Research Article

Endocrine mechanisms of adaptation of children and adolescents to educational activity

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ABSTRACT

Aim: The paper describes the results of a complex study of the functional state of the sympathetic-adrenal system and adrenal cortex of schoolchildren aged 11–15 years of both the genders in different periods of the school year, based on the daily excretion of epinephrine, norepinephrine, 17-ketosteroids, and 17-oxycorticosteroids. **Results:** The boys aged 14 and 15 years at the end of the school year show that there are a significant decrease in the age-related indicators of excretion of norepinephrine and metabolites of sex hormones against a background of prolonged and significant increase in glucocorticoids. In girls, the studied indicators vary within the age range, which indicates a more perfect character of adaptation reactions and high mobilization readiness of their organism. **Conclusion:** It is shown that, during the school year, the changes in the excretion of hormones and hormonal metabolites have a multidirectional character in the age-gender groups.

KEY WORDS: Adrenal cortex, Boys and girls aged 11–15 years, School year periods, Sympathoadrenal system

INTRODUCTION

Educational activity has a complex effect on the nervous and endocrine regulation mechanisms of physiological functions in the child's body. Mental stresses and the accompanying psychoemotional stress cause significant neuroendocrine changes, possible critical states of adaptation stress, maladaptation, and the development of a disease.[1] An exceptional role in providing adaptive reactions of the body is played by the functions of the sympathoadrenal and pituitary-adrenal systems.[2] The first is a nervous, regulatory link necessary to trigger the humoral mechanism of endocrine adaptive reactions. The second occupies a key position in the mechanism of transition of urgent adaptive reactions to the comprehensive development of long-term adaptation.[3] However, the adaptation reactions of children and adolescents are characterized by relative immaturity and instability, manifested in the physiological fluctuation of the production of hormones and mediators and changes in the sensitivity of the receptor apparatus of target tissues.[4] This increases the vulnerability of the child's body during exposure to external adverse factors: Physical and mental fatigue, hypodynamia, and emotional stress; this increases the risk of endocrine and neurovascular dysfunction during adolescence period.[5] The study of endocrine mechanisms of adaptation of children and adolescents to the study load is necessary for understanding the patterns of age formation of adaptive reactions, creating optimal conditions for their educational and life activity.

The objective of the research was to study the functional state of the sympathoadrenal system and the adrenal cortex in schoolchildren aged 11–15 years, taking into account their age, gender, and a period of the school year.

METHODS

The study involved boys and girls aged 11–15 years studying at secondary school No. 1 in Kazan, health groups 1 and 2. A total of 50 girls and 45 boys were monitored for 6 years continuously. The state of SAS was judged by the content of E and NE in urine using the fluorometric method.[6]

The state of AC was assessed by the content of 17-oxycorticosteroids (17-OCS) in urine, which are

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the main metabolites of cortisol, cortisone, and their derivatives, as well as the content of 17-ketosteroids (17-KS), 2/3 of which are synthesized from adrenal cortical androgens, and 1/3 from androgen gonads [Figure 1].[7] For the quantitative determination of 17- KS, the colorimetric method by N.V. Samosudova and Zh.Zh. Bass based on Zimmerman reaction in the modification by Krekhova[8] was used. 17-OCS was identified by Silber and Porter method based on the reaction with phenylhydrazine after enzymatic hydrolysis.[8] Urine was sampled 3 times during the school year.

Statistical processing of the data was carried out by conventional methods of variation statistics with the use of program package Microsoft Excel Windows 2007. To assess the significance of differences, a Student's *t*-test was used.

RESULTS

The analysis of the functional state of SAS and AC during the academic year was conducted, during which it was difficult to consider the influence of internal and external environmental factors, such as age-specific trends, mental and physical stresses, and seasonal fluctuations in neuroendocrine regulation, which are interrelated and interdependent, on the children's organism. It was found that the excretion of the studied hormones and hormonal metabolites varies during the school year, and the ratio of their functional activity is different in age groups (table). At the same time, up to the age of 14 years, the excretion of NE during the school year differs relative stability (at constant E values), with a certain tendency to increase from October to April at the age of 11 and 13 years, in contrast to 17-OCS, in which level increases significantly in boys aged 12 years by the end of the academic year by 1.82 μmol/day ($P < 0.05$).

The age-related trends in the formation of androgenic function of the AC and the activation of the sex glands are the most pronounced in schoolchildren at the age of 14 years when there is an increase in excretion of 17- KS in April as compared with October, 5.89 μmol/day ($P < 0.05$) [Figure 2]. Attention is drawn to the wavy character of the dynamics of excretion of androgen metabolites during the school year in boys aged 12, 13, and 14 years with a decrease in its intensity in winter and a more significant increase in the spring period ($P < 0.05$), which may be explained by seasonal fluctuations of the functional activity of the adrenal and sex glands and is consistent with the concept of neuroendocrine seasonal rhythms.[9] Special attention should be paid to boys aged 14 and 15 years who, against the background of the age-related increase in NE excretion observed from 13 to 14 years, experience its decrease by the end of the

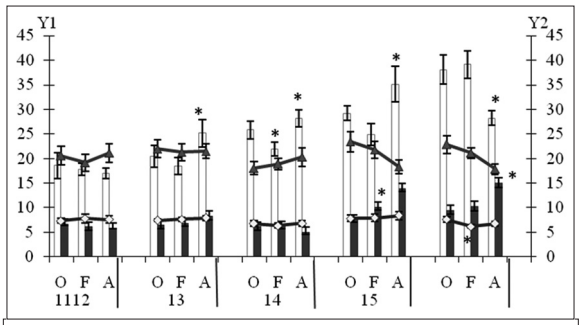

Figure 1: The change in excretion of catecholamines, metabolites of androgens, and glucocorticoids in boys 11–15 years old during the school year. The X-axis - age (years) and periods of the academic year (O - October; F - February; and A - April); Y1-axis - excretion of 17-ketosteroids (□) and 17-oxycorticosteroids (■) μm/day; Y_2-axis - excretion adrenalin (◊) and norepinephrine (▲) μg/day. *Differences are statistically significant by $P < 0.05$ in comparison to the previous period of the school year

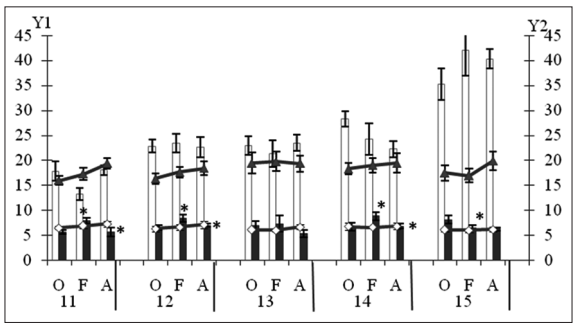

Figure 2: The change in excretion of catecholamines, metabolites of androgens, and glucocorticoids in girls 11–15 years old during the school year. The X-axis - age (years) and periods of the academic year (O - October; F - February; and A - April); Y1-axis – excretion of 17-ketosteroids (□), and 17-oxycorticosteroids (■) μm/day; Y_2 - excretion of adrenalin (◊) and norepinephrine (▲) μg/day. *Differences are statistically significant by $P < 0.05$ in comparison to the previous period of the school year

school year by 6.09 ($P < 0.05$) and 5.58 μg/day ($P < 0.05$) at the same age. Respectively, as compared with the beginning of the school year, which, on the one hand, may indicate an increase in the activity of the nervous link of the SAS during puberty, and on the other hand, the low profitability of its functioning in the process of educational activity of adolescents. At the same time, the dynamics of the glucocorticoid function of AC is the opposite: Excretion of 17-OCS, which at the beginning of the school year in boys aged 14 and 15 years is 7.59 ± 0.55 and 9.47 ± 0.60 μmol/day, increases by its end ($P < 0.05$), 1.8 and 1.5 times exceed its age-related level. Although the increase in glucocorticoids is the main adaptive reaction of the organism, the elevated level of cortisol is dangerous because of its catabolic effect on the children's organism, depressing effect on the lymphoid tissue, and immunity reactions.[4] Moreover, a high concentration of cortisol can cause inhibition of the biosynthesis

of sex hormones,[10] so it is possible that the sharp increase in excretion of 17-OCS, observed in boys aged 15 years, leads to a significant decrease in their level of androgens, and the content of which in urine at the end of the school year was 28.19 ± 1.48 μmol/ day, which is 9.85 μmol/ day less than in October, that is, 1.3 times lower than the age-related indicators of schoolchildren. This is an extremely unfavorable fact that can affect the prospect of adolescent puberty.

A different situation is observed in girls at all stages of the study, and their daily excretion of NE has a stable character, which is generally consistent with its age-related trends, indicating a high mobilization readiness of the schoolgirls' organism. In this case, the daily excretion of metabolites of glucocorticoids has a pronounced oscillatory character: There are an increase in 17-OCS from the beginning to the middle of the academic year at the age of 11–14 years ($P < 0.05$) and a decrease in their excretion from February to May, most pronounced at the age of 13 and 14 years ($P < 0.05$). Probably, the danger of depletion of glucocorticoids against the background of persistent tonic sympathetic influences an increase in NE, and their excessive catabolic influence on the body, especially during pubertal period, is prevented in girls aged 12–14 years by temporary regulatory inhibition of hormone synthesis and a decrease in excretion of 17-OCS, which was observed at the end of the school year. This is regarded as an important protective reaction of the child's organism, aimed at preserving the adaptive reserve and increasing the overall resistance.[4] The "androgen line" in girls is quite stable and does not coincide with periodic fluctuations in the excretion rates of glucocorticoids. The exception is the schoolgirls of 15 years old, whose change in the excretion of these hormonal metabolites acquires the opposite character: A sharp shift in 17- KS and their high values throughout the school year (ranging from 35.24 ± 3.10 to 40.28 ± 1.94 μm/ day) are observed in combination with a decrease in the excretion of metabolites of glucocorticoids - a decrease by 2.04 μm/day ($P < 0.05$) from the beginning to the end of the school year. This is consistent with the idea of the inhibitory effect of androgens on the enzymatic processes of steroid biosynthesis in the adrenal glands. In addition, the AC androgens can act as regulators of stable adaptation,[11] reducing in this case a high level of glucocorticoids in girls.

SUMMARY

1. Excretion of hormones and hormonal metabolites throughout the school year is multidirectional, indicating a special role of catecholamines and corticosteroids in ensuring adaptive reactions in schoolchildren.
2. A critical age period in the development of adaptation mechanisms in boys was revealed: 14 and 15 years old, and when at the end of the school year, there is a significant decrease in norepinephrine excretion and a decrease in the level of androgens, which is an extremely unfavorable factor that can influence the future prospect of puberty.
3. In girls, the studied indicators vary during the entire school year within the age range, which indicates a more perfect character of adaptation reactions and high mobilization readiness of their organism.

CONCLUSION

The conducted study showed that the educational activity of adolescents against the background of neuroendocrine changes in the period of puberty becomes stressful, suppressing the age dynamics of the development of adaptation systems, which is especially evident in boys and indicates the need to monitor the functional state of the schoolchildren's organism aimed at preventing pathological reactions in the growing organism.

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