Neuroendocrrinal Mechanisms of Adaptation to Sports Physical Loads

Angelina Vladimirovna Shakhanova*, Tatyana Vasilyevna Chelyshkova, Aslan Khangireevich Agirov, Kazbek Dovletmizovich Chermit and Andrey Aleksandrovich Kuzmin

Federal State-Funded Educational Institution of Higher Education, Adygea State University, Russian Federation, Maykop; nisadgu@yandex.ru; chelyshkova_t@mail.ru; tuadg@radnet.ru; chermit@adygnet.ru; kuzmin@adygnet.ru

Abstract

Objectives: The article is aimed at research of somatotropic function of boys’ pituitary gland and adrenal cortex in a state of relative rest and under physical load for adequate and complete assessment of their functional capabilities. Methods: Functional capabilities of somatotropic pituitary gland function were examined using PWC170 test. The level of activity of pituitary gland and adrenal cortex was examined by radioimmunoassay technique before the load and in 15 and 45 minutes after the load. The results were statistically processed according to the Student-Fisher variation, statistic technique and rank correlation method, the variability of parameters was assessed by means of the variability coefficient. Findings: To determine the functional reserve of pituitary gland and growth capabilities of the body, a comparative assessment of somatotropin dynamics was made in the state of relative rest and under various loads. The following results have been achieved: comparative assessment of pituitary gland response under different kinds of physical load, identification of its peculiarities, characteristics of general rules of pituitary gland response to the examined loads on boys in the course of somatic growth, simultaneous examination of the response of pituitary gland (with respect to somatotropin) and adrenal cortex (with respect to cortisol) under various loads. This paper shows that pituitary gland activity increases under physical load with PWC170 power. Pituitary gland response in the 45th minute is more significant than response in the 15th minute after the load. In each specific case, the trend of response (increase or decrease), incremental value of somatotropin and the rate of response were subject to the value of the initial level of pituitary gland activity. Application: This article is of practical value for hormonal therapy.

Keywords: Cortisol, Hormones, Physical Load, Pituitary Gland, Somatotropin, Young Sportsmen

1. Introduction

Somatic growth and sexual development are under complex hormonal control. Somatotropin plays a peculiar role in the system of hormonal regulation of functions of a growing body. Age-related aspects of somatotropic pituitary gland function have become a subject of research relatively recently [1-4]. In most cases, such studies are fragmentary and characterized with the following disadvantages: paucity of observations, heterogeneity of groups by age composition, inadequacy of methods applied. Most works were prepared by way of one-time determination of hormone in blood and within the limited range of functional statuses, generally, in the state of relative rest [5-12]. However, numerous studies show that concentration of somatotropin in the blood stream is characterized by periodic significant increases with generally low level thereof. Therefore, according to present-day understanding, the degree of increase of somatotropin concentration in response to stimulus is decisive for the characteristic of somatotropic pituitary gland function. This defined relevance of our work – research of somatotropic function of pituitary gland of boys both in a state of relevant rest and under physical load, which provides a means of adequate

*Author for correspondence
and sufficiently complete assessment of functional capabilities of pituitary gland (with respect to somatotropin) of boys in the course of somatic growth.

Generally, various functional loads are used to study somatotropic function of pituitary gland. The studies described in the literature provide an opportunity to conclude that physical load is the most promising. First, its effect on the body can be strictly dosed; second, motor activity is a way of everyday living of a child, and its positive effect on growth and development is specified in numerous works; third, it causes clear shifts of the level of pituitary gland functioning (with respect to somatotropin). It appeared relevant to us to analyze the response of pituitary gland under qualitatively different loads, which affect the level of secretory activity of endocrine organs, which cause restructuring in the adaptive systems of the body. In this regard, we planned to make a comparative assessment of the pituitary gland response under different kinds of physical load, to identify its peculiarities, to characterize general rules of pituitary gland response to the examined loads on boys in the course of somatic growth, to carry out simultaneous examination of the functional activity of pituitary gland (with respect to somatotropin) and adrenal cortex (with respect to cortisol) under various loads.

The purpose of the work is to study peculiarities of change of the functional activity of pituitary gland (with respect to somatotropin) and adrenal cortex (with respect to cortisol) on physical load of various power, to compare the nature and dynamics of the examined indicators under these loads.

2. Methods

In total, 174 apparently healthy boys aged from 8 to 17 have been examined. Functional capabilities of somatotropic pituitary gland function were examined with the use of PWC\textsubscript{170} test. Load was applied down to the limit by means of bicycle ergometer with cadence 60 revolutions per minute. It was proportioned on the basis of the weight of a test subject having the nature of work with the capacity increasing on a step by step basis. The level of activity of pituitary gland and adrenal cortex was examined by means of radioimmunoassay technique before the load and in 15 and 45 minutes after the load. Blood was sampled before the load from 9.30 a.m., 15 minutes before the load. Research was carried out with the written consent of the test subjects. Statistical processing of the results was carried out according to the Student-Fisher variation and statistic technique, as well as according to the rank correlation method, the variability of parameters was assessed by means of the variability coefficient.

3. Results and Discussions

The research shows that the initial level of somatotropin varied within the range from 0.5 to 12.0 ng/ml and averaged to 2.5±0.2 ng/ml, the coefficient of variability – 88% (Table 1). That is, the variability of single values of hormone level is high even under standard conditions. Increase of pituitary gland activity is observed in response to physical load. The most intensive growth of somatotropin is revealed in the 45\textsuperscript{th} minute after the load both compared to the initial level (p<0.001) and to the 15\textsuperscript{th} minute level (p<0.001). In the 15\textsuperscript{th} and 45\textsuperscript{th} minute, after the physical load variability of individual values of the hormone level is maintained, the variability coefficient changes insignificantly as compared to the initial level. The most significant absolute growth of the somatotropin level in response to the physical load is observed in the 45\textsuperscript{th} minute after the physical load.

The characteristics of the somatotropic function of the pituitary gland on the basis of just average value is insignificant, since the hormone level is not constant even under normal conditions. Therefore, we have applied additional criteria of assessment thereof, in particular, the trend of shifts. We have defined three types of response. The first type – decrease of the somatotropin level in response to the load, the second and the third types – increase of the hormone level in the 15\textsuperscript{th} and 45\textsuperscript{th} minutes, respectively (Table 2).

According to the approach generally accepted in endocrinology, just the two latter responses of the endocrine organ (including pituitary gland) to the stimulus are deemed as physiologic responses, the first type is generally considered as paradoxical response or the sign of pituitary gland dysfunction. Our research shows that pituitary gland activity can increase or decrease under the influence of physical load subject to the values of initial activity. The initial level of somatotropin was significantly higher under the first type of response as compared to the second and the third types (p<0.001 and p<0.05, respectively). Analysis of somatotropin level dynamics under different types of response shows that...
Table 1. Values (M±m) of concentration of somatotropin (ng/ml) in blood plasma of 112 boys under physical load (step-test)

| Examined indicator | Periods of Examination | | |
|--------------------|------------------------|---|---|
|                    | before the load | in 15 minutes | in 45 minutes |
| Absolute concentration | 2.5±0.2 | 3.4±0.3 | 5.0±0.4 |
| Variability coefficient | 88.0% | 94.1% | 79.0% |
| Growth of concentration | - | 28% | 92% |

Table 2. Dependence of the nature of pituitary gland response to the physical load on the initial level of somatotropin concentration

| Types of responses | Quantity of observations | Hormone concentration (ng/ml) | | |
|--------------------|--------------------------|-----------------------------|---|---|
|                    |                         | before the load | in 15 minutes | in 45 minutes |
| first              | 27                      | 6.8±0.8 (3.9-12.0) | 2.5±0.4 (0.3-7.7) | 2.7±0.4 (0.4-7.6) |
| second             | 29                      | 1.5±0.3 (0.5-5.9) | 5.5±0.7 (0.9-15.0) | 2.6±0.5 (0.6-7.4) |
| third              | 56                      | 2.3±0.2 (0.5-5.2) | 2.8±0.4 (0.3-7.1) | 7.4±0.5 (1.7-18.0) |

the higher is the initial hormone level, the higher is the chance of decrease thereof, the lower it is – the higher is the chance of increase thereof. Besides, certain relation is observed between the initial hormone level and the response rate: the lower the initial level is, the faster the response is.

Thus, the type and rate of pituitary gland response of boys to the functional load is determined by the initial level of its activity. The types of revealed responses are absolutely physiologically equivalent, since there were no differences in status of test subjects.

Analysis of individual values of somatotropin level of each test subject against the summarized values of the entire group provides some additional characteristics of pituitary gland functioning, which provides an opportunity to assess its adaptive capabilities. They include: functional reserve determined on the basis of difference between the minimum and maximum activity of somatotropic pituitary gland function, maximum and minimum hormone concentration of each test subject, individual range of fluctuations of its activity (difference between higher and lower concentration).

Maximum activity of boys’ pituitary glands under physical load of $PWC_{170}$ power averaged to 6.1±0.3 ng/ml, minimum activity – 1.7±0.1 ng/ml; amplitude of oscillation – 4.5±0.3 ng/ml[20-23].

Analysis of dynamics of the somatotropin level change in response to the physical load under the bicycle ergometry conditions during VO$_2$ max test showed that somatotropin concentration has increased significantly immediately after the load averaging to 7.7±2.7 ng/ml ($p<0.05$). The coefficient of variability has increased sharply up to 121.6%. Further, the pituitary gland activity remained at the same high level and, in principle, did not differ from the hormone level values immediately after the load; however, dynamics of the variability coefficient evidences further stabilization of the pituitary gland activity level in the 15th minute after the load (at first, the variability coefficient increased from 52% to 121% and then decreased to 70% without any further significant changes) (Table 3).

Dynamics of values of absolute growth of somatotropin concentration on the limited physical load during VO$_2$ max test reflected unidirectionality of the response, where just increase of the pituitary gland activity was observed. This occurs due to low initial activity of pituitary gland within the range of test subjects[22-23].

Maximum activity of boys’ pituitary gland during the entire research period equaled to 9.6±1.4 ng/ml, minimum activity – 0.9±0.1 ng/ml; amplitude of oscillation – 8.7±1.3 ng/ml. This evidences great reserve capabilities of pituitary gland under the conditions of limit physical load.

Generally, the analysis of obtained results demonstrated by boys under the conditions of physical load during VO$_2$ max test showed that although the most intensive increase of somatotropin concentration is revealed immediately after the load, a new level of functioning is stabilized in the 15th minute. After the load, pituitary gland remains in the state of consistently increased activity for no less than 45 minutes.

In order to study development of the somatotropic pituitary gland function of boys, we observed age dynamics of the somatotropin level and peculiarities of the pituitary gland response to physical load of $PWC_{170}$ power during various age periods.
All test subjects were divided into five age groups. Research results show that the background level of pituitary gland activity (before load) is characterized by undulating shifts during various age periods. Thus, the somatotropin level of boys aged 10–11 was significantly higher as compared to boys aged 7–9 (p<0.05). In the age of 12–13, the hormone level decreases significantly as compared to the previous age group (p<0.05). In further age period (14–15), the hormone level increases again (p<0.01), and only in the age of 16–17 it demonstrates virtually no changes as compared to the preceding period (Table 4).

We also noticed slight dispersion of individual values of hormone levels in early age periods with further increase thereof in the senior age. Particularly significant variability of the hormone level is observed in the age of 16–17.

The level of pituitary gland activity has increased in each age under the influence of the physical load. This increase was more clearly expressed in the 45th minute after load, while in the 15th minute the hormone level was significant only in case of boys aged 12–13 (p<0.01). In the age of 7–9 the hormone level significantly increased under the influence of the physical load in the 45th minute equaling to 4.0±1.0 ng/ml (p<0.05); however, in the age of 10–11 the trend of decrease of the hormone level under the influence of the load is revealed when concentration of somatotropin went below the initial level (p<0.05) in the 45th minute. In the next age period (12–13), the hormone level in the 15th and 45th minutes after the load increased significantly (p<0.01). In the age of 14–15, increase of the hormone level in the 45th minute was not significant as compared to the initial one, and in the 15th minute the hormone level was lower than the initial one. The age of 16–17 is characterized by significant increase of the somatotropin activity level in the 45th minute (p<0.05) and certain decrease thereof in the 15th minute.

Analysis of the somatotropin level in the 45th minute after the physical load shows that the value of the pituitary gland response trends to certain increase with age; however, in the age of 10–11 the pituitary gland activity even decreases as compared to the previous (p<0.05) and further age. The highest pituitary gland activity in response to the load is revealed in the age of 16–17, though the difference from other periods is insignificant (p>0.05).

The nature of age-related dynamics of the somatotropin level before the load and in the 45th minute after the load shows that the initial activity of the pituitary gland and the activity after the load increases with age – this evidences development of the somatotropic function of boys’ pituitary glands in the period of 8–17 years old. This development is uneven; the difference in the state of pituitary glands in the age of 10–11 and 12–13 years old draws special attention. In the age of 10, the initial hormone concentration averaged to 2.7±0.5 ng/ml, and in the age of 11 the initial level of somatotropin was 3.2±0.9 ng/ml (p>0.05). In the age of 10, the hormone level under the

### Table 3. Values (M±m) of concentration of somatotropin (ng/ml) in blood plasma of boys under the physical load (VO2 max test)

| Examined indicator          | Periods of Examination | 7-9  | 10-11 | 12-13 | 14-15 | 16-17 |
|----------------------------|------------------------|------|-------|-------|-------|-------|
|                            | before the load        | 1.7±0.6 | 3.6±0.7 | 1.8±0.6 | 3.7±0.6 | 3.8±0.7 |
|                            | immediately after load | 0.5–5.7 | 0.5–13.0 | 0.7–5.7 | 0.6–13.8 | 0.6–18.0 |
|                            | in 15 minutes          | 2.3±0.4 | 2.7±0.7 | 4.4±0.7 | 2.8±0.6 | 3.5±0.6 |
|                            | in 30 minutes          | 0.3–3.4 | 0.7–6.8 | 0.4–12.2 | 0.7–11.5 | 0.5–15.0 |
|                            | in 45 minutes          | 4.0±1.0 | 3.4±0.5 | 5.3±0.7 | 5.3±0.7 | 6.2±0.8 |
|                            | quantity of test subjects | 8 | 23 | 20 | 27 | 34 |
conditions of physical load increased in the 45th minute up to 3.9±0.9 ng/ml, and the extent of growth of the somatotropin level equaled to 1.5±0.8 ng/ml (p>0.05). In the age of 11, the hormone growth value in the 45th minute was negative: -1.6±1.0 ng/ml (p>0.05). Although within each age group the value of the pituitary gland response in the 45th minute was insignificant as compared to the initial level, comparative analysis demonstrates significant decrease of the level of pituitary gland functioning in the age of 11 as compared to the age of 10 (p<0.05). Therefore, decrease of pituitary gland activity (with respect to somatotropin) in the age of 10–11 as compared to other age groups revealed by us is generally accounted for the age of 11.

Analysis of the growth dynamics of activity of pituitary gland of boys aged 12–13 showed that in the age of 12 the initial concentration averaged to 2.4±0.9 ng/ml, and in the age of 13 the initial level was 1.3±0.2 ng/ml (p>0.05). In the age of 12 the hormone level under the conditions of physical load increased in the 45th minute up to 5.1±0.7 ng/ml, in the age of 13 – up to 5.3±0.9 ng/ml, i.e. revealed no significant differences as compared to such level in the age of 12. Thus, the lowest blood level of somatotropin without the load is observed in the age of 13 as compared to other age groups.

Cortisol, which accounts for about 80% of total hormones of adrenal cortex, plays an important role in adaptive responses of the body. Simultaneous study of the response of pituitary gland and adrenal cortex to various loads and comparative assessment of their potential capabilities are of peculiar interest and ensure broader description of the endocrinal aspects of stress reaction. Notwithstanding that one hormone (somatotropin) represents a central gland (pituitary gland), and the other (cortisol) – a peripheral gland (adrenals), somatotropin and cortisol are the products of final links in the regulation chain, and, therefore, it is reasonable to compare the level of somatotropin against cortisol under the conditions of stress loads.

The initial level of cortisol varied within the range from 1.3 to 105 ng/ml and averaged to 32.5±2.5 ng/ml, the coefficient of variability – 74.9 %. Significant decrease of adrenal cortex activity is observed in response to the physical load: cortisol concentration goes below the initial level, starting from the 15th minute after the physical load (p<0.01). The coefficient of variability of hormone level increases insignificantly after the load as compared to the initial one (Table 5).

### Table 5. Values (M±m) of concentration of cortisol (ng/ml) in blood plasma of boys under the physical load

| Examined indicator | Periods of Examination | before load | in 15 minutes | in 45 minutes |
|--------------------|------------------------|-------------|---------------|---------------|
| Absolute concentration | 32.3±2.5 | 22.5±2.3 | 24.5±2.5 |
| Variability | 105-1.3 | 125-1.6 | 106-1.3 |
| Variability coefficient | 74.9% | 98.7% | 97.7% |
| Growth of concentration | - | -11.2±3.7 | -10.0±3.2 |
| In percentage terms | - | 34.7% | 30.9% |

Three types of adrenal cortex response to the load are revealed. In most cases, the first type is observed – decrease of the cortisol level accompanied with high initial activity of adrenals (p<0.001). The second and the third types – increase of the hormone level in the 15th and 45th minutes, respectively (p<0.01 and p<0.001) – were observed less often.

The initial level of cortisol under the first type of response was significantly lower as compared to the second and the third types (p<0.001). It is evidenced that the nature of adrenal cortex response to the load is subject to the initial level of its activity (i.e. similar to the nature of the pituitary gland response with respect to somatotropin).

Decrease of the cortisol level (p>0.05) was observed immediately after the limit work on bicycle ergometer, followed by sharp increase (p<0.001) in the 15th minute. Hereafter, in the 30th minute a trend towards further increase of the cortisol level was observed; however, it was not as significant as the hormone level in the 15th minute (p>0.05). It was followed by insignificant decrease of its level in the 45th minute, while the cortisol concentration remained higher (p>0.05) than the initial level.

Variability of individual values under the physical load increased and became the most significant in the 30th minute after the load (84.2% against 51.3% initially); further, such coefficient demonstrated undulating fluctuations. The maximum activity of adrenal cortex (with respect to cortisol) during the research period equaled to 62.4±9.4 ng/ml, minimum activity – 26.6±6.4 ng/ml; amplitude of oscillation – 35.6± ng/ml (Table 6).

Thus, a different trend of the response of pituitary gland and adrenal cortex is observed under the influence of the physical load. The highest responsiveness of pituitary gland was observed in the 45th minute after the load,
Thus, somatotropin concentration reaches its maximum value immediately after the load and remains at such high level during further observation periods. Concentration of cortisol changes under the influence of the same load on a phased basis with interchange of decrease and increase of values.

Responsiveness of adrenal cortexes under the influence of the physical load during the bicycle ergometry is about 3.9 times lower than the responsiveness of pituitary gland under the same conditions.

Correlation analysis showed virtually no relation between the level of somatotropin and concentration of cortisol before load (r = -0.10; p>0.05). Under the load conditions, negative relation between the level of somatotropin activity and concentration of cortisol immediately after the load and in the 45th minute increases; however, it is not significant (r equaled to -0.63, -0.57, respectively, p>0.05). Close correspondence between the initial level of somatotropin activity and responsiveness of adrenal cortex under the influence of stimulus and, vice versa, between the background level of cortisol and responsiveness of somatotropin during various periods after the physical load, was not revealed. This is evidenced by low negative correlation between them during all terms of observance. Thus, analysis of peculiarities of the response of pituitary gland and adrenal cortex to the physical load of high power evidences results of analysis of their response to the physical load of relatively lower power. Pituitary gland is more sensitive to the physical load than adrenals; shifts of pituitary gland activity are more long-term and stable than shifts of adrenals activity. At the same time, pituitary gland and adrenal show more response to the physical load of higher power than the physical load of lower power. The nature of pituitary gland response is similar under both loads, while the nature of adrenal cortex response changed: instead of decrease of the cortisol level in the 15th and 45th minutes under low-power loads, increase occurs under higher-power load.

### 4. Conclusion

Thus, the pituitary gland activity increases under the physical load with PWC$_{170}$ power. The pituitary gland response in the 45th minute is more significant than response in the 15th minute after the load. In each specific case, the trend of response (increase or decrease), the incremental value of somatotropin and the rate of response were subject to the value of the initial level of pituitary gland activity.

### Table 6. Dependence of the nature of adrenals response to the physical load on the initial concentration (ng/ml) of cortisol in blood plasma of boys

| Type of response | Quantity of observations | Periods of Examination | Before the load | in 15 minutes | in 45 minutes |
|-----------------|-------------------------|------------------------|-----------------|---------------|---------------|
| First           | 51                      |                        | 16.8±2.0        | 17.1±2.5      |               |
|                 |                         | 1.9-41.2               | 34.5            | 35.2%         | p<0.001       |
|                 |                         | p<0.001                |                 |               |               |
| Second          | 19                      |                        | 40.7±7.94       | 18.8±4.5      |               |
|                 |                         | 125.0                  | 3.4-61.3        |               |               |
|                 |                         | p<0.05                 | 129.6%          | p<0.05        |               |
| Third           | 22                      |                        | 19.3±4.3        | 47.2±7.1      |               |
|                 |                         | 4.5-32.5               | 11.5-106.0      |               |               |
|                 |                         | p<0.05                 | 287.3%          | p<0.01        |               |

while the highest responsiveness of adrenal cortex was observed in the 15th minute. Besides, the responsiveness of pituitary gland is 3 times higher than the responsiveness of adrenal cortex under the influence of the same type. It is observed that the response of both pituitary gland and adrenal cortex in each particular case was subject to the value of their initial activity.

Similar nature of the dynamics of the variability coefficients of the values of both hormones under the physical load is revealed; it reaches its maximum level in the 15th minute after the load.

Correlation analysis showed no relation between the level of cortisol and somatotropin activity before the load and in the 15th and 45th minutes after the load. The level of cortisol activity in the 15th and 45th minutes of the physical load did not correlate to the initial level of somatotropin activity. Correlation dependence between the level of somatotropin activity in the 15th and 45th minutes after the load and background activity of cortisol was not found.

Analysis of interrelations between the level of cortisol activity and somatotropin level under the conditions of high (as to the power and volume) load (cycloergometric work up to the limit) reveals that dynamics of concentration of somatotropin and cortisol immediately after the load assume a reverse trend. Further, in the 15th minute, sharp increase of the cortisol level against the background of certain stabilization of the somatotropin level occurs. Further, in the 45th minute, insignificant decrease of the hormone level was observed, while the level of somatotropin showed virtually no changes in the 30th and 45th minutes.
The level, from which decrease of hormone concentration occurred, is significantly higher than the level, from which it increased.

The activity of pituitary gland and adrenals increases or decreases under the influence of the physical load provided that each test subject can demonstrate one of two physiologically equivalent types of response – increase (with relatively low initial level) and decrease (with relatively high initial level) of the concentration of hormone in blood. The nature of the overall result is determined by predominance of frequency of one of the response types and the extent of changes of hormone concentration under each of them.

5. References

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