Robust Classification of Endocardial Electrograms Fractionation in Human using Nearest Mean Classifier

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Abstract. *Complex fractionated atrial electrograms (CFAEs) may represent the electrophysiological substrate for atrial fibrillation (AF). Progress in signal processing algorithms to identify CFAEs sites is crucial for the development of AF ablation strategies. A novel algorithm for automated description of atrial electrograms (A-EGMs) fractionation based on wavelet transform and several statistical pattern recognition methods was proposed and new methodology of A-EGM processing was designed and tested in such a comprehensive form than ever before. The algorithms for signal processing, description and classification were developed and validated using a representative set of 1:5 s A-EGMs (n = 113) ranked by 3 independent experts into 4 classes of fractionation: 1 – organized atrial activity; 2 – mild; 3 – intermediate; 4 – high degree of fractionation. New feature extraction and classification algorithms used and tested here showed mean classification error over all classes ~ 5.9%, and classification error of highly fractionated A-EGMs of ~ 9%. These operator-independent and fully automatic algorithms for A-EGMs complexity description is the first usage of such novel approaches in A-EGMs processing and analysis and may be easily incorporated into mapping systems to facilitate CFAEs identification and help to guide AF substrate ablation.*

Keywords: Atrial fibrillation, catheter ablation, complex fractionated atrial electrograms, wavelet transform, classification.

1. Introduction

Significant progress has been achieved in the field of curative ablation of atrial fibrillation (AF) in recent years. While empirical isolation of pulmonary veins is usually an effective strategy in paroxysmal AF, targeting extrapulmonary substrate within left (right) atrium is often necessary in the case of persistent/permanent AF [1]. Both areas with high dominant frequency of atrial electrograms (A-EGMs) [2] and areas with complex fractionated atrial electrograms (CFAEs) [3] were shown to play a role in the maintenance of the arrhythmia. In order to identify those sites, great effort has been made to describe the patterns of activation in AF [4] and to quantify general characteristics of A-EGMs either in time- or frequency-domain [5, 6]. Recently, two software algorithms for time-domain analysis of CFAEs were implemented in commercially available mapping systems - CARTO (Biosense-Webster) and EnSite NavX system (St. Jude Medical). Both methods require initial setting of specific input parameters making them, at least to some extent, operator-dependent. We used algorithms for automatic classification (pattern recognition), based on description of signal, using features extracted from recorded and preprocessed signals. This approach is based on the idea that there are signal complexes [7] in every A-EGM signal, which are related to electrical activation of electropathological substrate during AF. These signal complexes – fractionated segments of A-EGM (FSs) can be found automatically and then used for several features extraction (degrees of freedom of the signal), which could be used for automatic evaluation of electrogram complexity (or level of fractionation) in next stages. In this paper we focus on evaluation of A-EGM signal complexity of A-EGMs recorded during AF. In this paper we bring the results of a novel robust method for A-EGM processing, based on the wavelet transform signal analysis, several feature extraction followed by classifier.

2. Subject and Methods

Experimental dataset of A-EGMs

Atrial bipolar electrograms were collected during left-atrial endocardial mapping using 4-mm irrigated-tip ablation catheter (NaviStar, Biosense-Webster) in 12 patients (9 males, aged 56±8 years) with persistent AF. The A-EGMs acquired before the ablation procedure were band-pass filtered (30-400Hz) and sampled at frequency of 977Hz by CardioLab 7000 (Prucka Inc.). Discontinuous recordings from distal catheter bipole during left-atrial mapping outside the pulmonary veins and their tubular ostia (in order to treat only the signals from sites that are usually targeted during extrapulmonary substrate modification) were exported in digital format and reviewed by independent expert. The fragments with inadequate endocardial contact, relatively high signal-to-noise ratio or artifacts were excluded. Remaining parts of recordings were split into not necessarily contiguous 1500 ms segments with stable signal pattern. The A-EGMs very close to the mitral annulus were discarded to prevent the interference of relatively sharp ventricular signals with atrial signal analysis. This yielded approximately 250 segments with high-quality A-EGMs. This set of A-EGMs was further scrutinized. Finally, selection of 113 such segments represented wide spectrum of A-EGMs including those very organized, extremely fractionated, and all intermediate forms.

Expert classification of A-EGMs

Although the degree of fractionation of the A-EGM signals in the experimental dataset was a continuous variable by nature, expert classification into categories was chosen for the purpose of our study. Three experts, who perform AF ablation procedures on regular basis, independently ranked raw A-EGMs into those 4 classes of fractionation (1 - organized activity; 2 - mild degree of fractionation; 3 - intermediate degree of fractionation; 4 - high degree of fractionation) according to the subjective perception of signals. This procedure was facilitated by the purpose-written software for displaying A-EGMs in the same aspect ratio as on real-time screen during the left atrium mapping. This software also allowed experts scrolling through all A-EGMs with the possibility to reorder them repetitively according to assigned classification until the final ranking were reached. No specific criteria for signal assessment (e.g. dominant frequency or percentage of continuous electrical activity) were given. The experts were asked to classify the A-EGMs by their subjective judgment according to how the ablation at particular site would be valuable for atrial debulking. They were only instructed to keep approximately equal percent occurrence for each A-EGM category.

A-EGMs processing, feature extraction and classification

A-EGM preprocessing algorithm described in [8] was used to filter and prepare signals for the phase of feature extraction. The algorithms for A-EGM feature extraction [9] were used to describe A-EGM complexity in a new way. Based on the Automated Fractionated segments Search (AFS) preprocessing algorithm [8], the algorithms automatically search for areas of the A-EGM signal, where local electrical activity is found (FSs), also described by Faes et al. as local activation waves (LAWs) [6]. Several features of A-EGM are then defined based on FSs description. Following features are therefore derived from the characteristics of the automatically observed FSs or LAWs:

1) A number of fractionated segments found by AFS in particular A-EGM signal in dataset.

2) Minimum of Inflection Points in found FSs in a particular A-EGM signal.
3) Maximum of Inflection Points in found FSs in a particular A-EGM signal. Arithmetical Mean value of Inflection Points added together in automatically found FSs.
4) Sum of width of all FSs found in particular A-EGM.
5) Minimal width of found FSs in particular A-EGM signal.
6) Maximal width of found FSs in particular A-EGM signal.
7) Arithmetical Mean value of inter-segment distance of automatically found FSs.

To determine the quality of the feature selection and to evaluate the automatic classification of the individual level of fractionation of A-EGM, we used Nearest mean classifier, where classes are represented by their mean (prototype) and which associate new sample with the class of nearest mean. Training data were used in 1:1 fashion (training:testing).

3. Results

The mean classification error across all classes obtained for the best performing Nearest mean classifier was achieved at ~ 5.9 %. The classification errors of this classifier for individual classes are shown in Table 1. This classifier was able to clearly discriminate classes 1 and 2 with 0% error, while classes 3 and 4 were more difficult to approach.

Table 1. Unweighted classification error for Nearest mean classifier using described 7 features.

Classes of fractionation	1	2	3	4
Error [%]	0	0	14.3	9.1

4. Conclusions

While the current methods are focused on dominant frequency classification or evaluation of electrogram fractionation, the above described method primarily eliminates segments of electrograms, where evidently no local electric activity is present and then future techniques will extract more features from the signal and describe complexity of electrogram based on found electrogram segments. In conclusion, we proposed a novel robust algorithm based on wavelet transform for automated and operator-independent assessment of A-EGMs fractionation to facilitate CFAEs identification and to guide AF substrate ablation. Because of the low computational costs it can be easily incorporated into real-time mapping systems provided it will be first validated off-line in larger and independent A-EGMs sample and compared with currently available algorithms. By now, its clinical value is unknown and warrants further investigation.

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