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Electrocardiographic spatial loops indicate organization of atrial fibrillation minutes before ablation-related transitions to atrial tachycardia

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Abstract

Background: During ablation for atrial fibrillation (AF), it is challenging to anticipate transitions to organized tachycardia (AT). Defining indices of this transition may help to understand fibrillatory conduction and help track therapy.
Objective: To determine the timescale over which atrial fibrillation (AF) organizes en route to atrial tachycardia (AT) using the ECG referenced to intracardiac electrograms.
Methods: In 17 AF patients at ablation (58.7 ± 9.6 years; 53% persistent AF) we analyzed spatial loops of atrial activity on the ECG and intracardiac electrograms over successive timepoints. Loops were tracked at precisely 15, 10, 5, 3 and 1 min prior to defined transitions of AF to AT.
Results: Organizational indices reliably quantified changes from AF to AT. Spatiotemporal AF organization on the ECG was identifiable at least 15 min before AT was established ($p = 0.02$).
Conclusions: AF shows anticipatory global organization on the ECG minutes before AT is clinically evident. These results offer a foundation to establish when AF therapy is on an effective path, and for a quantitative classification separating AT from AF.

Keywords: Atrial tachycardia; Fibrillation; ECG; Signal processing; Ablation

Introduction

Atrial fibrillation (AF) is the most common sustained arrhythmia in the world and a leading cause of hospitalization and death. Ablation is a widely used alternative to drug strategies to eliminate AF, but there are few indices to monitor whether current lesion sets are effectively organizing the arrhythmia or not. Hence, while AF frequently transitions to atrial tachycardia (AT) (Fig. 1), it is undefined if this organization occurs abruptly or gradually, and over what time period. This has mechanistic implications and hinders the development of indices to guide therapy.

We hypothesized that organization of AF towards AT may show stereotypical spatial patterns. This followed from our reasoning that AF termination to AT may reflect elimination of localized AF sources leaving a residual source [1], the anchoring of wavelets to ablation lesions [2], or the extensive compartmentalization of wavelets to organize them [3], which are often encountered clinically yet rarely tracked.

We set out to test our hypothesis by studying electrophysiologic organization transitions from AF to organized AT or atrial flutter in patients undergoing ablation for atrial fibrillation, using quantitative analyses of continuous ECG and intracardiac recordings.

Methods

Clinical protocol

We recruited 17 consecutive patients with AF undergoing ablation for routine clinical indications in whom ablation transitioned AF to organized atrial tachycardia. Patients were ≥21 years of age with AF refractory to at least 1 anti-arrhythmic medication, and were studied according to the Institutional Review Board of the University of California, San Diego.

All patients underwent clinical electrophysiological study after discontinuing anti-arrhythmic medications for at least 5 half-lives except amiodarone (≥30 days). In addition to routine catheters, all patients had intracardiac recordings selected in predetermined locations in the proximal coronary sinus, distal coronary sinus, and one additional intracardiac

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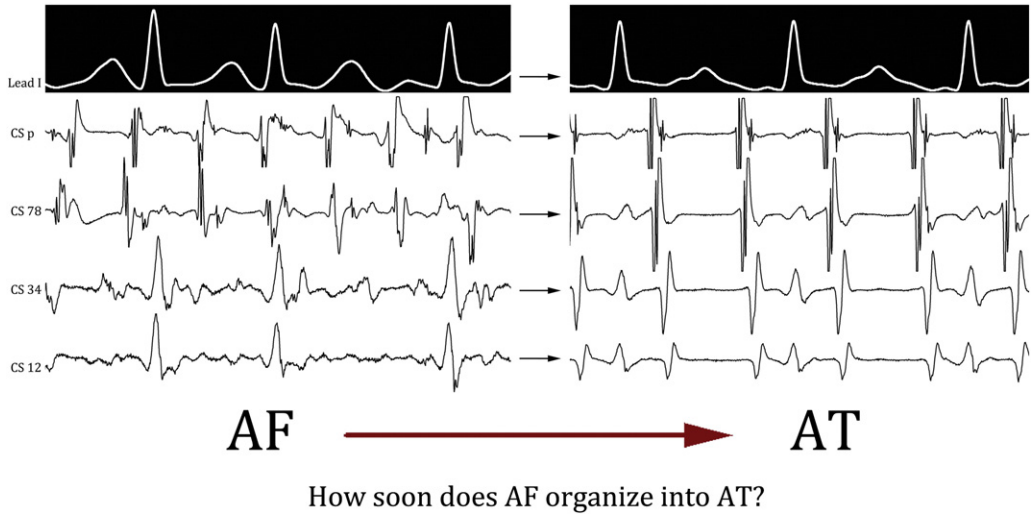

Fig. 1. Transition from AF to AT in a 33 year old male with persistent AF. The tracings were recorded 90 s from each other, and clinically, this appears to be an abrupt transition during ablation on visual inspection of surface and intracardiac electrograms.

electrode in left or right atria. Right atrial data were unavailable in one patient.

AF ablation proceeded via the standard-of-care approach of pulmonary vein isolation with substrate ablation in the left or right atria depending on clinical judgment. Extensive linear ablation was not performed in this series. In each case in this series, ablation converted AF to organized atrial tachycardia, which was also ablated in standard fashion using activation and entrainment mapping.

Rhythm diagnosis

All studies were performed in AF. Patients either presented initially in AF, or if in sinus rhythm, AF was induced with pacing and allowed to continue for >10 min before mapping was pursued. Patients presenting with clinical atrial tachycardia, those whose AF terminated in <10 min or those without continuous electrophysiological recordings at transitions from AF to AT were not included in this population.

Atrial fibrillation was defined in usual fashion as varying temporal and spatial atrial activation, using variable F-wave shape and cycle lengths on the ECG and in coronary sinus activation sequence (i.e. between CS electrodes) and timing (i.e. over time).

Organized **atrial tachycardia** was diagnosed as reproducible activation sequence, defined as consistent F-wave shape on the ECG or between CS electrodes. Macro-reentrant AT was confirmed by concealed entrainment and successful ablation [4,5], focal AT by intra-atrial activation occupying a short proportion of the tachycardia cycle arising from a small location [4] and confirmed by successful ablation [6]. Electroanatomic mapping systems (CARTO, Biosense Webster Inc., Diamond Bar, CA; NavX, St Jude Medical, St Paul, MN) were used when needed.

Measuring epochs of organization

First, we observed AF during a baseline period of 15 min prior to ablation under an IRB-approved protocol. Organizational indices were computed in this period to assess baseline. Second, we studied organization from AF to AT during ablation. The study design was to examine spatiotemporal dynamics of AF relative to the time of AT onset.

The transition from AF to AT was defined to ~1 s resolution by careful evaluation of annotated digital intracardiac and ECG recordings (Bard LabSystem Pro, Billerica, MA). The time point when spatial variations in atrial electrogram sequence (e.g. between CS electrodes) disappeared was considered the transition time to AT, confirmed by the consensus between 3 observers (TB, RT, JZ).

Acquisition of data and data processing

We recorded 12-lead surface ECGs (0.05–100 Hz bandpass-filtered) and bipolar intracardiac electrograms (30–250 Hz), each of which was digitized at 1 kHz and exported from our recorder (Bard, Billerica, MA). ECG analysis was performed on a PC using custom software developed by one of the authors (SMN) in *Labview* (National Instruments, TX) [7]. ECG analysis used leads V5, aVF and V1 to represent orthogonal leads X, Y and Z, respectively (Fig. 2A). Intracardiac electrograms were obtained from Coronary Sinus (CS) proximal, CS distal and a bipole at the right atrial free wall (during right atrial ablation) or left atrial lateral wall (during left atrial ablation), analyzed at 200 mm/s scale. Analysis was applied directly to each selected ECG or intracardiac leads [8].

Measures of spatiotemporal organization

Organization was assessed using loops of atrial activity over time using our described [7,9] and validated [10] method of generating time series of successive correlations to an atrial electrogram. This has the effect of filtering QRS complexes. In the XY plane, phase was computed by plotting X- versus Y-axis correlation-time series (for the ECG, leads V5 versus aVF) at each time-point (Fig. 2A–C); similarly for YZ (aVF/V1) and XZ (V5/V1) planes. This resulted in loops for successive cycles that represent spatial regularity. We also analyzed dominant frequency using an 8192 point Fast Fourier Transform to measure organization.