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Analysis of Electric Cardiac Signals – Methods and Application Results

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Introduction

The further progress of medical diagnostic technologies is unthinkable without development and usage of non-linear analysis methods based on chaos and complex systems theories. Till the second part of the past century the empirical and phenomenological approaches of medical data analysis and diagnostics were predominating in medicine. These methods couldn't assess the holism and complexity of human organism, as well as synergism and fractal characteristics of interactive vital systems of human organism. Synergistic concepts, ideas of dynamic chaos find wide use in analysis of real bioelectric signals. A nonlinear dynamics theory is applied for investigation of non stationary chaotic processes which are characteristic for human organism [1]. The first works in field of applying the nonlinear analysis methods in cardiology appeared more than two past decades before. In 1992 J. L. Subias published work where the heart was characterized as chaotic complex dynamic system and chaos theory methods were used for analysis of heart rhythm disorders [2]. Methods based on chaos theory were used for analysis of QT interval variability in aim to evaluate the dynamics and effectiveness of treatment for patients with heart failure [3]. The complex entropy of heart rhythm dynamics was also assessed for patients with heart failure [4]. There are a lot of works where nonlinear analysis methods are used for evaluation of heart rhythm characteristics [5–8].

One concept of presented work was try to assess the influence of physical activity to complexity of functional systems of human organism "All parts off body stay healthy, developed and slower get old, when they are used in moderation and do usual tasks. If these parts of body do nothing and stay without tasks, they leave not trained, tend to illness and quick get old". 460 – 400 years before the Christ said Hippocrates. It is obvious that exercising correctly and in time could protect us from illness, and secondly, if we got illness, the exercising could stop the progress of illness and helps to restore our health.

The main aim of this study was to calculate information dimension for parameters of integrated health evaluation model which reflect the different human physiologic functions. The next task was to evaluate behavior of information dimension in various investigated groups of persons (sportsmen, healthy persons, patients with ischemic heart disease) according to person physical activity.

Materials and Methods

The investigated contingent consisted of three groups: sportsmen (159 tests of men, 53 tests of women), asymptomatic persons (113 tests of men, 210 tests of women) and patients with ischemic heart disease (61 tests of men). These three groups involved persons with different degree of physical activity. Asymptomatic persons were divided into 6 groups according to gender (male and female) and age (20–30, 30–40 and 40–50 years). Groups of investigated persons and the mean of their age are given in Table 1.

Table 1. The number and age of investigated groups (M±SEM)

Group	Number	Age (M ± SEM)
Sportsmen	159	23.56 ± 0.40
Sportswomen	53	24.88 ± 0.65
Men	113	36.05 ± 0.60
20-30	27	28.37 ± 0.56
30-40	55	35.36 ± 0.35
40-50	31	43.97 ± 0.60
Women	210	33.97 ± 0.53
20-30	66	25.17 ± 0.44
30-40	100	35.14 ± 0.28
40-50	44	44.52 ± 0.50
Patients with ischemic heart disease	61	52.44 ± 1.56

The physical load was performed by provocative incremental bicycle ergometry and using modified Brooce protocol. The bicycle ergometry was started with 50W intensity and the power was increased every minute by 50W for men and 25W for women, and cycling frequency

60 cycles per minute was used. The loading was performed till the submaximal heart rate or appearance of clinical symptoms indicating the end of the test. A 12 lead ECG computer analysis system "Kaunas-Load", developed at the Institute of Cardiology in Kaunas University of Medicine was used [9].

We used the model of integral human organism functional state evaluation that integrates changes of three functional elements: P – periphery system (bones, muscles) , R – regulatory system (nervous), S – supplying system (heart, blood-vessels) [10]. Relation between these systems could be specified by several parameters, but we used the simplest and easier calculated ECG and arterial blood pressure (ABP) parameters: heart rate (HR), JT interval, systolic (S), diastolic (D) and pulse blood pressure (S-D).

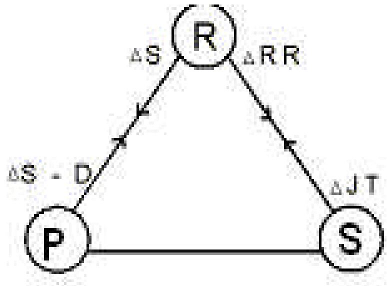

Fig. 1. Integrated model for functional state evaluation

Also we studied proportions between parameters (S-D) and S ((S-D)/S) and JT/RR, where *RR* is length of cardiac cycle. The initial data are discrete measurements in each level of load and rest for all discussed parameters.

For calculation of information dimension at first discrete points we interpolated with cubic interpolation spline [11]. Then we calculated function values in particular step h (h=0.01). During the research we found that information dimension depended on particular parameters values interval (for example heart rate can be from 50 to 220 beats per minute, JT interval can be from 0.15 to 0.36 second), so according intervals of possible changes, we normalized the initial data. Then we made the return map using calculated function values. After that, we calculated the information dimension for this map. There is algorithm for calculating information dimension.

Consider a square grid (box size ε) superimposed on an observed point pattern. Within each occupied grid unit, the number of points n_i is counted. Each count is then expressed as a proportional value:

$$P_i(\varepsilon) = \frac{n_i}{N}, \qquad (1)$$

where N is the total number of points in the set.

The "information function" is defined as

$$I \equiv -\sum_{i=1}^{N_\varepsilon} P_i(\varepsilon)\ln[P_i(\varepsilon)], \qquad (2)$$

where N_ε – the number of occupied boxes (quadrates) of size ε; $P_i(\varepsilon)$ – the natural measure, or probability that element *i* is populated, normalized so that

$$\sum_{i=1}^{N_\varepsilon} P_i(\varepsilon) = 1. \qquad (3)$$

The information dimension is then defined as

$$d_{\inf} \equiv -\lim_{\varepsilon\to 0}\frac{I}{\ln(\varepsilon)} = \lim_{\varepsilon\to 0}\sum_{i=1}^{N_\varepsilon}\frac{P_i(\varepsilon)\ln[P_i(\varepsilon)]}{\ln(\varepsilon)}. \qquad (4)$$

For the comparison of calculated information dimension, we compared the means of two populations. We assumed that distribution of information dimensions is normal, so we used two - sample t - test for means [14].

$$\begin{cases} H_0 : \mu_X = \mu_Y, \\ H_1 : \mu_X \neq \mu_Y. \end{cases}$$

Before that we did two-sample t-test for variances.

Results

In Table 2 and 3 the means of information dimension for all parameters (mean ± std) are presented.

Table 2. Means for investigated men groups

Parameter	Patients with ischemic heart disease	Asymptomatic men of different age	Sportsmen
(S-D)/S	0.48±0.12	0.65±0.14	0.77±0.13
JT/RR	0.54±0.13	0.62±0.11	0.64±0.11
RR	0.56±0.12	0.61±0.10	0.68±0.12
JT	0.56±0.12	0.62±0.11	0.67±0.10
S	0.70±0.12	0.73±0.11	0.77±0.08
S-D	0.55±0.13	0.65±0.13	0.81±0.12

Table 3. Means for investigated women groups

Parameter	Asymptomatic women of different age	Sportswomen
(S-D)/S	0.58±0.14	0.70±0.15
JT/RR	0.63±0.12	0.68±0.11
RR	0.58±0.09	0.72±0.12
JT	0.61±0.11	0.72±0.09
S	0.61±0.11	0.71±0.11
S-D	0.53±0.14	0.69±0.15

The means of information dimension of different investigated parameters for all studied groups of men are shown in diagram form (Fig. 2). We can observe the significant differences of means for all parameters. The means of information dimension for patients with ischemic heart disease are smaller as compared with means in sportsmen and healthy men groups. For some parameters - (S-D)/S, S-D (pulse blood pressure) we can see even different change tendencies as compared with such for other parameters.

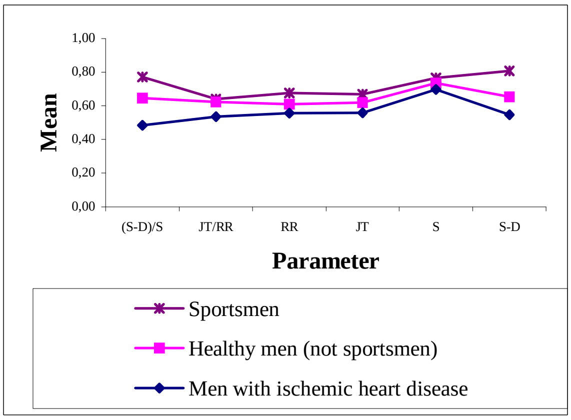

Fig. 2. The mean values ABP and ECG parameters for various groups of investigated persons

Two-sample t-test for means showed that in most cases means of information dimension significantly differs ($p < 0.05$) between investigated groups of men, the same for women. The sample of significant differences for RR interval is shown in Table 4.

Table 4. Two-sample t-test for means results for RR interval

Compared groups		t	p
Patients with ischemic heart disease	Asymptomatic men of different age	3.185	0.002
Patients with ischemic heart disease	Sportsmen	6.596	<0.001
Asymptomatic men of different age	Sportsmen	4.802	<0.001
Asymptomatic women of different age	Sportswomen	5.905	<0.001

Means of information dimensions not differs between groups of different age ($p > 0.05$), the same for men and women (Table 5).

Table 5. Two-sample t-test for means results for RR interval in different age groups

Compared groups		t	p
Men 20-30	Men 30-40	0.521	0.604
Men 20-30	Men 40-50	0.573	0.569
Men 30-40	Men 40-50	0.502	0.599
Women 20-30	Women 30-40	0.870	0.386
Women 20-30	Women 40-50	1.056	0.295
Women 30-40	Women 40-50	0.529	0.598

Existing difference between groups with different physical activity and absence of it in groups of different age and gender but with the same physical fitness can point out conclusion, that studied information dimension could be used as a measure of human functional state or healthiness. It integrates all features of reaction to load – the load and recovery as well.

Conclusions

The received results permit to conclude that information dimension as measure of complexity could detect the new earlier undisclosed information in cardiology. The Information dimension separated out the investigated persons according to gender, disease and physical activity. Information dimension didn't depend on age in the investigated groups of asymptomatic both men and women.

Acknowledgements

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The aim was to investigate the information dimension as measure of complexity of cardiovascular system. For this purpose the corresponding algorithms and programs for calculation of information dimension have been developed. When the integral evaluation of human physiologic state is performed, it is very important to evaluate the changes of main different functional systems. We analyzed parameters that characterize these systems and their functional relations by counting information dimension and searching for differences in various investigated groups of persons - sportsmen, healthy persons but not sportsmen, patients with ischemic heart disease. The study showed that means of information dimensions in studied groups with different physical activity were significantly different. The means of information dimensions do not differ between various age groups as well as between men and women groups. Ill. 2, bibl. 12 (in English; summaries in English, Russian and Lithuanian).

А. Вайнорас, Л. Гаргасас, Р. Юрконене, В. Юрконис, Г. Ярушявичус, К. Бершкене, З. Навицкас. Анализ электрических сигналов сердца – методы и результаты их применения // Электроника и электротехника. – Каунас: Технология, 2008. – № 5(85). – C. 81–84.

Цель – оценка информационной димeнсии как меры комплексности сердечно–сосудистой системы. Для достижения этой цели была осуществлена разработка алгоритмов и программного обеспечения для определения. При интегральной оценке функционального состояния человека очень важным является определение функционального статуса каждой из основных функциональных человеческого организма как в отдельности, так и в совокупности. Мы провели исследование тех параметров, которые характеризируют эти системы и связи между ними при подсчете информационной димeнсии и поиске её разницы в величине для различных групп обследуемых людей – спортсменов, практически здоровых лиц не спортсменов, а также больних ишемической болезнью сердца. Исследование показало, что средние величины информационной димeнсии достоверно отличались для групп людей с различной физической активностью и не было различия по возрасту и роду. Ил. 2, библ.12 (на английском языке; рефераты на английском, русском и литовском яз.).

A. Vainoras, L. Gargasas, R. Jurkonienė V. Jurkonis, K. Berškienė, Z. Navickas. Elektrinių širdies signalų analizė – metodai ir taikymo rezultatai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 5(85). – P. 81–84.

Tikslas buvo nustatyti informacinės dimensijos galimybes kardiovaskulinės sistemos kompleksiškumui vertinti. Siekiant šio tikslo buvo būtina sukurti atitinkamus algoritmus ir programas, skirtas informacinei dimensijai skaičiuoti. Vertinant žmogaus funkcinę būklę labai svarbu vertinti kiekvienos iš pagrindinių žmogaus funkcinių sistemų būseną atskirai bei siejant su kitomis sistemomis. Analizavome parametrus, kurie apibūdina šias sistemas bei funkcinius ryšius tarp jų, skaičiuodami informacinę dimensiją ir vertindami jos skaitinių reikšmių skirtumus įvairiose tiriamųjų grupėse – sportininkų, sveikų nesportuojančių asmenų bei išemine širdies liga sergančių asmenų. Tyrimo rezultatai leidžia daryti išvadą, kad informacinės dimensijos vidurkiai patikimai skyrėsi trijose tiriamųjų grupėse priklausomai nuo asmenų fizinio aktyvumo, o vyrų ir moterų bei įvairaus amžiaus grupėse jie nesiskyrė. Il. 2, bibl. 12 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).