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# AGE-RELATED ASPECTS OF AUTONOMIC-REGULATORY SUPPORT OF MORPHOFUNCTIONAL PROCESSES OF PUBERTY PERIOD IN HEALTHY ADOLESCENTS

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**Abstract.** ***Background.*** It is known that by adolescence, the basic neurohumoral mechanisms of autonomic regulation are considered complete. However, without understanding the age-related evolution of vegetative homeostasis, it is not possible to give an objective assessment of the correspondence of its level to the characteristics of pubertal processes. ***Purposes.*** To identify the patterns of dynamic changes in the system of vegetative homeostasis in children at the stages of postnatal ontogenesis to determine the degree of adequacy of the processes of controlling morphofunctional transformations of puberty. ***Materials and methods.*** A total of 145 healthy children were examined: 44 adolescents aged 13–17 made up the main group, 101 children from 1 year of age to 13 years were included in the comparison group. In this work, the method of heart rate variability analysis was used. ***Results.*** The article presents data on dynamic changes in the system of vegetative homeostasis, consisting in the transition from the predominance of centralization in young children to the dominance of controlling autonomy in the adolescent population. ***Conclusion.*** The revealed regularity is the basis of the postnatal ontogenetic development of vegetative-regulatory mechanisms for the formation of the optimal level of control of morphofunctional transformed processes of puberty.

**Key words:** *children, autonomic regulation, puberty*

# ВОЗРАСТНЫЕ АСПЕКТЫ ВЕГЕТАТИВНО-РЕГУЛЯТОРНОГО ОБЕСПЕЧЕНИЯ МОРФОФУНКЦИОНАЛЬНЫХ ПРОЦЕССОВ ПУБЕРТАТНОГО ПЕРИОДА У ЗДОРОВЫХ ПОДРОСТКОВ

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**Резюме.** ***Введение.*** Известно, что к подростковому возрасту основные нейрогуморальные механизмы вегетативной регуляции считаются завершенными. Однако без понимания возрастной эволюции вегетативного гомеостаза дать объективную оценку соответствия его уровня характеристикам пубертатных процессов не представляется возможным. ***Цель исследования.*** Выявить закономерности динамических изменений в системе вегетативного гомеостаза у детей на этапах постнатального онтогенеза для определения степени адекватности процессов управления морфофункциональными преобразованиями периода поло-

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вого созревания. ***Материалы и методы.*** Всего обследовано 145 здоровых детей: 44 подростка 13–17 лет составили основную группу, 101 ребенок от 1 года жизни до 13 лет вошли в группу сравнения. В работе использовался метод анализа вариабельности сердечного ритма. ***Результаты.*** В статье представлены данные о динамических изменениях в системе вегетативного гомеостаза, заключающихся в переходе от преобладания централизации у детей раннего возраста к доминированию управляющей автономии в подростковой популяции. ***Выводы.*** Выявленная закономерность — основа постнатального онтогенетического развития вегетативно-регуляторных механизмов по формированию оптимального уровня управления морфофункциональными преобразовательными процессами пубертатного периода.

**Ключевые слова:** *дети, вегетативная регуляция, пубертатный период*

## INTRODUCTION

The formation of autonomic-regulatory structures in children occurs in accordance with the general patterns of maturation of the functional systems of the child's body [1–3]. It is known that by adolescence, the main neurohumoral mechanisms of autonomic regulation are considered complete [4–6]. However, without understanding the age-related evolution of vegetative homeostasis (VH), it is not possible to make an objective assessment of the correspondence of the level of regulatory effects on the processes of formation of the reproductive function [7–10]. At the same time, the issues of optimization of the control mechanisms of autonomic regulation at the stages of postnatal ontogenesis, ensuring the optimal level of morphofunctional processes of the puberty, remain insufficiently studied in the literature [11–13]. Obviously, the results of such studies would contribute to the early diagnosis of predictors of psychosomatic pathology, which often debut in children of this age group [14–17].

## AIM

The aim of the study is to identify patterns of dynamic changes in the regulatory determinants of VH in children at the stages of postnatal ontogenesis in order to determine the degree of adequacy of the processes of controlling morphofunctional transformations of puberty, improving early diagnosis and targeted correction of their disorders.

## MATERIALS AND METHODS

A comparative controlled study of dynamic changes in inter-circuit, central and autonomous dominance in the VH system was conducted in 145 healthy children. The main group consisted of 44 adolescents (boys — 18, girls — 17) aged 13–17. The comparison group included 101 children: 22 — first year of life, 35 — 4–7 years and 44 (boys — 19, girls — 25) aged 8–12 years. The number of children in all groups was comparable, the ratio of boys and girls did not differ significantly ($p > 0,05$). Gender differences were taken into account in the groups of adolescent children. Inclusion criteria: children attending preschool institutions and comprehensive schools (except for children of the first year of life) from I and IIa health groups (f-112). Unorganized children aged 1–3 years were excluded due to significant differences in living conditions. The examination was conducted in a children's clinic with the conditions for electrophysiological studies observed. Informed consent was obtained from all subjects and their parents.

The autonomic-regulatory parameters were studied by analyzing the heart rate variability (HRV) using the VNS-Micro vegetotester 2000 Hz. The recording was made on short sections (at least 500 cardiac cycles) with subsequent processing using the Poli-Spectrum (Neurosoft, Russia) program. Statistical analysis was performed using the STATISTICA 20 (USA) program and included the Mann-Whitney U and Kruskal-Wallis tests. To compare variables in independent groups, the bootstrap version of the Satterthwaite test (heteroscedastic version of the Student's t-test) was used. Differences were considered statistically significant at $p < 0,05$.

## RESULTS

During the study, absolute values of the indicators of time and frequency analysis of HRV were compared, the results of which are shown in Fig. 1 and 2.

As it is shown in Fig. 1, the level of tension index SI, arbitrary units, and indicator of the adequacy of regulation processes AMo/Mo in children aged 13–17 years, compared with the data for children in the first year of life, significantly decreased: by 87,8 and 72,2% in the group of boys and by 87,3 and 73,2% in girls, respectively (all $p < 0.05$).

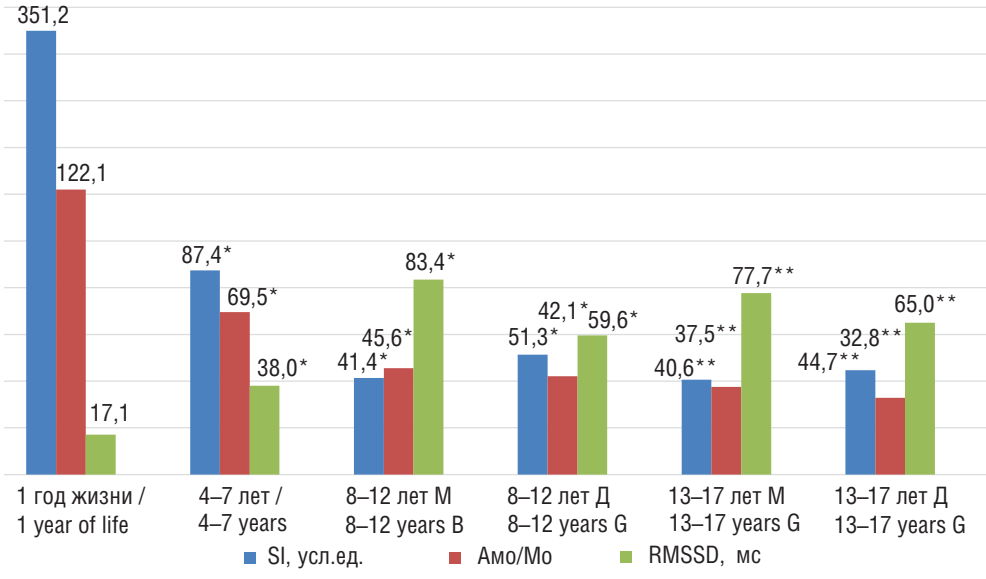


Fig. 1. Dynamic changes in absolute time region indicators of heart rate variability in healthy children, %. (Here and in Fig. 2 — statistical significance of the differences (p <0.05): * — indicators of the age group to the data of the previous one; ** — data of the group 13–17 years old to the indicator of the first year of life; B — boys; G — girls; SI, arbitrary units — tension index, AMo/Mo — indicator of the adequacy of regulation processes, RMSSD, ms — representative indicator of parasympathetic activity.)

Рис. 1. Динамические изменения абсолютных значений показателей временной области вариабельности сердечного ритма у здоровых детей, %. (Здесь и на рис. 2 — статистическая значимость различий (p <0,05): * — показателей возрастной группы к данным предыдущей; ** — данных группы 13–17 лет к показателю первого года жизни; М — мальчики, Д — девочки, SI, усл. ед. — индекс напряжения, AMo/Mo — показатель адекватности процессов регуляции, RMSSD, мс — репрезентативный показатель парасимпатической активности.)

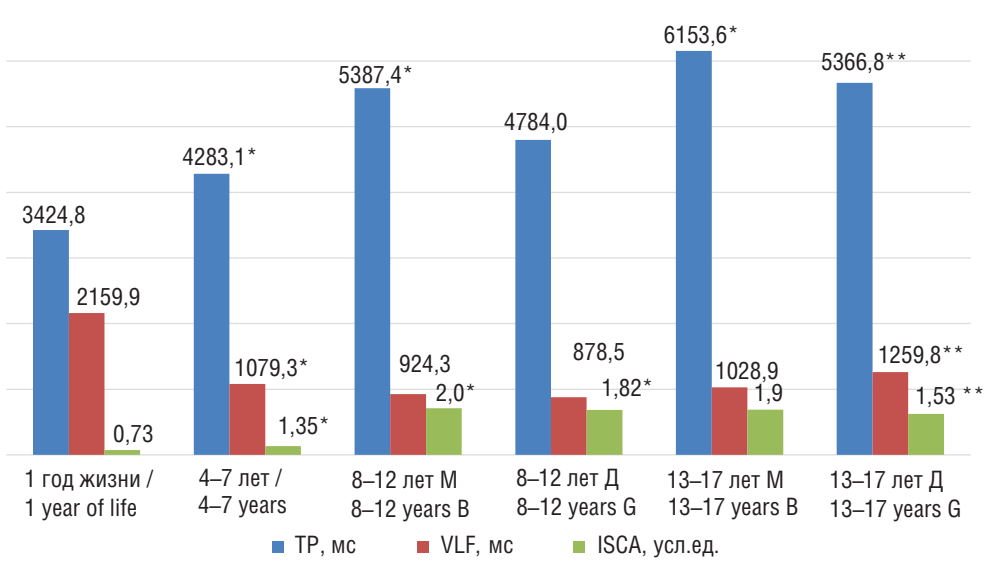


Fig. 2. Dynamic changes in absolute values frequency region indicators of heart rate variability in healthy children, %. TP, $ms^2$ — an indicator of the total power of waves in the heart rate variability spectrum; VLF, $ms^2$ — indicator of activity in the very low frequency range; ISCA — index of activation of subcortical structures

Рис. 2. Динамические изменения абсолютных значений показателей частотной области ВСР у здоровых детей. TP, $мс^2$ — показатель суммарной мощности волн спектра вариабельности сердечного ритма; VLF, $мс^2$ — показатель активности диапазона очень низких частот; ISCA — индекс активации подкорковых структур

As follows from the data in Fig. 2, by adolescence, children showed a significant change in the absolute values of the wave characteristics of HRV in the form of an increase in the total power of all ranges of the frequency spectrum of TR, $ms^2$ by 79,6 and 56,7% in boys and girls, respectively, which indicated the dominance of the autonomous circuit generations in the VH system (all

**Table 1. Dynamic characteristics of the spectrum type in children of the examined groups, ms²**

**Таблица 1. Динамические характеристики типа спектра у детей обследованных групп, мс²**

| Возраст / Age | Показатели частот, мс² / Frequency indicators, ms² | | | Тип спектра / Spectrum type |
|---|---|---|---|---|
| | HF, мс² (ms²) | LF, мс² (ms²) | VLF, мс² (ms²) | |
| 1 год / 1 year | 9,0 | 33,9 | 57,1 | VLF > LF > HF |
| 4–7 лет / 4–7 years | 40,8 | 32,1 | 27,1 | VLF > HF > LF |
| 8–12 лет / 8–12 years | 49,0 | 31,7 | 19,3 | HF > LF > VLF |
| 13–17 лет / 13–17 years old | 51,9 | 32,7 | 15,8 | HF > LF > VLF |

p <0,05). The revealed dynamic frequency shift towards the dominance of autonomy was accompanied by a weakening of the suprasegmental-segmental connection, as evidenced by an increased index of activation of subcortical structures ISCA by 2,5 and 2,1 times (all p <0,05). It should be emphasized that the reduction of biopotentials emanating from the very low frequency range VLF, ms² in children aged 13–17 years compared to the data of children in the first year of life: by 52,4 and 41,7% in boys and girls, respectively, indicated a significant decrease in energy-metabolic expenditure for regulatory processes (all p <0,05).

Table 1 provides information on the dynamics of relative values of regulatory parameters, so-called HRV spectrum type [3].

The data in the table indicate a high level of centralization in the control of functional systems in children in the first year of life, in which the dominant frequencies in the structure of the total power of spectrum waves (TP, ms²) are the biopotentials of the very low (VLF, ms²) and low (LF, ms²) frequency ranges. It has been shown that in the age group of 4–7 years, the influence of high-frequency oscillations (HF, ms²) in the regulatory process increases significantly, but by adolescence, the spectrum type begins to correspond to the optimal parameters (HF — 40–55%; LF — 25–35%, VLF — 6–15%) of frequency proportionality [8, 9].

It should be noted that in the groups of boys and girls, no reliable differences in the studied indicators that violate the general pattern of dynamic changes were revealed.

## DISCUSSION

It is known that ergotropic tension associated with high energy-metabolic expenditures, typical for young children, is dictated by the high vulnerability of the organism and the incompleteness of the formation of regulatory adaptation mechanisms. At the same time, such high energy-metabolic expenditures associated with control centralization in adolescent children could cause overstrain of adaptation mechanisms and depletion of the functional reserve.

The results of the study allowed us to identify a significant pattern of transition of the control function of the VH from high centralization in young children to dominant autonomy in adolescents. The physiological evolutionary determinism of such a transformation is due to the transition from energy-consuming ergotropic activity to an energy-saving regime of inter-circuit dominant autonomy in the control of functional systems, creating optimal conditions for the adequacy of the level of autonomic regulation to the requirements of pubertal processes.

## CONCLUSION

The revealed patterns are a conceptual basis for the postnatal ontogenetic maturation and development of the child's organism, and the transition to autonomy in the control of functional systems in adolescence should be considered the physiological essence of modulating the inter-circuit dominant. The results of the study may have not only theoretical significance, but also important practical application for pediatric practice as criteria for functional maturity and harmonious development of children at different age periods, as well as early diagnosis and correction of their disorders.

## ADDITIONAL INFORMATION

**Author contribution.** Thereby, all authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study.

**Competing interests.** The authors declare that they have no competing interests.

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**Consent for publication.** Written consent was obtained from legal representatives of the patients for publication of relevant medical information within the manuscript.

## ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

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**Конфликт интересов.** Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

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## REFERENCES

1. Antonova L.K., Kushnir S.M. Vegetativnaya regulyaciya u detej v postnatal'nom ontogeneze. [Autonomic regulation in children in postnatal ontogenesis]. Tver': RIC TGMU Publ.; 2018. (in Russian).
2. Nalobina A.N., Stockaya E.S. K voprosu o vozrastnoj fiziologicheskoj norme pri ocenke pokazatelej variabel'nosti serdechnogo ritma u detej pervogo goda zhizni. [On the Question of the Age Physiological Norm in the Assessment of Heart Rhythm Variability Indicators in Children of the First Year of Life]. Fundamental'nye issledovaniya (Biologicheskie nauki). 2014;12:2366–2372. (in Russian).
3. Shlyk N.I. Serdechnyj ritm i tip regulyacii u detej, podrostkov i sportsmenov. [Heart Rhythm and Type of Regulation in Children, Adolescents and Athletes]. Izhevsk: Udmurtskij universitet Publ.; 2009. (in Russian).
4. Pshenichnaya E.V. Ocenka vegetativnoj regulyacii serdechno-sosudistoj sistemy mal'chikov-podrostkov predprizyvnogo vozrasta. [Pshenichnaya E.V. Assessment of autonomic regulation of the cardiovascular system of adolescent boys of pre-conscription age]. Vrach. 2018;1(29):56–59. (in Russian).
5. Kalyuzhnyj E.A. Vegetativnaya regulyaciya funkcional'noj adaptacii shkol'nikov. Sovremennye nauchnye issledovaniya i innovacii. [Autonomic Vegetative regulation of functional adaptation of schoolchildren. State-of-the-art scientific research and innovation]. 2014;4(36):2. (in Russian).
6. Stepanova E.Yu. Nejrokardiointervalografiya v diagnostike vegetativnogo statusa pri korrekcii shkol'noj dezadaptacii u podrostkov. [Neurocardiointervalography in the diagnosis of vegetative status in the correction of school adaptation in adolescents]. Prakticheskaya medicina. 2017;2(1):89–92. (in Russian).
7. Alekseeva T.N. Osobennosti cerebral'noj gemodinamiki v zavisimosti ot vegetativnoj reaktivnosti u podrostkov s normal'nym arterial'nym davleniem. [Features of cerebral hemodynamics depending on vegetative reactivity in adolescents with normal arterial pressure]. Smolenskij medicinskij al'manah. 2017;3:67–74. (in Russian).
8. Nezhkina N.N., Kuligin O.V., Gasonova O.L. Psihofiziologicheskaya trenirovka v lechenii sindroma vegetativnoj distonii po simpatikotonicheskomu tipu i pervichnoj arterial'noj gipertenzii u detej i podrostkov. [Psychophysiological training in the treatment of vegetative dystonia syndrome according to sympathicotonic type and primary arterial hypertension in children and adolescents]. Permskij medicinskij zhurnal. 2021;38(2):30–36 (in Russian).
9. Daluwatte C. Simultaneously measured pupillary light reflex and heart rate variability in healthy children. Physiol Meas. 2012;33(6):1043–1052.
10. Maksimovich N.A. Arterial'naya gipertenziya i faktory riska u detej: obzor literatury. [Arterial Hypertension and Risk Factors in Children: A Literature Review]. Zhurnal Grodnenskogo gosudarstvennogo medicinskogo universiteta. 2020;(18):523–531. (in Russian).
11. Yarmuhamedova D.Z., Nuritdinova N.B., Shoalimova Z.M. Rasprostranennost' arterial'noj gipertenzii i faktorov riska u lic molodogo vozrasta. [Prevalence of arterial hypertension and risk factors in young persons]. Nauka, tekhnika i obrazovanie. 2021;3:60–63. (in Russian).
12. Baevskij R.M., Berseneva A.P. Vvedenie v donozologicheskuyu diagnostiku. [Introduction to Donozological Diagnostics]. Moskva: Slovo Publ.; 2008. (in Russian).
13. Kushnir S.M., Antonova L.K. Deviantnye i donozologicheskie sostoyaniya u detej podrostkovogo vozrasta. [Deviant and prenosological states in children of adolescence]. Tver': RIC TGMU Publ.; 2020. (in Russian).
14. Yusupova U.U. Sindrom vegetativnorj distonii u detej. [Syndrome of autonomic dysfuction in children]. Avicenna. 2017;12:45–49. (in Russian).

15. Eremina E.Yu. Pokazateli variabel'nosti serdechnogo ritma u pacientov s gastroezofageal'noj reflyuksnoj bolezn'yu. [Indicators of heart rhythm variability in patients with gastroesophageal reflux disease]. Eksperimental'naya i klinicheskaya gastroenterologiya. 2018;9:10–17. (in Russian).
16. Yiallourou S.R. Maturation of heart rate and blood pressure variability during sleep in term-born infants. SLEEP. 2012; 35(2):177–186.
17. Hanevold C.D. White coat hypertension in children and adolescents. Hypertension. 2019; 73(1):24–30.

## ЛИТЕРАТУРА

1. Антонова Л.К., Кушнир С.М. Вегетативная регуляция у детей в постнатальном онтогенезе. Тверь: РИЦ ТГМУ; 2018.
2. Налобина А.Н., Стоцкая Е.С. К вопросу о возрастной физиологической норме при оценке показателей вариабельности сердечного ритма у детей первого года жизни. Фундаментальные исследования (Биологические науки). 2014;12:2366–2372.
3. Шлык Н.И. Сердечный ритм и тип регуляции у детей, подростков и спортсменов. Ижевск: Удмуртский университет; 2009.
4. Пшеничная Е.В. Оценка вегетативной регуляции сердечно-сосудистой системы мальчиков-подростков предпризывного возраста. Врач. 2018;1(29):56–59.
5. Калюжный Е.А. Вегетативная регуляция функциональной адаптации школьников. Современные научные исследования и инновации. 2014;4(36):2.
6. Степанова Е.Ю. Нейрокардиоинтервалография в диагностике вегетативного статуса при коррекции школьной дезадаптации у подростков. Практическая медицина. 2017;2(1):89–92.
7. Алексеева Т.Н. Особенности церебральной гемодинамики в зависимости от вегетативной реактивности у подростков с нормальным артериальным давлением. Смоленский медицинский альманах. 2017;3:67–74.
8. Нежкина Н.Н., Кулигин О.В., Гасонова О.Л. Психофизиологическая тренировка в лечении синдрома вегетативной дистонии по симпатикотоническому типу и первичной артериальной гипертензии у детей и подростков. Пермский медицинский журнал. 2021;38(2):30–36.
9. Daluwatte C. Simultaneously measured pupillary light reflex and heart rate variability in healthy children. Physiol Meas. 2012;33(6):1043–1052.
10. Максимович Н.А. Артериальная гипертензия и факторы риска у детей: обзор литературы. Журнал Гродненского государственного медицинского университета. 2020;18:523–531.
11. Ярмухамедова Д.З., Нуритдинова Н.Б., Шоалимова З.М. Распространенность артериальной гипертензии и факторов риска у лиц молодого возраста. Наука, техника и образование. 2021;3:60–63.
12. Баевский Р.М., Берсенева А.П. Введение в донозологическую диагностику. М.: Слово; 2008.
13. Кушнир С.М., Антонова Л.К. Девиантные и донозологические состояния у детей подросткового возраста. Тверь: РИЦ ТГМУ; 2020.
14. Юсупова У.У. Синдром вегетативной дистонии у детей. Авиценна. 2017;12:45–49.
15. Еремина Е.Ю. Показатели вариабельности сердечного ритма у пациентов с гастроэзофагеальной рефлюксной болезнью. Экспериментальная и клиническая гастроэнтерология. 2018;9:10–17.
16. Yiallourou S.R. Maturation of heart rate and blood pressure variability during sleep in term-born infants. SLEEP. 2012;35(2):177–186.
17. Hanevold C.D. White coat hypertension in children and adolescents. Hypertension. 2019;73(1):24–30.