Prediction of Atrial Fibrillation Termination by Catheter Ablation using Adaptive Frequency Tracking of Atrial ECG Signals

Adrian Luca[1], Andrea Buttu[1], Jean-Marc Vesin[1], Patrizio Pascale[2], Laurent Roten[3], Christian Sticherling[4], Etienne Pruvot[2]

[1]Swiss Federal Institute of Technology, Lausanne, Switzerland
[2]Departement of Cardiology, Lausanne University Hospital, Switzerland
[3]Department of Cardiology, Inselspital, Bern University Hospital, Switzerland
[4]Division of Cardiology, University Hospital Basel, Switzerland

Abstract

Our study aims at determining whether the efficiency of step-wise catheter ablation (step-CA) of persistent atrial fibrillation (pAF) can be tracked using organization indices based on the harmonic components of atrial ECG signals until pAF termination. ECG time series devoid of QRST were recorded at baseline (pre-ablation), after pulmonary vein isolation and at the end of left atrium (LA) ablation. Using adaptive harmonic frequency tracking schemes, two organisation indices characterizing the relationship between the harmonic components of atrial ECG were computed. Patients in whom the pAF termination was achieved during ablation within the LA displayed greater baseline atrial ECG organization that further increased significantly at the end of LA ablation as opposed to patients in whom the pAF did not terminate. Estimation of the level of atrial ECG organization based on adaptive harmonic schemes appears as promising tool for tracking changes in pAF dynamics during CA and prediction of procedural outcome.

1. Introduction

Atrial fibrillation (AF) is the most common arrhythmia in clinical practice. Termination of persistent AF (pAF) by stepwise catheter ablation (step-CA) within the left atrium (LA) is associated with improved maintenance of sinus rhythm on the long term [1].

There is therefore a continuing interest in developing indices capable of tracking changes in pAF dynamics during CA and to identify patients more likely to achieve AF termination during the ablation procedure.

Concerning pre-ablation prediction of procedural outcome, multiple organization indices based either on intracardiac recordings [2-4] or on surface ECG signals [5, 6] have been proposed in the literature. In terms of intra-procedural tracking of AF complexity, several organisation indices have been used to predict whether pAF will terminate with additional ablation after pulmonary vein isolation (PVI), nevertheless with limited success. In patients in whom pAF continued after PVI, the intracardiac AF cycle length (AFCL) was shown not to change during step-CA, while other indices based on large intracardiac dipoles or on morphological variability of intracardiac recordings changed during the procedure [7, 8]. In [9], changes in surface atrial frequency during AF in response to linear left atrial ablation have been linked with procedural outcome. Our study aims at determining whether novel surface ECG organization indices, which are based on the harmonic components of AF activity, can track step-CA efficiency and predict pAF termination.

2. Methods

2.1. Patient population and ablation procedure

Electrophysiological study. All patients had effective oral anticoagulation for > 1 month. All antiarrhythmic drugs, with the exception of amiodarone and beta-blockers, were discontinued for > five half-lives before the ablation procedure. The ablation procedure was performed under general anaesthesia. Surface ECGs and intracardiac electrograms (EGMs) were continuously monitored and recorded at 2-kHz sampling rate (Axiom Sensis XP, Siemens) at baseline (*i.e.* before ablation) and during the entire CA procedure. In order to improve the recording of the antero-posterior activity of the atria, chest lead V_6 was placed in the back (V_{6b}) of each patient. A database was built containing continuous and synchronous recordings of both ECG and EGM signals segmented in epochs of 40-sec duration.

Ablation protocol and procedural endpoint. Stepwise CA was performed as described in [5, 10]. The ablation protocol included the following steps performed within

the LA: PVI, ablation of complex fractionated atrial electrograms (CFAEs) and linear ablation (roof and mitral isthmus). The procedural endpoint was reached when pAF was terminated into sinus rhythm (SR) or atrial tachycardia (AT). When pAF termination was not achieved, SR was restored by electrical cardioversion.

Patient population. The study group consisted of 34 consecutive patients of a mean age of 61 ± 7 years suffering from pAF on average for 19 ± 11 months. pAF was defined as continuous AF lasting longer than 4 months, resistant to either pharmacological or electrical cardioversion. pAF was terminated into SR or AT during CA within the LA in 68% (**left terminated group - LT**) of the patients, while in 32% (**not left terminated group - NLT**) it did not.

Overall, the two groups did not present significant differences except for the average duration of sustained AF that was significantly longer (25 ± 14 months) for the NLT group than that for the LT group (16 ± 8 months, $p < 0.05$).

2.2. Assessment of atrial ECG organization

Cancellation of QRST waves from 12-lead ECG recordings was performed to generate atrial ECG signals devoid of ventricular activity [11]. Then, the atrial ECG signals were down-sampled to 50 Hz. Finally, only the ECG precordial chest leads (V_1 to V_{6b}) were included in the study.

For each epoch of 40-sec duration, the fundamental frequency and its first harmonic were extracted using an adaptive frequency tracking algorithm [5, 10]. The harmonic frequency tracker consists of two parts: 1) a time-varying band-pass filter for extracting the oscillations presented in the input signal and 2) an adaptive mechanism for controlling the central frequency of this filter. It is noteworthy that this algorithm outperforms the traditional methods based on time-invariant bandpass filters, which on long duration segments, could be less accurate for extracting the components of AF signals [10].

The level of AF organization during step-CA was assessed using two organization indices based on the relationships between the fundamental frequency and the first harmonic of atrial ECG signals.

Adaptive Organization Index (aOI). The aOI is computed as the ratio between the power of the extracted components and the total power of the signal (by definition, AOI is bounded between 0 and 1) [5]. An aOI close to 1 is indicative of a high level of atrial ECG organization as most of the frequency content is concentrated in the fundamental and its first harmonic. Hence, aOI quantifies the temporal evolution of AF oscillations.

Adaptive Phase Difference (aPD). This index characterizes the phase difference between the 1st harmonic and the fundamental component extracted by the adaptive harmonic frequency tracker [5]. Once the phase difference is computed, its slope is locally estimated by a linear fit on centred sliding windows. aPD is computed as the variance of the local slope of the phase difference. Thus, small aPD values are indicative of regular AF oscillations due to a strong coupling between the fundamental and its first harmonic.

2.3. Statistical analysis

All values were expressed as a mean ± standard deviation. The statistical comparison between the two groups was performed by using the two-sample *t*-test. Results were considered to be statistically significant at $p<0.05$.

3. Results

Illustrative example. Figure 1 shows the temporal evolution of aOI and aPD measured on 40-sec epochs from lead V_1 during step-CA for an LT patient (left) whose pAF was terminated into an AT and for an NLT patient (right) remaining into AF after step-CA, respectively. Mean values of the two organization indices are also separately indicated (green color) for each phase: baseline - before ablation, PVI and LA ablation. Note the progressive organization occurring in the LT patient as depicted by the gradual increase in AOI and decrease in aPD during PVI and thereafter as compared to baseline. In contrast, the NLT patient values remained stable over the entire CA procedure.

Atrial ECG organisation at baseline and during catheter ablation. Figure 2 reports the evolution of mean aOI and aPD at baseline and during step-CA for LT and NLT patients.

aOI and aPD values were computed on atrial ECG epochs recorded at the following stages of the step-CA procedure:

BL: 2 minutes prior to the first ablation step;
end_PVI: the last 2 minutes of the PVI phase;
end_ABL: the last 2 minutes of LA ablation.

aOI showed a significant higher organization on lead V_1 ($p <0.005$) in patients with AF termination compared to patients in whom AF did not terminate. aPD was significantly lower for the LT group compared to NLT patients on both leads ($p <0.05$ for V_1 and $p <0.001$ for V_{6b}).

In LT patients, aOI increased significantly before pAF termination (end_ABL) as compared to BL, but remained unchanged in NLT patients.

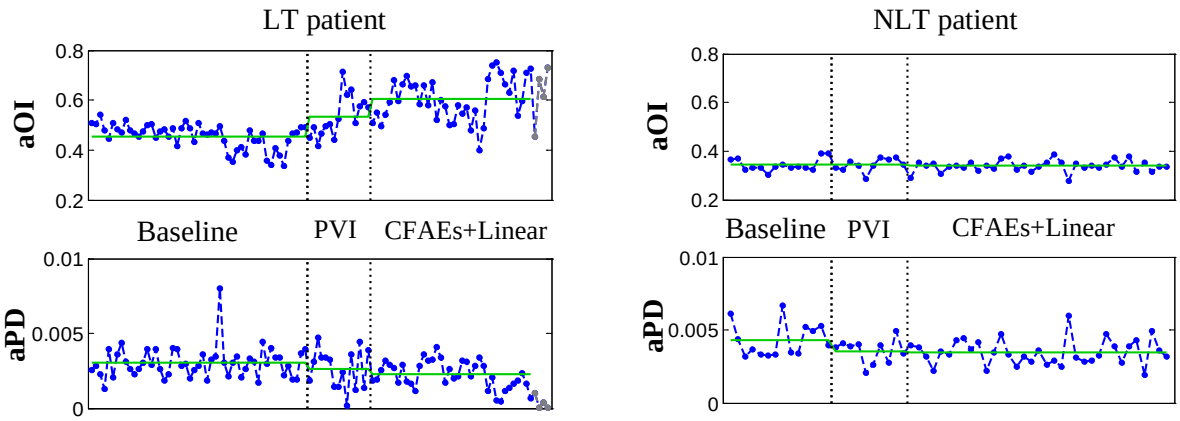

Figure 1. Temporal evolution of aOI and aPD measured on lead V_1 during step-CA for an LT patient (left) until pAF termination and for an NLT patient (right) at baseline, during PVI and LA ablation (CFAEs+Linear).

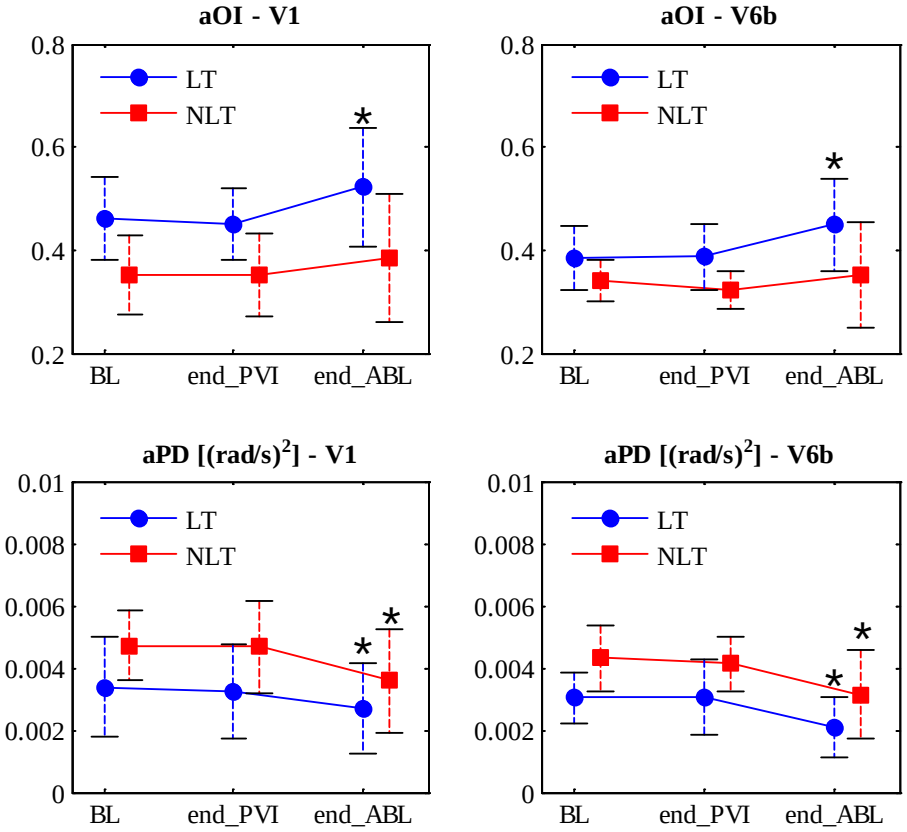

Figure 2. aOI and aPD values (mean±SD) for LT and NLT patients measured from lead V_1 and lead V_{6b} at baseline (BL), at the end of PVI (end_PVI) and at the end of LA ablation (end_ABL). *p < 0.05: end_ABL compared to BL. No significant difference in aOI and aPD was observed between end_PVI and BL in both groups.

Although, both groups displayed a significant decrease in aPD during step-CA, the pre-ablation level of organization in LT patients was significantly higher than that of NLT patients.

No significant changes in aOI and aPD were noticed during step-CA (compared to BL) for the remaining ECG chest leads.

4. Conclusion

Distinctive temporal evolution of atrial ECG organization was observed between LT and NLT patients during step-CA. Our study reveals a higher level of organization before ablation and a gradual increase in the organization

level of the atrial activity during CA in patients in whom AF was terminated within the LA. Altogether, these findings are suggestive of a higher electro-anatomical remodelling in non-terminated pAF and of a cumulative effect of ablation.

These conclusions are in agreement with the results reported in a previous study carried out on the same patient population presented here. In [3], the organization of right bipolar electrograms before and during CA procedure was assessed using the coarse-grained correlation dimension (a measure of the degree of regularity in atrial activation patterns of the EGM). During CA, the dynamics of atrial activation patterns in bipolar EGMs measured from the distal dipole of the catheter placed within the right atrial appendage displayed distinctive evolution between LT and NLT patients, with a significant organization increase before AF termination.

In conclusion, organization indices derived from the adaptive frequency tracking of atrial ECG signals appear as promising metrics for tracking changes in AF dynamics during CA for the prediction of the procedural outcome and selection of best candidates for CA of pAF.

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Address for correspondence.

Adrian Luca
EPFL SCI STI JMV - Station 11
1015, Lausanne, Switzerland
adrian.luca@epfl.ch