Seasonal Adaptation of the Cardiovascular System in Rabbits

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Analysis of the effects of seasonal changes in the myocardium on variability of arterial and intraventricular pressure in both ventricles showed that the objects of homeostatic regulation were the values of these parameters and their probability distribution. The adaptation mechanisms are mainly visualized by the analysis of the characteristics of probability distribution of the parameters (asymmetry and excess coefficients).

Key Words: *heart; seasonal patterns; adaptation; asymmetry; entropy*

Morphological analysis of rabbit myocardium during its seasonal changes revealed high variability of its structural elements, *e.g.* collagen content, numbers of capillaries and mitochondria [3,5].

We studied the mechanisms of adaptation of the cardiovascular (supra)system within the framework of seasonal morphofunctional changes in the rabbit myocardium.

MATERIALS AND METHODS

Experimental data used in this study were obtained at Department of Pathophysiology, Russian University of Peoples' Friendship, in 1984 on March 21-23, June 21-23, September 21-23, and December 21-23. Experiments were carried out on 480 intact male Chinchilla rabbits (2.6-3.5 kg). On day 21 of the first month of every season, systolic and diastolic blood pressure (BP), working intraventricular pressure (IPw) in the right (RV) and left (LV) cardiac ventricles, and the maximum RV and LV pressure (IPm) were measured every 3 h starting from 00.00 over 3 days.

For evaluation and comparison of seasonal variability, the parameters of the rabbit cardiovascular system in chronobiological experiment of 1984 were subjected to descriptive statistical analysis [2]. Seasonal arithmetic means, coefficients of variations, and seasonal indexes (seasonal percentage of the mean for all seasons) were calculated for these parameters. Asymmetry and excess coefficients were calculated for each parameter during every season in order to evaluate and compare variability of probability distribution of the values of parameters; entropic analysis was carried out on the basis of the relative entropy h notion [1,4,6] and R regulation coefficient [1,4]. In case of significant differences, asymmetry and excess of the probability distribution of the values of parameters indicate the impact of the seasonal factor for the rabbit cardiovacular work. The regulation coefficient $0<R<1$ determining the regulation mode for the parameter indicates how the probability variability of this parameter is regulated. It is assumed that at $0<R<0.1$ the regulation is stochastic, at $0.1<R<0.3$ quasidetermined, and at $0.3<R<1$ it is determined [4].

RESULTS

The data of descriptive statistical and entropic analyses are presented (Tables 1-3). Despite pronounced morphological seasonal changes in the rat myocardium [3,5], analysis of systolic and diastolic BP indicates that the mean BP values for all seasons

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are rather close (Table 1). Seasonal indexes of these parameters vary from 96 to 107% for systolic BP and from 94.3 t0 110.8% for diastolic BP. This indicates that these parameters are the objects of homeostatic regulation. Moreover, the ranges of changes in the coefficients of variations for the seasons are even narrower: 0.11-0.13 for systolic BP and 0.12-0.15 for diastolic BP, this indicating the existence of not only a contour of the functional system regulation for maintaining permanent values of its parameters, but also the adaptation potentialities of the cardiovascular system, universal for all seasons, realized by variability of systolic and diastolic BP parameters, which can be guaranteed by the stable status of this system.

On the other hand, the data demonstrating the type of probability distribution of BP values (asymmetry and excess coefficients; Table 1) indicate their pronounced variability, which suggests regarding these changes as adaptation. The asymmetry coefficient of systolic BP was significant for the spring, autumn, and winter, while the excess coefficient only for summer. The asymmetry and excess coefficients for diastolic BP were statistically significant in autumn. That is why the probability distributions of parameters with statistically significant

TABLE 1. Seasonal Changes in Systemic BP Parameters

Parameters	Spring		Summer		Autumn		Winter	
	systolic BP	diastolic BP	systolic BP	diastolic BP	systolic BP	diastolic BP	systolic BP	diastolic BP
Means	133.4±3.3	97.6±2.8	137.0±3.3	99.2±2.5	137.0±3.0	103.5±2.3	148.7±2.8	114.6±2.5
Seasonal index	96%	94.1%	98.5%	95.6%	98.5%	99.8%	107%	110.5%
Coefficient of variations	0.13	0.15	0.13	0.14	0.12	0.12	0.11	0.12
Coefficient of asymmetry	0.59*	-0.08	0.35	0.14	0.62*	0.57*	0.41*	0,02
Coefficient of excess	0.62	-0.41	0.9*	0.5	0.12	1.16	0.1	-0.3
Coefficient of regulation	0.2	0.19	0.19	0.16	0.14	0.24	0.13	0.12

Note. Here and in Tables 2, 3: $^*p<0.05$.

TABLE 2. Intraventricular Hemodynamic Parameters

Parameters	Spring		Summer		Autumn		Winter	
	LV IPw	RV IPw	LV IPw	RV IPw	LV IPw	RV IPw	LV IPw	RV IPw
Means	123.4±5.5	28.6±1.4	137.5±5.3	25.2±0.9	119.4±6.1	22.3±0.8	106.0±5.2	21.4±0.8
Seasonal index	101.5%	117.3%	113.1%	103.2%	98.2%	91.5%	87.3%	87.8%
Coefficient of variations	0.24	0.26	0.22	0.21	0.28	0.21	0.27	0.2
Coefficient of asymmetry	-0.02	0.14	-0.02	0.29	0.25	0.48*	-0.1	0.8*
Coefficient of excess	0.06	-0.06	-0.19	0.07	0.64	1.02*	-0.1	2.63*
Coefficient of regulation	0.15	0.14	0.11	0.16	0.2	0.17	0.18	0.296

TABLE 3. Characteristics of Reserve Potential of the Heart

Parameters	Spring		Summer		Autumn		Winter	
	LV IPm	RV IPm	LV IPm	RV IPm	LV IPm	RV IPm	LV IPm	RV IPm
Means	211.5±5.9	49.9±2.0	206.8±4.5	46.3±1.3	207.6±4.5	40.3±1.4	182.2±6.2	39.8±1.3
Seasonal index	104.7%	113.2%	102.4%	105.2%	102.8%	91.4%	90.2%	90.3%
Coefficient of variations	0.15	0.21	0.12	0.16	0.12	0.2	0.19	0.18
Coefficient of asymmetry	-0.23	0.55*	0.05	0.02	-0.25	0.44*	-0.5*	0.31
Coefficient of excess	0.06	0.44	1.33*	-0.07	0.4	0.68	-0.06	0.84*
Coefficient of regulation	0.14	0.17	0.26	0.12	0.19	0.2	0.16	0.19

coefficients of asymmetry or excess disagree with the normal curve, which fact should be taken into consideration in the analysis of all seasonal changes in the cardiovascular system in health and disease.

The asymmetry and excess coefficients for diastolic BP in autumn are most pronounced and significant, and hence, in this case cardiovascular function of rabbits depended, in addition to the seasonal factor, on the pronounced geomagnetic turbulence, which took place during the chronobiological experiment on September 21-23, 1984 [3,5]. Therefore, we can speak about the realization of the effects of seasonal, geo-, or heliomagnetic factors on the cardiovascular system only after analysis of the probability distributions of the studied parameters, realized in the asymmetry and excess coefficients.

One more question is how cardiovascular system integrates in the whole-body system under conditions of such variability in the values of its functional parameters. entropic analysis of empirical probability distributions of the values using the *R* coefficient of regulation really visualizes one more stable regulatory contour, providing the retention of probability distributions of this system's parameters within certain frames. The coefficient of regulation (*R*) for systolic and diastolic BP, despite the variability of the values during all seasons, remains within the quasidetermined mode of the parameter regulation: $0.1<R<0.3$ (Table 1). This mode is characterized by a certain balance between the stochastic and determined choice of regulation. It is the quasidetermined mode of regulation of systolic and diastolic BP that is utilized by a living system, as this mode promotes the optimal maintenance of these parameters' homeostasis and optimal economy of the internal energy of the system [4].

In addition to systemic BP, RV and LV IPw (Table 2) and RV and LV IPm (Table 3) were analyzed by the same method; the results of analysis of systemic BP values were confirmed in principle.

Seasonal variability of IPw values was more pronounced in comparison with systemic BP and IPm values for all seasons. Seasonal variability of IPm (except the summer LV IPm) was intermediate between systemic BP and IPw variabilities.

Seasonal differences in the $\Delta_{\text{coefficient of variations}}$ between LV and RV IPw and between systolic and diastolic BP coefficients of variations were statistically significant and positive for all seasons. The highest coefficients of variations for LV and RV IPw in comparison with systolic and diastolic BP values indicated a less stable reaction of LV and RV IPw in comparison with the systemic BP reaction, manifesting by greater changeability during adaptation to seasonal changes. The same conclusions were made when comparing the seasonal coefficients of variations of LV and RV IPw and LV and RV IPm.

It is noteworthy that changes in the seasonal variability of IPw values in comparison with systemic BP and IPm did not lead to changes in the mode of their stochastic distribution regulation, because the IP regulation coefficient (*R*) for all seasons remained within the framework of quasidetermined mode of parameters' regulation ($0.1<R<0.3$) for working and maximum IP.

Analysis of seasonal variability of *R* regulation coefficient individually for LV and RV indicated that their interactions were arranged so that the *R* coefficient of regulation for the entire heart remained virtually permanently within a narrow range, corresponding to the quasidetermined mode of regulation ($0.1<R<0.3$). This confirms the rightfulness of using the stochastic principle of integration of the cardiac functional systems in the total cardiovascular (supra) system.

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