Mathematical modelling of heart rhythm in dairy cattle

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Abstract. The article discusses the issues of mathematical modeling and processing of cardiointervalograms of cows with different vegetative regulation. An analysis of the sinus rhythm with subsequent mathematical processing of statistical parameters is presented. The work examines the variational pulsograms of an experimental group of animals, using correlation rhythmography, analyzes the scattergrams, autocorrelation clouds in cows with different levels of vegetative regulation. Studies of heart rate variability indicators for Jersey breed cows are relevant. This is a unique method that allows one to take into account the breed characteristics of cattle, predict milk productivity and increase the period of economic use. The stress index is an indicator that most fully informs about the degree of tension of the body's compensatory mechanisms, as well as about the level of functioning of the central circuit of the regulation of heart rhythm. Based on the stress index, the initial vegetative tone was calculated.

1. Introduction

The analysis of heart rate variability can be analyzed using mathematical statistics and be used as a new research method in the biomedical aspect. In this case, we can consider complex physiological phenomena that occur in the deep structures of the brain based on the registration of the sinus node.

HRV analysis is based on measuring time intervals between adjacent R-waves of ECG (R – R cardio intervals) and constructing a dynamic series of R – R intervals. This method of continuous (over a given period of time) recording the duration of the cardiac cycle is called cardiointervalography. To study and evaluate the functional reserves of the animal and human body, an analysis of the sinus rhythm is used, followed by mathematical processing of statistical parameters.

The mathematical processing of KRG allows obtaining a number of temporal, spectral, and geometric parameters, due to which an objective evaluation of the state of the autonomic nervous system, including its sympathetic and parasympathetic departments, is carried out.

The obtained variational pulsograms in animals with different initial vegetative tones were processed using correlation rhythmography. The essence of this method is that the obtained values of R – R cardio intervals (in the amount of 100 intervals) were sequentially put on the coordinate axes - abscissa axis x and ordinate axis y. As a result, clusters of points in the form of clouds, called scattergrams or autocorrelation clouds, were obtained on the graph.

The nature of the "clouds" location is as follows, the more these points are collected in a cloud, called the phase coordinates, and the more the "cloud" is received during the deposition of cardio intervals, the more pronounced the degree of variability of the cardiac sinus is. The resulting "cloud"
may turn out to be crowded - this indicates a low variability in the heart rate. According to the obtained “clouds”, when the cardio-interval is put on the x-axis and the y-axis, one can judge the presence of heart rhythm disturbance [1].

One of the founders of studies of heart rate variability and electrophysiological parameters of cattle was T.V. Ippolitova. She conducted research that included studying the resistance of highly productive cows to extreme factors. In the course of them, the author established parameters of electrocardiograms of cows in sagittal leads in the conditions of traditional industrial technology, the state of the cardiovascular system of cows was also established [2].

Orbovic E.V. studied parameters of heart rate variability and features of autonomic regulation of cardiac activity in horses using a mathematical method of analysis of cardiac rhythm [3].

In her work [4] Shapkaits O.A. studied the electrocardiographic characteristics of the heart in dogs of small breeds, such as schi-Tzu, toy Terrier, Yorkshire Terrier, which were characterized by different ages and live weight up to 10 kg and developed breed-specific criteria for the diagnosis of the functional state of the cardiovascular system. She first identified the parameters of the electrocardiogram in small dog breeds, as well as established age-related electrocardiographic features in the studied animals [4].

In this regard, the aim was to study the variability of the heart rate of animals and to analyze it with the help of mathematical processing.

2. Materials and methods
The studies were carried out in the livestock complex LLC Vakinsko Agro, located in the village of Vakino (Ryazan region, Rybnovsky district) on cows of Jersey breed in the amount of 103 heads. Clinical and electrocardiographic parameters were measured in the studied animals.

A clinical examination and a general study of the cardiovascular system were carried out according to the methods of clinical examination of animals by B.V. Usha. Clinical parameters included: examination and determination of the general condition of the animal by hairline, skin and mucous membranes [5-6].

The physiological and functional state of the cardiovascular system was evaluated by the method of heart rate variability. To record the ECG, we used the CONAN – 4.5 comprehensive electrophysiological laboratory in the frontal lead system according to the Roschevsky method 2 - 3 hours before a meal. Statistical processing of the results was carried out in Statistica 10 program with the calculation of the following parameters: arithmetic mean (M), arithmetic mean error (m), Student’s t-test. The differences were considered significant at p < 0.05.

3. Results and discussion
In the course of studying the animals, cows of the Jersey breed were divided into 4 groups based on parameters of the stress index.

The autocorrelation cloud of cows of the first group with the expected initial vegetative tone - vagotonia, is presented in Figure 1, based on the research data [7, 8].

Based on the analysis of Figure 1, the obtained “cloud”, when setting cardiac intervals on the axes, shows a crowded arrangement of points, which indicates the predominance of the parasympathetic part of the autonomic nervous system, which is characterized by a small number of cardiac contractions, which are characterized by bradycardia and a high degree of variability of cardiac sinus. Autonomous regulation circuit predominates in these animals of this group and it indicates the sufficiency of the adaptive capabilities of the body to maintain autonomic homeostasis.

The autocorrelation cloud of cows of the second group with the expected initial vegetative tone - eutonia, is presented in Figure 2, based on the study [9, 10].

The analysis of the scattergram (Figure 2) shows that the cloud of phase coordinates has a crowded position in the coordinate system and points are sufficient to talk about the predominance of the equilibrium state in this group - the parasympathetic and sympathetic equilibrium of the autonomic nervous system, due to the relatively high degrees of heart rate variability. This indicates the

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predominance of the autonomous regulation loop and the sufficiency of adaptive capabilities to maintain equilibrium vegetative homeostasis.

**Figure 1.** Scattergram of cows with initial vegetative tone vagotonia

The autocorrelation cloud of cows of the third group with the expected initial vegetative tone - sympathicotonia, is presented in Figure 3, based on the study.

**Figure 2.** Scattergram of cows with initial vegetative tone - eutonia
Based on the analysis of Figure 3, the resulting “cloud” when setting cardio intervals on the axes shows a crowded arrangement of points and the approach of points to 0, which indicates the predominance of the sympathetic department, during the central nervous system work the central circuit is included in the work of regulatory mechanisms. Autonomous regulation circuit predominates in the animals of this group, which indicates the sufficiency of the adaptive capabilities of the body to maintain autonomic homeostasis. An analysis of the scattergram obtained when processing an electrocardiogram of this kind is characteristic of animals which can be described as spending their strategic functional reserves, and even a lack of adaptive reserves for an adequate reaction.

The autocorrelation cloud of cows of the fourth group with the expected initial vegetative tone - hypersympathicotonia, is presented in Figure 4, based on the study.

![Figure 3. Scattergram of cows with initial vegetative tone - sympathicotonia](image1)

![Figure 4. Scattergram of cows with initial vegetative tone - hypersympathicotonia](image2)

The analysis of the scattergram of the cows of the fourth group (Figure 4) shows the extension of the coordinates of the points set on the axes and their crowded-stretched arrangement of points. The
resulting "cloud" of the production of electrocardiograms of animals of this group indicates a low heart rate variability and activation of the higher centers of the autonomic nervous system, the predominance of the sympathetic division and intervention of the central circuit in the work of regulatory mechanisms. This analyzed group is characterized by an increased number of cardiac contractions characterized by tachycardia and a low degree of variability of cardiac sinus. The animal’s cardiovascular system is at the stage of loading and mobilizing all its reserves, which can lead to disruption of homeostasis, that is, a shift in sympathetic activity to hyperactivity.

4. Conclusion

Thus, when analyzing the heart rate variability of the cows of the Jersey breed, we used the mathematical processing of the obtained numerical values during the decoding of the electrocardiogram. Correlation rhythmography is one of the effective methods for analyzing variational pulsograms in animals with different initial vegetative tone.

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