Characterization of Regional Conduction Velocity During Atrial Fibrillation in High and Low Spatial Resolution Intracavitary Recordings

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Abstract

A regional characterization of conduction velocity (CV) could help to understand the specific pathophysiology of atrial fibrillation (AF) in each patient, allowing a greater degree of personalization of ablation strategies and increasing their success rate.

Regional characterization from low spatial resolution intracavitary electrical recordings with basket catheter (electrode spacing 6-10 mm) was compared to high-resolution mapping with grid catheter (electrode spacing 2-3 mm). A robust multi-approach method was used to measure CVs in recordings obtained during AF episodes in 5 patients (72 ± 8 years) with both recording systems.

In N=222 measurements, 74% of the CV estimation obtained with low-resolution mapping presented an error of less than 150 mm/s with respect to closest high-resolution mapping estimation. CV maps obtained with the low-resolution mapping showed similar regional variations as those obtained from the grid, limited to their respective spatial resolutions, and were able to reproduce the inter-patient variability.

Estimation of regional CV during AF can be obtained from both high- and low-resolution mapping catheters, with reproducible outcomes, which can be a promising tool for therapy personalization.

1. Introduction

Despite advances in the treatment for atrial fibrillation (AF) patients, the effectiveness of ablation strategies remains limited, and therefore tools are needed to help stratify patients and personalize therapies. One of the key elements in the pathophysiology of AF is the progressive alteration of the atrial substrate, mainly characterized by a reduction in conduction velocity (CV) and shortening of the action potential. CV, or wavefront propagation velocity, is a spatially heterogeneous variable that reflects local myocardial conditions. During AF progression, a global reduction in CV has been reported, as a consequence of electrical remodeling, as well as localized reductions attributable to the appearance of fibrotic tissue [1]. It has been observed that atrial regions with reduced CV are more likely to harbor arrhythmic mechanisms such as functional reentries or rotors. In addition, CV gradients between regions may produce fragmented or chaotic conduction patterns. Consequently, these regions may be complementary therapeutic targets, especially in cases where pulmonary vein isolation is not sufficient to reverse the arrhythmia. Therefore, regional characterization of the atrium in terms of CV could be a promising tool for both diagnosis and patient stratification, as well as for personalized guidance of ablation procedures, improving their accuracy.

To obtain an optimal regional characterization of CV in the atrium during AF, high-resolution electrical mapping covering the entire atrial surface would be necessary. However, CV estimation during AF, where different wave directions and propagation domains can coexist, is not a trivial task. We previously proposed a robust method to estimate CV in AF recordings [2], presented on low-resolution (basket catheters). The aim of this work is to compare CV measurements obtained from low spatial resolution recordings, with those obtained from high-resolution mapping, as well as to compare their respective maps, in order to evaluate if high- and low-resolution CV measures provide similar estimations.

2. Materials and Methods

2.1. Intracavitary Signals

Intracavitary left atrial recordings from 5 patients (3 men, 72 ± 8 years) obtained during ablation procedures at Stanford Hospital (CA, USA) were used. Two types of signals were available for each patient, considered as high-resolution and low-resolution catheters in terms of spatial covering. On the one hand, 60 s recordings obtained with a 64-channel basket catheter (low-resolution, electrode spacing 6-10 mm, 2-4 catheter recordings per patient) to which a QRS complex detection and cancellation algorithm was applied to eliminate ventricular interference

[3]. On the other hand, high-resolution mapping of the entire atrial surface was performed using a grid-type catheter (16 electrodes, 2-3 mm spacing) with bipolar signals of 1 s duration. Position of each recording electrode and anatomical surface were also exported from the electro-anatomical navigator system.

2.2. Conduction Velocity Estimation

To measure the CV from basket signals, the previously presented method [2] was applied to groups of 3 electrodes separated by less than 15 mm (Figure 1a). This technique for measuring CVs during AF episodes is based on providing robustness to the measurements by using 4 different approaches to calculate the relative differences in activation time between the 3 signals in each activation. Two separately applied preprocessing methods (1: 45 Hz low pass filter to remove high frequency noise; 2: 2 - 20 Hz band pass filter to keep only the spectral band in which the atrial activity has higher power) were combined with two techniques for detecting delay in activation time: classic maximum in the time derivative (Figure 1b) and based on phase shift detection that maximizes cross-correlation between channels (Figure 1c). From the

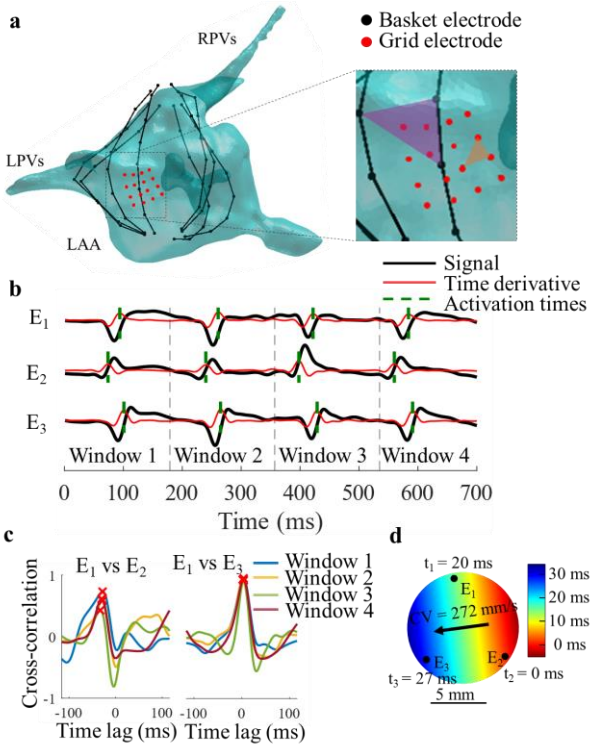


Figure 1. a) Atrial anatomy (green), basket catheter (black) with a set of 3 measurement electrodes (purple triangle) and grid catheter (red) with a measurement set (orange triangle). b) Activation time detection based on dvdt. c) Delay estimation based in cross-correlations method. d) Calculation of CV in a group of 3 electrodes.

relative differences in activation time, the conduction in the vicinity of the electrodes was approximated to a plane wave and the CV in the direction of propagation was calculated (Figure 1d). CV estimations along 60 s recordings were aggregated for each group of 3 electrodes, and only CV measurements with stable estimations (more than 40% of the measurements were within ± 150 mm/s) were accepted.

This method of CV measurement was adapted to the characteristics of the grid signals, as due to the short duration of the signals (1 s), very few atrial activations were available (3-5). The 2-20 Hz bandpass filter was replaced by a Botteron filter [4]. To increase the number of samples per region and maintain the robustness of the method, we grouped the CV estimations along all groups of 3 electrodes on less than 12 mm from each electrode. Then, as in low-resolution cases, only CV measurements with stable estimations per electrode (more than 40% of the measurements were within ± 150 mm/s) were accepted.

In addition to CV measurements, cycle length (CL) was also estimated as the time lag that maximized the signal autocorrelation using different pre-processing configurations, including unipolar and bipolar electrograms in for basket signals, and selecting their median value.

To compare the results obtained from both types of catheters, the high-resolution (grid) measurement closest to each low-resolution (basket) measurement was selected and the Wilcoxon signed-rank test that evaluates the equality of medians in paired distributions was used. Besides, the CV and CL values obtained by both recording systems were projected onto the atrial geometry of the electro-anatomical navigator to obtain CV and CL maps. For this purpose, a weighted average of the 3 closest CL/CV recordings was assigned to each node of the atrial geometry, using the inverse of the square distance as weights. Finally, the projected CL/CV values were smoothed by applying a three-dimensional Gaussian filter with $\sigma = 2$.

3. Results

From the 3.2 ± 0.8 basket positions available for each patient, we obtained 44 ± 34 CV measurements that satisfied the acceptance criteria of the measurement method, as well as 205 ± 54 CL measurements. Figure 2a shows the CV results obtained, for an example patient, at each basket measurement point compared to the nearest grid measurement (N=52 CV estimations). The distribution of basket measurements (392 ± 172 mm/s) faithfully reproduced the one obtained with the grid mapping (361 ± 99 mm/s, p=1). Figure 2b shows the absolute error obtained at each measurement location, where 77% of the measurements showed an error inferior to 150 mm/s.

Figure 3a and b shows CL measurements of the same

patient. In this case, CL was measured at 222 points and, again, the basket measurement (207 ± 28 ms) closely reproduced the results obtained with the grid (189 ± 32 ms, p=1). Regarding the errors obtained, they were less than 30 ms in 62% of the measurements.

Along the whole dataset, there were no statistically significant differences between the CV measures obtained with the basket and the grid (N=222, p=0.83), and 74% of the CV measurements had an error of less than 150 mm/s. For CL measurements, deviations between high- and low-resolution mapping were less than 30 ms in 64% of cases.

To evaluate the ability of the measurements obtained with the basket to regionally characterize the atrial electrophysiology, the maps obtained by projecting the measurements onto the atrium were compared with those obtained from the grid. Figure 2c shows the CV maps obtained for the example patient from both mapping techniques. It was found that the regional characterization obtained from the basket data is similar to the more accurate grid characterization. Specifically, both maps showed a higher CV region between the appendage and left pulmonary veins, while the posterior wall and right pulmonary veins were shown as the slowest region in both cases. Figure 3c shows the CL maps obtained using the basket and grid data. Again, the maps obtained are qualitatively similar. The grid showed a shorter CL in the appendage and inferior wall and a longer CL in the pulmonary veins, posterior wall and valve. These regional differences were reproduced in the map obtained with the basket using a lower spatial resolution.

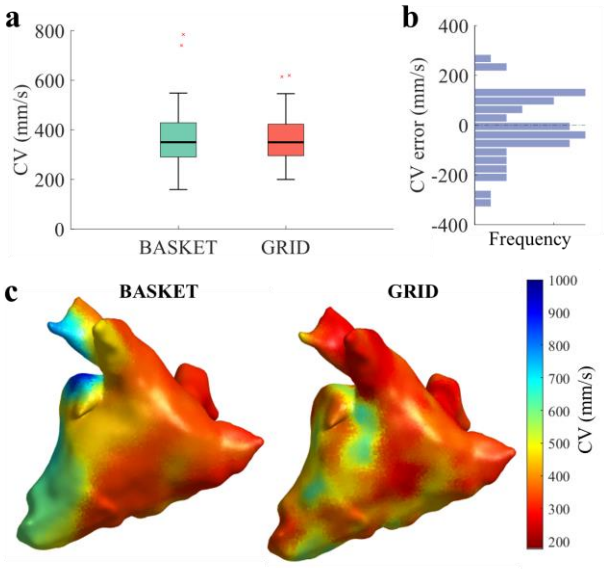


Figure 2. a) CV measurements in patient #2 from basket signals (green) and at the nearest grid electrode (orange). b) Absolute error in basket vs grid local CV estimation. c) Regional distribution of basket (left) and grid (right) CV measurements on the atrial anatomy.

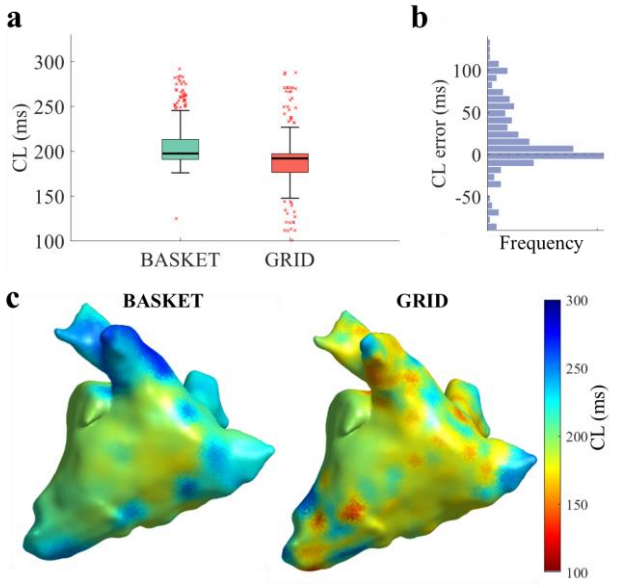


Figure 3. a) CL measurements in patient #2 from basket signals (green) and at the nearest grid electrode (orange). b) Absolute error in basket vs grid local CL estimation. c) Regional distribution of basket (left) and grid (right) CV measurements on the atrial anatomy.

Finally, Figure 4 shows a summary of the CL and CV distributions, obtained by projecting both biomarkers on their respective atrial geometries. From high-resolution (grid) data, inter- and intra-patient variability was observed in terms of both CV and CL. This variability was reproduced from the patient with the fastest conduction (414 ± 67 mm/s in the basket vs 388 ± 105 mm/s in the grid, 79% of the measurements with an error of less than 150 mm/s) to the patient with the slowest conduction (355 ± 58 mm/s in the basket vs 337 ± 55 mm/s in the grid, error less than 150 mm/s in 94% of cases). As well as, from the patient with the shortest activation period (215 ± 20 ms in the basket vs 193 ± 18 ms in the grid, 61% of measurements with a deviation of less than 30 ms) to the one with the longest (247 ± 18 ms in the basket vs 235 ± 36 ms in the grid, error less than 30 ms in 71% of cases).

4. Discussion and Conclusions

In this study, a previously developed method for estimating conduction velocity in intracavitary electrical recordings, was applied to regionally characterize atrial electrophysiology and compared between low and high spatial resolution systems. For the same 5 patients, similar global and regional CV were estimated from signals obtained on high-resolution mapping, grid-type catheters covering the entire atrial surface (2-3 mm spacing), respect to those estimations obtained on a low-resolution, basket-type catheter (6-10 mm spacing). To complete the

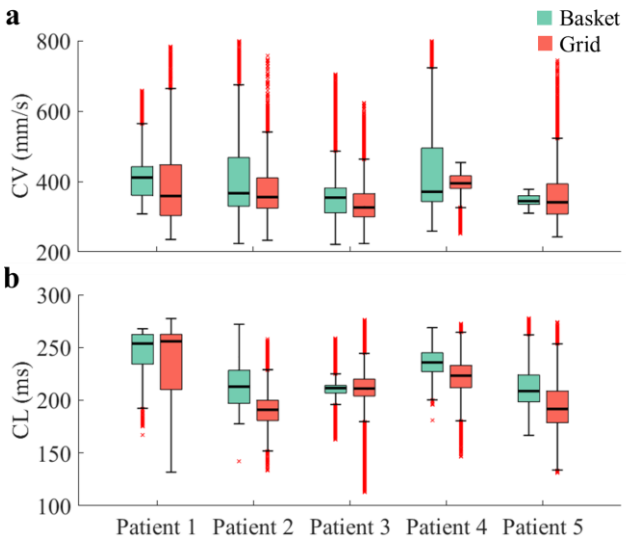


Figure 4. Regional CV (a) and CL (b) values using basket (green) and grid (orange) estimations.

comparative analysis, CL was also compared between both mapping catheters with similar trends. Finally, measurements obtained with both recording methods were projected onto the atrial geometries to reveal maps on both biomarkers. Measurements obtained from the low-resolution catheter (basket) presented acceptable deviations respect to the nearest high-resolution measure, both in terms of CL and CV (74% of CV measurements with error < 150 mm/s and 64% of CL measurements with error < 30 ms). In addition, the CV distributions obtained with both methods did not present statistically significant differences. The errors in the CV values obtained between the two mapping systems could be related to the spatial scale at which each system operates. The average regional velocity in a 15 mm radius area may not coincide with the local velocities in each sub-region belonging to that area because propagation may not be uniform.

Electro-anatomical mapping demonstrated that measurements obtained from low-resolution are able to identify regions of slow conduction, in a similar way as with high-resolution mapping, although with the limitations of the mapping resolution system. These slow conduction regions can be related to remodeling and fibrotic infiltration associated with disease progression [5], i.e., they are potentially proarrhythmic regions and targets for ablation. Therefore, CV measurements obtained from high- and low-resolution recordings could be used for the development of personalized tools for guidance of ablation strategies, according to the regional information provided by the mapping catheters. Furthermore, the electrophysiological characterization obtained with these mapping techniques could be used for personalization of digital twins, reproducing the specific electrophysiological activity characterized on each patient [6]. This preliminary study carried out in 5 patients and limited to the left atrium will be extended to a larger cohort, including right atrial recordings, and validated against clinical outcomes.

Acknowledgments

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