A Quantitative Analysis on the Intracardiac Electrogram Contact During Ventricular Tachycardia Ablation

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Abstract

Cardiac arrhythmias are currently treated with ablation procedures, which are guided by X-ray cameras and intracardiac electrograms (EGM) recordings. Recently, the use of catheters with force sensors have been proposed for improving the contact of the sensing catheter over the heart wall, aiming to guarantee the reliability of electrical measurements. Manufacturers of the equipment used for this type of studies have suggested that the catheter has to take a reading above or equal to 5g. We aimed to determine whether the waveform of the EGM can provide us with some information about the good contact conditions of the catheter on the endocardium, by using the recorded force as a gold standard. We first performed a correlation analysis of EGM morphology in terms of the force threshold, and then we made a multivariable analysis based on the Fisher discriminant. The database to be analyzed came from 11 patients (8 males) with mean age of 64.9 years, where 1161 EGM signals were obtained. The EGM set corresponded to the voltage maps of the left ventricle during sinus rhythm. The correlation coefficient between consecutive EGM beats larger and lower than 0.8 in EGM morphology showed similar ratios of averaged force in those beats with larger force (49% vs 46% for force>5g), 29% vs 28% for force<5g. Fisher discriminant analysis yielded error probability larger than 0.3 for the best discrimination case. These previous results show that the EGM morphology seems to have limited information about the catheter contact when scrutinized with simple signal processing methods.

1. Introduction

The function of myocite cells in the heart is to conduct the electrical impulses and to make possible the cardiac mechanical contraction [1]. Cardiac arrhythmias are characterized by changes in the cardiac frequency, due to several causes, such as automatism alterations, triggered activity, or reentry [2]. Nowadays, these alterations are treated with the so-called cardiac ablation procedure, which consists of finding the diseased area of the heart causing the arrhythmia and removing it by using two possible methods, namely, radio-frequency or low temperature application on that tissue region. The diagnosis of these affected areas in the heart is tackled with electrophysiological studies, which consist of the insertion of electrode catheters through the veins of the neck or leg for displaying and then recording the electrical activity in the heart [3]. During electrophysiological studies, an X-ray camera is used in order to determine if the catheter is properly located on the interior of the heart. In addition, these studies are also supported by intracardiac navigation systems, such as NavX® or Carto® [4, 5].

Recently, the use of catheters with force sensors have been proposed for improving the contact of the catheter over the heart wall, aiming to guarantee the reliability of the electrical measurement. The manufacturers of the equipment used for this type of studies have suggested that the catheter has to take a reading above or equal to 5g [5], the rationale for using this threshold being that the catheter is surrounded by blood, which produces a force of less than 5g interacting with the sensor. In a recent study [5], the use of the catheter with the force sensor was used to correct a voltaje map of the left ventricle obtained from navigation systems, with the purpose of determining areas of myocardial scar. The used criteria on the electrogram (EGM) amplitude were to distinguish among scar ($<$ 0.5 mV), low voltage ($0.5 - 1.5$ mV), and normal ($>$ 1.5 mV), with a reference to force higher than 5g. This criterion was taken because when reviewing the test results, the EGM amplitude was higher (lower) than 1.5mV with force lower (higher) than 5g, so that this could represent a loose contact from the catheter when acquiring EGMs with low recorded

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force.

In this work, we aimed to determine whether the waveform of the EGM can provide us with some information about the good contact conditions of the catheter on the endocardium, by using the recorded force as a gold standard. We first performed a correlation analysis of EGM morphology in terms of the force threshold, and then we made a multivariable analysis based on the Fisher discriminant criterion. For this purpose we used a database of 1161 EGM from 11 patients, previously assembled in [5].

The outline of the paper is as follows. In Section 2, the database of the cases to be studied is described. In Section 3, the conducted experimental methods are summarized, Section 4 presents the discussion and conclusions of the present work.

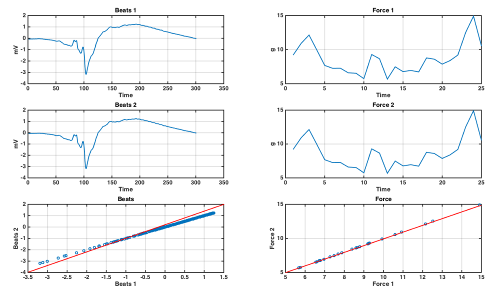
2. Patients and EGM Database

The patients data were assembled from clinical trial with identifier NCT01639365, see *clinicaltrials.gov* for details. The database to be analyzed came from 11 patients (8 males) with age 64.9 (38-80) years [5], where 1161 EGM cases were obtained. This database consisted of recordings in surface ECG and intracardiac EGM sampled at 1KHz and recordings of the force sensor sampled at 85 Hz. The EGM signals corresponded to the voltage maps of the left ventricle during sinus rhythm. The data acquisition was performed with navigation systems Carto®3 [6] and Navistar catheter Thermo Cool [7].

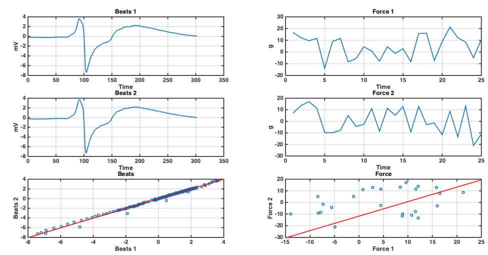
During the electrophysiological study, spatial locations were labeled as fragmented or delayed potentials, and color coded maps were adjusted to locate voltage channels (control map). The force information was registered by the system at each point, but the operator did not have it available for the acquisition of the control map. After, the operator was offered contact information and he proceeded to new catchment areas points to correct improper contact at those previously acquired (final map). The contactless points in the control map were classified as scar (< 0.5 mV), low voltage ($0.5 - 1.5$ mV), and normal (> 1.5 mV) in the original study.

3. Methods

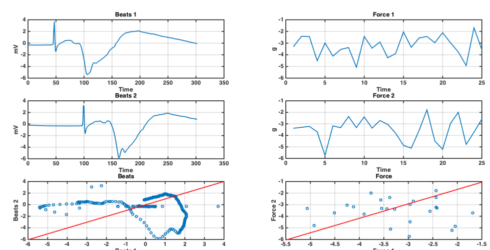
In the present study, we compared the morphology of the beat and force signal, by using statistical methods, as described next. The data classification was done by using classical statistical criteria, including Correlation Analysis for straightforward comparison and multivariable analysis in terms of Fisher Discriminant. In this section, we summarize both methods.



(a)



(b)



(c)

Figure 1. Examples of correlation analysis between two nonconsecutive beats and the signals recorded by the force sensor catheter: (a) Example of EGM and force CC higher than 0.8 (b) Example of EGM CC higher than 0.8 and force CC lower than 0.8; (c) Example of EGM and force CC lower than 0.8. Diagonal in red.

3.1. Correlation Analysis on Morphology

Linear correlation coefficient (CC) ($\sigma_{x,y}$) (1) is defined as the ratio between the covariance and the product of the standard deviations of two random variables X and Y, as follows,

$$\sigma_{x,y} = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \quad (1)$$

where σ_{xy} is the covariance between X and Y variables, and σ_x (σ_y) is the standard deviation of X (Y) variable.

For the present analysis, we fixed a threshold of 0.8 for CC indicating high positive relationship [8], i.e., two signals are considered as highly similar when their CC is larger than this threshold In Figure 1(a), an example is shown for which EGM and force CC are in both larger

Table 4. Classification of beats morphology, using the criterion of correlation with a threshold of 0.8 and standard deviation lower than 2 of the signal of the force sensor in the catheter.

Beat	$\sigma_{x,y}$ > 0,8			$\sigma_{x,y}$ <0,8		
	747			414		
Force	$f_1\&f_2$ >5	$f_1\&f_2$ <5	Other	$f_1\&f_2$ >5	$f_1\&f_2$ <5	Other
	371	220	156	194	116	4
$\sigma_1\&\sigma_2$ >2	216	54	60	124	39	39
	58,22%	24,55%	38,46%	63,92%	33,62%	37,50%
$\sigma_1\&\sigma_2$ <2	65	99	33	25	37	22
	17,52%	45,00%	21,15%	12,89%	31,90%	21,15%
Other	90	67	63	45	40	43
	24,26%	30,45%	40,38%	23,20%	34,48%	41,35%

Table 5. Classification of morphology, using the criterion of correlation with a threshold of 0.8. The correlation with a threshold of 0.8, mean higher than 5g and standard deviation lower than 2 of the signal of the force sensor in the catheter.

Beat	$\sigma_{x,y}$>0,8					
	747					
Force	$\sigma_{x,y}$>0,8			$\sigma_{x,y}$<0,8		
	76			671		
	$f_1\&f_2$ >5	$f_1\&f_2$ <5	Other	$f_1\&f_2$ >5	$f_1\&f_2$ <5	Other
	68	6	2	303	214	154
$\sigma_1\&\sigma_2$ >2	51	3	2	165	51	58
	75,00%	50,00%	100,00%	54,46%	23,83%	37,66%
$\sigma_1\&\sigma_2$ <2	10	0	0	55	99	33
	14,71%	0,00%	0,00%	18,15%	46,26%	21,43%
Other	7	3	0	83	64	63
	10,29%	50,00%	0,00%	27,39%	29,91%	40,91%
Beat	$\sigma_{x,y}$<0,8					
	414					
Force	$\sigma_{x,y}$>0,8			$\sigma_{x,y}$<0,8		
	9			405		
	$f_1\&f_2$ >5	$f_1\&f_2$<5	Other	$f_1\&f_2$>5	$f_1\&f_2$ <5	Other
	9	0	0	185	116	104
$\sigma_1\&\sigma_2$ >2	8	0	0	116	39	39
	88,89%	0,00%	0,00%	62,70%	33,62%	37,50%
$\sigma_1\&\sigma_2$ <2	0	0	0	25	37	22
	0,00%	0,00%	0,00%	13,51%	31,90%	21,15%
Other	1	0	0	44	40	43
	11,11%	0,00%	0,00%	23,78%	34,48%	

Table 1. Classification of beats morphology, using the criterion of correlation with 0.8 threshold.

Beat	
$\sigma_{x,y}$ >0,8	$\sigma_{x,y}$ <0,8
747	414
64,34%	35,66%

Table 2. Classification of morphology and beat signal of the force sensor located in the catheter, using the criterion of correlation with 0.8 threshold.

Beat	$\sigma_{x,y}$ >0,8	$\sigma_{x,y}$ <0,8
	747	414
Force		
$\sigma_{x,y}$ >0,8	76	9
	10,17%	2,17%
$\sigma_{x,y}$ <0,8	671	405
	89,83%	97,83%

than the threshold. Similarly, Figure 1(b) (and (c)) shows examples where the correlation is higher than 0.8 for EGM but lower than 0.8 for force (lower than 0.8 for both). We compared in our analysis for each EGM signal two non-

Table 3. Classification of beats morphology, using the criterion of correlation with threshold 0.8 and mean higher than 5g of the signal of the force sensor in the catheter

Beat	$\sigma_{x,y}$ >0,8	$\sigma_{x,y}$<0,8
	747	414
Force		
$f_1\&f_2$ >5	371	194
	49,67%	46,86%
$f_1\&f_2$ <5	220	116
	29,45%	28,02%
Other	156	104
	20,88%	25,12%

consecutive heartbeats and their corresponding force sensor readings. Under this criterion, the first classification was made by matching the morphology of the EGM, then the force sensor data related during each beat, and finally the combination of both groups.

According to criteria issued by cartography cardiac systems manufacturers [9], the EGM reading can be considered as correct (in terms of catheter contact) when the average strength of the sensor exceeds 5g. Hence, we classified the beats into 3 groups: (a) averaged force in beats 1 and 2 is greater than 5g threshold in both; (b) averaged force in beats 1 and 2 is lower than 5g threshold in both; (c) averaged force is greater than the threshold in one beat but lower in the other.

As shown in Table 1, this simple analysis determined that applying the criterion of correlation beats, the 64.34% of cases exhibited a high correlation. In Table 2, the classification with threshold-correlation criterion yielded that within the subgroup of beats with high correlation, 10.17% of cases satisfied the condition of maintaining a correlation above the threshold in the signals emitted by the sensor force, whereas in the sub group of beats with low correlation, 2.17% of cases raised satisfied the condition.

By relating the mean force expressed in Table 3, in the high correlation subgroup the 49.67%, met this condition, while in the low correlation subgroup the 46.86% met the condition, showing in this case a very similar distribution in the two sub groups.

By including the parameter of less than 2 standard deviation, as seen in table 4, it was determined that within the subgroups classified for high correlation and the average force greater than 5 g, the 17.52% fulfilled the conditions, whereas the average subgroups in their low correlation and force minor than 5 g, 12.89%, mets the conditions.

Table 5 shows an additional analysis in which the correlation parameters are involved, and mean strength and standard deviation are presented. By maintaining the criterion that indicates whether the correlation is high for the EGM, the correlation strength is high, the average power is greater than 5 and the standard deviation would be less than 2, this measure would be accepted as valid. In this case 10.29% of cases meet the conditions. Keeping classical statistical criteria to classify these cases, it was determined that high correlation in the beating occurs at a rate of 64.34%.

3.2. Fisher Discriminant Analysis

A simple approach with Fisher Discriminant Analysis consisted on building the input space with all the samples in a beat for both the EGM and the force signals (mean and standard deviation for each available beat in a series of two consecutive ones). We changed the threshold for classifying into contact vs non contact, to scrutinize the relevant information in the waveforms. A trend to improve classification is seen at high CC threshold (Fig. 2), which should be scrutinized with other input parameters.

4. Conclusions

The determination of the contact by just analyzing the morphology of EGM and force signals with simple methods does not yield enough quality. Oncoming work is devoted to extend this work to nonlinear methods and to establish a clearer experimental analysis setup.

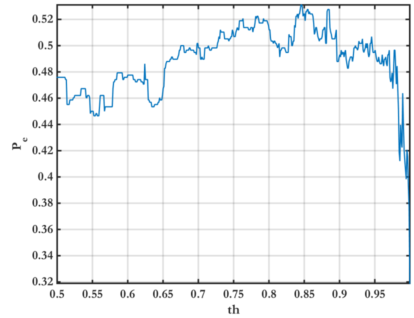


Figure 2. Error probability as a function of CC used as threshold for Fisher Discriminant Analysis.

Acknowledgements

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