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Tsitsino Abakelia, Ketevan Lashkhi, Sophio Kakhadze.
BRIDGING GAP BETWEEN PRE AND POSTOPERATIVE PROSTATE BIOPSIES: PI RADS CORRELATION WITH FINAL HISTOPATHOLOGICAL DATA

Sopio Gvazava, Vladimir Margvelashvili, Nino Chikhladze, Diana Duluf, Corinne Peek-Asa.
A RETROSPECTIVE STUDY OF THE MAXILLOFACIAL INJURIES IN TWO EMERGENCY DEPARTMENTS IN TBILISI, GEORGIA

EXPENDITURE ON MEDICINES IN A MULTIDISCIPLINARY HOSPITAL IN ALMATY BASED ON ABC /VEN ANALYSIS

Tchernev G.
NITROSOGENESIS OF SKIN CANCER: THE NITROSAMINE CONTAMINATION IN THE CALCIUM CHANNEL BLOCKERS (AMLODIPINE), BETA BLOCKERS (BISOPROLOL), SARTANS (VALSARTAN/LOSARTAN), ACE INHIBITORS (PERINDOPRIL/ ENALAPRIL), TRICYCLIC ANTIDEPRESSANTS (MELITRACEN), SSRI (PAROXETINE), SNRI (VENLAFAXINE) AND METFORMIN: THE MOST PROBABLE EXPLANATION FOR THE RISING SKIN CANCER INCIDENCE

INFLUENCE OF PROFICIENCY OF SYNTHETIC FOLIC ACID ON THE NEUROLOGICAL SYMPTOMS OF RATS

Zamzam AR. Aziz, Entedhar R. Sarhat, Zaidan J. Zaidan.
ESTIMATION OF SERUM FERROPORTIN AND LIVER ENZYMES IN BREAST CANCER PATIENTS

Tereza Azatyan.
THE RHEOENCEPHALOGRAPHIC STUDY OF THE INTERHEMISPHERIC ASYMMETRY OF CEREBRAL BLOOD FLOW IN HEALTHY AND MENTALLY RETARDED CHILDREN

Ahmed T. Jihad, Entedhar R. Sarhat.
ALTERED LEVELS OF ANTI-MULLERIAN HORMONE AND HEPcidIN AS POTENTIAL BIOMARKERS FOR POLYCYSTIC OVARY SYNDROME

EFFECTS OF DIMETHYL SULFOXIDE ON HIPPOCAMPAL ACTIVITY IN A ROTENONE-INDUCED RAT MODEL OF PARKINSON’S DISEASE

Labeeb H. Al-Alsadoon, Ghada A. Taqa, Maha T. Al-Saffar.
EVALUATION OF PAIN-KILLING ACTION OF ACETYLSALICYLIC ACID NANOPARTICLES ON THERMAL NOCICEPTION IN MICE

Olesia Kornus, Anatolii Kornus, Olha Skyba, Iryna Mazhak, Svitlana Budnik.
FORECASTING THE POPULATION MORTALITY RATE FROM CARDIOVASCULAR DISEASES AS A CONDITION OF THE ECONOMIC SECURITY OF THE STATE

Safi K. Yahya, Haiman A. Tawfiq, Yasir Saber.
STIMULATION OF B3-RECEPTOR-INDUCED CENTRAL NEUROGENIC EDEMA AND VITIATED ELECTROLYTE HOMEOSTASIS IN EXPERIMENTAL RODENT MODEL

PRODUCTIVITY AND SELENIUM ENRICHMENT OF STEVIA IN HYDROPONIC AND SOIL CULTIVATION SYSTEMS IN THE ARARAT VALLEY

Ezzuldin Yaseen Aljumaily, Ali R. Al-Khatib.
HARDNESS AND ELASTIC MODULUS ASSESSMENT FOR TWO ALIGNER MATERIALS BEFORE AND AFTER THERMOCYCLING: A COMPARATIVE STUDY

Tchernev G.

Manish Tyagi, Uzma Noor Shah, Geetika Patel M, Varun Toshniwal, Rakesh AshokraoBhongade, Pravesh Kumar Sharma.
THE IMPACT OF SLEEP ON PHYSICAL AND MENTAL HEALTH: IMPORTANCE OF HEALTHY SLEEP HABITS

Musayev S.A, Gurbanov E.F.
DYNAMICS OF THE MECHANICAL FUNCTION OF THE LEFT ATRIUM IN PATIENTS WITH ISCHEMIC MITRAL VALVE REGURGITATION
Abrahamovych Orest, Abrahamovych Uliana, Chemes Viktoriia, Tsyhanyk Liliya, Mariia Ferko.
INDICATORS OF BONE METABOLISM IN PATIENTS WITH RHEUMATOID ARTHRITIS WITH IMPAIRED BONE MINERAL DENSITY: CHARACTERISTICS, THEIR FEATURES AND DIAGNOSTIC VALUE..............................................................99-104

THE ROLE OF IMMUNOTHERAPY IN CANCER TREATMENT: CHECKPOINT INHIBITORS, CAR-T CELLS, AND VACCINES......105-112

A METHOD FOR IMPROVING THE PROFESSIONAL PERFORMANCE AND RELIABILITY OF PERSONS DRIVING HIGH-SPEED VEHICLES........................................................................................................113-116

Bhupesh Goyal, Sandeep Bishnoi, Suphiya Parveen, Devanshu Patel J, Yasmeen, Anupama Nanasaheb Tarekar.
MANAGING ARTHRITIS PAIN: MEDICATIONS AND LIFESTYLE CHANGES..............................................................117-122

Sergienko Ruslan, Vovchenko Anna, Kravchuk Lyudmila, Zinchenko Vitaliy, Ivanovskia Olha.
ANALYSIS THE RESULTS OF SURGICAL TREATMENT AND EARLY REHABILITATION OF PATIENTS WITH MASSIVE TEARS THE ROTATOR CUFF THE SHOULDER........................................................................................................123-128

NEURODEGENERATION AND NMDA........................................................................................................129-136

Dilshad Ahmad Usmani, Kavina Ganapathy, Devanshu Patel J, Anchal Saini, Jaya Gupta, Shalini Dixit.
THE ROLE OF EXERCISE IN PREVENTING CHRONIC DISEASES: CURRENT EVIDENCE AND RECOMMENDATIONS........137-142

Tchernev G.
Controversies and paradoxes in melanoma surgery: consolidating two surgical sessions into one and sparing the sentinel lymph node- a possible guarantee of recurrence-free survival..............................................................................................143-146
THE RHEOENCEPHALOGRAPHIC STUDY OF THE INTERHEMISPHERIC ASYMMETRY OF CEREBRAL BLOOD FLOW IN HEALTHY AND MENTALLY RETARDED CHILDREN

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Abstract.

Aim: The features of functional organization of hemodynamic processes in brain basins of healthy children and children with mild mental retardation depending on the nature of asymmetry and gradient of cerebral blood filling are investigated.

Materials and methods: The study was executed in the scientific laboratory of the special and inclusive education department of the Armenian State Pedagogical University after Kh. Abovyan and Armenian State Institute of Physical Culture and Sport. The study involved children aged 8 to 11 years, a total of 131. The 73 of them were healthy school children and 58 children with a low degree of mental retardation. Each category of subjects was divided into 2 age groups: 8-9 years and 10-11 years.

Results: According to the results of the study, in the control group, 88% of the examined patients showed a hyperfrontal pattern in terms of RI (rheogramm amplitude). In seven children, the hypermastoidal pattern was observed, and in the two children of the control group, no significant differences between the RI values in the frontal and mastoidal basins were found. Conclusion: The study involved 131 children aged 8 to 11 years old. 73 of them were healthy with normal physical and mental development as well as 58 children with a weak degree of mental retardation. The study was undertaken to determine which sport and physical activity allowed children with mental retardation.

Established that the parameter of TPWV in 8-9-year-old and 10-11-year-old schoolchildren of the control group was significantly higher than that of experimental children in the frontal, bimastoidal and hemispheric basins.

The hypermastoidal gradient pattern of IPVR was recorded in 55.2% of children in the control group, 13.8% of children have a hyperfrontal pattern, and 31% of schoolchildren lacked a reliable ($p>0.05$) gradient of peripheral vascular resistance between the bifrontal and bimastoidal basins, which indicates the same level of resistance of the vascular wall in the compared pools. Note that, in 8-year-old schoolchildren, only the hypermastoidal pattern of IPVR was recorded. In children 9-11 years old, either the absence of a gradient was revealed, or the gradients of both signs were established. Thus, in children of 8-9 years of age, the magnitude of the gradient is positively related to the age of children ($r=0.75$). Also with age, there is a decrease in resistance in the frontal and mastoidal basins, but to a greater extent in the frontal ones, which leads to a decrease in the gradient relative to 8-9 years old. A correlation between the brain IPVR in the frontal pool ($r=0.54$) and age was observed in children 10-11 years old. It is possible that the fall in resistance of the vascular wall of the frontal pool in this age group ensures intensive maturation of the frontal lobes.

Key words. Hemodynamic processes in brain, method of rheoencephalography, brain interhemispheric asymmetry, mental retardation, cognitive impairment, chronic brain hypoxia.

Introduction.

To examine the functional interhemispheric asymmetry of brain blood flow in the examined groups of children, we used rheoencephalographic technique.

The paper presents the results of empirical studies of rheoencephalographic indicators of the brain of children in norm and mental retardation. The parameters of blood circulation of the brain of healthy children and children with mental retardation at the age of 8-11 years, reflecting the state of different parts of the vascular system of the brain.

We also analyzed and compared age-specific changes in the functional organization of hemodynamic processes in healthy children aged 8-11 years and children diagnosed with mental retardation and mild intellectual development.

On our opinion, in children with mental retardation, violation of the vascular tone of the brain microcirculation is a factor contributing to cognitive failure. At the same time, chronic brain hypoxia observed in mental retardation is likely to destabilize regulatory functions, leading to the disintegration of systemic brain activity.

Blood supply to the brain depends on two vascular systems, the blood flow in which is able to complement each other. At the same time, the internal carotid arteries normally provide the largest blood flow to the brain and have a direct effect on the state of cerebral circulation [1-3].

The image of cerebral circulation seems to be a dynamic mosaic with a continuously changing local blood flow in various areas, due to the redistribution of blood flow from areas less active in functional terms in areas with intense activity, with a relative constancy of the total blood flow to the brain [3-5].

Self-regulation is crucial for adequate blood supply to the brain and is characterized by the ability of the cerebral vessels to maintain a relatively unchanged volume velocity of the cerebral blood flow when perfusion pressure changes.

Between the system of carotid and vertebral arteries there is a connection aimed at maintaining adequate cerebral blood flow with decreasing in the diameter of some arteries and increasing the diameter of others, which indicates the compensatory-adaptive interdependence of these two blood supply main routes of the brain [6-8].

Morphological asymmetry of cortical branches of paired vessels in the right and left hemispheres has been studied in a number of studies [9-11]. There are studies concerning asymmetry of morphological parameters of extracranial parts of main arteries: common carotid arteries [12,13], vertebral arteries [7,13,14]. At the same time, there is a small number of studies in which the parameters of paired vessels were compared.

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taking into consideration sex [7,12,13], in the dynamics of their changes in different age periods [13,15].

Currently, the literature lacks a clear understanding of the interhemispheric features of cerebral blood flow in children of primary and secondary school age with mental retardation, which indicates the relevance of further study of this issue.

The objectives of the study were to establish the features of the functional organization of hemodynamic processes depending on the nature of asymmetry and gradient of cerebral blood filling in the brain basins of healthy children and children with mild mental retardation to determine the degree of physical activity of these children [16,17].

**Materials and methods.**

The study was executed in the scientific laboratory of the special and inclusive education department of the Armenian State Pedagogical University after Kh.Abovyan. The study involved children aged 8 to 11 years, a total of 131. 73 of them are healthy schoolchildren and 58 children with a low degree of mental retardation. Each category of subjects was divided into 2 age groups: 8-9 years and 10-11 years.

**The control group of healthy schoolchildren:**

- 8-9 years old - 38 children, including 20 girls and 18 boys.
- 10-11 years old 35 children of them 17 girls and 18 boys.

**Experimental group of children with mental retardation:**

- 8-9 years old - 28 children, 11 of them girls and 17 boys.
- 10-11 years old 25 children, including 12 girls and 13 boys.

The selection of children in the experimental group was made on the basis of accompanying documents with an approved diagnosis of “mental retardation of a mild degree”.

After reviewing the results of clinical, laboratory, pedagogical and psychological examinations, family members and guardians signed a voluntary agreement for the child to participate in scientific research.

To study the functional interhemispheric asymmetry of the cerebral blood flow of the examined groups of children, the rheoencephalographic technique was used.

In recent years, rheoencephalography (REG) as a method of research of cerebral blood circulation has not lost its relevance. Comparison of the data of REG and ultrasound dopplerography (USDG) showed that REG provides more information about the functional state of the microcirculatory channel.

The physiological technique of rheoencephalography, based on the rheographic registration of cerebral blood flow in the basins of basal (basilar), internal carotid arteries, as well as transverse bi-temporal, bi-frontal and bi-occipital rheovasography, allows to assess the asymmetry of blood flow in the same areas of the brain. This method is used to a greater extent for the integral assessment of cerebral blood supply in individual vascular basins, rather than in specific brain structures.

The survey was carried out on a computerized complex "Diamant-RCSM (rheo-cardio-spiro monitor)" in a specially equipped soundproof electrophysiological laboratory. The subject had the opportunity to adapt to the conditions of the study for 5-10 minutes.

The dynamics of the REG tracked in 4 leads: frontal-mastoidal left and right hemispheres (FM L, FM R), which allows to judge the state of blood flow in the basin of the internal carotid arteries; bifrontal (FF) indicating the blood flow to the frontal regions of the cerebral hemispheres; bimastoidal (MM), reflecting the characteristics of blood flow in the vertebral-basilar basin.

The analysis of rheographic waves is carried out in 2 directions:
- evaluation of quality characteristics - interpretation of the wave shape;
- evaluation of quantitative characteristics - digital processing.

Digital analysis of the REG wave includes a quantitative assessment of a number of indicators that characterize mainly the tone and elasticity of blood vessels.

According to the literature, adults are characterized by the presence of a hyperfrontal gradient of blood flow, i.e., greater values of the amplitude of the rheographic curve and cerebral blood flow volume in the vessels of the anterior cerebral artery basin compared to the basin of the vertebrobasilar system.

The absence of hyperfrontal pattern according to volume blood flow data in children 8-9 years old and its presence only in a part of adolescents, 12-13 years old is associated with functional immaturity of frontal regions of children of 8-9 years old.

In the literature for REG-indicators the presence of gradient values is described only for rheographic index and venous outflow index, but the peculiarities of blood supply of the basin depend on other indices of the vascular channel state.

Thus, to date, the formation of blood flow gradient between frontal and mastoidal brain basins in 8–11-year-old children in norm and at UW has been insufficiently studied.

The question of the existence of blood flow gradients in smaller parts of the cerebral vascular system also remains open.

Digital analysis of cerebral blood flow in children were calculated the average values of the following parameters of rheoencephalography:
- rheographic index (RI), characterizing the degree of pulse blood filling of large arteries. The rheographic index is the ratio of the amplitude of the REG wave to the value of the standard calibration signal. We used a 0.1-Ohm calibration signal. The rheographic index is estimated in relative units or fractions of Ohms.
- indicator of peripheral vascular resistance (IPVR), reflecting the total lumen of small vessels.
- venous outflow index (VOI), indicating the tone of medium and large veins.
- diastolic index (DSI), characterizing the state of small veins.
- time of pulse wave velocity (TPWV).
- dicrotic index (DCI), indicating the state of the small arteries.
- modulus of elasticity (ME), reflecting the elasticity of the artery wall.

The presence of cerebral blood flow asymmetry was determined by rheographic index for each child individually.

At the preliminary stage of data processing, all rheoencephalogram indices were calculated and analyzed separately for boys and girls. Correlation analysis of differences in different-sex children in the control group and the group of children with EI aged 8 to 11 years did not reveal significant differences in cerebral blood flow parameters, so in the future REG parameters of intracranial macrohemodynamics of different-sex children were analyzed together.
To assess the asymmetry of blood supply to the brain basins, we calculated the asymmetry coefficient (AC) of blood flow (by RI) of the hemispheric basins (FM-L, FM-R) for each child individually, and also individually calculated the reliability of differences between the RI of the right and left hemispheres using the formula:

$$CA = \frac{(RI_{FM-R} - RI_{FM-L})}{(RI_{FM-R} + RI_{FM-L})} \times 100\%$$

According to the literature, adults are characterized by the presence of a hyperfrontal gradient of blood flow, i.e., greater values of the amplitude of the rheographic curve and cerebral blood flow volume in the vessels of the anterior cerebral artery basin compared to the basin of the verteobasilar system.

The absence of hyperfrontal pattern according to volume blood flow data in children 8-9 years old and its presence only in a part of adolescents, 12-13 years old is associated with functional immaturity of frontal regions of children of 8-9 years old.

In the literature for REG-indicators the presence of gradient values is described only for rheographic index and venous outflow index, but the peculiarities of blood supply of the basin depend on other indices of the vascular channel state.

Thus, to date, the formation of blood flow gradient between frontal and mastoidal brain basins in 8–11-year-old children in norm and at mental retardation has been insufficiently studied.

The problem of the existence of blood flow gradients in smaller parts of the cerebral vascular system also remains open.

Correlation analysis showed the absence of correlation between cerebral blood flow parameters of children with EI and their age, which is apparently associated with delayed maturation of brain structures in this group of children.

**Results.**

According to the results of the study, in the control group, 88% of the examined patients showed a hyperfrontal pattern in terms of RI (rheogram amplitude). In seven children, the hypermastoidal pattern was observed, and in the two children of the control group, no significant differences between the RI values in the frontal and mastoidal basins were found.

Consequently, the hyperfrontal gradient of RI is already formed by the age of 8, and in the group of 10–11-year-old children the difference in blood supply to the anterior and posterior regions of the brain only increases.

The distribution of the modulus of elasticity (ME) pattern in healthy children was as follows: 56% had a hyperfrontal pattern, 31% of children had a hypermastoidal pattern, and 13% of children in the control group did not have a predominance of values of this indicator. The average value of the elastic modulus decreases with age in both basins. However, in the frontal basin this decrease is insignificant, while for the mastoidal there is a significant decrease in the ME value in the group of 10-11 years, which leads to the appearance of a reliable hyperfrontal pattern in this group (g = 0.48; p <0.05).

In 68% of cases in healthy children, the DCI gradient had a hypermastoidal pattern, which suggests that the tone of the arteries of the small caliber of the mastoidal basin is higher than the frontal, in 11% of children it is hyperfrontal, and 21% of the children did not have significant differences in the tone of the arteries of the small caliber. Comparison of DCI values shows that in the group of 10-11-year-old children there is an unreliable increase in the index compared with the group of 8-9 years. Correlation analysis revealed the dependence of the DCI gradient on age (r = 0.7) in children 8–9 years old, which indicates a deepening of the gradient in this age group.

The hypermastoidal gradient pattern of IPVR was recorded in 55.2% of children in the control group, 13.8% of children have a hyperfrontal pattern, and 31% of schoolchildren lacked a reliable (p> 0.05) gradient of peripheral vascular resistance between the bifrontal and bimastoidal basins, which indicates the same level of resistance of the vascular wall in the compared pools. Note that, in 8-year-old schoolchildren, only the hypermastoidal IPVR pattern was recorded. In children 9-11 years old, either the absence of a gradient was revealed, or the gradients of both signs were established. Thus, in children of 8–9 years of age, the magnitude of the gradient is positively related to the age of children (r = 0.75). Also with age, there is a decrease in resistance in the frontal and mastoidal basins, but to a greater extent in the frontal ones, which leads to a decrease in the gradient relative to 8-9 years old. A correlation between the brain IPVR in the frontal pool (r = 0.54) and age was observed in children 10–11 years old. It is possible that the fall in resistance of the vascular wall of the frontal pool in this age group ensures intensive maturation of the frontal lobes.

The DSI gradient had a hypermastoidal pattern in 79.3% of the subjects. Consequently, in most healthy children, small veins in the basal arteries basins are more toning than in the basins of the anterior arteries. The majority of schoolchildren of control group are characterized by a hyper-frontal pattern of DSI and 3.5% do not have a difference in the tone of the small-caliber veins of the bifrontal and bimastoidal basins. The magnitude of the DSI gradient correlates with venous outflow rates in children 8–9 years old (r = 0.7), and in children of the older subgroup there is no such correlation relationship (r <0.4), therefore, the gradient of small veins is formed by 11 years. In 89.7% of the examined schoolchildren in the control group, the venous outflow index was higher in the mastoidal basin. At the same time, with a higher tone of the venous vessels in the frontal area, a greater tone of its arterial bed and a higher amplitude of the program were detected.

With age, a tendency to decrease in the VOI was revealed. In subjects aged 8–9 years, the magnitude of the VOI gradient positively correlates with age (r = 0.61). Thus, at 8–9 years of age, a high hypermastoidal gradient is characteristic of the VOI, that is, the large veins of the posterior cerebral arteries pool have a greater tone, and by the age of 10–11 this pattern is likely to be already formed. It should also be noted that the majority of children in the control group (96.6%) are characterized by a hyperfrontal gradient of TPWV, i.e., after systole TPWV to the pool of the posterior cerebral arteries less than to the frontal zones. According to the results of the research, it turned out that the pattern of ratios of indicators has age dynamics. Thus, for a group of healthy children, the gradient of parameters of rheoencephalograms characterizing the state of large arteries (RI) and veins of different caliber (VOI, DSI) is already established by the age of eight, as evidenced by the absence of further age-related changes and the prevalence of blood filling...
and the degree of venous outflow in the frontal pool. The DKI gradient, which characterizes the regional differences in the tone of the small arteries, is formed in an adult type by the age of 10, which reflects the predominance of the tone of these vessels in the basins of the posterior cerebral arteries.

The ratio of the total lumen of all small vessels (IPVR gradient) at 8-11 years of age continues to form. At the same time, dynamic age-related changes are aimed at reducing resistance in the basins of the anterior cerebral arteries. The gradient of the tone of large arterial vessels (ME) is actively formed, the change of which goes in the direction of the prevalence of tone in the frontal areas. Thus, the pattern of ratios of the values of the REG indicators, that is, the ratio of the tone of the veins and arteries of different caliber, begins to take shape in childhood, providing functional maturation of the frontal brain. This process is characterized by unevenness and heterochronicity. The emerging gradients of the values of the indicators reflect changes in the regulation of the vascular bed, which are associated with an increase in the functional activity of the frontal areas and lead to an improvement in their blood supply conditions.

An analysis of the REG parameter values in children with mental retardation with different gradients of blood supply to the brain basins showed that a hyperfrontal gradient along RI was detected in 70.6% of children in the experimental group, i.e., in the experimental group, the predominance of the amplitude of the rheoencephalogram in the frontal area is found to be 17.4% less than in the control group. The distribution of variants of the gradient ME, reflecting the tone of the arteries of large and medium caliber in the experimental group, in general, corresponds to the control group. In 47% of children in the experimental group, the tone of the small arteries in terms of the DKI index has a hypermastoidal pattern, in 32.4% it is hyperfrontal, in 20.6% of children with mental retardation, there are no significant differences in DKI between the bifrontal and bimastoidal zones.

The age dynamics of the formation of a DKI gradient between regions is not established. The prevalence of peripheral vascular resistance in the frontal or occipital areas is the same in children of the experimental group (38.25%) each. At the same time, 23.5% of children made up a group without an IPVR gradient. We registered no significant age-related changes in the IPVR gradient in children of the experimental group. The predominance of the small vein tone (DSI) in the pool of the posterior cerebral arteries relative to the anterior (hypermastoidal gradient) is characterized by 44% of schoolchildren with EI, i.e., 35.3% less than the representation of this pattern in the control group, and in the frontal pool - 38% is also higher than in the control group by 21.1%. The absence of a gradient, DSI was recorded in 17.7% of children of the experimental group (5 times more than in children without a gradient in the control group).

In the experimental group, 50% of schoolchildren (29 people) had a hyperfrontal VOI gradient, and in the control group, only 3.1% (2 people), which is 14.5 times higher than that of healthy children. Children with hypermastoidal distribution of large veins in the experimental group 32.4%, and in the control group - 89.7%, i.e., the hypermastoidal VOI pattern in children with mental retardation occurs 2.77 times less frequently than the examined healthy schoolchildren.

The distribution of IPVR patterns among schoolchildren in the experimental group is as follows: 20.6% is a hyperfrontal gradient, 50% is hypermastoidal, 29.4% of children do not have a significant predominance of IPVR in the compared basins (p> 0.05).

The interdependence of different, considered by us, characteristics of cerebral blood flow in different parts of the vascular bed of the brain is confirmed by the data of correlation analysis. The mean values of such parameters of rheoencephalograms as: RI, IPVR, TPWV, VOI, DSI, DKI, ME of one basin are interconnected with the average values of this parameter of the opposite basin (bifrontal with bimastoidal basins of the cerebral hemispheres of the brain) in children of the control and experimental groups, forming the average and high positive correlation relationships (0.55> r <0.96).

A comparative analysis of the indicators of REG by age subgroups (8-9 years and 10-11 years) of the control and experimental groups showed that at 8 years of age, the RI value of the bimastoidal area was significantly lower in the control group relative to children with mental retardation (p <0.05). In children of the control group of 10–11 years, the RI value in the bifrontal region is significantly higher than in children of the experimental group due to its lowering in the children of the experimental group by 10–11 years. It was also shown that in children of the experimental group the hemispheric indices of the venous outflow were significantly higher than IVO of the left and right hemispheres relative to the children of the control group (p <0.05), as well as in the frontal pool (p <0.05). The value of IVO in the basin of the posterior cerebral arteries is not significantly different in children of 8-11 years of age in both groups. In addition, it was established that the parameter of TPWV in 8-9-year-old and 10-11-year-old schoolchildren of the control group was significantly higher than that of experimental children in the frontal, bimastoidal and hemispheric basins.

Conclusion.

The age range from 8 to 11 years is the time to improve the systemic activity of the brain. At this time, the active maturation of the cortex and the commissures of the brain, the specialization of the cerebral hemispheres, as well as the formation of the mechanisms of regulation of the cerebral blood flow occurs. In our work, we studied the characteristics of rheoencephalographic indices of the brain of children in normal and mental retardation. The parameters of blood circulation in the brain of healthy children and children with mental retardation at the age of 8-11 years, reflecting the state of various parts of the vascular system of the brain, were analyzed. We also analyzed and compared the age peculiarities of changes in the functional organization of hemodynamic processes of conditionally healthy children 8–11 years old and children diagnosed with mental retardation and delayed intellectual development of a mild degree in conditions of calm wakefulness.

In healthy children aged 8-9 years, there is an increase in the difference in the tone of the arteries of large, medium (ME) and small caliber. (DKI), large vein tone (VOI) and small caliber (DSI), as well as the level of peripheral vascular
resistance between the bifrontal region and the vertebra-basilar basin of the cerebral blood flow. In 10-11 years, there is a drop in vascular resistance in the frontal area. The amplitude of rheoencephalogram does not correlate with the age of the children examined, which indicates an earlier formation of this parameter. According to the results obtained in our study the average values of the parameters of the REG by sex groups differed, but the statistical analysis using the methods of correlation by the Student’s t-criterion of reliable sex differences in the parameters of cerebral blood flow in children in the control group and the group of children with delayed mental development did not reveal. On our opinion, in children with mental retardation, dysregulation of the vascular tone of the system of macrohemocirculation of the brain is a factor contributing to cognitive insufficiency. At the same time, in chronic brain hypoxia observed in mental retardation, destabilization of regulatory functions is likely to occur, leading to disintegration of the systemic activity of the brain.

The absence of asymmetry of mean linear blood flow velocity, sex differences and asymmetry of shear stress indicates that the right and left UVB, regardless of sex, retain such hemodynamic parameters of blood flow (diameter, resistance, volumetric flow velocity), which are necessary for normal blood supply of both hemispheres of the brain.

Thus, the conducted research shows that children of 8-9 years old with mild and moderate mental retardation of various etiologies, especially boys, differ from their peers by lagging behind in the development of functional brain asymmetry, which leads to less pronounced lateralization of the brain, global undifferentiation of non-verbal activity of the left hemisphere, low level of development of spatial perception, especially spatial orientation in such differentiated relations as right - left.

According to the results of our research, children with a low degree of mental retardation can be involved in sports without restrictions if they do not have physical disabilities.

In further publications we will present the results of our physiological and psychological studies of interhemispheric asymmetry and interhemispheric interaction in normal and mentally retarded children.

REFERENCES