Quantitative Relation between Chaotic Features of Surface Electrocardiogram and Intracardiac Electrogram

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Abstract

The aim of this research is to find relations between chaotic features of the Intracardiac Electrogram signal and the surface ECG based on Partial Least Square (PLS) Regression. Intracardiac Atrial Fibrillation database from Physionet (IAFDB) is selected database for this paper, and Correlation dimension (CD), Largest Lyapunov Exponent (LLE) and Spatial Feeling Index (SFI) are considered features.

Coefficients of a linear formula between the chaotic features of ECG and Electrogram were computed for each region (bipolar electrodes) by PLS Regression method. Formulas acquired for estimating CD of Electrogram using those of surface ECG in AF patients was efficient, while efforts to obtain relations for LLE and SFI did not yield significant results. Moreover, it led to an important observation that the closer bipolar electrodes were to the heart apex, the greater coefficients of lead II would be.

Results of this study propose a way to eliminate the risk of invasive procedure of Electrogram recording, reduce psychological stress of patients and reduce the cost.

1. Introduction

Atrial Fibrillation (AF) is the important cause of mortality and morbidity in most of the countries [1]. Therefore, better understanding of this arrhythmia has the effective role in its prediction and treatment. Prognosis of AF is achievable with accurate understanding of heart dynamics.

Electrocardiography (ECG) is a non-invasive record of electrical activity of heart from the body surface [5]. Another method to record heart signals is Intracardiac Electrogram (EGM) [10]. In this recording, electrodes are placed inside the heart, and they record the electrical activity of the same region of heart that they are placed on [4].

By utilizing the new information available in chaotic features, better understanding of some aspect of heart dynamics can be achieved. Common chaotic features like Correlation Dimension, Largest Lyapunov Exponent and Spatial Feeling Index were used in this paper. Literature shows that these features have significantly different for healthy vs. arrhythmic heart, men vs. women and night vs. day [2-9].

EGM signals provide interesting information about electrical activity of internal regions of heart. Up to now physicians usually extract information from time intervals in each of ECG and EGM, mean and variance of these intervals and the time position of EGM signals vs. ECG waves (P, QRS & T) [11]. However, recording of EGM signals is expensive; it has the risk of invasive procedure such as infection; and patients usually have stress for this recording.

In some studies, finding common features between ECG and EGM were considered to omit the need of EGM recording. In one of these studies, the Blind Source Separation (BSS) algorithm was used, which is a well-known method in signal processing. The AF process had been deconstructed into its independent components and from the point of view of these components it was shown that the surface ECGs include the same information as the intra atria Electrogram [12].

In this research, in order to omit the need of EGM recording for diagnosis, the chaotic features (CD, LLE and SFI) of ECG and EGM were extracted. So the exact question of this study is: How we can achieve chaotic features of EGM from chaotic features of ECG?

2. Materials and method

2.1. Data collection

In this research, data obtained from database of Atrial Fibrillation in Physionet [13]. This database consists of endocardial recordings from the right atria of five patients in atrial fibrillation. Only four data of this database were useful in this study, because, in signal of one of them the time of injecting drug is not determined. A decapolar catheter (including five bipolar electrodes) with 2-5-2mm spacing was placed in four separate regions of the heart. In each region, the five bipolar signals were recorded along with three surface ECG leads. In a Catheter, bipolar electrodes are labeled (distal to proximal) CS12, CS34, CS56, CS78 and CS90. Regions are:

AFW: The whole catheter rests against the atrial free wall

IVC: The proximal tip of the catheter (CS90) is near the annulus of the inferior vena cava

SVC: The distal tip of the catheter (CS12) is near the annulus of the superior vena cava

TVA: The distal tip (CS12) is near the tricuspid valve annulus

The database contains a set of four records (one for each placement) for each of the four patients. Each record includes eight signals (Intracardiac: CS12 - CS90, or ECG: II, V1, aVF). The placements of Intracardiac catheters are shown in Figure1. And the detail of this placement is shown in Physionet [13].

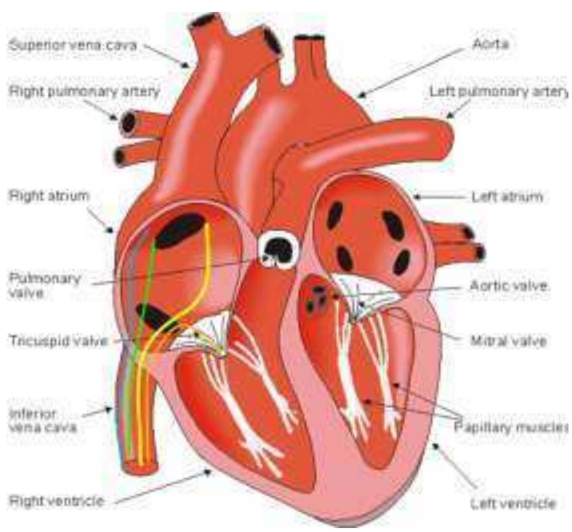

Figure 1. The placement of catheters in right atria; Blue: AFW, Green: SVC, Yellow: IVC, Orange: TVA.

2.2. Pre-processing

Pre-processing for ECG contained Baseline wander removal and notch (50 Hz) and bandpass (0.5Hz - 250 Hz) filtering because of the motion artifact but for EGM, it contained Baseline wander removal only. The frequencies of fibrillatory waves are above 4 Hz and the mentioned filtering doesn't affect on these waves.

2.3. Feature extraction

CD and LLE in the 3 dimension embedding space and SFI in 2 dimension embedding space were calculated. CD and LLE [14-16] are computed with Opentstool toolbox [17] and a program was written to calculate SFI in Matlab 7.5B [9]. Some of the different methods were studied to find the best delay for reconstructing embedding space. In Experience, the time position that Autocorrelation function is equal to 1/e (e: Euler number) become the best way to finding the finest delay [6].

CD returns the complexity of the system. The more the complexity, the more the CD would be. LLE returns the concept of divergence of neighboring trajectories and sensitivity to initial condition. LLE is positive for chaotic signals and SFI returns an index for dispersal and is used to quantify the degree of variability in the signals [7].

2.4. Statistical analysis of data

In the studied database, 4 Intracardiac catheters (AFW, IVC, SVC and TVA) are placed in the right atria of heart for each patient. For each catheter, ECG signals of 3 lead (LeadII, V1, aVF) were recorded. Therefore, for one patient, 3×4=12 signals of surface ECG exists in the database. Furthermore, for each Intracardiac catheter, 5 Intracardiac signal (from 5 place in the same catheter: CS12, CS34, CS56, CS78, CS90) were recorded. Therefore, for one patient, 4×5=20 EGM exist. In order to finding relation between chaotic features of surface ECG and EGM, Partial Least Square regression method with the use of Minitab15 software was applied. PLS is especially helpful when predictors (independent variable) are highly collinear or ordinary least squares regression produces coefficients with high standard errors. PLS reduces the number of predictors to a set of uncorrelated components and applies least squares regression on these components. PLS fits multiple response variables (dependent variable) in a single model if they are correlated. Usually, predictor variables are plotted on the x-axis and response variables are plotted on the y-axis. a_1, a_2,…,a_n are the coefficient that make the relation between x_i and y_j.

$$y_1=\text{constant}+ x_1a_1+x_2a_2+\ldots+x_na_n \quad (1)$$

In PLS there is Cross-validation method that calculates the predictive ability of potential models to determine the suitable number of components to maintain in model [18]. Leave-one-out method for cross-validation was used in this research. In this study 3 variable, chaotic features of LeadII, V1 and aVF, were determined as multiple responses. 20 variables (CS12-afw, CS34-afw… CS90-

afw, CS12-ivc… CS90-ivc, CS12-svc... CS90-svc, CS12-tva… CS90-tva) were set as independent variables in the model.

3. Result

According to the explained method, following results were obtained. At Table1, for example, for bipolar electrode CS12 on AFW catheter for chaotic feature of CD this relation was found:

$$CD_{CS12}=a_1 \times CD_{LeadII}+a_2 \times CD_{V1}+a_3 \times CD_{aVF}+Constant \qquad (2)$$

a_1= -2.2029; a_2= 2.36819; a_3=0.16934;
Constant=1.03231

In Table2, standard coefficients were computed after standardization of variables by subtracting mean from the variable and dividing the result of this subtraction into variance of variable. Normalized variables are suitable for comparing coefficients.

As shown in Table 1&2, every mathematical relation between CD of surface ECG and EGM had Probability value (Pval) less than 0.05. However, some of these relations for SFI and LLE didn't yield significant results. For example, for coefficients which estimate CS78-IVC, Pval=0.824 (Table4). As marked in red in table1&2, the closer bipolar electrodes were to the heart apex, the greater coefficients of lead II would be. Generally, for CD this qualitative relation is correct.

As marked in red in Table3, this relation is correct too. TVA catheter is shown in Figure1 in orange. This catheter is a curve; because, it is entered into the Tricuspid valve. So close or far from apex for bipolar electrodes on this catheter, are different reasonably. But for SFI tables, in general, the qualitative relation was seen rarely; that's why one or more relations have Pval more than 0.05. In Table4 and other obtained tables related to LLE this relation wasn't seen (Because Pval >0.05 in some of the quantitative relations). Here there is an example for creating relation using tables with standard coefficients for bipolar electrode CS56 on TVA Catheter for chaotic feature of SFI (As shown inTable3):

$$\text{Normalized } SFI_{CS56}= b_1 \times \text{Normalized } SFI_{LeadII} + \ldots b_2 \times \text{Normalized} SFI_{V1}+b_3 \times \text{Normalized } SFI_{aVF} \qquad (3)$$

b1= -0.00417; b2= 0.97658; b3=1.22050;

Therefore, significant relations were estimated between Correlation Dimension of surface ECG and EGM in this study. These relations propose a way to diagnose AF and other cardiac arrhythmia without EGM recording. Further investigation of the results of this paper, can reduce the number of people that need EGM for diagnosing their disease.

4. Conclusion

The aim of this study was to find formulas estimating CD, LLE and SFI of EGM using those of surface ECG.

Table 1. [1]The result of PLS for Correlation Dimension

Catheter	AFW				
electrodes	CS12	CS34	CS56	CS78	CS90
Pval	0.024	0.007	0.024	0.000	0.009
Rsquare	0.530675	0.623726	0.530586	0.797359	0.608690
Constant	1.03231	-0.34990	1.58026	1.63036	1.50875
LeadII	-2.2029	-1.45447	-0.41904	-0.25863	1.46049
V1	2.36819	1.09576	-0.77940	-0.14305	-0.52487
aVF	0.16934	1.79629	0.84718	-0.24579	-1.19411

Table 2. The result of PLS for CD with standard coefficients in AFW catheter

catheter	AFW (Standard Coefficient)				
electrodes	CS12	CS34	CS56	CS78	CS90
Pval	0.024	0.007	0.024	0.000	0.009
Rsquare	0.530675	0.623726	0.530586	0.797359	0.608690
Constant	0.000000	0.000000	0.000000	0.000000	0.000000
LeadII	-0.677272	-0.521191	-0.293994	-0.398232	0.810721
V1	0.715326	0.385785	-0.537251	-0.216411	-0.286259
aVF	0.065160	0.805617	0.743900	-0.473691	-0.829620

Table 3. The result of PLS for Spatial Feeling Index in TVA catheter

catether	TVA (Standard Coefficient)				
electrodes	CS12	CS34	CS56	CS78	CS90
Pval	0.000	0.001	0.000	0.000	0.000
Rsquare	0.931579	0.633939	0.793489	0.735127	0.723461
Constant	0.000000	0.000000	0.000000	0.000000	0.000000
LeadII	0.380966	-0.271906	-0.00417	-0.06144	-0.07771
V1	0.593188	-0.031902	-0.97658	-1.02358	-1.03461
aVF	0.030223	-0.514231	1.22050	1.16290	1.14360

[1] The result of each PLS regression is four tables for four catheters (AFW, IVC, SVC and TVA) and in this paper only one table and one catheter for each chaotic feature are shown due to the limited space.

Table 4. The result of PLS for Largest Lyapunov Exponent in IVC Catheter

catheter	IVC(Standard coefficient)				
electrodes	CS12	CS34	CS56	CS78	CS90
Pvalue	0.000	0.017	0.001	0.824	0.000
Rsquare	0.691438	0.466064	0.664074	0.029402	0.861696
Constant	0.000000	0.000000	0.000000	0.000000	0.000000
LeadII	-0.110119	-0.265878	-0.581318	0.0884196	-0.268865
V1	0.332092	-0.349597	-0.200078	0.0838076	-0.475656
aVF	0.686736	-0.250490	0.387680	0.0295077	-0.455748

Formulas acquired for estimating CD of EGM using those of surface ECG in AF patients were efficient, but formulas estimated for LLE, and SFI did not yield significant results.

We conclude that 20 regression formulas (about CD) can estimate dynamic of EGM from Surface ECG and suggest surveying this relation on more clinical experiment data.

5. Further work

In this study, some parameters such as age, gender, time of signal recording (day or night), type of drug therapy before recording and type of Fibrillation aren't considered. If these parameters are considered, it might be possible to reach the best relation between chaotic feature of ECG and EGM.

It is possible to study about other disease and their relations between chaotic features of ECG and EGM. If the result is the same, we could generalize these relations for patients with hyper pressure, progressive heart failure, etc. who couldn't have EGM recording. And find the way for simple diagnosing for their disease. The authors of this paper decided to study about these points for further work.

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