ВНУТРЕННИЕ БОЛЕЗНИ

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DIAGNOSTICS OF CHRONIC HEART FAILURE BY THE DURATION OF VENTRICULAR SYSTOLE

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The objective of the study was to investigate systolic duration on the basis of the QT interval in an ECG. We observed 246 coronary heart disease and hypertensive patients. 134 of them had a functional stress test for revealing latent heart failure. Systolic duration reflects ventricular contractile function. The difference between the values in the actual QT interval and the one corrected for the heart rate is indicative of myocardial contractile dysfunction and heart failure. We have found ventricular systole elongation in patients' ECGs, which expressly depends on heart failure severity. Functional stress tests help to reveal that in the event of asymptomatic chronic heart failure. They cause the QT interval prolongation, and therefore, contractile dysfunction of the ventricles. So, heart failure is based on contractile dysfunction of the cardiac muscle. Refs 19. Tables 2.

Keywords: systole, QT interval, myocardial contractility, heart failure, stress tests.

ДИАГНОСТИКА ХРОНИЧЕСКОЙ СЕРДЕЧНОЙ НЕДОСТАТОЧНОСТИ ПО ДЛИТЕЛЬНОСТИ СИСТОЛЫ ЖЕЛУДОЧКОВ

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У 246 больных ишемической болезнью сердца и гипертонической болезнью исследовали продолжительность систолы по величине интервала Q–T электрокардиограммы. Для выявления скрытой сердечной недостаточности 134 больным проводились нагрузочные пробы. Длительность систолы отражает сократительную функцию желудочков. Отклонение величины фактического интервала Q–T от корригированного является показателем нарушения сократимости миокарда и сердечной недостаточности. У больных установлено удлинение систолы желудочков, которое находится в прямой зависимости от выраженности сердечной недостаточности. При бессимптомном течении хронической сердечной недостаточности выявить ее помогают функциональные нагрузочные пробы. Они вызывают удлинение интервала Q–T, а значит, нарушение сократительной функции желудочков. В основе сердечной недостаточности лежит нарушение сократительной функции сердечной мышцы. Библиогр. 19 назв. Табл. 2.

Ключевые слова: систола, интервал Q–T, сократимость миокарда, сердечная недостаточность, нагрузочные пробы.

Electrocardiography is widely applied in clinical use to identify morphological changes in heart. There are some difficulties about the diagnostics of functional disorders of the heart. First of all, it refers to the study of the contractile function of the heart muscle. Usually, in routine ECG diagnostics, we can judge about this function only indirectly, in those cases where patients have disease that can be associated with heart failure (HF). Indirect signs of HF are complete bundle branch block, the decline or rise of ST segment below or above the contour line, pathological Q wave, atrial fibrillation, etc. [14].

The options of ECG application for hearty functionality studies have evidently not been exhausted yet. It is necessary to pay attention to the time parameters of the cardiac cycle which determine the rate and heart rhythm, the duration of systole, diastole, and cardiocycle. The time factor is a targeted characteristic of heart muscle rate and the heart rate in general [15]. It is the rate that governs the strength and speed of contraction and relaxation of the heart muscle. The strength and speed of contraction are well known to be determined by the cyclic actin-myosin interaction, associated with ATP hydrolysis. It is regulated by the Ca^{2+}-dependent troponin-tropomyosin complex. The maximum contractile force of the heart muscle is determined by the condition of actin and myosin connections and pulling force which can be simultaneously developed in each of those connections.

Contraction rate is determined by the time during which the actin and myosin connection develops pulling force, disconnects and releases actin centers for new interaction [2; 5]. Contraction rate is considered to be a measure of myocardial contractility. Systole prolongation may indicate impaired myocardial function [3; 16]. Increased duration of isovolumic contraction and the duration of systole in general is the result of contractile speed reduction of the process, i.e., non-simultaneous interaction between actin and myosin. The prolongation of isovolumic contraction phase increases the duration of the expulsion period, prolongs the mechanical systole, reduces initial speed in ventricular pressure. Such changes are observed in circulatory failure.

Systole prolongation can be used to detect deficiency in myocardial contractility and the detection of heart failure. Attempts to use this parameter as a systolic indicator have been unsuccessful [16], and the method has not been found useful in clinical practice. It is due to high variability of systole and its relation to the cardiac cycle.

The duration of ventricular systole is dependent on heart rate and gender characteristics of patients. With the increase of heart rate, the duration of systole is reduced, and the ratio of the cardiac cycle to systole is increased, both in patients and in healthy subjects. Therefore, the elongation of ventricular systole relatively to the cardiocycle as it is cannot indicate impaired myocardial contractility and heart failure. The duration of systole at the same heart rate is different in males and females.

The situation can be resolved by using the deviation of the actual value of the systole from the corrected one. Systole actual time can be easily determined by the size of the Q-T interval in the ECG. The due QT interval corrected for heart rate (QTcB) is calculated by Bazett's formula:

$Q-T = K\cdot\sqrt{R-R}$, where K is equal to 0.40 in females and 0.37 in males. Based on another alternative of the formula $\left(K = \dfrac{Q-T}{\sqrt{R-R}}\right)$, it is possible to determine the actual K factor for each patient and compare it with the standard value. Studies of these parameters in 132 patients have revealed almost complete identity. The difference range is 1 %, and it falls within the mathematical error. The deviation of the actual Q-T interval and corrected Q-T interval has been 17.4 % on the average, and the deviation between the actual K factor and the standard one is 17.5 %. Deviations of these parameters from the control values equally reflect one and the same process, contractile dysfunction of the ventricles. To diagnose heart failure, one of those parameters is sufficient.

In this study, we used the deviation between the actual Q-T interval and corrected QT to identify ventricular contractile dysfunction and heart failure. This technique allows to eliminate variability in the duration of systole, associated with both heart rate and gender characteristics of the patients. This rule has been confirmed in the studies of CHF patients, by the deviation ratio of the cardiac cycle from systole to the golden ratio [7; 10].

The objective of the study was to investigate the possibility of estimating the contractile function of the heart muscle and chronic heart failure on the basis of ventricular systole duration in patients with coronary heart disease and hypertension.

The study involved 246 patients with coronary heart disease (effort angina, postinfarction cardiosclerosis) and hypertension, who had obvious or latent heart failure. The age of patients ranged from 43 to 76. There were 137 males and 109 females. All patients underwent clinical, laboratory and instrumental tests: radiography, electrocardiography, and echocardiography.

To reveal asymptomatic forms of heart failure, 134 patients had a functional stress test. The control group included 45 healthy subjects (26 males and 19 females) aged 20–35. Ventricular contractile function was assessed by using the difference between the values of the actual and the reference duration of ventricular systole, expressed as a percentage. The results are shown in Table 1.

Table 1. **Prolongation of ventricular systole in CHF patients**

Title	Healthy subjects	Heart disease patients	CHF Class I	CHF Class II	CHF Class III	CHF Class IV
% deviation Q–T	0.85 ± 0.35	22.8 ± 1.5*	9.9 ± 1.2*	17.2 ± 1.2*	26.5 ± 2.2*	40.3 ± 2.3*

* $p \leq 0.01$

It was found that the index under study was only a little different from the Q-T interval corrected for the heart rate in healthy subjects. This, again, confirms the fact that the index can be used as a control parameter.

The duration of ventricular systole in the group of heart disease patients was 22.8 ± 1.5 % higher than in the control group ($p \leq 0.01$). The difference between the values of the actual and the control QT intervals depended on the degree of heart failure severity. Ventricular systole prolongation in CHF Class I patients was 5–14 % (9.9 ± 1.2 %). Moreover, the duration of systole in 20 % of CHF Class I patients was the same as the control values. With progression of the CHF increased the duration of ventricular systole (QT interval), in patients with CHF Class II the deviation of this value amounted to 15–24 %. Further increase of systole duration was observed in patients with CHF Class III (25–34 %) and CHF Class IV (over 35 %).

So, prolonged ventricular systole compared to the reference value determines not only the presence of heart failure, but also its severity. These indicators can be used to assess myocardial contractility, the identification of heart failure and its severity.

Functional stress tests are widely used in cardiology to reveal coronary circulation disorders. They can be applied for revealing asymptomatic heart failure. These tests contribute to the manifestation of latent heart pathology, not diagnosed at rest. They help to determine its severity or compensatory potential of the circulatory system. On exertion, the need for myocardial oxygen is increased. There is a mismatch between oxygen demand and its actual delivery to the tissues during the latent or overt coronary disease [4]. Lack of oxygen negatively affects the contractile function of the myocardium. Physical exercises cause the degradation of the function and increase the severity of heart failure.

To reveal latent and to confirm oligosymptomatic HF, 56 patients were involved in submaximal stress tests on a cycle ergometer. ECG was recorded before and during the exercise. 78 patients had 24-hour holter ECG monitoring. HF was revealed by the change of ventricular systole during the exercise, rather than by the ECG variability. To do so, we selected ECG segments with the minimum and maximum heart rate at daytime. The first segment of the ECG reflects the rest period, the second one — the exercise [11]. Patients were uniformly divided into 3 groups. The first group included those patients who had no signs of heart failure. The second group of patients had signs of heart failure like shortness of breath during normal physical activity. The third group included patients with obvious signs of heart failure: shortness of breath, weakness, ankle swelling.

Data pertaining to the change of systole duration before and during the exercises in healthy and sick subjects are presented in Table 2.

Table 2. **Change in time of systole in healthy subjects and patients with heart diseases during the physical activity**

Title	Percentage deviation Q-T			
	Stress tests		Holter monitor	
	Prior to the exercises	During the exercises	Prior to the exercises	During the exercises
Healthy subjects	1.3 ± 0.48	1.6 ± 0.6	1.5 ± 0.4	1.8 ± 0.7
Patients with heart diseases	16.8 ± 1.8	23.7 ± 2.3	17.4 ± 1.8	25.6 ± 2.6
Group 1	0.7 ± 0.4	11.2 ± 0.8	5.5 ± 1.3	15.1 ± 2.1
Group 2	11.6 ± 1.1	18.3 ± 1.9	15.3 ± 1.5	21 ± 2.4
Group 3	26.8 ± 2.1	37.3 ± 2.6	25.6 ± 2.1	43.2 ± 0.9

It should be noted that there was no significant difference between the indicators reflecting ventricular systole in patients who had exercise testing in comparison with patients who had 24-hour holter ECG monitoring ($p \geq 0.05$). In both cases, those changes were unidirectional during the exercise. It was found that the deviation of actual systole duration from the reference value at rest was 1.3 ± 0.48 %. During the physical exercise, it increased to 1.6 ±0.6 % ($r \geq 0.05$). These indicators were significantly different in healthy and sick subjects at rest. The actual duration of systole was higher than the correct one at 16.8 and 17.4 %, in sick subjects. During the exercise, it increased to 23.7 and 25.6 %.

Prolonged ventricular systole during exercise depended on the severity of heart failure. There were no changes of Q-T interval of the ECG in the majority of Group 1 patients. Only 6 out of 17 patients who had ECG monitoring, had prolonged ventricular systole, which is confirmed by a moderate increase in the Q-T interval (5.5 ± 1.3 %). During exercise, all patients in that group had actual Q-T prolonged in relation to the corrected Q-T interval ($p \leq 0.05$). Despite of the lack of clinical CHF symptoms, patients were detected with contractile dysfunction of the ventricles, and hence the heart failure. Patients in Group 2 presented the elongation of ventricular systole at rest, which increased during the exercise stress, so it indicates the presence of myocardial contractility disorders. Patients in Group 3 tend to significant elongation of the ventricular systole, both at rest and during exercise stress, which confirms their CHF Class III.

Hence, exercise stress promotes the detection of latent forms and confirms clinical forms of heart failure. To diagnose the HF, we can use exercise testing on a bicycle ergometer and the load during ECG monitoring. Both of these methods are widely used in the clinic for detecting painless cardiac ischemia and can be successfully used for the diagnostics of HF.

Exercise stress allows to identify myocardial contractile dysfunction in patients with heart disease, to diagnose asymptomatic forms of heart failure, and to confirm its clinical variants. The data presented confirm the statement that the systole reflects the contractile function of the myocardium, and its deviation from the reference value indicates ventricular contractile dysfunction and HF development.

The magnitude of ventricular systole deviation from the reference value, expressed in percentage, indicates not only heart failure, but also its severity. Direct relationship has been revealed between the severity of heart failure and Q-T interval prolongation relative to the corrected value. The larger the deviation between the Q-T interval and the reference Q-T interval, the higher HF class is. Physical exercise caused an increase of this indicator in patients, thus it revealed or confirmed chronic heart failure.

Previous studies have shown that prolonged systole represents ventricular contractile dysfunction. The study results have been obtained in patients with myocardial infarction and post-infarction cardiosclerosis, whose heart muscle damage is uncontroversial [12].

It has been found that the more extensive damage to the myocardium, the longer ventricular systole is. Moreover, there is direct relationship between the duration of ventricular systole and the degree of myocardial contractility disorders, detectable by echocardiography.

The more contractility is impaired, the longer ventricular systole is. The greatest prolongation of ventricular systole related to the reference values found in patients with global ventricular contractile dysfunction. Increased duration of ventricular systole may serve as a measure of myocardial contractile (systolic) dysfunction. The same pattern has been detected in patients with post-infarction cardiosclerosis.

The dysfunction of heart muscle contractility is the basis for the development of acute and chronic heart failure. In patients with chronic heart diseases, the prolongation of the interval Q-T of ECG was revealed, hence, the systolic dysfunction of the heart muscle, which is the reason for the development of heart failure.

Normal indicators of Q-T interval in some patients at rest does not mean they are free from HF. Physical exercise leads to prolonged ventricular systole, which indicates heart muscle contractile dysfunction. Such a pattern is usually observed in patients at early stages of heart disease. Myocardial contractile dysfunction and the severity of heart failure aggravate with the disease progression.

The results of these studies are completely in line with our earlier data [8; 9] on revealing heart failure based on the golden ratio of heart functioning. Deviation of ratio between Q-T interval and R-R from the golden ratio reflects heart failure severity.

Myocardial contractile dysfunction is a major reason for the development of heart failure. Ventricular systole elongation was observed in all patients with coronary artery disease and hypertension, if not at rest, then at exercise stress. This means that they have ventricular systolic dysfunction. These data do not reflect the opinion by some researchers who believe that in 20-30 % of patients with cardiovascular disease and in up to 50 % of older people, the development of heart failure is based on diastolic dysfunction, with no systolic dysfunction involved [1; 18]. Furthermore, they distinguish diastolic heart failure [13; 17; 19]. However, it is difficult to imagine that in the development of heart failure is involved, only one of the functions of the contractile process of cardiac muscle. Contraction and relaxation of the heart muscle are the two phases of the contractile process. The dysfunction of one phase incurs the dysfunction of the other phase. Apparently, such a representation is related to the lack of reliable methods for the diagnosis of diastolic dysfunction [1; 6].

In the study of cardiac cycle phases in CHF patients, we have found that this syndrome is characterized with longer systole and significantly shorter diastole as compared with control values [7; 10]. In this way, we can talk about the dysfunction of both phases of the cardiac cycle, which contributes to the development of heart failure.

Conclusion. The method of HF diagnostics based on deviation between ventricular systole prolongation and its reference value is simple and requires no additional sophisticated equipment. It is enough to record the ECG at rest, and, to reveal latent forms, during exercise. Increased duration of ventricular systole (Q-T interval at ECG) by more than 4 % indicates the dysfunction of myocardial contractility and heart failure development in patients. The magnitude of the deviation Q-T interval from the corrected Q-T can tell not only about the HF, but also about the degree of its severity. Physical exercise stress can detect asymptomatic and confirm the clinical forms of heart failure. In all patients, contractile dysfunction of the ventricular myocardium has been revealed.

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