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MODELING OF NON-INVASIVE GLUCOSE MONITORING IN DIABETES

Republic of Uzbekistan
Ulugbek Urazkulovich Turapov
(Associate Professor, PhD, Information Systems and Technologies, TCAU)
Republic of Kazakhstan
Musabek Islamovich Akilbayev
(Vice-Rector for Science, PhD, Professor, Peoples' Friendship University, Academician A. Kautbekov)
Gulnar Urazalievna Madalieva
(Senior Lecturer, Peoples' Friendship University, Academician A. Kautbekov)

Abstract: Today, the number of patients with diabetes mellitus (DM) is increasing year by year in the world. In order to maintain blood glucose levels at a normal level, patients with diabetes mellitus need to set daily norms for themselves, such as diet, insulin, and other means of lowering blood sugar, and strictly adhere to them. For this, patients need to regularly check their blood glucose levels at home or in medical institutions. Currently, glucose measurement is widely used in clinical diagnostic laboratories. When determining the level of glucose in the human body using a standard glucometer, the patient experiences painful sensations. In addition, with each new measurement, the patient can infect himself with some disease or infection that enters the body with blood (for example, hepatitis C, AIDS). Also, daily pricking of the patient's finger with a needle causes various inconveniences for the patient. Therefore, the diagnosis of diabetes mellitus is becoming more and more difficult. In such a situation, the use of non-invasive methods of measuring glucose levels is effective. This article studies the issue of mathematical modeling of glucose level monitoring in diabetes mellitus based on electrical resistance (ER) values obtained from bioactive points (BAPs) informative for the BD of the human body.

Key words. bioactive active points, invasive, non-invasive, glucometer.

Introduction

Noninvasive monitoring of blood glucose levels does not harm human tissues. Therefore, in addition to invasive medical methods of measuring glucose levels based on blood sampling, noninvasive measurement methods using various devices (glucometers) have emerged [1,2,3]. With the help of such glucometers, it is possible to regularly check glucose levels at home in a noninvasive way. The noninvasive method allows for easy and quick regular monitoring. For the first time, researchers became interested in noninvasive diagnostic methods for determining blood glucose levels more than 30 years ago [4]. Since then, more than a dozen types of glucose measurement methods with different effects have appeared. These methods are usually divided into optical, microwave and electrochemical methods [5,6]. A noninvasive method for determining blood glucose levels and hemoglobin using infrared radiation has been developed [7].

Scientists in South Korea have proposed a revolutionary non-invasive method for measuring blood glucose levels using an electromagnetic wave transmitted under the skin through a sensor. Studies have shown that a sensor implanted under the skin using an electromagnetic wave can detect even small changes in dielectric conductivity as a result of changes in blood sugar levels [8]. Information on determining glucose levels without taking blood from a patient and monitoring them using non-invasive methods is currently sufficiently documented [9-11].

The human body is a complex system, which contains a set of bioactive points (BAPs). In ancient Chinese medicine, it is believed that there are more than 1000 BAPs in the human body and that they are intrinsically linked to 14 meridians (channels) (of which 12 are paired, i.e. symmetrical and 2 are unpaired), and that maintaining their biophysical parameters in a normal state and distributing the energy flow between the meridians in a uniform manner creates a healthy environment in the human body [12]. It has been proven that these meridians are intrinsically linked to all internal organs in the human body. It has been proven that when a person becomes ill, all pathological signs reach these meridians first through nerve fibers and then to the existing BAPs before their symptoms are detected. Disease leads to a disruption of the balance of the meridians, and it has been proven that diseased BAPs appear in some meridians, and there are also sharp changes in the amount of biophysical parameters in them [12].

J. Nakatani, M.D. Hyodo, A.I. Nechushkina showed that acupuncture can be used to create a system for diagnosing diseases using the electropuncture diagnostic method (EPDU), and proved that in diseases, imbalances occur in the existing meridians of the human body and the appearance of diseased BPNs between the meridians [13]. To identify imbalances in the meridians, J. Nakatani's "Riodoraku" system was created, which combines ancient oriental medicine with modern medicine. Currently, active scientific research is being conducted on the use of the capabilities of BAPs in medicine [14].

The authors proposed using the values of the electrical resistance of bioactive points located in the meridians of the human body in the diagnosis and treatment of diabetes mellitus [15]. For this purpose, a biomeasuring device was developed that allows measuring the values of the electrical resistance in BAPs [16]. As a result of the studies, it was observed that the electrical resistance (ER) in the BAPs of patients with type 1 and 2 diabetes is higher than the electrical resistance (ER) in the informative BAPs of the body of healthy people. In particular, while the ER in healthy people has values of 22.5-139.0 kOhm, in patients with type 1 diabetes this indicator varies from 92.4-659.4 kOhm, and in patients with type 2 diabetes it varies from 251.8-695.4 kOhm [15]. This means that the electrical resistance of the biphasic points on the skin changes as a result of changes in the body of patients. This article studies the issue of mathematical modeling of glucose level monitoring in diabetes mellitus based on the electrical resistance values obtained from BFNs. For this purpose, the most important BAPs informative for diabetes mellitus in 12 paired meridians are first identified using the paired comparison method. Using the identified informative BAPs, the diagnosis of diabetes mellitus is modeled.

Paired comparison method. In order to identify informative BAPs for diabetes mellitus, we use the paired comparison method for a group of experts. To do this, each expert independently compares to what extent the BAP in each pair of meridians is more important than the other in diagnosing diabetes mellitus. Information on the location of BAPs in the meridians is presented in Table 1 [12,17,18].

Table 1. Informative BAPs in the Riodoraku system

№	The name of the meridians	The arrangement of the BAPs in the meridians	In the meridians of BAPs

			Chinese name
1.	Lung	P-9	Thay-yuan
2.	Large intestine	Gi-4	He - gu
3.	Stomach	E-42	Chun - yan
4.	Pancreas	Rp-3	Thay-bay
5.	Heart	C-7	Shen -men
6.	Small intestine	IG- 4	Wang-gu
7.	Urinary tract	V-64	Tsing-gu
8.	Liver	P- 3	Tay-si
9.	Pericardium	Mc-7	Da-lin
10.	Three burners	Tr- 4	Yan-chi
11.	Gallbladder	Vb- 40	Tsyu-suy
12.	Spleen	F-3	Tay-chun

To determine which of the 12 pairs of BAPs in the human body are important in diagnosing diabetes mellitus, each expert fills in a **12×12** T-comparison matrix. The value of the t_{ij} element of the comparison matrix indicates how important, in the opinion of the expert, which of the i and j meridians is more important than the other. The degree of importance is expressed in fractions of one, where for each i and j meridian the equality $t_{ij}+t_{ji}=1$ is appropriate. If the i meridian is more important in diagnosing diabetes mellitus than the j meridian, then $t_{ij}>0,5$ (if the i meridian is more important than the j meridian, then the value of the t_{ij} element is closer to one). If meridian i is less important than meridian j in diagnosing diabetes mellitus, then $t_{ij}<0,5$ (if meridian j is more important than meridian i, then the value of element t_{ij} is closer to zero) [19].

The importance of the BAPs that can be used in diagnosing diabetes mellitus according to the data from each source (expert) is calculated. The score Si given by each expert E_k ($k=\overline{1,3}$) on the importance of BAPs i ($i=\overline{1,12}$) is calculated as the sum of the elements of the i-th row of the comparison matrix as follows:

$$S_i=\sum_{j\neq i,\ j=1}^{n} t_{ij},\ n=12,\ i,j=\overline{1,12}.$$

As a result of taking into account the opinion of all experts, the following relationship can be used to determine the general assessment of the importance of BAPs:

$$C_i=\sum_{m=1}^{k} S_m,\ k=3,\ i=\overline{1,12}.$$

Using the generalized ratings of the importance of BAPs, the weighting of BAPs according to the level of importance can be determined from the following equation:

$$V_i=C_i/\mathrm{C},\ ,\ i=\overline{1,12}.$$

Here C- is the sum of the generalized estimates of the importance of BAPs, i.e. $C=\sum_{i=1}^{n} C_i,\ n=12.$

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For the convenience of the text, we use the following designations of bioactive points: T1 Tay-yuan; T2 He-gu; T3 Chun-yang; T4 Tay-bay; T5 Shen-men; T6 Wang-gu; T7 Jin-gu; T8 Tay-si; T9 Da-lin; T10 Yang-chi; T11 Tsyu-suy; T12 Tay-chun.

[12,17,18] Pairwise comparison matrices filled in based on data from sources (in our case, experts) are presented in **Table 2**, and the calculation results are presented in **Table 3**.

Table 2. Pairwise comparison matrices.

Pairwise comparison matrix completed based on source 1												
	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**T_{10}**	**T_{11}**	**T_{12}**
T_1	-	0,6	0,3	0,2	0,1	0,8	0,1	0,1	0,2	0,3	0,8	0,6
T_2	0,4	-	0,7	0,1	0,2	0,1	0,2	0,2	0,3	0,8	0,4	0,6
T_3	0,7	0,3	-	0,1	0,3	0,3	0,4	0,2	0,1	0,7	0,4	0,8
T_4	0,8	0,9	0,9	0	0,8	0.9	0,8	0,9	0,8	0,8	0,8	0,9
T_5	0,9	0,8	0,7	0,2	-	0,8	0,4	0,4	0,6	0,9	0,8	0,8
T_6	0,2	0.9	0,7	0,1	0,2	-	0,3	0,2	0,1	0,6	0,4	0,6
T_7	0,9	0,8	0,6	0,2	0,6	0,7	-	0,4	0,7	0,9	0,8	0,7
T_8	0,9	0,8	0,8	0,1	0,6	0,8	0,6	-	0,4	0,8	0,7	0,8
T_9	0,8	0,7	0,9	0,2	0,4	0,9	0,3	0,6	-	0,8	0,7	0,9
T_{10}	0,7	0,2	0,3	0,2	0,1	0,4	0,1	0,2	0,2	-	0,4	0,6
T_{11}	0,2	0,6	0,6	0,2	0,2	0,6	0,2	0,3	0,3	0,6	-	0,6
T_{12}	0,4	0,4	0,2	0,1	0,2	0,4	0,3	0,2	0,1	0,4	0,4	-
Pairwise comparison matrix completed based on source 2												
	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**T_{10}**	**T_{11}**	**T_{12}**
T_1	-	0,4	0,6	0,2	0,1	0,3	0,2	0,3	0,2	0,4	0,6	0,4
T_2	0,6	-	0,4	0,2	0,3	0,4	0,2	0,1	0,2	0,6	0,6	0,3
T_3	0,4	0,6	-	0,3	0,2	0,4	0,1	0,3	0,2	0,6	0,4	0,1
T	0	0	0	-	0	0	0	0	0	0	0	0

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4	,8	,8	,7		,8	,8	,7	,6	,8	,8	,8	,7
T5	0,9	0,7	0,8	0,2	-	0,8	0,4	0,6	0,6	0,8	0,7	0,6
T6	0,7	0,6	0,6	0,2	0,2	-	0,3	0,4	0,1	0,6	0,6	0,3
T7	0,8	0,8	0,9	0,3	0,6	0,7	-	0,4	0,4	0,9	0,8	0,7
T8	0,7	0,9	0,7	0,4	0,4	0,6	0,6	-	0,4	0,9	0,8	0,7
T9	0,8	0,8	0,8	0,2	0,4	0,9	0,6	0,6	-	0,8	0,9	0,6
T10	0,6	0,4	0,4	0,2	0,2	0,4	0,1	0,1	0,2	-	0,4	0,4
T11	0,4	0,4	0,6	0,2	0,3	0,4	0,2	0,2	0,1	0,6	-	0,4
T12	0,6	0,7	0,9	0,3	0,4	0,7	0,3	0,3	0,4	0,6	0,6	-

Pairwise comparison matrix completed based on 3rd source

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
T1	-	0,6	0,6	0,2	0,3	0,4	0,3	0,1	0,2	0,6	0,4	0,4
T2	0,4	-	0,4	0,1	0,2	0,6	0,3	0,2	0,3	0,6	0,4	0,2
T3	0,4	0,6	-	0,1	0,2	0,4	0,3	0,2	0,2	0,6	0,2	0,3
T4	0,8	0,9	0,9	-	0,8	0,8	0,6	0,6	0,6	0,9	0,7	0,8
T5	0,7	0,8	0,8	0,2	-	0,7	0,6	0,7	0,6	0,8	0,7	0,7
T6	0,6	0,4	0,6	0,2	0,3	-	0,2	0,1	0,2	0,6	0,4	0,3
T7	0,7	0,7	0,7	0,4	0,4	0,8	-	0,8	0,6	0,8	0,7	0,8
T8	0,9	0,8	0,8	0,4	0,3	0,9	0,2	-	0,6	0,8	0,7	0,7
T9	0,8	0,7	0,8	0,4	0,4	0,8	0,4	0,4	-	0,7	0,8	0,9
T10	0,4	0,4	0,4	0,1	0,2	0,4	0,2	0,2	0,3	-	0,4	0,3
T11	0,6	0,6	0,8	0,3	0,3	0,6	0,3	0,3	0,2	0,6	-	0,4
T12	0,6	0,8	0,7	0,2	0,3	0,7	0,2	0,3	0,1	0,7	0,6	-

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Table 3. According to the importance level of BAPs **calculation results.**

	1 source	2 source	3 source	C_i	V_i
S_1	4,1	3,7	4,1	11,9	0,060
S_2	4	3,9	3,7	11,6	0,059
S_3	4,3	3,6	3,5	11,4	0,058
S_4	8,4	8,3	8,4	25,1	0,129
S_5	7,3	7,1	7,3	21,7	0,111
S_6	3,4	4,6	3,9	11,9	0,060
S_7	7,3	7,3	7,4	22	0,113
S_8	7,3	7,1	7,1	21,5	0,110
S_9	7,2	7,4	7,1	21,7	0,111
S_{10}	3,4	3,4	3,3	10,1	0,052
S_{11}	4,4	3,8	5	13,2	0,068
S_{12}	3,1	5,8	5,2	14,1	0,072

Based on the results of the calculations, it can be seen that the following BAPs are of great importance in the diagnosis of diabetes mellitus according to the values of the parameters V_i $(i=\overline{1,12})$ (Table 3):

Tay- bay, Shen-men, Yan-gu, Da-lin, Tay- si.

In the modeling process, it is advisable to use data obtained from these BAPs for all calculations.

As is known, taking into account the main factors affecting the process, various technical, economic and other issues can be successfully solved using mathematical modeling [20,21]. In modeling the process of measuring glucose levels in diabetes mellitus, the values of the ER measured in the five BAPs identified above are used as the main factors. The linear model of the dependence of blood glucose levels on the values of electrical resistances in BAPs looks like this:

$$y=a+b_1x_1+b_2x_2+...+b_{10}x_{10}. \qquad (1)$$

The following notations are used here:

x_1 – *Tay-bay* ER amount measured from the left side of the Tay-bay bioactive point;
x_2 – *Tay-bay* ER amount measured from the right side of the Tay-by bioactive point;

x_3 – *Da-lin* ER amount measured from the left side of the Da-ling bioactive point;
x_4 – *Da-lin* ER amount measured from the right side of the Da-ling bioactive point;
x_5 – *Vang -gu* ER amount measured from the left side of the Yang-xi meridian;
x_6 – *Vang –gu* ER amount measured from the right side of the Yang-xi bioactive point;
x_7 – *Tay-si* ER amount measured from the left side of the Tay-si bioactive point;
x_8 – *Tay-si* ER amount measured from the right side of the Tay-si bioactive point;
x_9 – *Shen-men* ER amount measured from the left side of the Shen-men bioactive point;
x_{10}– *Shen-men* – The amount of ER measured on the right side of the Shen-men bioactive point.

Using the least squares method to determine the values of the unknown coefficients $b_1,b_2,...,b_{10}$ in equation (1), we can obtain the following system of equations [22]:

$$\sum \hat{y} = na + b_1 \sum x_1 + b_2 \sum x_2 + ... + b_{10} \sum x_{10} ,$$

$$\sum yx_1 = a\sum x_1 + b_1 \sum x_1^2 + b_2 \sum x_2 x_1 + ... + b_{10} \sum x_{10} x_1 , \qquad (2)$$

$$...$$

$$\sum yx_{10} = a \sum x_{10} + b_1 \sum x_1 x_{10} + b_2 \sum x_2 x_{10} + ... + b_{10} \sum x_{10}^2 .$$

In multiple linear regression, replacing the variables into a standardized (normalized) form makes calculations easier, and all variables and relationships are expressed on a standardized scale. For this purpose, the variables in equation (1) can be replaced as follows:

$$\hat{y} = \frac{y - \bar{y}}{\sigma_y} , \qquad \hat{x}_i = \frac{x_i - \bar{x}_i}{\sigma_{x_i}} \qquad (i = \overline{1,10}).$$

Here σ_y, σ_{x_i} -are the standard deviations of the variables y and x_i.

After the change of variables, the linear multiple regression equation on the standardized scale becomes:

$$\hat{y} = \beta_1 \hat{x}_1 + \beta_2 \hat{x}_2 + ... + \beta_{10} \hat{x}_{10} . \qquad (3)$$

The coefficients in the original linear multiple regression equation are determined by the standardized coefficients in equation (3) as follows:

$$b_i = \frac{\sigma_y}{\sigma_{x_i}} \beta_i \ (i = \overline{1,10}), \quad a = \bar{y} - b_1 \bar{x}_1 - b_2 \bar{x}_2 - ... - - b_{10} \bar{x}_{10}, \qquad (4)$$

where $\bar{y}$, $\bar{x}_i$ – are the arithmetic mean values of the variables **y** and x_i respectively.

The standardized variables $\hat{y}$ and $\hat{x}_i$ $(i = \overline{1,10})$ and the standardized coefficients β_i $(i = \overline{1,10})$ are dimensionless. Therefore, it is possible to compare the effect of arbitrary variables on the arbitrary variable. Since the variables and regression coefficients are on different scales, this could not be done using the natural-scale $b_i$coefficients.

Applying the least squares method to equation (3) of linear multiple regression on a standardized scale, we can obtain the following system of linear equations:

$$r_{yx_1} = \beta_1 + \beta_2 r_{x_2 x_1} + \beta_3 r_{x_3 x_1} + ... + \beta_{10} r_{x_{10} x_1},$$

$$r_{yx_2} = \beta_1 r_{x_1 x_2} + \beta_2 + \beta_3 r_{x_3 x_2} + ... + \beta_{10} r_{x_{10} x_2}, \qquad (5)$$

$$... \quad ... \quad ... \quad ... \quad ... \quad ... \quad ... \quad ...$$

$$r_{yx_{10}} = \beta_1 r_{x_1 x_{10}} + \beta_2 r_{x_2 x_{10}} + \beta_3 r_{x_3 x_{10}} + ... + \beta_{10} .$$

In the system of equations (5), the correlation coefficients are determined by the following equalities:

$$r_{xy}=\frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2}\sqrt{\sum(y_i-\bar{y})^2}}. \qquad (6)$$

Here x_i, y_i– are the values of the arbitrary variable and the function in the i-th experiment, respectively, $\bar{x}=\frac{1}{n}\sum_{i=1}^{n}x_i$ – x means the average value of the variable ($\bar{y}$ is similar).

Experimental results. According to the recommendations of medical specialists, it is advisable to study the values of the EC in the BAPs separately for healthy people up to 24 years old, up to 40 years old and older. Since in these groups the influence of functional processes on changes in the average values of informative parameters related to age was observed.

As a result of processing the experimental results based on the biomeasurement device proposed in [16], the fluctuation limits of ER amounts of glucose and BAPs in healthy people (ER in BAPs from 22.1 kOhm to 139.0 kOhm when the blood glucose level is 3.5-5.5 mmol/l) according to the types of DM (by type 1 ER in BAPs when the blood glucose level is 6.5 mmol/l to 21 mmol/l From 92.4 kOm to 659.4 kOm; when the blood glucose level is from 6.5 mmol/l to 21 mmol/l, the ER in BAPs is found to change from 251.8 kOm to 695.4 kOm. The results of the arithmetic mean values of the ER s determined by the biomeasuring device developed by the authors in the BAPs of patients with type 1 and type 2 diabetes were used (Table 4) [16].

Table 4. Electrical resistance values at bioactive points
(x_i, $i=\overline{1,10}$, kΩ) and glucose levels in humans (y, mmol/l).

	y	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
24 years old, healthy	5	55,8	67,2	135,5	81,8	125,4	59,1	82,2	55,4	50,3	50,3
40 years old, healthy	5,3	54,9	54,2	139	91,1	102,5	89,2	100,7	75,5	43,3	41,5
Type 1 diabetes mellitus	6,2	369,9	447,5	461,3	329,9	490,6	659,4	336,1	361,4	170,9	248,6
Type 2 diabetes	7	441,4	310,2	546,4	524,4	681,4	670,4	541,8	412,4	539,2	356,3

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The values of the correlation coefficients calculated using the formula (6) of the system of equations (5) are as follows:

$r_{yx_1}=0,96,\ r_{yx_2}=0,77,\ r_{yx_3}=0,97,\ r_{yx_4}=0,99;\ r_{yx_5}=0,98;$
$r_{yx_6}=0,93;\ r_{yx_7}=0,99;\ r_{yx_8}=0,96;\ r_{yx_9}=0,94;\ r_{yx_5}=0,98.$

$r_{x_1x_2}=0,9;\ r_{x_1x_3=}0,9998;\ r_{x_1x_4}=0,97;\ r_{x_1x_5}=0,99;$

$r_{x_1x_6}=0,99;\ r_{x_1x_7}=0,97;\ r_{x_1x_8}=0,96;\ r_{x_1x_9}=0,85;\ r_{x_1x_{10}}=0,99.$

$r_{x_2x_3}=0,9;\ r_{x_2x_4}=0,78;\ r_{x_2x_5}=0,84;\ r_{x_2x_6}=0,95;$
$r_{x_2x_7}=0,77;\ r_{x_2x_8}=0,92;\ r_{x_2x_9}=0,54;\ r_{x_2x_{10}}=0,83.$

$r_{x_3x_4}=0,98;\ r_{x_3x_5}=0,99;\ r_{x_3x_6}=0,988;\ r_{x_3x_7}=0,97;$
$r_{x_3x_8}=0,998;\ r_{x_3x_9}=0,86;\ r_{x_3x_{10}}=0,99.$

$r_{x_4x_5}=0,99;\ r_{x_4x_6}=0,93;\ r_{x_4x_7}=0,998;$
$r_{x_4x_8}=0,96;\ r_{x_4x_9}=0,95;\ r_{x_4x_5}=0,99.$

$r_{x_5x_6}=0,96;\ r_{x_5x_7}=0,99;\ r_{x_5x_8}=0,98;\ r_{x_5x_9}=0,91;\ r_{x_5x_{10}}=0,999.$

$r_{x_6x_7}=0,93;\ r_{x_6x_8}=0,995;\ r_{x_6x_9}=0,77;\ r_{x_6x_{10}}=0,96.$

$r_{x_7x_8}=0,96;\ r_{x_7x_9}=0,95;\ r_{x_7x_{10}}=0,99.$

$r_{x_8x_9}=0,83;\ r_{x_8x_{10}}=0,98;\ r_{x_9x_{10}}=0,92.$

By substituting these values of the correlation coefficients into the system of equations (5), we can obtain the following system of linear algebraic equations for the standardized unknown coefficients β_i $(i=\overline{1,10})$

R×β=A. (7)

The determinant of the matrix R participating in the matrix equation (7) is nonzero, and its elements consist of the correlation coefficients:

1, 0, 1,0 0,9 0, 0, 0, 0,8 0,9
00 90 0 7 0,99 99 97 96 5 9
0, 1, 0,9 0,7 0, 0, 0, 0,5 0,8
90 00 0 8 0,84 95 77 92 4 3
1, 0, 1,0 0,9 0, 0, 1, 0,8 0,9
00 90 0 8 0,99 99 97 00 6 9
0, 0, 0,9 1,0 0, 1, 0, 0,9 0,9
97 78 8 0 0,99 93 00 96 5 9
0, 0, 0,9 0,9 0, 0, 0, 0,9 0,9
99 84 9 9 1,00 96 99 98 1 9
0, 0, 0,9 0,9 1, 0, 1, 0,7 0,9
99 95 9 3 0,96 00 93 00 7 6
0, 0, 0,9 1,0 0, 1, 0, 0,9 0,9
97 77 7 0 0,99 93 00 96 5 9

0, 0, 1,0 0,9 1, 0, 1, 0,8 0,9
96 92 0 6 0,98 00 96 00 3 8
0, 0, 0,8 0,9 0, 0, 0, 1,0 0,9
85 54 6 5 0,91 77 95 83 0 2
0, 0, 0,9 0,9 0,99 0, 0, 0, 0,9 1,0
99 83 9 9 99 96 99 98 2 0

The matrices A and β are column matrices, which consist of the following elements:

$$A=\left\|\begin{matrix}0{,}965\\0{,}774\\0{,}970\\0{,}993\\0{,}982\\0{,}932\\0{,}995\\0{,}962\\0{,}936\\0{,}984\end{matrix}\right\|,\qquad \beta=\left\|\begin{matrix}\beta_1\\\beta_2\\\beta_3\\\beta_4\\\beta_5\\\beta_6\\\beta_7\\\beta_8\\\beta_9\\\beta_{10}\end{matrix}\right\|.$$

By solving the system of equations (7), we can obtain the values of the standardized coefficients β_i $(i=\overline{1,10})$:

$$\beta=\left\|\begin{matrix}-0{,}03\\0{,}19\\-0{,}18\\0{,}38\\-1{,}38\\0{,}06\\0{,}82\\0{,}12\\0{,}17\\0{,}88\end{matrix}\right\|$$

Then the standardized form of linear multiple regression looks like this:

$$\hat{y}=-0{,}03\hat{x}_1+0{,}19\hat{x}_2-0{,}18\hat{x}_3+0{,}38\hat{x}_4-1{,}38\hat{x}_5+$$
$$+0{,}06\hat{x}_6+0{,}82\hat{x}_7+0{,}12\hat{x}_8+0{,}17\hat{x}_9+0{,}88\hat{x}_{10}. \qquad (7)$$

In equation (7), it can be seen that $\beta_5=-1{,}38$; $\beta_7=0{,}82$; $\beta_{10}=0{,}88$. This indicates that the ER values on the left side of the **Yan-gu** and **Tay-si** bioactive points and on the right side of the **Shen-men** bioactive point are of great importance in diagnosing DM.

The coefficients of the initial equation of linear multiple regression can be determined according to formula (4) as follows:

$b_1=-0{,}0016$; $b_2=0{,}0116$; $b_3=-0{,}0099$; $b_4=0{,}021$;

$b_5=-0{,}0572$; $b_6=0{,}0021$; $b_7=0{,}0443$; $b_8=0{,}0075$;

$b_9=0{,}0086$; $b_{10}=0{,}0669$; $a=-6{,}14$.

Then the equation of the linear multiple regression in its original, i.e. unstandardized, form is as follows:

$$y=-6{,}14-0{,}0016x_1+0{,}0116x_2-0{,}0099x_3+0{,}021x_4-0{,}0572x_5+$$
$$+0{,}0021x_6+0{,}0443x_7+0{,}0075x_8+0{,}0086x_9+0{,}0669x_{10}. \qquad (8)$$

From the unstandardized equation (8) of linear multiple regression, it can be seen that an increase in the ER values by 1 kΩ on the left side of the **Tay-si** bioactive point and on the right side of the **Shen-men** bioactive point leads to an increase in the blood sugar level by 0.0443 mmol/l, i.e. 44.3 µmol/l (micromol/liter) and 66.9 µmol/l, respectively.

Figure 1 shows the comparison of blood glucose levels determined by the unstandardized form of linear multiple regression equation (8) (blue) and biochemically (red). This figure shows that equation (8) allows for a sufficiently accurate determination of blood glucose levels based on the EC values measured in BFNs and the diagnosis of diabetes mellitus.

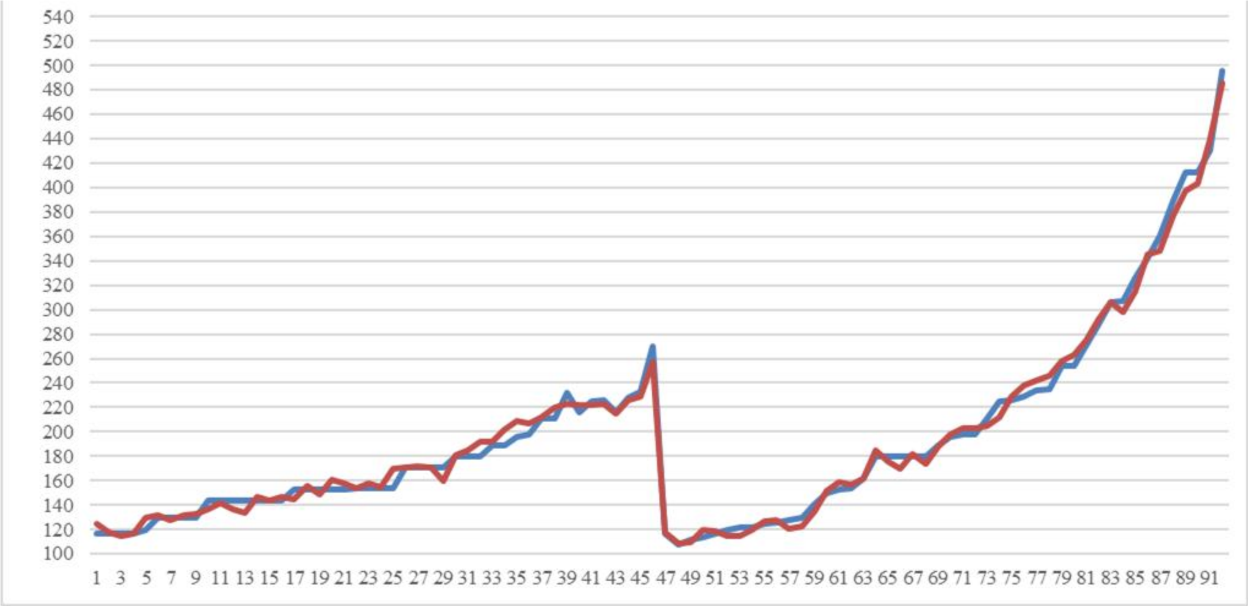

Figure 1. Mathematical model (blue color) and biochemically obtained (red color) blood glucose levels.

Conclusion In summary, the accuracy rate compared to our noninvasive method of determining blood glucose levels in QD, determined by a mathematical model with a biochemical method, was 95%.

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