Modifications on Regularity and Spectrum of Ventricular Fibrillation Signal Induced by Physical Training

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Abstract

The objective of this work is to study the modifications on cardiac response during ventricular fibrillation (VF) induced by physical training. The analysis was performed in the frequency domain of VF, and the regularity of the signal was also considered.

Two sets of records were acquired: control (G1: without physical training, N=10), and trained (G2, N=9). Cardiac registers were obtained using a 240-electrodes matrix located on left ventricle of isolated rabbit heart. A Langendorff system was used to maintain the heart perfusion. VF was induced by increased frequencies.

To analyze the time course of VF, records were processed in 4-second segments. For every segment and channel, Welch periodogram with Hanning window, two non-overlapped sections and zero padding, was computed. Parameters considered in frequency domain are: dominant frequency (DF) and normalized energy (NE: spectral energy in the window DF±1Hz, normalized by spectral energy in 5-35Hz band).

For every segment and channel, a regularity analysis of VF was performed, obtaining the regularity index (RI), which is a measure of similarity among local activation waves present in every channel.

Mean values for the parameters (DF, NE and RI) of the whole set of electrodes were computed for every segment. Obtained results show that DF is lower for trained rabbits (G1: 18.234±1, 241Hz; G2: 14.370±0, 866Hz; p<0.001). NE is greater for this group (G1: 0.140±0.006; G2: 0.263±0.017; p<0.001), suggesting a greater spectral concentration around DF. Finally, a greater regularity has been observed in the fibrillation signal for trained group (IR, G1: 0.756±0.026; G2: 0.834±0.014; p<0.001).

As a summary, the results suggest that both spectral characteristics and regularity of VF signal are clearly different for G1 and G2 groups. The trained group (G2) shows greater regularity, lower DF and spectral dispersion. These factors should be interpreted as a more stable cardiac response to VF

1. Introduction

Different authors propose that physical exercise produces a protective effect against cardiac arrhythmias due to the modification of the sympathetic-vagal balance in the autonomic nervous system. This fact produces an increase of the parasympathetic activity generating a decrease of the cardiac frequency [1,2]. Other studies have shown that sudden death might appear more often in case of a decrease the parasympathetic tone [3], as well as an antiarritmic effect when vagal activity increase [4].

Nevertheless, there are not clear results about the intrinsic heart effects of the regular physical training. It has been observed an increase of the action potential duration of the ventricular cardiocites [5]. Thus, it is needed to study the modifications of other miocardic excitability parameters such as the refractoriness, which is correlated with the spectral DF [6].

The objective of this work is to study the intrinsic modifications on cardiac response during ventricular fibrillation (VF) induced by physical training. Isolated hearts have been used, which eliminates the influence of the autonomic nervous system. In addition, myocardial perfusion has been maintained during the arrhythmia, allowing to study VF in stable conditions without the effect of other factors like metabolic deterioration, which can introduce time and spatial modifications on activation patterns during VF.

The analysis was performed in the frequency domain of VF, and the regularity of the signal was also considered. The Regularity Index (RI), proposed by Faes et al. for atrial fibrillation [7,8], quantifies signal regularity by analyzing the similarity of Local Activation Waves (LAW) along a temporal window. Due to the fact that the analysis of regularity compares only the morphology of the LAW, other information of interest such as the period of activation is lost [9]. Therefore, this analysis is combined with spectral analysis.

2. Methods

VF mapping records were acquired in the Cardiac Electrophysiology Laboratory at the university of Valencia using a 256-channel commercial mapping system (MAPTECH, Waalre, The Netherlands). Records were acquired with a 240-electrode matrix on left ventricle of a rabbit isolated heart, perfused with a Langendorff system.

Two groups of records were considered: control (G1: without physical training, N=10), and trained (G2, N=9). The animals of G2 were trained on a treadmill following a protocol of training of certain intensity. Registers' duration is 5.5 minutes, at a sample frequency of 1 kHz. VF was induced by increasing pacing frequencies.

A pre-processing stage was implemented to analyze signal quality, rejecting those channels with low amplitude or very noisy. In order to study the time course of fibrillation, records were processed in consecutive 4-second segments. For every segment and channel, Welch periodogram with Hanning window, two non-overlapped sections and zero padding was computed. Parameters considered in frequency domain are: Dominant Frequency (DF) and Normalized Energy (NE: spectral energy in the window DF±1Hz, normalized by spectral energy in 5-35Hz band).

Regularity analysis of VF was performed obtaining RI for every 4-second segment and channel. RI is a measure of similarity degree among local activation waves for every channel. The algorithm used is a modification of the original one [7,8] to adapt it to the electrophysiological characteristics of the cardiac model used in this work [10]. The steps of the algorithm are:

1. Pass-band filtering to cancel baseline wander, atrial activity and higher frequency noise (FIR filter, order 40, pass-band: 5–35 Hz, Kaiser window).

2. LAW detection. The criterion used is based in the maximum negative derivative of LAW.

3. Obtaining activation times. It is computed the barycenter of the wave, defined as the time that divided in two equal parts the local area of the modulus of the

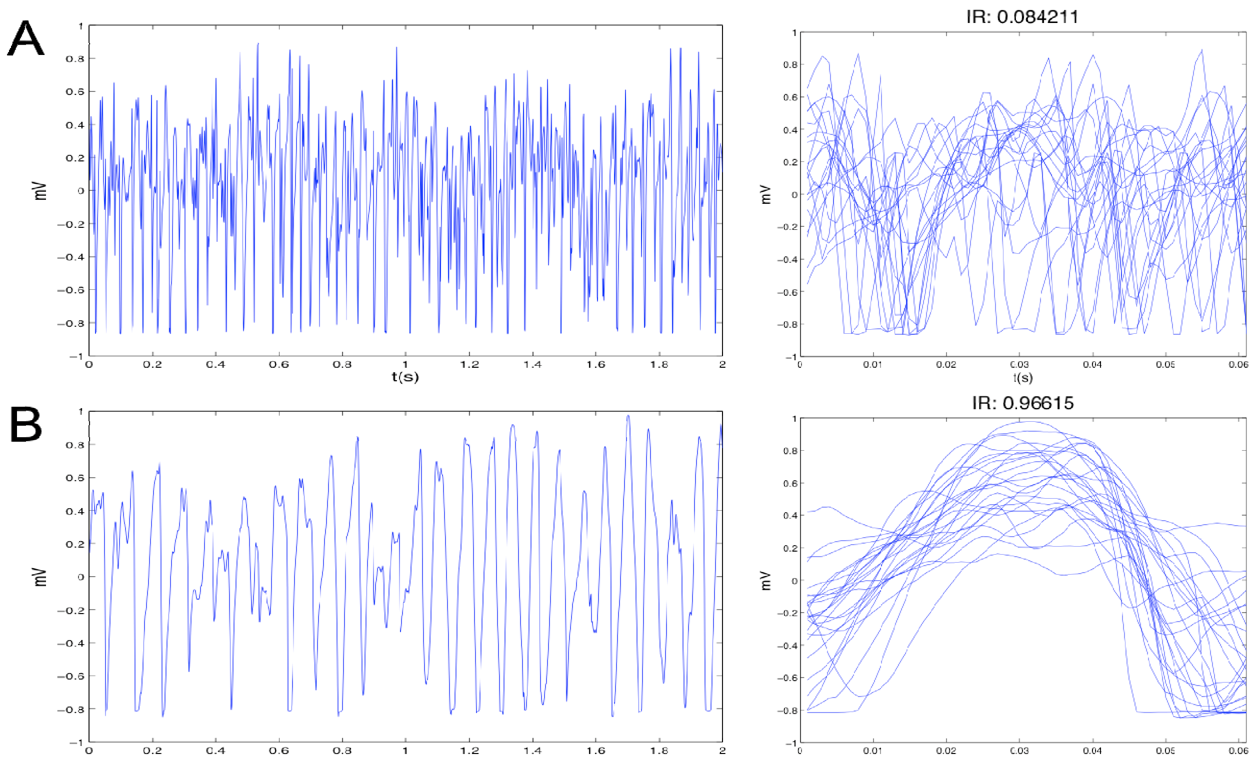

Figure 1. Example of obtained values for RI in two cases: non-trained (A) and trained (B). Left plots show VF signal and right plots show the correspondent LAW detected and superposed. RI values are higher for more regular shape waves.

signal [7]. The following transformation is applied to the signal:

$$s_f(n) = \sum_{i=0}^{(\frac{L}{2}-1)} |s(n-i)| - \sum_{i=1}^{\frac{L}{2}} |s(n+i)|$$

where L is the LAW length in samples (L=50). The activation time for every detected LAW corresponds to the ascending zero crossing of $s_f(n)$ nearest to the detection point.

4. LAW is normalized to prevent amplitude variations.

5. To evaluate the similitude between two LAW, xi and xj, their distance is calculated as:

$$d(x_i, x_j) = \arccos(x_i \cdot x_j)$$

6. To obtain the regularity index among the N activation waves detected in a channel, the distances between all the possible pairs of LAW are calculated. RI is obtained as:

$$RI_x = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}{}_{j\neq i}\Theta(\varepsilon - d(x_i, x_j))}{N(N-1)}$$

where Θ is the Heaviside function and ε is the threshold of similarity between two LAW (ε=0.8).

Figure 1 shows an example of RI values for two cases of VF obtained from two different records. In the right plots, detected LAW are superposed to show pattern differences. In case A (G1), there is a high variability in the morphology of the LAW, generating a low value of RI. In case B (G2), the pattern regularity of the LAW is higher, and RI is higher too.

For every segment, a map with the value of the parameter for each of the 256 electrodes was generated. Figure 2 shows the corresponding maps to DF, NE and RI.

For every parameter, group differences have been analyzed using a Student-t test for two independent samples, and the variance homogeneity was determined by Levene's test.

3. Results

The mean values for the parameters (DF, NE and RI) of the whole set of electrodes were computed for every time segment. Table 1 shows the average results for both dataset groups.

As observed in the table, DF is remarkably lower for trained rabbits, as in case of autonomic nervous system influence. Therefore, physical training seems to have intrinsic effects in the electrophysiological characteristics of the cardiac cells.

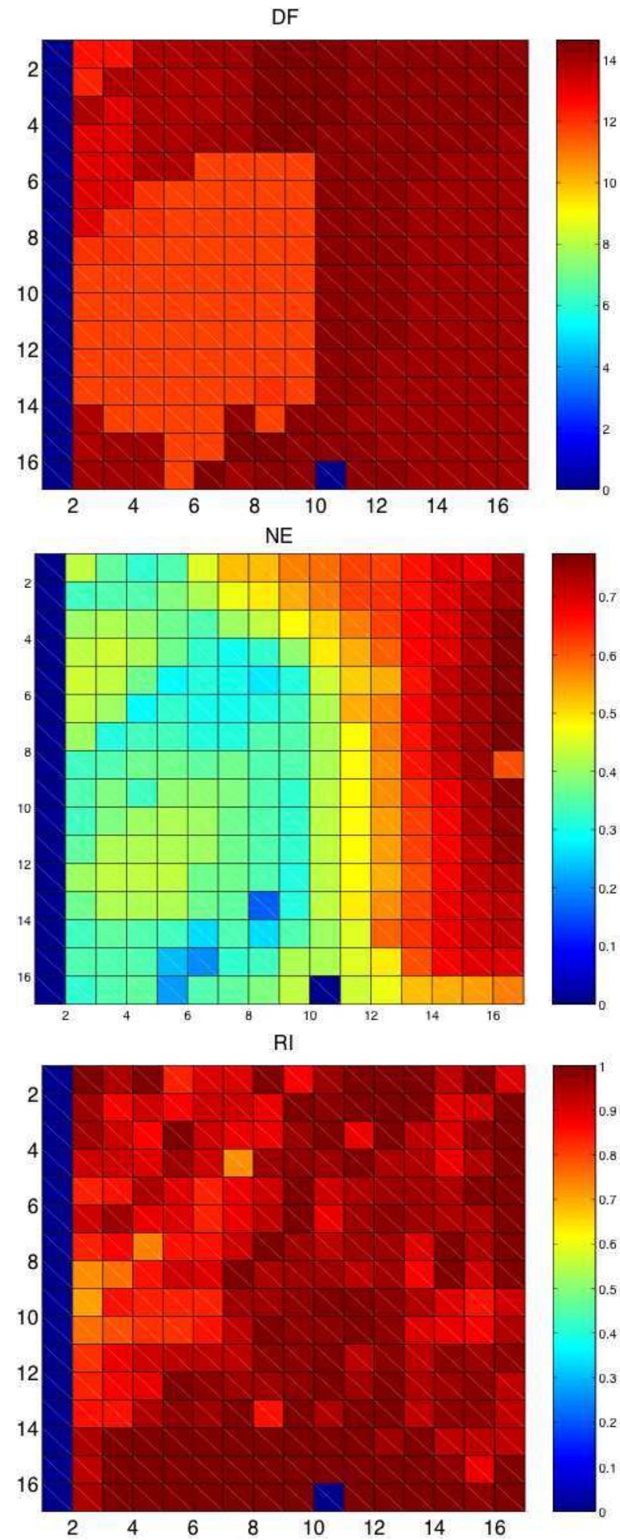

Figure 2. Maps of DF, NE and RI generated for the matrix of electrodes at a time segment. Axes represent the row and column index of the matrix.

GROUP	N	DF	NE	RI
1	10	18.234±1.241	0.140±0.006	0.756±0.026
2	9	14.370±0.866	0.263±0.017	0.834±0.014
p		< 0.001	< 0.001	< 0.001

Table 1. Results of the parameters (average and standard deviation). Group: 1 (non-trained), 2 (trained). N: number of cases. DF: dominant frequency (Hz). NE: normalized energy (n.u.). RI: regularity index (n.u.). p: statistical significance.

The results obtained for the rest of parameters exhibit a similar trend. NE is greater for G2, suggesting a greater spectral concentration around DF, namely a lower spectral dispersion. Finally, a greater regularity has been observed in the fibrillation signal for the trained group G2.

Figure 3 shows the time course of the analyzed parameters. For every time segment, the value for all the records of every group is plotted. As can be seen, DF is always lower for G2. In addition, NE and RI always exhibit greater values in the training group.

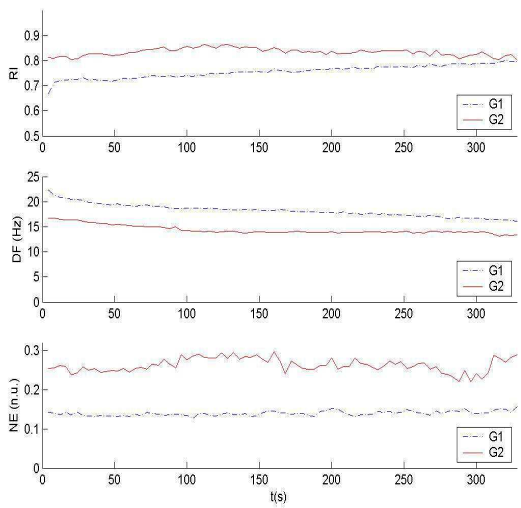

Figure 3. Time-course of the analyzed parameters for both data groups.

4. Discussion and conclusions

This work studies the intrinsic modifications of cardiac response during VF induced by physical training. Three parameters have been analyzed (DF, NE and RI) in two groups of records (non-trained and trained rabbits). The study has been performed on isolated hearts to eliminate the influence of the nervous system.

The results suggest that both spectral characteristics and regularity of VF signal are clearly different for G1 and G2 groups. The trained group (G2) shows greater regularity, lower DF and spectral dispersion. These factors should be interpreted as a more stable cardiac response to VF, and are due to intrinsic modifications in electrophysiological characteristics of heart induced by physical training.

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