

Analysis of Spatial and Temporal Evolution of Regularity Maps during Ventricular Fibrillation

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Abstract

The analysis of cardiac mapping allows investigating the structure of ventricular fibrillation (VF). This work analyzes regions of interest (ROI) on cardiac maps obtained from the regularity analysis of VF records, providing information about signal regularity at each time instant and its spatial distribution.

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. Two groups of records were considered: control (G1: without physical training, N=10), and trained (G2, N=9).

Records were processed in consecutive 4-second segments. Regularity index (RI) was obtained for every segment and channel. RI is a measure of similarity degree among local activation waves for every channel. A map with the RI value of each channel was computed for the 82 register segments.

To analyze the spatial distribution of RI, a threshold value was determined experimentally and applied to the map in order to obtain the ROI. Two parameters were calculated: ROI spatial number (ROI_{sn}, a measure of spatial fragmentation), and ROI spatial area (ROI_{sa}, the percentage of area map occupied by ROI).

In case of the time course of ROI, two additional parameters were computed: the number of electrodes which value had changed respect to the threshold in two consecutive maps (ROI_{en}, which is related with the change size), and the cumulative absolute differences of RI values for the electrodes which are changed (ROI_{ed}).

Obtained results for spatial analysis show that the number of ROI is lower for trained rabbits (ROI_{sn}; G1: 4.465±1.120; G2: 2.227±0.623; p<0.001), but ROI spatial area is greater than the control group (ROI_{sa}; G1: 76.235±5.355%; G2: 88.163±2.885%; p<0.001).

Time-course analysis shows that more electrodes change between consecutive maps in the control group (ROI_{en}, G1: 22.455±6.702; G2: 13.877±2.485; p<0.001). No significant differences were found for ROI_{ed} (G1: 18.509±6.932; G2: 18.619±4.196; n.s.).

To conclude, ROI analysis on RI maps applied to trained and no trained rabbits groups shows that VF cardiac response is more irregular and spatially fragmented in no trained group. In addition, regularity maps are more stable with time in trained group.

1. Introduction

Myocardial activation during fibrillatory processes is complex; several authors have proposed different theories to explain its origin and continuity, such as the non-uniform propagation of multiple activation fronts or the presence of mother rotors, among others [1].

The epicardic cartography of ventricular activation provides information about myocardial activation characteristics during ventricular arrhythmias, allowing a quantitative analysis of time-space distribution of cardiac fibrillatory activity [1].

Using epicardic cartography, Regions of Interest (ROI) can be defined, showing a qualitative description of image's structure. ROI have been used in multiple applications of activity detection in biosignal mapping records, as in maps of brain activation [2]. In the field of VF analysis, Choi et al [3] have applied ROI detection as a method to obtain information about the frequency dispersion produced in a fibrillatory signal over time as a function of the spatial localization, and it has also been used to determine the life-span of the ROI as a function of frequency.

Regularity index (RI), proposed by Faes et al. for atrial fibrillation [4], quantifies the signal regularity by analyzing the similarity of Local Activation Waves (LAW) along a temporal window. This work analyzes

regions of interest (ROI) in cardiac maps obtained from the regularity analysis [5] of VF records, providing information about signal regularity at each time instant and its spatial distribution.

In order to analyze the effects of physical training in the spatial distribution of VF regularity and its time-course, isolated heart rabbit has been used and myocardial perfusion has been maintained during the arrhythmia. This experiment allows to study VF under stable conditions without the effect of other factors like metabolic deterioration, which can introduce time and spatial modifications on activation patterns during VF.

The animals in G2 were trained on a treadmill following a protocol of training with specific intensity. Registers duration was 5.5 minutes, at a sample frequency of 1 kHz. VF was induced by increasing pacing frequencies.

So that the time course of fibrillation can be studied, records were processed in consecutive 4-second segments. A pre-processing stage was implemented to analyze signal quality, rejecting those channels with low signal amplitude or noisy.

The VF analysis of regularity was performed obtaining RI for every segment and channel. The algorithm used in this work is a modification of the original algorithm

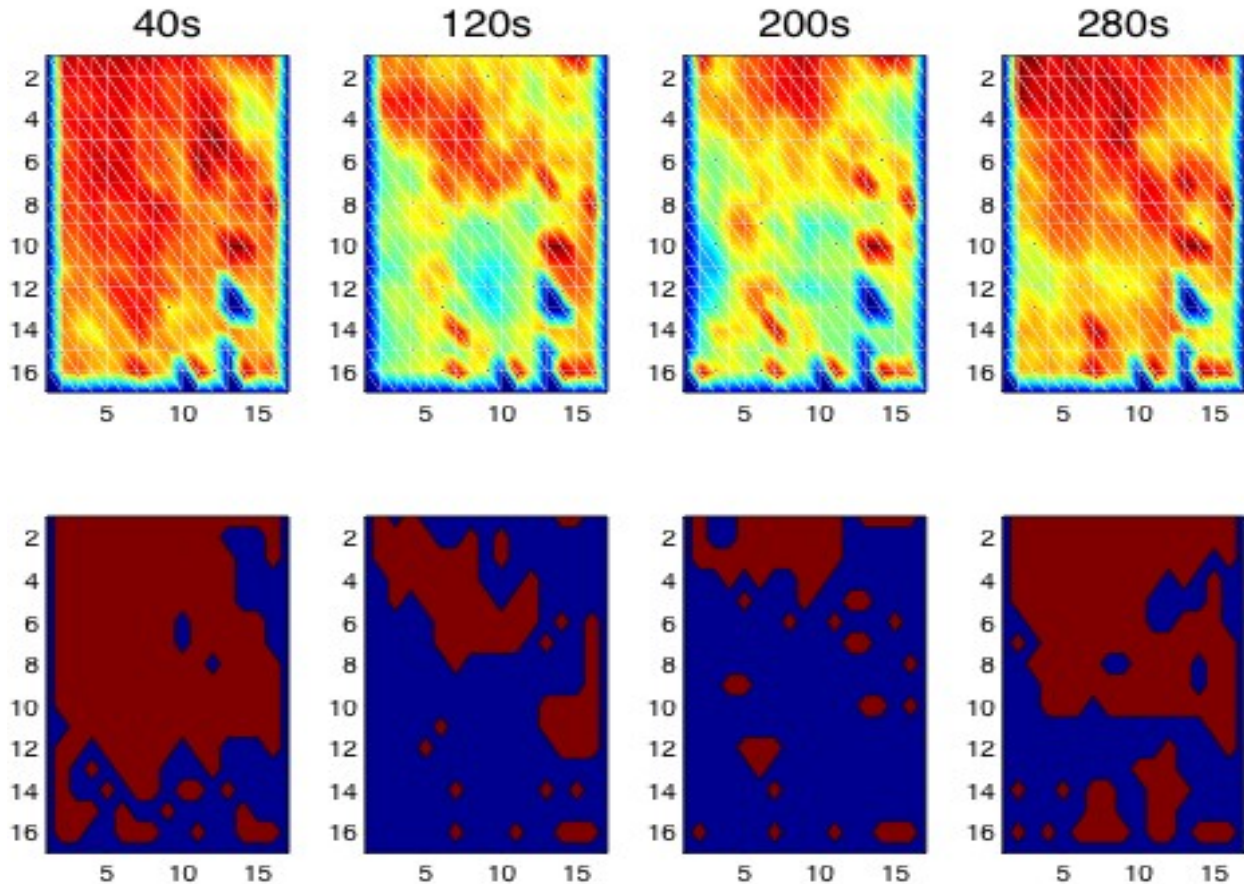


Figure 1. Example of obtained VF maps for different times from the same record. Top: RI maps. Bottom: ROI detected from the correspondent RI map. Axis: row and column index of the electrode matrix

2. Methods

VF mapping records were acquired at the Cardiac Electrophysiology Laboratory of the University of Valencia, using a 256-channels commercial mapping system (MAPTECH, Waalre, the Netherlands). Records were acquired with a 240-electrode matrix localized on left ventricle of 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).

proposed in [4] to adapt it to the electrophysiological characteristics of the cardiac model used [6].

A map with the RI value for each channel was computed for the 82 register segments. To obtain the ROI, a threshold value was assessed experimentally and applied to the map ($th_RI=0.7$). Finally, every electrode is assigned to the ROI according to the threshold value and a neighborhood criteria (close electrodes above the threshold) [7].

To analyze the spatial distribution of RI, two parameters were calculated:

- ROI spatial number (ROIsn: the number of ROI detected in the map: a measure of spatial fragmentation).
- ROI spatial area (ROIsa: the percentage of the area map occupied by ROI).

Figure 1 shows an example of RI maps for different time segments and their associated ROI. High regularity in VF produces large and grouped ROI (high ROIsa), which implies a low number of ROI (low ROIsn).

To study the time course of ROI, two additional parameters were computed:

- The number of electrodes whose value changed with respect to the threshold in two consecutive maps (ROIen, related to the change of size).
- The cumulative absolute differences of RI values for the electrodes which are changed (ROIed).

In case of figure 1, maps change over time producing fragmentations and associations of ROI, producing variations in the number of electrodes included in the ROI (ROIen). A high variability of ROIen implies variations on signal regularity.

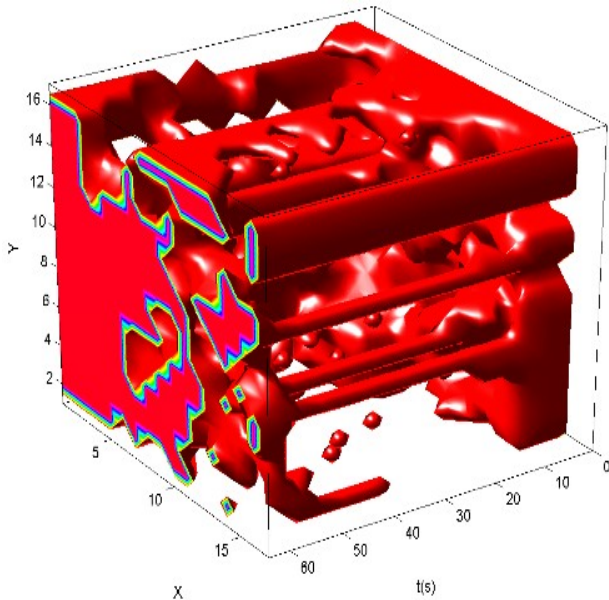


Figure 2. Time-course diagram of RI maps for a record. Axes X-Y represent the row and column index of the matrix.

Figure 2 shows an example of the time course of RI maps for a record. As it can be observed, some electrodes maintain a high regularity over time, while other electrodes show different fragmentation degrees.

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

Mean values for the analyzed parameters of the complete set of electrodes were computed for every time segment. Table 1 shows the results for both data groups.

GROUP	ROIsn	ROIsa	ROIen	ROIed
1	4.47±1.12	76.24±5.36	22.46±6.70	18.51±6.93
2	2.23±.62	88.16±2.89	13.88±2.49	18.62±4.20
p	< 0.001	< 0.001	< 0.001	n.s.

Table 1. Results of the parameters (average and standard deviation). Group: 1 (non-trained), 2 (trained). ROIsn (ROI spatial number), ROIsa (ROI spatial area, in %), ROIen (number of electrodes that change in two consecutive maps), ROIed (cumulative absolute differences of RI values for the electrodes which are changed, n.u.).

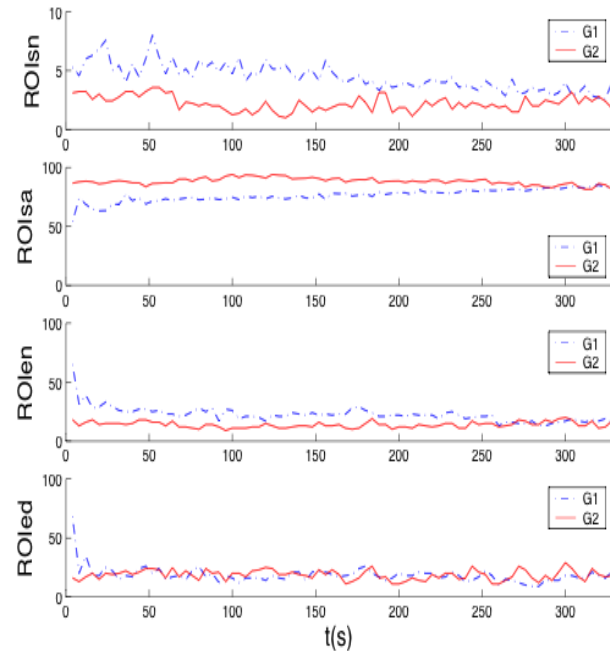


Figure 3. Time-course of the analyzed parameters for both groups. Group: G1 (non-trained), G2 (trained). ROIsn (ROI spatial number), ROIsa (ROI spatial area, in %), ROIen (number of changing electrodes), ROIed (cumulative absolute differences of RI, n.u.).

Obtained results for spatial analysis show that the number of ROI (ROIsn) is lower for trained rabbits (G2), but ROI spatial area (ROIsa) is greater than the control group (G1). The time-course analysis shows that more electrodes change between consecutive maps in case of the control group (ROIen). No significant differences were found for ROIed.

Figure 3 shows the time-course of analyzed parameters, the mean value for the records of every group

is plotted. As can be observed, ROIs number is always lower for G2, and the area of the electrode matrix with high regularity (ROI_s) is higher.

In addition, the time variation in the number of electrodes included in a ROI (ROI_n) is lower for trained group. Nevertheless, ROI_n values are similar for both groups.

4. Discussion and conclusions

This work studies the intrinsic modifications on cardiac response during VF induced by physical training analyzing regions of interest (ROI) on cardiac maps. The maps were obtained from the regularity analysis of VF records, providing information about signal regularity at each time instant and its spatial distribution.

Four parameters have been analyzed (ROI_n, ROI_s, ROI_n and ROI_d) in two groups of records (non-trained and trained rabbits). The study has been performed on isolated hearts to eliminate the nervous system influence.

A greater regularity has been observed in the fibrillation signal for trained group. The maps for G2 showed wider areas of signal regularity and lower fragmentation than in G1. In addition, this situation is more stable with time, and the ROI are more permanent in case of group G2.

These results 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.

Acknowledgements

This work was supported in part by the Spanish Ministry of Science and Innovation: Plan Nacional de I+D+I, Acción Estratégica: "Deporte y Actividad Física", project DEP2007-73234-C03-02.

References

- [1] Chorro FJ, Cánoves J, Guerrero J, Mainar L, Sanchís J, Llavador E, Such LM, López-Merino V, Such L. Cartografía epicárdica de la activación reentrante durante la fibrilación ventricular. Estudio experimental. *Rev Esp Cardiol* 2000; 53: 1356-1364.
- [2] Coulon O, Bloch I, Frouin F, Mangin J. The structure of PET activation maps. *HBM'97, Third International Conference on Functional Mapping of the Human Brain, Copenhagen, Neuroimage* 5, S391, 1997.
- [3] Choi B, Nho W, Liu T, Salama G. Life span of ventricular fibrillation frequencies. *Circ Res*, 91, 2002, pp. 339-345.
- [4] Faes L, Nollo G, Antolini R, Gaita F, Ravelli F. A method for quantifying atrial fibrillation organization based on wave morphology similarity. *IEEE Trans. Biomed. Eng.*, vol. 49, pp. 1504–1513, Dec. 2002.
- [5] Ravelli F, Faes L, Sandrini L, Gaita F, Antolini R, Scaglione M, Nollo G. Wave similarity mapping shows the spatiotemporal distribution of fibrillatory wave complexity in the human right atrium during paroxysmal and chronic atrial fibrillation. *J Cardiovasc Electrophysiol*, 2005;16: 1071-1076.
- [6] Guerrero J, Bataller M, Serrano A, Chorro J, Alberola A, Such L. Análisis de regularidad en fibrilación ventricular: aplicación a registros de mapeado cardíaco. 26th Congreso Anual de la Sociedad Española de Ingeniería Biomédica, 2008; 96-99.
- [7] Guerrero J, Chorro J, Bataller M, Muñoz J, Espí J. Análisis tiempo-frecuencia de mapas de activación cardíaca en fibrilación ventricular. 22th Congreso Anual de la Sociedad Española de Ingeniería Biomédica, 2008; 147-150

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