maps of highest dominant frequency–filtered BSPM recordings allow prior and real-time noninvasive localization of atrial reentries during AF, enabling further physiologically based rationale for personalized AF ablation procedures.

Videos of rotor trajectories accompany this article at http://www.cardiacep.theclinics.com/

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[a] Cardiology Department, Hospital General Universitario Gregorio Marañón, Calle Doctor Esquerdo 46, Madrid 28009, Spain; [b] Bio-ITACA, Universitat Politècnica de València, Camino de Vera s/n, Valencia 46022, Spain; [c] Center for Arrhythmia Research, Department of Internal Medicine, University of Michigan, 2800 Plymouth Road, Ann Arbor, MI 48109, USA

* Corresponding author.

E-mail address: oberen@umich.edu

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INTRODUCTION

Atrial fibrillation (AF) is the most common arrhythmia seen in clinical practice and is associated with increased risk of stroke, heart failure, and death.[1] Although antiarrhythmic drugs have limited efficacy, the demonstration of AF triggers in the atrial sleeves of the pulmonary veins (PVs) has led to a significant improvement in therapy.[2,3] Several ablative strategies have been developed with the objective of creating circumferential lesions around the PV ostia.[4] Empiric circumferential pulmonary vein isolation (CPVI) is effective in ~70 to 80% of patients with paroxysmal AF and has become therapy of choice for drug-refractory AF in these patients.[5] However, results still remain suboptimal because of the presence of non-PV sources maintaining AF.[4,6,7] Moreover, the success rate of CPVI in the more prevalent persistent and long-lasting AF populations is significantly lower and extensive substrate-based ablation strategies have been used with conflicting results.[8,9]

Experimental and clinical data from the authors' laboratory support the hypothesis that both acute and persistent AF in the sheep and some groups of human patients is not a random phenomenon. Studies analyzing the spatiotemporal organization of waves and dominant frequency (DF) in the isolated sheep heart demonstrate that AF maintenance in this model depends on localized reentrant sources in the left atrium (LA) and fibrillatory conduction in its periphery.[10–15] As a natural consequence of these studies, the authors translated the analysis on the organization of DF to human AF and found that AF reentrant sources are localized primarily to the PVs and LA posterior wall in the case of paroxysmal AF but elsewhere in the case of persistent AF.[16–20] Several of these observational studies showed that AF could be eliminated by directly ablating AF-driving sources or "rotors" that exhibit high-frequency, periodic activity, based on either electrogram (EGM) visual analysis, DF analysis, or panoramic endocardial mapping.[2,17–19,21–25] Recently, the first randomized clinical trial, RADAR-AF, demonstrated that, in paroxysmal AF patients selective ablation of sites responsible for AF maintenance is as effective as CPVI and decreased ablation risks.[26] These results demonstrate that an ablation procedure based on a more target-specific strategy aimed at eliminating high-frequency sites responsible for AF maintenance is efficacious and is safer than empirically isolating all the PVs.

Therefore, it would be arguably desirable to noninvasively identify the location of the sources responsible for AF maintenance before the procedure to design the ideal ablation strategy for each individual AF patient as well as to be able to perform a panoramic real-time localization of sources during the procedure.[27,28] Although the highest-frequency sources in paroxysmal AF are most commonly located in the junction of the LA with the PVs, they have also been identified elsewhere in the atria and may shift in time. Recent studies by the authors' group have shown that panoramic, global, atrial noninvasive frequency analysis is feasible in AF patients and may allow the identification of high-frequency sources before the arrival at the electrophysiology laboratory for ablation. Body surface map (BSPM) replicates the endocardial distribution of DFs and can identify small areas containing the high-frequency sources that result in fibrillatory conduction to the reminder of the atria and may decrease the time required for the search and elimination of the highest DF (HDF) site.[29] Moreover, the authors recently showed that phase maps of surface potentials during AF after HDF filtering allowed the observation of driving reentrant patterns ("rotors") with spatiotemporal stability for greater than 70% of the AF time.[30] Thus, as shown in the following sections, the ability of BSPM to detect sites driving AF may enable a noninvasive personalized diagnosis and treatment of patients with AF.

THE NONINVASIVE MAPPING SYSTEM

In the authors' studies, AF patients wore a custom-made, adjustable vest with 64 electrodes covering the entire torso surface (**Fig. 1**) during the ablation procedure.[17,29,30] The vest included recording electrodes on the anterior (N = 28), posterior (N = 34), and lateral sides (N = 2) of the torso. In addition, 3 limb leads were recorded and used to generate the Wilson terminal. The BSPM vest was placed before the catheterization and fastened anteriorly, allowing access to the patient's chest in case external electrical cardioversion was needed during the course of the study. Surface unipolar electrocardiographic recordings were obtained by using a commercial system for bio-potential measurements (Active Two, Biosemi, The Netherlands) at a sampling frequency of 2048 Hz and stored on hard disk for off-line analyses.[31] Ventricular activity was removed from the unipolar recordings before analysis numerically or by application of adenosine.[29]

SPECTRAL ANALYSIS OF BODY SURFACE POTENTIAL MAPPING

Previous studies have highlighted the major role of maximal DF (DFmax) sources in the maintenance of AF in animals and humans.[14,17,32] Arguably,