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DEVELOPMENT OF COMPUTERIZED METHODS FOR ESTIMATION OF PERIPHERAL BLOOD CIRCULATION IN CHILDREN UNDER SCREENING INVESTIGATIONS

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Experience gained in estimation of the conditions of peripheral hydrodynamics in children with various forms of vegetative dysfunctions was used to develop algorithms for diagnosis of hemodynamic disturbances, a set of recording devices, and software using statistical probability diagnostic methods.

Recent studies have revealed wide distribution of vegetative disturbances in children in the Republic of Belarus. Results of scientific and practical developments show substantial heterogeneity both of clinical and pathogenetic variants of arterial hypertensions and vegeto-vascular dystonias.

As a rule, the first clinical signs of arterial hypertension and vegeto-vascular dystonia are exhibited as various kinds of failures of pheripheral hemodynamics that can be adequately treated given their timely diagnosis.

In the last five years, using extensive clinical material, we have studied the characteristics of functioning of the vegetative nervous system in children with different variants of neurocirculatory dystonia, and gained experience in estimating conditions and peculiarities of the peripheral hemodynamics with the various forms of dysfunctions.

All this has allowed us to approach the development of a comprehensive hard- and software expert system for estimation of the conditions of the peripheral hemodynamics and diagnosis of early signs of the diseases. As this system is based on a PC, it can be used for extensive screening examinations of large groups of children and for identification of peripheral hemodynamic failures in early developmental stages in order to organize differentiated individual curative and preventive medical care.

The system operates with a large sample of indices in the rheovasograms recorded by the method of tetrapolar rheography, simultaneously with a cardiointervalogram. We used conventional estimation methods and calculated the main indices such as pulse wave transmission time, inflow and outflow times, pulse rate and their relations that characterize rather completely the different variants of peripheral dystonias.

As a control base was being formed, arterial pressure levels, weight, height, and weight height ratios in children were taken into consideration.

Thus, the result of examination is represented in the data base by the record consisting of 12 indices, and in terms of statistical mathematics it determines the position of a certain point in a 12-dimensional space of indices.

Although the amount of clinical information used for formation of the initial control data base was rather limited, it appeared possible to select sufficiently representative symptomatic signs and to isolate five standard variants of neurocirculatory dystonia, characterized by basic differences in the blood inflow and outflow phases and the tone of arterioles and venules.

So, the types of dystonias in the children can be briefly characterized as follows:

type 1: normal periods of blood inflow and venous outflow, no failure of vascular tone;

type 2: shortened blood inflow period; normal venous outflow period tending to elongation; some signs of weakened tone of arterial vessels;

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type 3: normal blood inflow period; elongated venous outflow phase; some signs of vein constriction;

type 4: elongated blood inflow and outflow periods; some signs of angioconstriction;

type 5: substantial elongation of the pulse wave transmission time; a trend to elongation of the blood inflow phase and to shortening of the venous outflow phase; some signs of decreased resistance of peripheral arterial vessels.

Thus, records in the control data base determine a set of control points grouped in particular regions according to the isolated clinical variants or classes of neurocirculatory dystonias in the multidimensional space of signs.

However, the region in the space of signs determining the various classes partially overlap one another. Such overlaps make the problem of classification of failures in some of the children examined much more difficult.

This uncertainty can be eliminated using statistical probability methods [1-4], which were a basis for our programs that were included in a software package for estimation of conditions of peripheral blood circulation in children. One of the methods used in this study is based on estimation of the correspondence of a set of indices in a patient examined to each of the isolated classes with the aid of multidimensional sign distribution functions.

Having known the character of the distribution of the frequency values for each of the indices in the various classes, it is possible to reduce the problem of assignment of a particular set of signs to some of the classes to determination of the probability of such a set of signs appearing in a particular class. Comparing the resultant probabilities and choosing a maximum probability, it is possible to isolate a priority class, i.e., to solve the diagnostic problem.

Apart from useful information, experimental data used to obtain the sign frequency distributions contain an erroneous component that distorts the shape of the distributions. This can be caused by both measurement errors and statistical spread of experimental data, when their amount is rather small. So, parameters in the distribution law are found by approximation of the normal curve with the least squares method [1, 4].

The approximation can be carried out by solving a system of nonlinear equations in which both the average a_0 and the standard deviation σ, or by solving nonlinear equations for a_0 and σ alternatively with the aid of iterations, using the results of solution obtained at the previous step as initial data for the subsequent step. The second way appeared preferable because of shorter computer time and simplicity and efficiency of realization of the computation algorithms.

Equations approximating the normal distribution look as follows:

$$\sum_{i=1}^{n} (A_{1i} e^{A_{2i}} + A_{3i}) e^{A_{2i}} = 0\,, \quad A_{1i} = (B_i - 1)\frac{1}{\sqrt{2\pi\,\sigma^2}}\,,$$
$$A_{2i} = -\frac{B_i}{2\sigma}\,, \quad A_{3i} = \left(1 - \frac{B_i}{\sigma}\right)\frac{g_i}{\sigma}\,, \quad B = \frac{(x_i - a_0)^2}{\sigma}\,; \qquad (1)$$

$$\sum_{i=1}^{n} (A_1 e^{A_{2i}} - g_i) A_{3i} e^{A_{2i}} = 0\,, \quad A_1 = \frac{1}{\sqrt{2\pi}\,\sigma}\,,$$
$$A_{2i} = -\frac{A_{3i}}{2\sigma^2}\,, \quad A_{3i} = x_i - a_0\,, \qquad (2)$$

where x_i is the values of the sign to which normalized frequencies of their appearance g_i correspond; n is the number of values of g_1; q_0 is the mathematical expectation; σ is the standard deviation.

Equation (1) is solved for σ, and equation (2) for a_0.

Using the resulting one-dimensional densities, it is possible to obtain a multidimensional normal probability density distribution function. The one-dimensional normal distribution functions correspond to the functions that result from intersection of a multidimensional function by the plane of the coordinate system. In order to substitute equality for the correspondence, the one-dimensional distribution functions should be normalized. In normalization, the fact was taken into consideration that the multidimensional normal distribution is formed by multiplication of one-dimensional indipendent distributions. The normalization is carried out as follows:

$$f_x(0)\, f_y(0)\, f_z(0) \ldots \quad = M .$$

After the normalization

$$f_x^n(0) = f_y^n(0) = f_z^n(0) = \ldots = M ,$$

hence the normalization factors N_1 follow:

$$f_x^n(0) = N_x f_x(0) ; \quad f_y^n(0) = N_y f_y(0) ; \quad f_z^n(0) = N_z f_z(0) ; \ \ldots$$

$$N_X = \frac{M}{F_x(0)} = F_Y(0)\, F_Z(0) \ldots , \quad N_Y = \frac{M}{F_y(0)} = F_X(0)\, F_Z(0) \ldots ,$$

$$N_Z = \frac{M}{F_z(0)} = F_X(0)\, F_Y(0) \ldots$$

Thus, for the probability density function of the multidimensional normal distribution, the equality is satisfied:

$$f_{xyz\ldots}(0, 0, 0, \ldots, 0) = f_x^n(0) = f_y^n(0) = f_z^n(0) = \ldots = M .$$

The value of the multidimensional function for a concrete point can be found without knowledge of the analytical expression for $f_{xyz} \ldots$.

The approach suggested is illustrated by an example of a two-dimensional normal distribution function that can be extended to a multidimensional case.

Let f_x, f_y be normal density distribution functions with known distribution parameters, while the function f_{xy} is unknown.

The problem consists in evaluation of $f_{xy}(x_t, y_t)$ for a point in the space with the coordinates x_t, y_t. The normalization factors are

$$N_x = f_y(0) , \quad N_y = f_x(0) .$$

Since any intersection of f_{xy} by a horizontal plane is an ellipse, in the axis $0x$ there exists such a point a, just as the point b exists in the axis $0y$. For them the equation is valid:

$$f_{xy}(x_t, y_t) = f_{xy}(a, 0) = f_{xy}(0, b) = f_x^n(a) = f_y^n(b) .$$

Values of f_{xy} for all points that belong to this ellipse are the same. Depending on the height at which the function is intersectioned by the plane, the values of a and b (that belong to the intersectionellipse) change and the ratio $a/b \neq$ const, since the distributions f_x and f_y are different.

Now, the following system will be considered:

$$a = F_1(\xi) , \quad b = F_2(\xi) , \quad \xi = f_x^n(a) = f_y^n(b) ,$$

where $F_1(\xi)$ and $F_2(\xi)$ are inverse functions for $f_x^n(x)$ and $f_y^n(y)$; ξ is the unknown variable, $\xi \in [0, f_{xy}(0, 0)]$.

It is necessary to determine $F_1(\xi)$ and $F_2(\xi)$. To do this, use will be made of the expression for the one-dimensional density distribution function:

$$f(x) = \frac{N_x}{\sqrt{2\pi}\,\sigma_x} \exp\left\{-\frac{(x - x_0)^2}{2\sigma_x^2}\right\}.$$

Hence

$$x = x_0 + \sigma_x \left(2 \ln \frac{N_x}{f_x^n(x)\,\sigma_x \sqrt{2\pi}}\right)^{1/2}.$$

Substitution of a for x gives:

$$F_1(\xi) = a = x_0 + \sigma_x \left(2 \ln \frac{N_x}{\xi\, \sigma_x \sqrt{2\pi}}\right)^{1/2}. \qquad (3)$$

Applying similar transformations to the coordinate y, we have

$$F_2(\xi) = b = y_0 + \sigma_y \left(2 \ln \frac{N_y}{\xi\, \sigma_y \sqrt{2\pi}}\right)^{1/2}. \qquad (4)$$

This approach is valid, since $f_t^n(a) = f_y^n(b) = \xi$.

In view of the fact that the point (x_t, y_t) lies on the ellipse with the semiaxes $\| a - x_0 \|$ and $\| b - y_0 \|$, after normalization, we have

$$\frac{x_{nt}^2}{a_n^2} + \frac{y_{nt}^2}{b_n^2} = 1, \qquad (5)$$

where

$$x_{nt} = x_t - x_0; \quad a_n = \| a - x_0 \|;$$

$$y_{nt} = y_t - y_0; \quad b_n = \| b - y_0 \|.$$

It is convenient to reduce the system of nonlinear equations (3)-(5) to the form

$$\frac{x_{nt}^2}{\sigma_x^2\, 2 \ln \dfrac{N_x}{\sqrt{2\pi}\,\sigma_x \xi}} + \frac{y_{nt}^2}{\sigma_y^2\, 2 \ln \dfrac{N_y}{\sqrt{2\pi}\,\sigma_y \xi}} = 1.$$

The interval of solutions for ξ is found from the condition

$$\ln \frac{N_x}{\sqrt{2\pi}\,\sigma_x \xi} \geq 0,$$

Hence

$$\xi \in 0 \div \frac{N_x}{\sqrt{2\pi}\,\sigma_x} = 0 \div M,$$

where $M = f_{xy}(0, 0)$.

Solution of the nonlinear equation gives one value of ξ. Since $\xi = f_x^n(a) = f_y^n(b) = f_{xy}(x_t, y_t)$, the problem is considered to be solved. For a multidimensional case the considerations are similar.

The algorithm considered here can be used to estimate the probability of appearance of a particular test point in each of the classes by comparing the values of multidimensional normal distribution functions. Apart from the method described above, in making diagnosis some other criteria are also used, including those based on closeness of minimax signs to the syndrome criteria.

Thus, experience gained in estimation of the conditions of the peripheral hemodynamics in children with various forms of vegetative dysfunctions allowed the authors to reveal diagnostic criteria based on analysis of the indices in the rheovasogram, to develop algorithms for diagnosis of hemodynamic failures with a control data base, and to create a set of recording devices and software, using statistical probability methods of distinguishing between different versions of hemodynamic failures.

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