On Cardiac Activity Characterization from Implantable Cardioverter Defibrillator Electrogram Analysis: is Far-Field Better?

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Abstract

The new generation of Implantable Cardioverter Defibrillators (ICDs) allows storage of intracardiac electrograms (EGMs) recorded immediately before the onset of malignant ventricular tachyarrhythmias (VTs) and during their course. Although all devices base most of diagnostic parameters on the bipolar EGMs, some of them allow two types of EGM recordings: bipolar (potential is obtained between two electrodes at the tip of the electrocatheter) and far-field (potential is recorded between the tip of the electrocatheter and the active can device).

The main objective of this work is to study which differences can be observed from the analysis of bipolar or far-field EGMs when deterministic chaos methods are being applied to bipolar or far-field EGM recordings.

For this analysis we considered 20 EGMs obtained from 6 patients with ICDs. Some of the EGMs contain VT episodes, other are collected in basal heart conditions.

Within the limited set of EGM considered in this work, results indicate that far field recordings, monitoring the whole heart activity, allow better characterization of heart substrate, and they are more indicated when deterministic chaos analysis would be applied.

1. Introduction

In the last decades new mathematical concepts, developed from chaos theory, have been used to characterize and to gain a deep insight into the behavior of cardiac electrical activity [1,2,3]. In this paper we considered phase space reconstruction and correlation dimension analysis. It is not our purpose to present here the mathematical analysis. Readers not aware about it can find all the required information in [4,5,6,7,8]. The algorithms that have been used in this paper to estimate the correlation dimension are described in [3]. We also applied test to determine consistency of the estimated dimension by means of reliability indices described in [9].

One of the major issues, related with the study of cardiac arrhythmias, is the initiation of ventricular tachycardia (VT) or fibrillation (VF), and the underlying heart mechanisms which determine such a transition. Kaplan and Cohen [10] analyzed electrocardiographic (ECG) tracings from anesthetized fibrillating dogs, and concluded that there were no *attractor* associated with ventricular fibrillation; Casaleggio et al [11] demonstrated that there were a remarkable difference in epicardial single cells activity of Langendorff perfused white rabbit hearts while the heart was in sinus rhythm (SR) or in ventricular fibrillation (VF). Finally, Casaleggio et al [12], analyzing an ECG tracing (MIT207) from MIT-BIH Arrhythmia Data Base now available at http://www.physionet.org [13], found that a change in heart dynamic occurred in the holter recording obtained immediately before the onset of a ventricular fibrillo-flutter, or 15 minutes before it.

This led to the very interesting question about the study of the onset of malignant VT/VF: might a wider understanding of the mechanism involved in the onset of malignant tachyarrhythmias lead to the definition of simple parameters for short time prediction of VT/VF episode?

St Jude Medical Implantable Cardioverter Defibrillators (ICDs) are able, at least in some of their device (Amgstrom, Contour and Profile) to record up to 2 minutes of signal centered around a recognized VT episode. In practice we can set the device in such a way to analyze about 90 seconds of EGM tracing immediately before the onset of any malignant VT/VF recognized by the implanted device itself, and we can compare it with the EGM recording obtained at every follow-up when the heart activity is in basal condition.

Since these ICDs allow two types of EGM recordings (Bipolar or Far-Field), the purpose of the present work is to perform a preliminary analysis aimed to choose which

one, between the bipolar or far-field electrogram recording performs better when state space or dimension analysis would be applied to it.

We can consider this work as a first little step toward the big aim of predicting VT/VF mentioned above.

2. Patients and signals

A detailed picture explaining how Far-Field and Bipolar recordings are measured within the heart is show in Figure 1.

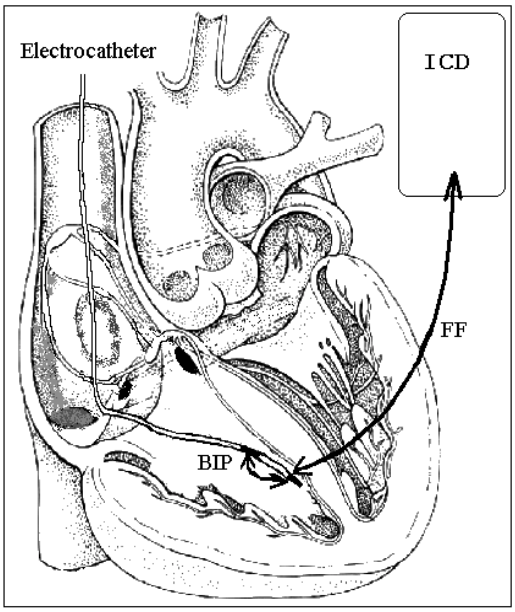

Figure 1: Bipolar (BIP) and Far-Field (FF) types of EGM recordings.

From Figure 1 we note that *bipolar* EGM (BIP in the Figure) measures the electrical heart activity between proximal and distal electrodes closed to the tip of the electrocatheter; in this way they allow an excellent monitoring of the local electrical activity. F*ar-field* EGM (FF in the Figure) measures the heart activity from the tip of the electrocatheter to the can of the device (active can); thus it permits to obtain a wider dipole which includes information about the whole electrical heart activity. In particular the measured dipole includes ventricular activity, and we expect that they can monitor also the repolarization phase expressed by the T-wave, which is very often neglected in bipolar acquisition.

This preliminary analysis has been performed on 6 subjects implanted with ICD. In Table 1 some information about the subjects are reported. All the patients were affected by Coronary Artery Disease (CAD), some of them by Dilated Cardio-Myopathy (DCM); NYHA (New York Heart Association) Class is II for all the patients.

Table 1: Information about implanted subjects (see text)

ICD	Sex	Age	Aethiology	# Bip	#FF
11118	M	75	CAD, DCM	4(3)	1(0)
11130	M	72	CAD, DCM	2(2)	
11271	F	59	CAD, DCM		2(2)
2168	M	67	CAD	4(2)	
22686	M	65	CAD, DCM		3(2)
29977	M	53	CAD		4(3)

From the 6 patients we retrieved 10 EGMs in bipolar (# Bip) and 10 EGM in Far-Field recordings (# FF). In Table 1 the number of EGM which includes both VT episode and pre-VT sinus rhythm are indicated in brackets, the remaining EGMs are obtained from the patients at the follow up and represent the basal EGM condition.

3. Results and discussion

In Figures 2 qualitative results obtained from basal heart condition are shown. All the details about phase portrait construction and D_2 estimation are not explained here, and they are described in [3,9].

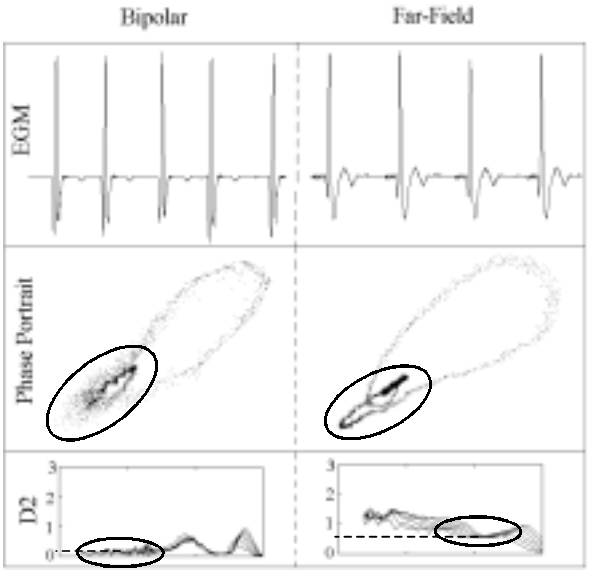

Figure 2: Results from basal EGM recordings obtained during sinus rhythm. In the Figure are shown the time series (upper panels), the bi-dimensional phase portraits (middle panels) and derivative of the log-log plots (lower panels) for bipolar (right panels) and far-field (left panels) EGM records.

Figure 2 shows typical bipolar and far-field analysis obtained from ICD EGMs when the heart is in sinus rhythm.

In the upper panels are reported the EGMs, while the corresponding bi-dimensional phase portraits and derivative of the log-log plots are shown in middle and lower panels.

Looking at the time series from Figure 2 we note that the T-wave is not visible in the bipolar EGM, while an electrical activity after each QRS complex can be identified in the far-field recording.

A deep analysis of the bi-dimensional portrait of the phase space lead to the observation that a more defined geometrical pattern is present in far-field signals, while it is more spread in bipolar (evidenced by an ellipsis). The presence of a well defined geometrical pattern in the phase portrait is a positive indication of a deterministic low-dimensional underlying dynamic. Its absence leads to the possible conclusion that the analyzed time series was generated by an high-dimensional or stochastic system. Although we do not have simultaneously recorded far-field and bipolar EGM, we are confident that this difference is simply due to the fact that far-field recording is better for this type of analysis.

This observation is confirmed by correlation dimension analysis. Looking at the derivative of the log-log plot, the important point to observe is the presence of flat intervals (evidenced by an ellipsis in the Figure), and the ordinate value corresponding to the flat intervals (indicated by dashed line in the Figure). This value can be an interesting indication of the number of degrees of freedom that the underlying system needs to produce such a time series. In practice a correlation dimension value (D_2) closed to zero indicates that the underlying system could be a fixed point (something death from the biological point of view), D_2 closed to 1 indicates a periodical activity (very regular intracardiac electrical activity), greater D2 values indicate the presence of un underlying non-linear system which requires D_2 variable to be defined, etc.

Indeed we can see from Figure 2 that in bipolar D_2 analysis there is a plateau, but the corresponding D_2 values are very closed to zero. This is clearly a pitfall since the analyzed signal is very far from being a constant value. Thus it is reasonable to conclude that the D_2=0 dimension obtained by bipolar EGMs may be due to some artifacts. In [14] similar type of artifacts have been investigated and they were shown to be related to the presence of many points of the time series at the baseline. This is very common in bipolar signal where, outside the QRS waves, practically no electrical activity is observed; this characteristic of the signal, according to [14], may yield to a strong underestimation of the correct correlation dimension value.

In conclusion also the correlation dimension analysis confirm that more reliable results are obtained using far-filed EGM recordings.

Similar consideration can be carried out from the analysis of Figure 3, where EGMs obtained at the onset of a tachycardia episode and during its course are analyzed.

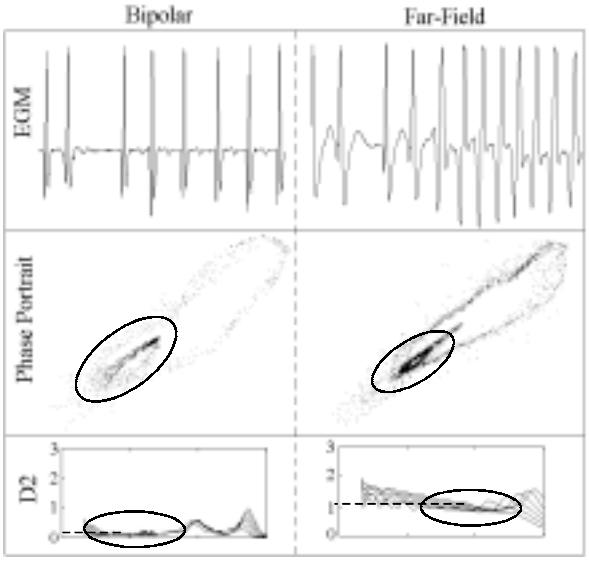

Figure 3: Results from EGMs recorded during tachycardia episodes. In the Figure are shown the time series (upper panels), the bi-dimensional phase portraits (middle panels) and derivative of the log-log plots (lower panels) for bipolar (right panels) and far-field (left panels) EGM records.

All the comments made to Figure 2 practically apply also to Figure 3 and they are not repeated here.

Although it is not the aim of this work to compare between deterministic chaos analysis performed on sinus rhythm EGMs vs. VT episodes, a remark about this point can be addressed, now. As it can be seen from the Figures 2 and 3, although the far-field analysis of both cases of basal heart condition and VT episode give D2 values very low, it is quite common to obtain D2 values slightly higher when VT episodes are analyzed. In the bipolar recordings results closed to zero are often obtained in both cases. Analyzing far-field signals instead, in our data set, we roughly found that basal condition leaded to D2 values closed to 0.7-0.9, while VT episodes leaded to D2 values closed to 1 or slightly higher. Still it is the opinion of these authors that no conclusion about the dynamics of basal heart condition nor VT heart condition can be drawn until the number of analyzed EGMs will be sufficiently high. This to avoid misleading conclusion, as

it already happened in the past dealing with deterministic chaos methods [15].

4. Conclusion

In the last decades Implantable Cardioverter Defibrillators (ICDs) showed to be important devices to prevent sudden cardiac death. Some of these devices are able to make intracardiac EGM recording triggered by recognized malignant ventricular tachycardia episodes.

In this paper we analyze 20 EGMs obtained from 6 St Jude Medical ICDs implanted in cardiac patients. These devices allow two types of EGM recordings: bipolar (monitoring with care local intracardiac activity) and far-field (monitoring whole heart activity).

The analysis is carried out using deterministic chaos methods, namely the phase space reconstruction and the correlation dimension estimation.

Aim of this paper is to investigate which type of EGM recording is more indicated when the intracardiac electrical activity is studied by means of deterministic chaos methods.

Although the number of cases is still very limited, results show that far-field recordings allow more detailed reconstruction of the state space, likely because they include important information about the whole cardiac substrate which are not present in bipolar signals.

Thus, far-field EGM analysis seems to be more indicated than bipolar EGM analysis to insight whole heart activity.

It is the opinion of the authors that these studies might lead in the future to the definition of markers for short time prediction of malignant tachyarrhythmias onset.

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