PREOPERATIVE STATE OF AUTONOMIC REGULATION IN PATIENTS WITH ADOLESCENT IDIOPATHIC SCOLIOSIS

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Objective. To analyze the state of autonomic regulation of the heart rate in patients with adolescent idiopathic scoliosis before the upcoming surgical treatment of spinal deformity.

Material and Methods. The study included 30 patients with adolescent idiopathic scoliosis who were admitted for surgical treatment from January to April 2021. There were 28 female and 2 male patients. The heart rate variability (HRV) registration was carried out on the VNS-micro vegetotester, with Poly-Spectrum.NET software, Neurosoft (Russia). The study was conducted for 5 minutes in the supine position and for 5 minutes after the active orthostatic test. Temporal and spectral indicators of heart rate were analyzed.

Results. When analyzing HRV at rest, an increase in the temporal indicators of the heart rate and the power of high-frequency wave oscillations was recorded, which indicates both an increased activity of autonomic regulation in general and the predominance of the regulatory influence o of the parasympathetic division of the autonomic nervous system. A decrease in all spectral components during an active orthostatic test and an increase in stress index values by 3.5 times indicate a significant stress of regulatory systems.

Conclusion. Analysis of HRV in patients with adolescent idiopathic scoliosis at rest revealed increased autonomic activity with a predominant effect of the parasympathetic division of the autonomic nervous system. The state of exercise-induced energy deficit, registered after an active orthostatic test, indicates a significant preoperative stress of the regulatory systems and refers this category of patients to a group of increased risk of complications associated with hemodynamic instability.

Key Words: adolescent idiopathic scoliosis, autonomic nervous system, central regulation, autonomic regulation, heart rate variability, stress inde.

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An autonomic nervous system, presented in the body by suprasegmental and segmental levels of control, regulates all internal processes, ensures homeostasis, supplies energy to all types of vital activity and performs adaptive-trophic function [1–2]. Heart rate variability (HRV) analysis is used to study and assess autonomic regulation. This is due to the fact that it reflects not only the heart function but also the degree to which the integrative brain system aimed at adaptive regulation under various changing circumstances can work effectively, providing control over the periphery [3–5].

Nowadays HRV analysis is applied in anesthetic practice and also in patients in intensive care units. It permits to identify the stress of regulatory systems and the threat of adaptation disruption with the risk of developing critical conditions [6–8]. The relationship between the type of autonomic regulation, the disease progress, and the tolerance of various loads was shown. A close relationship between the type of autonomic regulation and the processes of adaptation to various types of activity and response to stress factors was identified in adolescents [2, 9, 10]. For example, an abnormal responsiveness of the hypothalamic-pituitary-adrenal axis in adolescents may increase stress-induced hormonal responses, which in turn raises the chance of various psychological dysfunctions [11, 12].

In some cases, adolescence is associated with the incidence of orthopedic pathology, in particular, spinal deformity. Adolescents with idiopathic scoliosis (IS) requiring surgical treatment is a special population of patients, owing to long-term exposure to multiple stress factors and also an accelerated progression of deformity in this age period. Physical limitations associated with pain syndrome, dysfunction of major organs (shortness of breath, tachycardia) in severe spinal deformities, a feeling of physical disability, anxiety and stress before an advanced procedure, and other traumatic factors result in a decrease in the quality of life and psychological maladjustment [11, 13, 14]. More specifically, the assessment of the psychological status of patients with IS showed various pathological conditions in 16 % of the examined; the most frequent were disorders with obsessive and phobic symptoms and neurotic depression [15]. Moreover, the progression of spinal deformity results in a change in proprioceptive impulses from the trunk muscles reflexively associated with the cardiovascular system. There is information that spinal deformity increases the activity of the sympathetic division of nervous system. Also, it can cause circulatory disorders [16]. Recently published data from a systematic literature review and meta-analysis on the study of HRV in children and adolescents report that post-traumatic stress disorder and stress in depression are followed by an autonomic nervous system dysfunction. Hyperactivation of the sympathetic nervous system occurs as well as a decrease in the activity of the parasympathetic nervous system causing low HRV, which may result in deterioration in the condition of the cardiovascular system [17, 18]. According to Anderson's review article [19], a decrease in HRV in injuries correlates with the risk of hypotension after administration of general anesthesia and intrathecal local anesthesia. Meanwhile, the author points out that currently no study has assessed the prognostic value of HRV analysis in patients admitted for surgery.

We have found only a few publications of domestic authors devoted to the study of HRV in scoliosis in the early stages of the disease when surgical treatment remains unnecessary [20, 21]. No data concerning similar foreign studies have been found.

The hypothesis of the study was the suggestion that spinal deformity and multiple stress factors experienced by adolescents with IS define clinically significant features of HRV.

The objective is to analyze the state of autonomic regulation of the heart rate in patients with adolescent idiopathic scoliosis before the upcoming surgical treatment of spinal deformity.

Material and Methods

Patients

The prospective cohort single-center study included 30 patients aged 13-16 with adolescent idiopathic scoliosis who were admitted for surgical treatment of spinal deformity at the Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan from January to April 2021. There were 28 female and 2 male patients.

Inclusion criteria: IS incidence, adolescence, planned primary correction of spinal deformity.

Exclusion criteria: the presence of an arrhythmia requiring drug administration that affect the heart rhythm.

Most of the patients were admitted to the hospital with the required preoperative examination results. The preoperative stage duration was minimal and comprised 1–2 days. The nature of the upcoming additional examination was explained to the patients in an individual conversation. All teenagers perceived the information with interest; there were no refusals to participate in the study.

Techniques

The heart rate variability (HRV) registration was carried out on the VNS-micro vegetotester with Poly-Spectrum. NET software, Neurosoft (Russia). Before the start of the examination, a maximally calm atmosphere was provided in the ward; inductive stimuli were excluded. The study was conducted for 5 minutes in the supine position and for 5 minutes after the exercise stress test (verticalization of a patient). – Heart rate (HR) as well as the main time and spectral indicators of HRV were analyzed. The time indicators included RRmin (ms) – the minimum interval duration; RRmax (ms) – the maximum interval duration; SDNN (ms) – the standard deviation of the RR intervals; RMSSD (ms) is the square root of the sum of squares of differences in the values of consecutive pairs of RR intervals; pNN50 (%) – a percentage of consecutive RR intervals that differ by more than 50 ms. The spectral parameters of HRV included TP (ms^2/Hz) – the total power of the spectrum; VLF (ms^2/Hz) – the spectrum power of the very low-frequency HRV component; LF (ms^2/Hz) is the spectrum power of the low-frequency component; HF (ms^2/Hz) is the spectrum power of the high-frequency component; LF/HF – the ratio of sympathetic and parasympathetic effects of HRV; SI (1/s2) is a stress index (the degree of stress of regulatory systems and centralization of heart rhythm regulation). The analysis of the data obtained was performed in comparison with the values of the physiological optimum established for this age group of patients [10].

The study was approved by the Biomedical Ethics Committee of the Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan (018/22 from Protocol 005/22 as of July 06, 2022). It also complies with international and domestic legislative documents: the ethical standards of the World Medical Association Declaration of Helsinki "Ethical Principles for Medical Research Involving Human Subjects" and the Order of the Ministry of Health of the Russian Federation No. 200n of April 1, 2016 "Concerning Approval of the Rules for Good Clinical Practice". All participants gave the voluntary consent to the study.

Statistical analysis

Statistical calculations were performed in the RStudio program (version 1.4.1106 © 2009–2021 RStudio, PBC) using R language (version 4.0.5). Shapiro-Wilk test was used to check the normality of the data distribution. The homogeneity of the variances for the data recorded at rest and during the orthostatic test was studied by Fisher's F-test. Due to the failure to comply with the necessary conditions of normality and homogeneity of variances for parametric criteria, the values between at rest and orthostatic test were compared using Mann–Whitney U-test with the calculation of the displacement (difference) of distributions as a pseudomedian of value differences and the construction of 95 % CI to assess the bias. The pairwise dependencies for the difference between the condition at rest and the orthostatic test were examined by calculating the Spearman's rank correlation coefficients and visual evaluation of the scatter graphs. The differences were considered statistically significant at the achieved significance level of $p < 0.05$.

Results

The average age of patients was 14 [13; 16]. The average pulse rate at rest was consistent with the age standard. Meanwhile, there was an irregular heart rate, as evidenced by the difference between the maximum and minimum duration of RR intervals, which exceeds 350 ms. The verticalization of the patient was accompanied by an increase in HR by 41 %, which slightly exceeds the physiological norm, and the rate approached the regular one. Table 1 provides data on HR dynamics and the main values of HRV time parameters at rest and during an active orthostatic test.

Table 2 shows the data on the dynamics of the HRV spectral parameters at rest and during an active orthostatic test.

The calculation of the Spearman's rank correlation coefficient (r) revealed a strong correlation dependence of TP changes during an active orthostatic test, both with a change in the power of low-frequency waves ($r = 0.95$) and high-frequency waves ($r = 0.90$).

Fig. shows the diagnostic findings of patient N., aged 14. HRV indicators are shown at rest (background recording) and during an active orthostatic test.

Discussion

It has been established that HRV at any age is a visual representation of the influence of complex interdependent neurohormonal mechanisms on the heart rate [1, 3]. The time sequence of heart rate is characterized by a wide range of variability. Combined with the fact that the sympathetic influence on the heart rate proceeds too slowly to produce changes in the heartbeat, parasympathetic influences are the only ones that can cause rapid changes in the heart rate [1, 3, 4, 22]. The literature data suggest that the analysis of HRV indicators of the time domain and frequency components of spectral power provides an assessment of the activity of the links of the autonomic nervous system in various pathological conditions and diseases [5, 17, 23–26]. The peculiarities associated with the gender and age of the subjects have already been established [2, 20, 26]. After studying 189 healthy participants of various age groups, Abhishekh et al. [27] have concluded that the sympathetic nervous system tone rises with an increase in the age of the subjects. The published study results suggest that the assessment of parasympathetic activity at rest promotes the identification of adolescents with an increased risk of developing cardiovascular diseases and metabolic syndrome [28]. Nowadays, the limits of conditional age norms for temporal and spectral HRV indicators have already been established, which are regarded as a functional optimum for relatively healthy adolescents [2].

It is understood that an increase in the time domain of HRV, as well as high-frequency waves, which occupy 15–25 % of the total power of the spectrum, indicate the effect of the parasympathetic division of the autonomic nervous system on the heart rate. Low-frequency waves, which account for 15–40 %, show the influence of the sympathetic division of the autonomic nervous system. The contribution of humoral influences on the heart rate is displayed in very low-frequency wave oscillations and is normally 15–35 % of the total spectrum power [1, 4, 29].

An increase in the time indexes of HRV and high-frequency wave oscillations registered at rest, in comparison with the established physiological range for the studied age category, indicates both enhanced activity of the autonomic nervous system as a whole and the predominance of the regulatory influence on the heart rate of its parasympathetic division. In this connection, the values of stress-index, which characterizes the degree of stress of regulatory systems (the degree of prevalence of central regulatory mechanisms over autonomous ones), were in the limits of the reference ranges for the studied age category. The results are consistent with the data presented by other researchers. According to them, adolescents with scoliotic deformities reveal signs of mobilization of functional reserves to counter the existing pathology with a shift in the processes of regulation of heart rate to the predominance of the parasympathetic division of the autonomic nervous system [21].

The study previously performed by N.I. Shlyk [2] on HRV in children, adolescents, and athletes, considering the idea of a dual-circuit model of heart rate management, permitted the author to identify 4 types of autonomic regulation of heart rate: 2 with the prevalence of the central control circuit, and other 2 with the prevalence of the autonomous control circuit. It is suggested to use the stress-index values and the power of a very low-frequency component of the wave spectrum as criteria for categorizing the subjects to a certain regulation type. In the author's opinion, a type with a moderate prevalence of autonomous regulation is optimal. The values of these indicators received by us during the registration of HRV at rest give the possibility to attribute patients with IS to this type of autonomic regulation.

An active orthostatic test assesses a baroreflective control, which is responsible for maintaining a blood pressure level. It is known that a normal physiological response during an active orthostatic test is regarded as a drop in the total power of the spectrum by 1.5–3 times, and an increase in the power of the waves of the low-frequency component by the same times [1]. When conducting an active orthostatic test, a paradoxical response was registered in patients with IS: a decrease in the power of all spectral components in comparison with the values obtained at rest (TP – by 38 %, LF – by 55 %, HF – by 12 %, VLF – by 57 %). The decrease of HF, VLF, TP, and LF/HF was statistically significant. Meanwhile, the values of all components of the spectrogram were lower than the determined average physiological values for adolescence. Simultaneously, an increase in the stress-index values characterizing the stress degree of regulatory systems (the prevalence of the activity of central regulatory mechanisms over autonomous ones) was recorded by more than 3.5 times. The registered decrease in all spectral components and the stress-index dynamics when performing an active orthostatic test suggest a significant stress of regulatory systems. Thus, the statement that patients with IS have an optimal type of regulation is true only at rest. Even a little exercise caused the suppression of the autonomous level of regulation of the heart rate with the connection of central mechanisms, which signifies the depletion of the body's reserves and the

Table 1

Dynamics of heart rate and main values of time indicators of heart rate variability

Indicator	At rest MED [IQI]	Orthostatic test MED [IQI]	Comparison using paired Mann — Whitney *U*-test	
			difference [95% CI]	p level
HR	78.00 [70.05; 86.15]	110.40 [96.95; 119.15]	30.80 [25.80; 36.10]	<0.001*
RRmin, ms	594.00 [552.25; 656.75]	441.00 [361.00; 487.00]	-175.75 [-223.50; -116.00]	<0.001*
RRmax, ms	1110.50 [913.75; 1577.75]	756.50 [685.00; 978.50]	-363.50 [-516.50; -247.00]	<0.001*
SDNN, ms	65.50 [55.00; 83.75]	40.50 [32.25; 63.00]	-28.00 [-38.00; -17.00]	<0.001*
RMSSD, ms	65.50 [46.50; 86.50]	22.00 [13.75; 55.00]	-43.00 [-59.00; -26.50]	<0.001*
pNN50, %	32.50 [12.25; 46.75]	1.60 [0.58; 5.70]	-27.10 [-35.55; -18.40]	<0.001*
SI, 1/s2	63.23 [22.42; 98.11]	206.22 [129.10; 385.39]	162.16 [103.62; 247.05]	<0.001*

MED — median; IQI — interquartile interval from the first to the third quartile; CI — confidence interval;
* statistically significant differences.

Table 2

Dynamics of main values of spectral indicators of heart rate variability

Indicator	At rest MED [IQI]	Orthostatic test MED [IQI]	Comparison using paired Mann — Whitney *U*-test	
			difference [95% CI]	p level
TP, ms^2/Hz	4415.00 [3096.25; 6846.75]	1706.50 [1124.00; 3527.25]	-2315.75 [-4464.50; 787.50]	0.008*
VLF, ms^2/Hz	1179.50 [841.00; 2470.50]	680.00 [432.25; 1098.00]	-533.26 [432.25; 1098.00]	0.004*
LF, ms^2/Hz	1301.50 [666.50; 2318.25]	717.00 [523.25; 1319.25]	-394.75 [-1134.50; 243.00]	0.210
HF, ms^2/Hz	1907.00 [1267.25; 2918.00]	229.50 [109.50; 872.75]	-1378.00 [-2470.50; -836.00]	<0.001*
LF/HF	0.90 [0.46; 1.12]	2.77 [1.42; 4.62]	2.47 [1.42; 4.62]	<0.001*

MED — median; IQI — interquartile interval from the first to the third quartile; CI — confidence interval;
* statistically significant differences.

conversion of the optimal level of regulation to a dysregulatory level [2].

It is said that the power of VLF waves is closely associated with the psychological and emotional status of the subjects. Besides, the power of VLF waves is connected with thermoregulation; it is able to characterize metabolic processes and reflect the presence of energy deficit. It is believed that a high level of VLF is an indicator of hyperadaptation and a reduced level of VLF is an indicator of energy deficit [1, 2, 4]. The registered increased values of VLF at rest, i.e., the initial state of autonomic regulation, suggest the presence of hyperadaptation in patients with IS. Interesting is the fact of a significant decrease in the VLF index during an active orthostatic test in comparison with the values at rest. This, in our view, was a clear manifestation of the exercise-induced energy deficit.

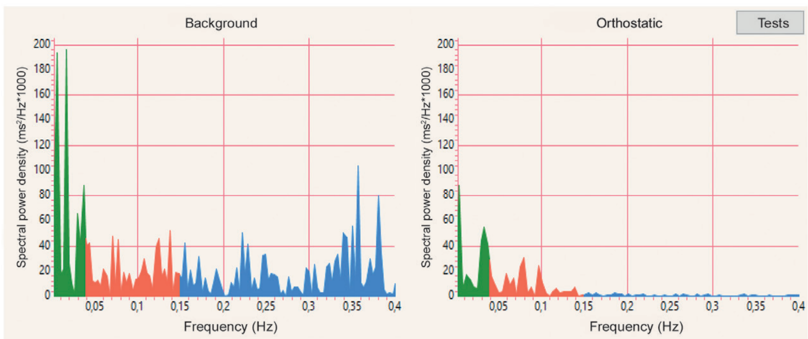

Fig.
Spectrogram of patient N., 14 years old

The established features of HRV in patients with IS have enabled us to conclude that patients with IS belong to the group of elevated risk for the development of intraoperative and postoperative complications associated with hemodynamic instability, and may also affect the efficiency of postoperative rehabilitation. The results obtained confirm the hypothesis of the study.

Knowing the preoperative features of HRV in the studied category of patients before the upcoming complex corrective intervention will allow for the optimal choice of pharmacological components of anesthesia considering their various effects on the circulatory system. The specific features of HCV (prolonged non-physiological prone position, significant blood loss) themselves are associated with the risk of developing hemodynamic disorders. In addition, it is essential to ensure adequate pharmacological protection in the conditions of surgical aggression with maximum preservation of autonomic balance. HRV registration in combination with central hemodynamic indicators can be an effective technique of an intraoperative hemodynamic monitoring, allowing to minimize complications of anesthesia associated with hemodynamic instability.

The results presented are only the first records of the preoperative condition of the autonomic nervous system in patients with IS requiring surgical treatment. The main limitations of the study are the number of participants and the design – a selective cohort with the unavailability of its own comparison groups. Additionally, our aim was not to identify a possible relationship between the preoperative condition of the autonomic nervous system in the studied category of patients with the duration of the disease, the severity of spinal deformity, the intensity of pain syndrome, and individual psychological characteristics. Addressing these challenges in the course of further prospective research may make its own clarifications to the results obtained.

Conclusion

Analysis of HRV in patients with adolescent idiopathic scoliosis at rest revealed an increased autonomic regulation with a predominant effect of the parasympathetic division of the autonomic nervous system on the heart rate. The development of the state of exercise-induced energy deficit, registered after an active orthostatic test, indicates a significant stress of the regulatory systems and refers this category of patients to a group of increased risk of intraoperative and postoperative complications associated with hemodynamic instability.

Preoperative assessment of regulatory processes will enable timely, from an individualized perspective, to identify a decrease in adaptive capabilities and to choose the right technique of anesthetic management of the planned surgical intervention to minimize possible complications associated with hemodynamic instability.

The study had no sponsors. The authors declare that they have no conflict of interest.

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