PREOPERATIVE RAPID DETERMINATION OF TYPES OF AUTONOMIC REGULATION IN ADOLESCENTS WITH IDIOPATHIC SCOLIOSIS

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Objective. To establish the types of autonomic regulation in patients with adolescent idiopathic scoliosis based on the analysis of heart rate variability at the preoperative stage.

Material and Methods. The study included 69 adolescents with idiopathic scoliosis, who underwent cardiointervalogram recording with subsequent spectral analysis at rest and during an active orthostatic test in order to assess the reserves of autonomic regulation. Very low frequency oscillations of the spectrogram, stress index of regulatory systems, and the total power of the spectrum were analyzed. Four types of autonomic regulation were determined: type I with moderate predominance of sympathetic and central regulation, type II with pronounced predominance of sympathetic and central regulation, type III with moderate predominance of parasympathetic regulation, and type IV with pronounced predominance of parasympathetic regulation.

Results. At rest, a moderate predominance of sympathetic activity and central regulation with moderate stress of regulatory systems, or type I regulation was observed in 15 (22%) patients; a sharp increase in the activity of central regulation with the development of a state of vegetative dysfunction, or type II regulation — in two (3%) patients; a moderate predominance of parasympathetic activity, or type III regulation — in 39 (56%) examined patients; and a pronounced predominance of parasympathetic regulation with overstrain of the regulatory systems, or type IV regulation — in 13 (19%) patients. After the orthostatic test, most of the examined patients, 44 (64%), had type I regulation, while type II was registered in seven (10%) patients, type III — in 14 (20%), and type IV — in four (6%) patients.

Conclusion. The background state of autonomic regulation of the heart rate in most adolescents with idiopathic scoliosis reflects the stability of adaptation mechanisms. Orthostatic testing allows identifying cases of instability of regulatory system associated with the risk of hemodynamic instability due to the moderate predominance of sympathetic autonomic regulation observed in most patients.

Key Words: idiopathic scoliosis; heart rate variability; orthostatic test; adaptation reserve.

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The prevalence of idiopathic scoliosis (IS) among adolescents is 2–4% [1]. Surgical correction of spinal deformity is associated with prolonged non-physiological positioning of the patient during surgery, aggressive manipulation, significant blood loss volume, and a high risk of intraoperative hemodynamic instability [2, 3]. The intraoperative hemodynamic status is also influenced by the patient's initial cardiovascular and autonomic nervous system (ANS) condition, as well as the medications used for anesthesia [4–6]. In this regard, ensuring intraoperative hemodynamic stability is a key task of anesthetic management [7]. The risk of developing life-threatening postoperative complications can be minimized by sustaining adequate perfusion pressure both during anesthesia and during surgery [8], which is also essential for the accelerated recovery of patients after spinal deformity correction [9–11].

To improve the reliability of corrective procedures in adolescents with IS, it is essential to examine the status of the body's regulatory systems by determining heart rate variability (HRV) [12–14]. HRV disorders indicate a high risk of developing life-threatening complications, including hemodynamic ones [15, 16]. It is understood that the functional state of regulatory systems and their reactivity in adolescents are primarily determined by the type of autonomic regulation that coordinates the cardiovascular system [17, 18].

The predominance of central or autonomic regulatory mechanisms in heart rate control determines the body's various adaptive reserves. It is known that the predominance of central regulation of heart rate variability and high sympathetic nervous system activity indicates low adaptive capacity of the cardiovascular system [17].

There is currently a limited amount of information in scientific sources on the state of autonomic regulation of heart rhythm in adolescents with IS: some authors note the predominance of the sympathetic [19], others — the parasympathetic component of the ANS [20, 21], including signs of energy deficiency after an active orthostatic test [21].

The evidence available in scientific sources is inconsistent and requires clarification, especially from the perspective

of evaluating the adaptive reserves of patients with IS prior to elective surgery.

The objective is to establish the types of autonomic regulation in patients with adolescent idiopathic scoliosis based on the analysis of heart rate variability at the preoperative stage.

Material and Methods

A prospective single-center study included 69 adolescent patients: 58 (84%) females and 11 (16%) males, who were hospitalized for elective surgery for IS at the Department of Pediatric Orthopedics of the Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan. Study period: January 2021 – October 2024.

Inclusion criteria: adolescence (11–17 years old); primary diagnosis – IS; elective primary surgical correction of spinal deformity; written informed consent of the patient and/or legal representative (if the patient is under 15 years old) to participate in the study.

Ineligibility criteria: history of surgical correction of heart defects; presence of arrhythmia requiring antiarrhythmic therapy; no written informed consent from the patient and/or legal representative.

Exclusion criteria: deterioration of general condition (dizziness, loss of consciousness) during active orthostatic testing; refusal to continue the study once it has begun.

Cardiointervalogram recordings were made with the "VNS-micro" device, utilizing the "Poly-Spectrum.NET" software (Neurosoft, Russia). Silence was maintained in the ward as much as possible. The patients were lying on their backs, breathing calmly and remaining silent. Electrodes were placed on their forearms, and cardiointervalograms were recorded for five minutes, which is the standard duration for this technique.

An active orthostatic test was performed to evaluate the reactivity of regulatory systems: patients, on command and immediately, assumed an upright position next to the bed with electrodes attached to their arms; recording continued for another five minutes. The HRV recording protocol with subsequent spectral analysis was generated automatically.

To classify subjects according to their type of autonomic heart rate regulation, we use a rapid diagnostic method based on the analysis of the following parameters: very low frequency oscillations of spectrogram VLF (ms) as a marker of the influence of the central regulatory circuit; the stress index (SI) of regulatory system (conventional units); and total spectral power TP (ms) (Table 1) [17].

Additionally, the age, height, body weight of patients, and the extent of the primary spinal deformity (in degrees according to Cobb) were analyzed.

Statistical analysis was performed using the basic R language packages (version 4.2.0). The mean values of continuous variables were described by the median (Me), and the spread was described by the interquartile range [Q1; Q3] due to the small sample sizes and non-normality of distributions according to the Shapiro–Wilk test. Variables in groups of autonomic regulation types were compared using the Mann–Whitney U test, with multiple comparison errors in the achieved significance values of p corrected using Hochberg method. The difference was considered statistically significant for $p < 0.05$. Sample size calculations were not performed.

The study was approved by the local ethics committee of the Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan of the Russian Ministry of Health (extract from protocol 011/20 No. 047/20 dated December 16, 2020). All participants in the study or their legal representatives gave their written informed voluntary consent to participate in the study and to publish the results of the study in open access.

Results

The results of patient distribution by type of autonomic regulation after analysis of HRV data obtained at rest are provided in Table 2.

The data in Table 2 indicate that the background preoperative state of heart rate regulation in most patients was characterized by a moderate predominance of parasympathetic activity, which is the optimal type of regulation and indicates sufficient compensatory potential of the body.

The main features of the patients, corresponding to the established types of autonomic regulation at rest, are shown in Table 3.

According to the data given in Table 3, a comparative analysis of the main features of patients with established types of autonomic regulation showed no statistically significant differences in the indicators, which proves that the study data is consistent.

The HRV data obtained during the orthostatic test are shown in Table 4.

According to the data, the percentage ratio of established types of autonomic regulation of heart rhythm changed in response to exercise. In most patients, heart rate regulation after exercise testing was provided by the activity of the sympathetic nervous system with the involvement of the central regulation.

Discussion

The efficacy of using the HRV analysis to assess the mechanisms of autonomic regulation of heart rhythm to identify a decreased ability of the body to adapt in normal and pathological conditions has been confirmed in various studies [16, 22, 23]. It is understood that stress factors influencing the activation of the sympathetic nervous system affect the background indicators of autonomic regulation. Previously conducted studies have shown that increased sympathetic tone of autonomic regulation of heart rhythm significantly reduces individual resistance to stress situations, whereas moderate predominance of parasympathetic influences is seen as a factor increasing individual resistance [17, 24, 25].

It is important for anesthesiologists to evaluate the balance between the sympathetic and parasympathetic parts of the autonomic nervous system before surgery [2, 3, 21]. This data is essential for selecting the most effective method

Table 1
Types of heart rhythm regulation

Type	Criteria	
	SI, conventional units	VLF, ms^2
Moderate predominance of sympathetic and central regulation — type I	>100	>240
Pronounced predominance of sympathetic and central regulation — type II	>100	<240
Moderate predominance of parasympathetic regulation — type III	>30 и <100	>240
Pronounced predominance of parasympathetic regulation — type IV	<30	>240 TP >8000

SI — stress index; VLF — very low frequency oscillations; TP — total spectral power.

of anesthesia, as intraoperative systemic hemodynamic parameters depend not only on the type of autonomic regulation of heart rhythm but also on the medications used for anesthesia [26–28]. Furthermore, predicting the adequate sympathoadrenal response enables minimizing potential intraoperative and postoperative hemodynamic complications, as well as creating conditions for accelerated recovery [7].

To evaluate the preoperative autonomic status based on HRV data, we used the criteria for rapid diagnosis of autonomic regulation proposed by N.I. Shlyk and E.A. Gavrilova [17]. In our study, most patients at rest had a moderate predominance of the parasympathetic component, which is the optimal condition for the adaptation system. Other authors also point to the prevalence of the parasympathetic component of the ANS in regulating heart rhythm in patients with scoliosis from the age of 13 [20].

For anesthesiologists, though, it is vital to have an idea of the mechanisms of hemodynamic adaptation when exposed to factors affecting cardiac output. In the context of surgery for scoliosis, these factors include the prone position of the patient, blood loss, and the effects of anesthetics. To reproduce this condition, an easily performed active orthostatic test can be used, which, by affecting venous return of blood to the heart, provides an opportunity to study compensatory hemodynamic and autonomic shifts [16, 17, 27]. The HRV indicators during orthostatic test can be used to evaluate the contribution of various components of the ANS to the regulatory mechanisms [29, 30]. In our study, the orthostatic test revealed that 74% of patients exhibited a response characterized by varying degrees of increased sympathetic nervous system activity with engagement of central regulatory mechanisms (Type I and II regulatory patterns). This response is physiologically unfavorable, indicating stress of regulatory systems and a dysregulation between the autonomic and central regulation. This circumstance requires the removal or reduction of the impact of possible risk factors. For the category of patients under study, this means timely detection of sympathovagal imbalance and individual selection of anesthesia techniques, considering the vagolytic or sympathomimetic mechanism of action of medications used for anesthetic management. Other authors have also pointed out the significance of determining the type of autonomic regulation in a specific individual under stress test conditions to obtain accurate information about the body's regulatory processes [29, 31, 32].

The results of this study do not contradict our previous conclusions, namely that adolescents with IS experience preoperative regulatory system stress, which is a risk factor for intraoperative hemodynamic instability [21]. However, the

Table 2
Distribution of patients by types of autonomic regulation at rest, Me [Q1; Q3]

Type of autonomic regulation	Patients, *n* (%)	VLF, ms^2	SI, conventional units	TP, ms^2
I	15 (22)	624.0 [508.0; 911.5]	179.9 [167.4; 242.6]	1580.0 [1154.0; 3824.0]
II	2 (3)	134.5 [126.2; 142.8]	501.5 [483.9; 519.1]	397.0 [300.5; 493.5]
III	39 (56)	1106.0 [777.0; 1444.0]	59.0 [48.0; 78.1]	3689.0 [2878.5; 4538.0]
IV	13 (19)	2900.0 [2578.0; 18402.0]	13.4 [7.6; 14.6]	15922.0 [9085.0; 110850.0]
Mann–Whitney *U* test, *p* value of differences between types of autonomic regulation	—	I/III: 0.006 I/IV: <0.001 III/IV: <0.001	I/III: <0.001 I/IV: <0.001 III/IV: <0.001	I/III: 0.005 I/IV: <0.001 III/IV: <0.001

Me — median; [Q1; Q3] — interquartile range; VLF — very low frequency oscillations; SI — stress index; TP — total spectral power.
TP — общая мощность спектра.

Table 3

Main characteristics of patients corresponding to the established types of autonomic regulation at rest, Me [Q1; Q3]

Type of autonomic regulation	Patients, *n* (%)	Age, years	Height, cm	Weight, kg	Primary curve of spinal deformity according to Cobb, degrees
I	15 (22)	15.0 [13.5; 16.0]	163.0 [160.0; 166.0]	53.0 [45.5; 59.0]	56.0 [52.0; 65.5]
II	2 (3)	13.5 [13.2; 13.8]	163.5 [162.8; 164.2]	48.5 [47.2; 49.8]	89.5 [68.2; 110.8]
III	39 (56)	15.0 [14.0; 16.0]	160.0 [155.5; 167.0]	48.0 [45.0; 57.5]	67.0 [51.0; 78.5]
IV	13 (19)	15.0 [13.0; 16.0]	165.0 [151.0; 168.0]	53.0 [43.0; 61.0]	62.0 [53.0; 75.0]
Mann–Whitney *U* test, *p* value of differences between types of autonomic regulation	–	I/III: 0.836 I/IV: 0.925 III/IV: 0.923	I/III: 0.492 I/IV: 0.908 III/IV: 0.719	I/III: 0.511 I/IV: 0.747 III/IV: 0.983	I/III: 0.284 I/IV: 0.580 III/IV: 0.540

Me – median; [Q1; Q3] – interquartile range.

Table 4

Distribution of patients by types of autonomic regulation after orthostatic test, Me [Q1; Q3]

Type of autonomic regulation	Patients, *n* (%)	VLF, ms^2	SI, conventional units	TP, ms^2
I	44 (64)	718.5 [504.0; 983.0]	174.9 [137.6; 323.9]	1709.5 [1179.2; 2271.0]
II	7 (10)	182.0 [122.5; 192.5]	708.6 [380.0; 1051.2]	436.0 [298.0; 722.0]
III	14 (20)	3423.0 [1516.8; 13009.2]	46.3 [36.2; 62.2]	14028.5 [5059.0; 52475.5]
IV	4 (6)	9203.0 [4478.2; 22260.0]	5.4 [4.8; 7.4]	38221.5 [20843.5; 88202.8]
Mann–Whitney *U* test, *p* value of differences between types of autonomic regulation	–	I/II: <0.001 I/III: <0.001 I/IV: <0.001 II/III: <0.001 II/IV: 0.006 III/IV: 0.645	I/II: <0.001 I/III: <0.001 I/IV: <0.001 II/III: <0.001 II/IV: 0.006 III/IV: <0.001	I/II: <0.001 I/III: <0.001 I/IV: <0.001 II/III: <0.001 II/IV: 0.006 III/IV: 0.442

Me – median; [Q1; Q3] – interquartile range; VLF – very low frequency oscillations; SI – stress index; TP – total spectral power.

methodology of our previous study did not involve differentiating between the predominance of the sympathetic and parasympathetic branches of the autonomic nervous system or determining the types of regulation, and the results presented were the outcome of analyzing a single data sample.

We consider the lack of analysis of the entire range of HRV indicators to be the main limitation of the study. Nevertheless, this approach was chosen intentionally, thereby avoiding an excessive amount of digital data, and the HRV indicators selected for analysis provided information that fully met the research objectives.

Conclusion

The express test for determining the types of autonomic regulation of heart rhythm can be used for preoperative evaluation of the autonomic nervous system. Individual typological characteristics of the ANS in adolescents with IS reveal different adaptive responses of autonomic regulation at rest and under stress. The type of autonomic regulation of the patient should be assessed using the results of an active orthostatic test.

The study had no sponsors. The authors declare that they have no conflict of interest.
The study was approved by the local ethics committee of the institution.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

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