Modeling of cardiac arrhythmias and blockades as the unity of fractal and anti-fractal antonyms

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***Abstract* —** Different technologies were used for mathematical modeling of biological rhythms. The purpose of our study is to simulate cardiac arrhythmia and blockade as a unity of opposites, pairs of fractal and anti-fractal antonyms. We proposed and tested algorithms for solving these problems. Our concept is presented in the form of a step-by-step analysis of myocardial electrical instability. The methodology of this analysis: the initiation of electrical instability of the myocardium in a particular case; definition of arrhythmic and blockade types; search for cardiac arrhythmias and conduction components as a unity of opposites, antonyms; selection of basic and additional pairs of antonyms, oxymorons; identification of these pairs; the conversion of these results into fractal and / or anti-fractal antonyms; representation of this data in the form of graphical models. Additional investigations were included the graph theory, topology, convex analysis. The proposed algorithms, graphical models contribute to the understanding of arrhythmogenesis, triggers and resonators of these processes; improving the quality of diagnosis as a prerequisite to correct treatment.

***Keywords* —** Fractal and anti-fractal antonyms, modeling of heart electrical instability.

I. Prerequisites of Myocardial Electrical Instability Diagnosis, Modeling of Cardiac Arrhythmias and Blockades as the Unity of Opposites, Fractal and Anti-fractal Antonym Pairs

Different technologies were used for mathematical modeling of biological rhythms [1]-[2]. For example, the concept of a contracting excitable medium that is capable of conducting non-linear waves of excitation that in turn initiate contraction [2]. These kinematic deformations have a feedback effect on the excitation properties of the medium [2]. Electrical characteristics resemble basic models of cardiac excitation that have been used to successfully study mechanisms of reentrant cardiac arrhythmias in electrophysiology [2]. It's presenting of a computational framework that employs electromechanical and mechanoelectric feedback to couple a three-variable FitzHugh–Nagumo-type excitation-tension model to the non-linear stress equilibrium equations, which govern large deformation hyperelasticity [2]. Models that describe propagation in the heart generally consist of two parts: a model of the cardiac cell, and a model describing cellular interconnections [2]. Excitation of a cardiac cell is brought about by the change in potential across the cell membrane, due to transmembrane fluxes of various charged ions [2].

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It's known that discrimination of electrocardiogram (ECG) signals using non-linear dynamic parameters is of crucial importance in the cardiac disease therapy and chaos control for arrhythmia defibrillation [3]. The four nonlinear parameters considered for cardiac arrhythmia classification of the ECG signals are spectral entropy, Poincaré plot geometry, largest Lyapunov exponent and detrended fluctuation analysis which are extracted from heart rate signals [3]. Linguistic variables (fuzzy sets) are used to describe ECG features, and fuzzy conditional statements to represent the reasoning knowledge and rules [3].

The purpose of our research is modeling of cardiac arrhythmias and blockades as the unity of opposites, fractal and anti-fractal antonym pairs.

II. The Methodology of Cardiac Arrhythmias and Blockades Modeling as the Unity of Opposites, Fractal and Anti-fractal Antonym Pairs

Our concept is presented as step by step analysis of electrical myocardial instability. The methodology of this analysis:

- Initiation of myocardial electrical instability in concrete case;
- Determination of arrhythmic and blockade types;
- Searching of disturbance heart rhythm and conductivity components as unity of opposites, antonyms;
- Selection of basic and additional antonym pairs;
- Conversion of these results as fractal and/ or anti-fractal antonyms;
- Presentation of these data as graphical models by Dragon language [4].

Conversion of cardiac arrhythmias and blockades as fractal and/ or anti-fractal antonyms by genetic algorithm promote understanding of arrhythmogenesis, triggers and resonators of these processes; improve the quality of diagnosis as precondition to correct treatment.

Genetic algorithm may be fractal and /or anti-fractal producing machine. We take a pairs of chromosomes, consisting from fractals and/ or anti-fractals. Chromosome genes may be sets and anti-sets: Cantor, Julia, Mandelbrot, von Koch, Sierpinski carpet, Sierpinski Triangle, Sierpinski anti-Triangle, the Sierpinski gasket, the Sierpinski anti-gasket, Peano curve, Peano anti-curve, the Hilbert curve, Darer pentagon, Cantor square, tricorn and multicorns. As a result of crossing-over (one-, two-point or multi-point), we get new offspring chromosomes consisting from different combinations of genes.

New chromosomes allow to analyze physical, mathematical, biomedical data.

Results of modeling of cardiac arrhythmias and blockades as the unity of opposites, fractal and anti-fractal antonyms is presented on language "Dragon" [4] (fig. 1).

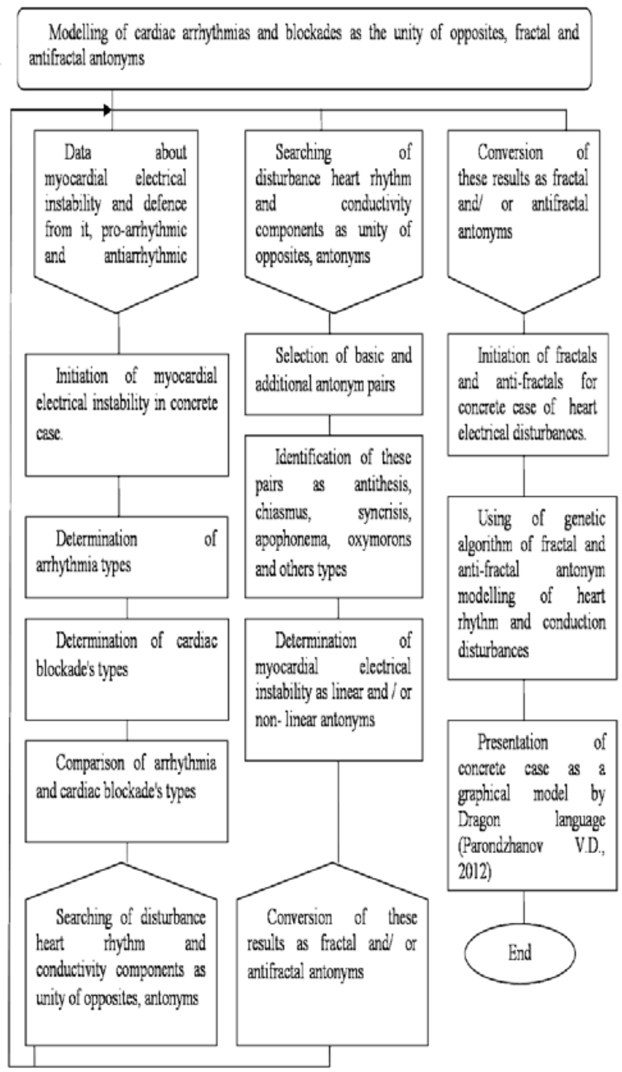

Fig. 1. Modelling of cardiac arrhythmias and blockades as the unity of opposites, fractal and antifractal antonyms

Genetic algorithm of fractal and anti-fractal antonym modeling of heart rhythm and conduction disturbances is presented on language "Dragon" [4] (fig. 2).

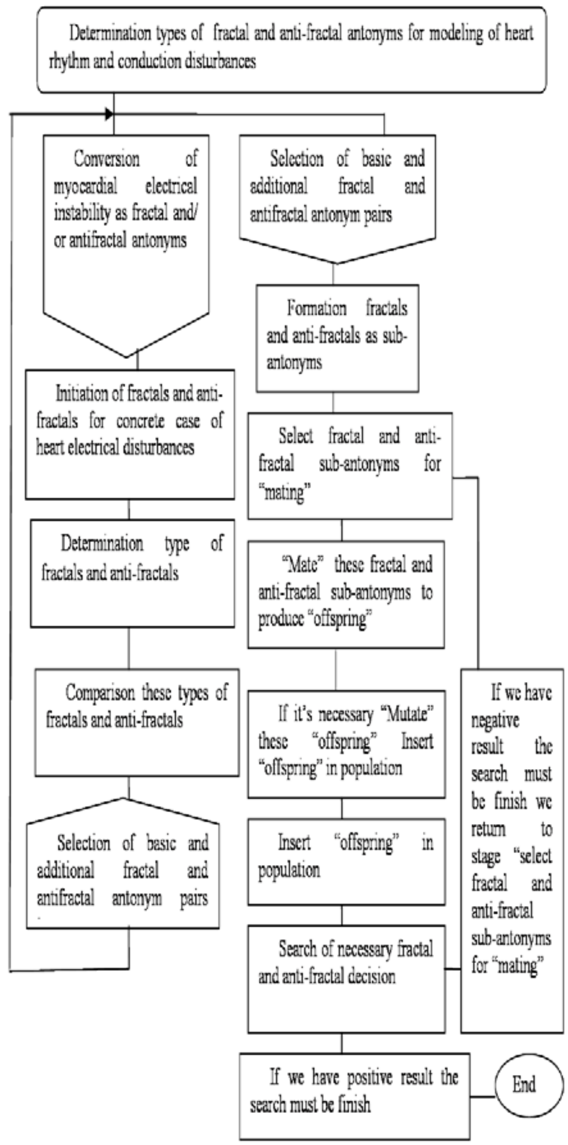

Fig. 2. Genetic algorithm of fractal and anti-fractal antonym modelling of heart rhythm and conduction disturbances

Additional investigations were included the graph theory, topology, convex analysis. We used qualitative and quantitative analysis of ECG in standard, inverted, 3D forms (as rotation bodies of ECG's elements); constructing graphs, including "Gift wrapping" algorithm. Characteristics of ECG by distance between points, perimeters, and angles of polygons of complexes allowed to determine peculiarities of electromagnetic picture, triggers and resonators of heart electrical instabilities. Analysis of graphs as networks of node-waves with their ribs can be the basis for improving the quality of diagnosis.

III. Implementation of Modeling of Cardiac Arrhythmias and Blockades as the Unity of Opposites, Fractal and Anti-fractal Antonym Pairs

Examples of linear and nonlinear antonym pathogenesis of arrhythmias and blockades as result of unity [5]:

- Sinus node dysfunction as sinoatrial blockade II stage and atrial fibrillation;
- Sinus node dysfunction as tachy- brady- syndrome – bradycardia may originate in the sinus, atria, atrioventricular junction, or ventricle; the tachycardia is usually caused by atrial flutter or fibrillation, although it can also be caused, albeit less commonly, by reentrant supraventricular tachycardia in the sinus node or atrial muscle;
- Binodal syndrome as: Sinus node dysfunction - sinus bradycardia, alternating bradycardia and atrial tachyarrhythmias (bradycardia-tachycardia syndrome), sinus pause or arrest, and sinoatrial (SA) exit block. Various supraventricular tachyarrhythmias, such as atrial fibrillation and atrial flutter. Trifascicular Block - Right Bundle Branch Block (BBBB) with Both Left anterior fascicular block (LAFB) and Left posterior fascicular block (LPFB) give AV III block.
- Both Left anterior fascicular block (LAFB) and Left posterior fascicular block (LPFB) equal Left Bundle Branch Block (LBBB);
- Both Left and Right Bundle Branch Block (BBBB);
- Bifascicular Block - Right Bundle Branch Block (BBBB) with Left anterior fascicular block (LAFB);
- Bifascicular Block - Right Bundle Branch Block (BBBB) with Left posterior fascicular block (LPFB);
- Pair racemic, pirouette ventricular extrasystoles as sum of LVE (left ventricular extrasystole) and RVE (right ventricular extrasystole);
- Sum of the ventricular extrasystole and supraventricular extrasystoles; pair ventricular- supraventricular extrasystoles - Moebius arrhythmia; substitutive rhythms;
- Mechanisms of WPW syndrome: impulse is conducted on additional pathway with functional block of usual (normal) conduction system (pathway);
- Mechanisms of left ventricular extrasystole: excitation of left ventricular with functional block of right bundle-branch;
- Mechanisms of right ventricular extrasystole: excitation of right ventricular with functional block of left bundle-branch;
- Pair pirouette ventricular premature beats accompanied by followed by serial functional blockade of both bundle-branches;
- Multitopic ventricular bigeminy with serial functional blockade of both bundle-branch block;
- Pair pirouette ventricular premature beats accompanied by followed by serial functional blockade of both bundle-branch;
- Both Left Bundle Branch Block (LBBB) and Right Bundle Branch Block (BBBB);

Examples of linear and nonlinear, fractal and anti-fractal antonym pathogenesis of arrhythmias and blockades as result of unity [5]:

- arrhythmia triggers and resonators as conduction disturbances;
- functional arrhythmia, organic conduction disturbance;
- functional and organic arrhythmia, functional conduction disturbance;
- functional arrhythmia, functional and organic conduction disturbance;
- organic arrhythmia, functional and organic conduction disturbance;
- organic arrhythmia, functional conduction disturbance;
- organic arrhythmia, organic conduction disturbance;
- functional arrhythmia, functional conduction disturbance;
- functional and organic arrhythmia, functional and organic conduction disturbance.

Examples of oxymoron pathogenesis of arrhythmias [5]: The Moebius like space orientation of depolarization processes were characterized by the change of supraventricular pacemaker and ectopic activity onto the ventricular one. In the patients with sick sinus syndrome, the Moebius like arrhythmias were displayed as a combination of supraventricular and ventricular extrasystoles, pair fibrillation and flutter transformation from atria to ventricles. The patients with complete atrioventricular block showed the Moebius like changes of depolarization /repolarization geometry as the alternation of proximal and distal ventricular rhythms [6]. The specifics of the geometry of depolarization and repolarization processes in the patients with full atrioventricular block and binodal disease can be considered in elaborating differential treatment programs to be used in microcomputers for implantable cardiac [6]. Analysis of the cardiac depolarization /repolarization geometry may serve as additional criteria for sudden death [6]. The proposed technology of solving clinical problems by system and anti-system comparison, presented as a graphical model and program by languages "Dragon", promotes understanding of complex principles of clinical medicine, improve the quality of diagnosis as precondition to change of the treatment.

Electrical instability of the heart is derived from its structural and electrical remodeling [7]-[8]. Rhythm and conduction disturbances can be represented by various known fractals and anti-fractals. Genetic algorithm for fractal, anti-fractal modeling of the heart rhythm and conduction disorders reduced to the formation of population, each person which is a chromosome, which reflects a certain type of myocardial electric instability. Each chromosome consists of genes, where each gene is a certain fractal, anti-fractal element of atrial and ventricular depolarization-repolarization changes. The criteria for selection and evaluation of its results is conformity the spatial organization of the electromagnetic processes as a combination of fractals, anti-fractals with certain spin, chirality and structural, electrical remodeling of the heart. If it’s necessary, we use the operator of mutations to improve modeling of pathogenic mechanisms, fractal and anti-fractal foundations of the heart rhythm and conduction disorders, myocardial electrical instability. The goal of making optimization and modeling decision is to achieve a compiling of individual fractal and/ or anti-fractal combination that were selected models of cardiac structural and electrical disturbances.

Rhythm and conduction disturbances can be represented by various known fractal and anti-fractal structural, electrical remodeling of the heart. So Sierpinski napkin may reflect small and large sclerotic processes in the myocardium, as a result of chronic and acute forms of coronary artery disease (fig. 3). At the same time, this kind of fractal and Cantor set may reflect multiple foci of atrial depolarization during atrial fibrillation. Koch set may be a prototype, model of CLC, WPW syndromes; left, right bundle branch blockades. Tricorn and multicorns anti-fractals can be a model of re-entry effect. Prospects for further research on modeling of cardiac arrhythmias and blockades as the unity of opposites, fractal and anti-fractal antonym pairs are additional use of convex analysis and optimization. We have some interesting results of using analysis of rotation bodies of electrocardiogram elements in the patients with rhythm and heart conductive disturbances for clarify pathogenesis peculiarities, making diagnosis decisions [9]-[10]. Characteristics of volume, surface, laminar and turbulent data, spin, chirality of rotation bodies of electrocardiogram elements give us possibilities to determine depolarization and repolarization electro-magnetic picture, Moebius strip like transitions and iteration, state of electrical heart instabilities [9]-[10]. For example, qualitative and quantitative assessment of depolarization-repolarization processes in the patients with complete blockade of the right and / or left bundle branch block allowed to differentiate myocardial infarction, postinfarction cardiosclerosis, and cardiomyopathy [9]-[10].

Principles of additional electrocardiogram analysis are presented by some examples (fig. 3,4) [11]-[15]:

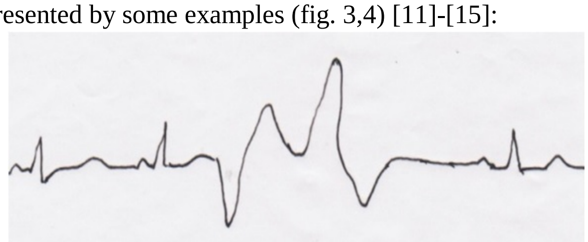

Fig. 3. Pair pirouette ventricular premature beats

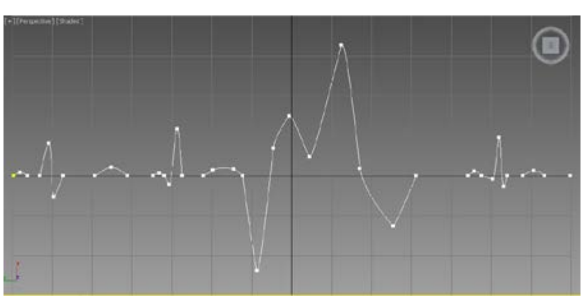

Fig. 4. Pair pirouette ventricular premature beats as scheme

Characteristics of volume, surface, laminar and turbulent data, spin, chirality of rotation bodies of electrocardiogram elements give us possibilities to determine depolarization and repolarization electro-magnetic picture, oxymoron, fractal and anti-fractal, Moebius strip like transitions and iteration, state of electrical heart instabilities [8,9].

Examples (fig. 5) [11]-[15]:

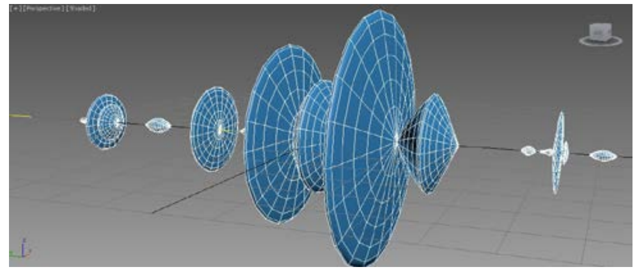

Fig. 5. Rotation bodies of electrocardiogram elements in the patient with pair pirouette ventricular premature beats [16,17,18]

3D ECG analysis opens possibilities for making differential diagnosis for Moebius strip like disturbances of heart electrical activities, as sick sinus node, binodal syndrome; for myocardial infarction and postinfarction cardiosclerosis, and cardiomyopathy; for multimorbidity [11]-[15]. .

Principles of electrocardiogram analysis by construction of the convex hull, by “Gift wrapping” algorithm for determination the relationship between the investigated electrocardiogram’s complexes as Moebius strip like constituents in the patients with pair pirouette ventricular premature beats (fig. 6) [11]-[15].

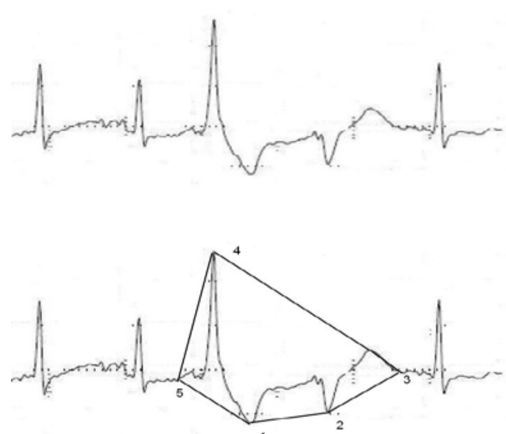

Fig. 6. The convex hull of ECG complexes as Moebius strip like constituents in the patients with pair pirouette ventricular premature beats

IV. Conclusion

Thus, the proposed technology of making electrical myocardial instability diagnosis decisions by system and anti-system comparison, formation fractal and anti-fractal cardiac arrhythmic and blockade antonym pairs.

These algorithms presented as a graphical models by Dragon language. Understanding electrical myocardial instability mechanisms improve the quality of diagnosis as precondition to treatment changes.

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