http://doi.org/10.35784/iapgos.3654 *received: 15.05.2023 | revised: 08.06.2023 | accepted: 12.06.2023 | available online: 30.06.2023*

CARDIOMETABOLIC RISK PREDICTION IN PATIENTS WITH NON-ALCOHOLIC FATTY LIVER DISEASE COMBINED WITH SUBCLINICAL HYPOTHYROIDISM

Olena Kolesnikova[1], Olena Vysotska[2], Anna Potapenko[1], Anastasia Radchenko[1], Anna Trunova[2], Nataliya Virstyuk[3], Liudmyla Vasylevska-Skupa[3], Aliya Kalizhanova4, Nazerka Mukanova[5]

[1]Government Institution "L. T. Malaya Therapy Institute of the National Academy of Medical Science of Ukraine", Kharkiv, Ukraine, [2]National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, [3]Ivano-Frankivsk National Medical University, Ivano-Frankivsk, Ukraine, [3]Vinnytsia Mychailo Kotsiubynskyi State Pedagogical University, Vinnytsia, Ukraine, [4]Institute of Information and Computational Technologies, Almaty, Kazakhstan, [5]Gymnasium No. 159 named after Y. Altynsarin, Almaty, Kazakhstan

Abstract. *One of the most common diseases of our time is non-alcoholic fatty liver disease (NAFLD). Recently published research results indicate that patients with NAFLD along with traditional risk factors for cardiovascular diseases (CVD) have "new" risk factors such as endothelial dysfunction (ED), carotid intima-media thickness (CIMT), an increase in the CRP level, as well as risk factors combined into the Framingham scale. It is also known that combination of NAFLD with subclinical hypothyroidism (SH) forms an abnormal metabolic phenotype, which is associated with cardiometabolic risk factors. The study of cardiometabolic predictors and vascular markers in patients with NAFLD in combination with SH will provide an opportunity to improve the strategy of cardiovascular events prevention in such comorbid patients.*

Keywords: cardiometabolic risk, non-alcoholic fatty liver disease, subclinical hypothyroidism, prediction, binary regression logistic analysis, validation of prognostic models

PRZEWIDYWANIE RYZYKA KARDIOMETABOLICZNEGO U PACJENTÓW Z NIEALKOHOLOWĄ STŁUSZCZENIOWĄ CHOROBĄ WĄTROBY W POŁĄCZENIU Z SUBKLINICZNĄ NIEDOCZYNNOŚCIĄ TARCZYCY

Streszczenie. *Niealkoholowe stłuszczenie wątroby (NAFLD) jest jedną z najczęstszych chorób naszych czasów. Ostatnio opublikowane wyniki badań sugerują, że pacjenci z NAFLD, wraz z tradycyjnymi czynnikami ryzyka chorób sercowo-naczyniowych (CVD), mają "nowe" czynniki ryzyka, takie jak dysfunkcja śródbłonka (ED), grubość błony wewnętrznej i środkowej tętnicy szyjnej (CIMT), podwyższony poziom CRP i czynniki ryzyka połączone w skali Framingham. Wiadomo również, że połączenie NAFLD z subkliniczną niedoczynnością tarczycy (SH) tworzy nieprawidłowy fenotyp metaboliczny związany z czynnikami ryzyka kardiometabolicznego. Badanie predyktorów kardiometabolicznych i markerów naczyniowych u pacjentów z NAFLD w połączeniu z SH pozwoli na ulepszenie strategii zapobiegania zdarzeniom sercowo-naczyniowym u takich współistniejących pacjentów.*

Słowa kluczowe: ryzyko kardiometaboliczne, niealkoholowe stłuszczenie wątroby, subkliniczna niedoczynność tarczycy, rokowanie, binarna analiza regresji logistycznej, walidacja modeli prognostycznych

Introduction

In recent years, an increasing number of cardiovascular pathologies worldwide makes it necessary to search for new risk factors that could serve as an indicator and determine the likely prognosis of patients with somatic diseases. Currently, the concept of "cardiometabolic risk" is increasingly used in clinical practice. It involves the risk of developing cardiovascular diseases and/or type 2 diabetes, combining both classical ("traditional") risk factors such as smoking, high levels of low-density lipoprotein cholesterol (LDL-C), arterial hypertension, an increase in glucose level, and factors directly associated with abdominal (especially visceral) obesity – insulin resistance (IR), low high-density lipoprotein cholesterol (HDL-C), hypertriglyceridemia, and an increase in proinflammatory markers [8]. The attention of researchers is attracted by the search for early predictors of cardiometabolic changes and vascular markers – markers of inflammation (C-reactive protein, CRP), dyslipidemia, IR, tumor necrosis factor – α (TNF-α), endothelial dysfunction (ED) indicators such as circulating desquamated endothelial cells (CDECs), vascular endothelial growth factor (VEGF), that could act as a "predictive" [1, 7].

One of the most common diseases of our time is non-alcoholic fatty liver disease (NAFLD) – a chronic liver disease that is considered as a component of some diseases associated with IR, such as metabolic syndrome (MS), obesity, and diabetes. The development of NAFLD is very closely associated not only with abdominal obesity, but also has a significant effect on the formation of cardiometabolic risk factors such as hypertriglyceridemia, a decrease in HDL-C level, hypertension, hyperglycemia, thereby increasing the degree of cardiometabolic risk itself and affecting the prognosis and life expectancy of patients [8, 18].

Recently published research results indicate that patients with NAFLD along with traditional risk factors for cardiovascular diseases (CVD) (obesity, diabetes, MS and others) have "new" risk factors such as endothelial dysfunction (ED), carotid intima-media thickness (CIMT), an increase in the CRP level, as well as risk factors combined into the Framingham scale (age, gender, hypertension, hyperlipidemia, smoking). Also, "traditional" cardiovascular risk factors include: markers of chronic inflammation, hyperhomocysteinemia, impaired blood viscosity, as well as substances that the endothelium secretes (NO, Willebrand factor, P-selectin, adhesion molecule ICAM-1 and VCAM-1, endothelin-1, PAI-1) [7, 8].

According to The Rotterdam Study, 28% of patients with NAFLD have signs of subclinical hypothyroidism (SH) [10, 11]. Targher G. et al. revealed a link between thyroid hormones and serum liver enzyme activity (levels of thyroid stimulating hormone (TSH), alanine aminotransferase (ALT), γ-Glutamyl Transpeptidase (GGTP)) in a study involving a large cohort of patients [1, 8].

Atherogenic dyslipidemia already occurs during SH and the early stages of NAFLD. It is characterized by an increase in the level of very low-density lipoprotein cholesterol (VLDL-C), LDL-C, and may also occur due to the thyroid hormone deficiency, which leads to a decrease in LDL receptors in the liver, as a result of a decrease in hepatic total cholesterol excretion, and then — to an increase in LDL-C and VLDL-C levels. The combination of NAFLD with SH forms an abnormal metabolic phenotype, which is characterized by the presence of dyslipidemia, hyperinsulinemia and IR associated with oxidative stress and endothelial dysfunction [12, 14].

Thus, the study of cardiometabolic predictors and vascular markers in patients with NAFLD in combination with SH will provide an opportunity to broaden understanding of the mechanisms of cardiometabolic risk formation and to individualize the strategy of cardiovascular events prevention in a comorbid patient within this framework.

One of the rapidly progressing trends in clinical medicine is undoubtedly the predicting of diseases using special scales. The SCORE scale (or the electronic version of HeartScore),

popular in Europe, is limited to the age of 45–64 years, while the age range in the PCE scale was much wider – 20–79 years old, but it is recommended to use it in the range of 40–79 years [3, 19].

Solving the problems of medical forecasting often involves the use of regression models. For example, Weibull regression was used in the SCORE scale, Cox regression was used in the second version of the GRACE scale, and the logistic regression was used in the CHA2DS2-VASc scale [2, 20]. One of the principal limitations of the scales is the impossibility of an individual assessment, since scales can only give a probabilistic risk assessment for a group of patients with given levels of risk factors.

Preventive treatment of CVD is largely based on model creation methods for assessing the "absolute risk" of future cardiovascular events in order to substantiate decisions about therapeutic approaches [5].

Neural networks widely used in medical science. Kojuri J. et al. [6] reported on the development of a neural network that predicts acute myocardial infarction for two weeks.

Jasnickij L. and Cherepanov F. [17] showed in their article the possibility of creating neuroexpert medical systems, allowing to perform long-term prognosis of the diseases development to predict the occurrence of new diseases in future periods of the patient's life.

The introduction of machine learning allows increasing the accuracy of prediction of cardiovascular events [15]. However, the use of a large array of heterogeneous data instead of selected patient cohort can reduce the accuracy of risk classification and the proximity of the forecast to the frequency of real events [4, 9, 13, 16].

The subject of the present work is creating a model for predicting cardiometabolic risk in patients with NAFLD in combination with SH.

The paper presents the results of the GI "L.T. Malaya Therapy Institute of the National Academy of Medical Science of Ukraine" scientific research on the topic: "Influence of factors of cardiovascular development on premature aging" (security number 0117U003031).

1. Materials and methods

71 patients were selected to create a prediction model for cardiometabolic risk in patients with NAFLD in combination with SH. All patients were divided into three groups as follows:
Group 1 – low risk patients (6 patients);
Group 2 – patients with moderate risk (43 patients);
Group 3 – high-risk patients (22 patients).

The following factors were used as potential predictors: age, body mass, waist circumference, thigh circumference, CRP, CDECs, CIMT, VEGF level; telomeres in the blood; telomeres in the buccal epithelium, total cholesterol (TC), triglycerides (TG), VLDL-C, HDL-C, atherogenic coefficient, ALT, aspartate aminotransferase (AST), GGTP, alkaline phosphatase (ALP), HbA1C, TSH, free tyroxine (free T4), free triiodothyronine (free T3), anti-thyroid peroxidase antibodies (TPOAb). All indicators were encoded and placed according to the 27-dimensional vector, which takes into account the absence, which displays the value of each metric.

Mathematical processing of the results was carried out using the SPSS19 application package for Windows.

2. Results of binary regression logistics analysis

49 patients of the first and second groups were analyzed to construct an equation of logistic regression, which determines the probability of having a moderate cardiovascular risk (CVR), taking into account the considered indicators.

Comparison of groups 1 and 2 showed that among all the evaluated factors, the length of the telomeres in the buccal epithelium, the levels of CRP, CDECs had the statistically significant effect on the probability of development of moderate cardiometabolic risk in patients with NAFLD in combination with SH. As a result, the regression function was constructed. It included 3 indicators (table 1).

The binary logistic function selected from the training sample looks like:

$$\hat{P} = \left[1 + e^{-(11.024X_1 + 0.533X_2 + 1.256X_3 - 25.352)}\right]^{-1} \quad (1)$$

where $\hat{P}$ is the probability of developing moderate CVR in patients with NAFLD in combination with SH.

Table 1. Factors of moderate cardiometabolic risk

Code	Factor
X_1	Telomere length in the buccal epithelium
X_2	CRP
X_3	CDECs

The calculated coefficients of the regression function and the results of checking their significance are presented in table 2. All variables are significant ($p < 0.05$) and selected correctly according to Wald's statistics.

Table 2. Regression function coefficients

Indicators (X_i)	Coefficients (b_i)	Standard errors (S_i)	Wald's criterion (W_i)	Significance (p_i)
X_1	11.024	5.487	4.037	0.045
X_2	0.533	0.290	3.384	0.046
X_3	1.256	0.662	3.599	0.048
Constant	-25.352	11.348	4.991	0.025

The quality of the regression model approximation was estimated using the similarity function. In our study, G = 11,612 at p = 0.001, that is as a whole the informative indications isolated as independent variables have a significant effect on the development of cardiometabolic risk in patients with NAFLD in combination with SH. The Cox and Schell, and Nagelkerke indices indicate that the dispersion part explained by the developed logistic model stands at 75.8% (table 3).

Table 3. Characteristics of the model of binary logistic regression, created to determine the probability of developing moderate cardiometabolic risk in patients with NAFLD in combination with SH

-2 Log Credibility (G)	R^2 of Cox and Shell	R^2 of Nagelkerke	χ^2	p
11.612	0.397	0.758	24.822	0.001

The figure 1 shows the classification diagram. The distribution point was P = 0.5. The closer the value of the predicted probability is to unit, the higher the probability of developing moderate cardiometabolic risk in patients with NAFLD in combination with SH is.

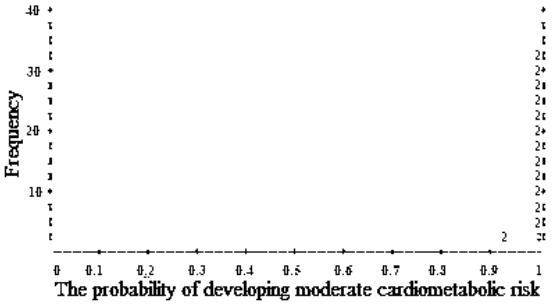

Fig. 1. Chart of classification. Symbols: 1 – low risk patients; 2 – patients with moderate risk

The results of the classification of patients in a training group using the developed prognostic model are given in table 4.

5 patients of the total number of patients with low risk, equal to 6, were correctly and 1 was mistakenly attributed to the moderate risk group.

Of the total number of patients with moderate risk of 43 people, 42 patients were accurately identified and 1 was

erroneously assigned to a group of low-risk patients. In general 47 cases out of 49 were correctly identified, representing 95.9%.

A general assessment of the agreement between the influence of risk factors found in the model and the actual occurrence of an adverse outcome was carried out using the Hosmer-Lemeshow (HL) test.

The resulting low value of HL = 4.391 at a significance level of $p > 0.05$ ($p = 0.820$), indicates the minimum differences between observed and predicted frequencies and the high quality of the selected regression model.

Table 4. Classification results of the model of binary logistic regression, created to determine the probability of moderate CVR in patients with NAFLD in combination with SH

Observed groups		Presumed groups		
		Risk		% correctly predicted
		Low	Moderate	
Risk	Low	5	1	83.3±15.23
	Moderate	1	42	97.7±2.29
Total percentage				95.9±2.83

The ROC analysis of the obtained model (figure 2) confirmed its effectiveness and excellent predictive quality. The area under curve (AUC) was 0.977 at p = 0.001.

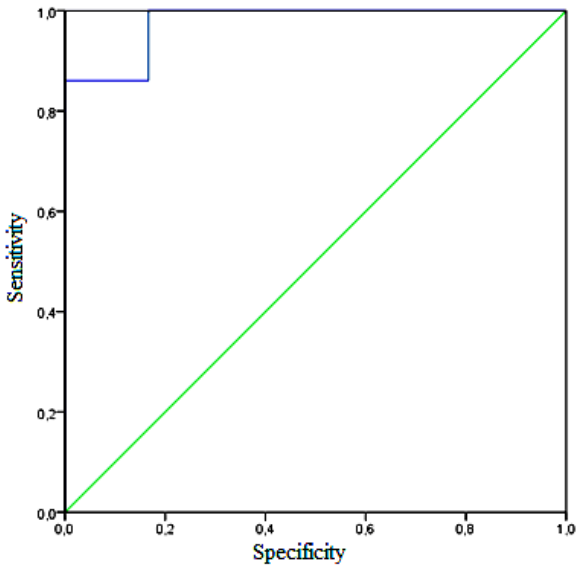

Fig. 2. ROC Curve

Thus, a mathematical model has been developed that includes metabolic risk factors such as the length of telomeres in the buccal epithelium, CRP and CDECs, to determine effectively and qualitatively the probability of forming moderate cardiometabolic risk in patients with NAFLD in combination with SH.

Data from 65 patients in the second and third groups were analyzed for the purpose of constructing a prediction model of cardiometabolic risk of higher gradations in patients with NAFLD in combination with SH. As a result of the binary logistic regression analysis, an equation has been obtained, which determines the likelihood of developing high CVR in patients with NAFLD in combination with SH:

$$\hat{P} = \left[1 + e^{-(4.366X_1 + 0.860X_2 + 0.009X_3 + 0.871X_4 - 19.391)}\right]^{-1} \quad (2)$$

where $\hat{P}$ is the probability of developing high CVR in patients with NAFLD in combination with SH;
X_1 – telomere length in the blood;
X_2 – LDL-C;
X_3 –VEGF;
X_4 – TSH.

Comparison of 2nd and 3rd groups therefore showed that of all of the factors evaluated, telomere length in blood, LDL-C, VEGF and TSH had a statistically significant effect on the likelihood of high cardiometabolic risk developing in patients with NAFLD in combination with SH.

All variables are significant ($p < 0.05$) and selected correctly according to Wald's statistics (table 5).

Table 5. Regression function coefficients

Indicators (X_i)	Coefficients (b_i)	Standard errors (S_i)	Wald's criterion (W_i)	Significance (p_i)
X_1	4.366	1.738	6.311	0.012
X_2	0.860	0.437	3.872	0.049
X_3	0.009	0.004	6.661	0.010
X_4	0.871	0.361	5.820	0.016
Constant	-19.391	4.787	16.407	0.001

In the study, G = 39.297 at p = 0.001 shows that independent variables have a significant contribution to predict the dependent variable in general. The part of the dispersion, explained by logistic regression according to R^2 of Cox and Schell stands at 68% (table 6).

Table 6. Characteristics of the model of binary logistic regression, created to determine the probability of developing high cardiometabolic risk in patients with NAFLD in combination with SH

-2 Log Credibility (G)	R^2 of Cox and Shell	R^2 of Nagelkerke	χ^2	p
39.297	0.680	43.905	0.001	39.297

A chart of classification of patients in the second and third study groups is presented in fig. 3 with the help of the developed mathematical model for predicting high cardiometabolic risk in patients with NAFLD in combination with SH.

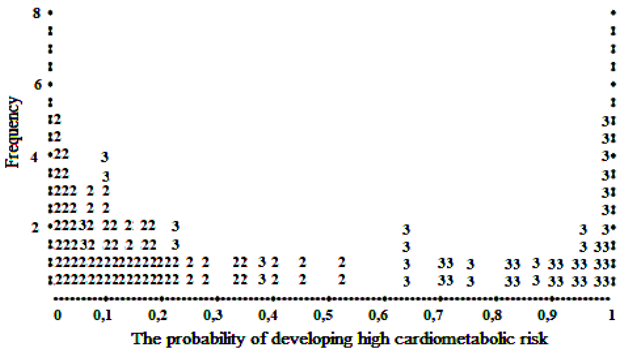

Fig. 3. Chart of classification. Symbols: 2 – moderate risk patients; 3 – high-risk patients

The value of P = 0.5 served as the limiting point of distribution. The closer the value of the predicted probability is to unity, the higher the degree of cardiometabolic risk in patients with NAFLD in combination with SH is. The classification results presented in table 7 indicate that in general 59 cases were correctly identified out of 65 that is 90.8%.

Table 7. Classification results of the model of binary logistic regression, created for the determination of the probability of development of high CVR in patients with NAFLD in combination with SH

Observed groups		Presumed groups		
		Risk		% correctly predicted
		Moderate	High	
Risk	Moderate	41	2	95.3±3.23
	High	4	18	8.8±8.23
Total percentage				95.9±2.83

The resulting low value of HL = 10.905 at a level of significance p = 0.143 indicates the high quality of the selected model. The ROC analysis of the resulting model (figure 4) confirmed the excellent quality of the developed model: the AUC value was 0.919 (p = 0.001).

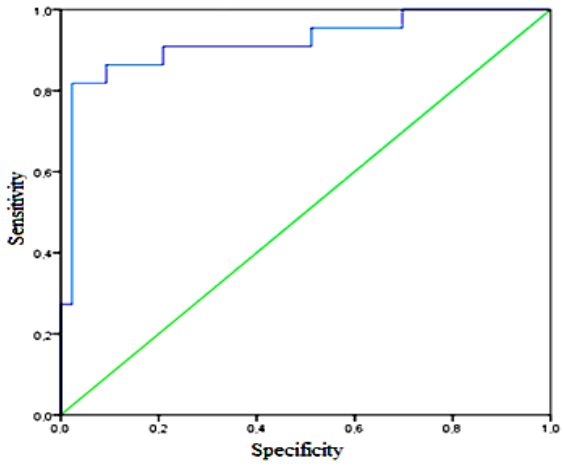

Fig. 4. ROC Curve

Thus, blood serum indices – LDL-C; VEGF; TSH and the length of telomeres in the blood may be factors that determine the probability of forming cardiometabolic risk of higher gradations in patients with NAFLD and SH.

3. Validative review of developed prognostic models

The usefulness of the developed mathematical models has been tested in practice while predicting the development of cardiometabolic risk in patients with NAFLD in combination with SH, who were screened and treated at the Government Institution "L.T. Malaya Therapy Institute of the National Academy of Medical Science of Ukraine". 34 patients were examined and divided into the following groups:
Group 1 – moderate-risk patients (9 patients);
Group 2 – high-risk patients (17 patients).
Group 3 – high-risk patients (8 patients).

The results of testing the model of binary logistic regression, created to determine the probability of moderate CVR development in patients with NAFLD in combination with SH, are presented in table 8.

Table 8. Classification results of the model of binary logistic regression, created to determine the probability of moderate CVD development in patients with NAFLD in combination with SH, on the test sample

Observed groups	Predicted results (n)		% correctly predicted
	Group 1	Group 2	
Group 1	9	0	100,0
Group 2	1	16	94.1±6.03
Total percentage			96.2±3.92

According to the results obtained, the outlook for 25 examined patients was made unmistakably. Thus, it was confirmed in 96.2% of cases.

The results of checking the model of binary logistic regression, created to determine the likelihood of high CVD in patients with NAFLD in combination with SH, are presented in table 9.

Table 9. Classification results of the model of binary logistic regression, created to determine the probability of moderate CVD development in patients with NAFLD in combination with SH, on the test sample

Observed groups	Predicted results (n)		% correctly predicted
	Group 2	Group 3	
Group 2	16	1	94.1±5.71
Group 3	1	7	87.5±11.69
Total percentage			92.0±5.43

The outlook was unmistakably accurate for 24 patients surveyed according to the results. Thus, the forecast was confirmed in 92.0% of cases.

That means, that the application of synthesized logistic models will allow predicting the development of cardiometabolic risk, which will ensure early diagnosis and appointment of treatment and prevention measures in order to avoid the development of cardiometabolic complications of high gradations.

4. Conclusions

The developed mathematical models allow predicting the degree of cardiometabolic risk in patients with NAFLD in combination with SH based on the of cumulative changes in lipid, carbohydrate states, thyroid function compensation, vascular factors and telomere lengths as a marker for vascular aging. The application of the proposed prognostic models in clinical practice allows to achieve an improvement in the quality of the cardiometabolic risk determination in patients with NAFLD in combination with SH due to the identification of factors that influence the progression of cardiometabolic changes in patients with NAFLD precisely in combination with SH, and the improvement of the applied mathematical apparatus, which in turn will help the physician to prescribe adequate treatment and preventive measures and improve the quality of medical services provision for patients with NAFLD in combination with SH.

References

[1] Bano A., Chaker L., Plompen E. P. C., et al.: Thyroid Function and the Risk of Nonalcoholic Fatty Liver Disease: The Rotterdam Study. J Clin Endocrinol Metab. 101(8), 2016, 3204–3211.
[2] Belyalov F. I.: Prognozirovaniye i shkaly v kardiologii 2ye-izd. MEDPRESS-inform, Moscow 2018.
[3] Belialov F. I.: Risk prediction scores of diseases. Complex Issues of Cardiovascular Diseases 7(1), 2018, 84–93 [http://doi.org/10.17802/2306-1278-2018-7-1-84-93].
[4] Georgiyants M., Khvysyuk O., Boguslavskaya N. et al.: Development of a mathematical model for predicting postoperative pain among patients with limb injuries. Eastern-European Journal of Enterprise Technologies 2, N4(86), 2017, 4–9 [http://doi.org/10.15587/1729-4061.2017.95157].
[5] Graham I., Atar D., Borch-Johnsen K. et al.: European guidelines on cardiovascular disease prevention in clinical practice: full text. Eur. J. Cardiovasc. Prev. Rehabil. 14, 2007, S1–S113.
[6] Kojuri J., Boostani R., Dehghani P., Nowroozipour F., Saki N.: Prediction of acute myocardial infarction with artificial neural networks in patients with nondiagnostic electrocardiogram. Journal of Cardiovascular Disease Research. 6(2), 2015, 51–60.
[7] Kolesnikova E. V.: Sovremennyy patsiyent s zabolevaniyem pechenii patologiyey serdechno-sosudistoy sistemy: kakoy vybor sdelat? Contemporary gastroenterology 2(76), 2014, 85–94.
[8] Kolesnikova O. V., Nemtsova V. D.: Effect of preventive measures for major metabolic parameters in patients with non-alcoholic fatty liver disease and cardiovascular risk. The ESC Textbook of Preventive Cardiology. Comprehensive, practical, and the official textbook of the European Association for Cardiovascular Prevention and Rehabilitation. Oxford University press, 2015.
[9] Koval S. M., Snihurska I. O., Vysotska O. et al.: Prognosis of essential hypertension progression in patients with abdominal obesity. Wójcik W., Pavlov S., Kalimoldayev, M. (Eds.): Information Technology in Medical Diagnostics II. Taylor & Francis Group, CRC Press, Balkema book, London 2019.
[10] Krak I. V., Kryvonos I. G., Kulias A. I.: Applied aspects of the synthesis and analysis of voice information. Cybernetics and Systems Analysis 49(4), 2013, 589–596.
[11] Krak I., Kondratiuk S.: Cross-platform software for the development of sign communication system: Dactyl language modelling. 12th International Scientific and Technical Conference on Computer Sciences and Information Technologies – CSIT, 2017, 1,8098760, 167–170
[12] Ludwig U., Holzner D., Denzer C. et al.: Subclinical and clinical hypothyroidism and non-alcoholic fatty liver disease: a cross-sectional study of a random population sample aged 18 to 65 years. BMC Endocr Disord. 15. 2015, 41.
[13] Ross D. S., Burch G. B, Cooper D. S. et al.: American Thyroid Association Guidelines for Diagnosis and Management of Hyperthyroidism and other causes of Thyrotoxicosis. Thyroid 26(10), 2016, 1343–1421.

[14] Sinn D. H., Cho S. J., Gu S. et al.: Persistent Nonalcoholic Fatty Liver Disease Increases Risk for Carotid Atherosclerosis. Gastroenterology 151(3), 2016, 481–488.
[15] Strashnenko A. N., Vysotskaya E. V., Demin Y. A. et al.: A method for prognosis of primary open-angle glaucoma. International Review on Computers and Software 8, 2013, 1943–1949.
[16] Weiwei He, Xiaofei An, Ling Li et al.: Relationship between Hypothyroidism and Non-Alcoholic Fatty Liver Disease: A Systematic Review and Meta-analysis. Front Endocrinol (Lausanne) 8, 2017, 335.
[17] Weng S. F., Reps J., Kai J., Garibaldi J. M., Qureshi N.: Can machinelearning improve cardiovascular risk prediction using routine clinical data? PLOS ONE 12(4), 2017, e0174944 [http://doi.org/10.1371/journal.pone.0174944].
[18] Wójcik W., Pavlov S., Kalimoldayev M.: Information Technology in Medical Diagnostics II. Taylor & Francis Group, CRC Press, Balkema book, London 2019.
[19] Yakubovska S., Vysotska O., Porvan A. et al.: Developing a method for prediction of relapsing myocardial infarction based on interpolation diagnostic polynomial. Eastern-European Journal of Enterprise Technologies 5(9(83)), 2016, 41–49 [http://doi.org/10.15587/1729-4061.2016.81004].
[20] Yasnitsky L. N., Cherepanov F. M.: Neyroekspertnaya sistema diagnostiki, prognozirovaniya i upravleniya riskami serdechno-sosudistykh zabolevaniy. Prikladnaya matematika i voprosy upravleniya 3, 2018, 107–126.

Prof. Olena Kolesnikova
e-mail: kolesnikova1973@gmail.com

Deputy director for Scientific work, head of the Department for the study of aging processes and prevention of metabolic-associated diseases.
Government Institution "L.T. Malaya Therapy Institute of the National Academy of Medical Science of Ukraine".
Scientific interest: information technologies in medicine.

http://orcid.org/0000-0001-5606-6621

Prof. Olena Vysotska
e-mail: o.vysotska@khai.edu

Head of the Department of Radio-Electronic and Biomedical Computerized Means and Technologies.
National Aerospace University "Kharkiv Aviation Institute".
Scientific interest: information technologies in medicine.

http://orcid.org/0000-0003-3723-9771

Ph.D. Anna Potapenko
e-mail: annav1611sh@gmail.com

Researcher at the Department for the study of aging processes and prevention of metabolic-associated diseases, Endocrinologist of the second qualification category.
Government Institution "L.T. Malaya Therapy Institute of the National Academy of Medical Science of Ukraine".
Scientific interest: information technologies in medicine.

http://orcid.org/0000-0002-1658-0156

Anastasia Radchenko
e-mail: anastasha.radchenko@gmail.com

Postgraduate student of the department of studying aging processes and prevention of metabolic-associated diseases.
Government Institution "L.T. Malaya Therapy Institute of the National Academy of Medical Science of Ukraine".

http://orcid.org/0000-0002-9687-8218

Ph.D. Anna I. Trunova
e-mail: a.pecherska@khai.edu

Associate professor of the Department of Radio-Electronic and Biomedical Computerized Means and Technologies National Aerospace University "Kharkiv Aviation Institute".
Scientific interest: information technologies in medicine.

http://orcid.org/0000-0001-7069-0674

Prof. Nataliya Virstyuk
e-mail: if_dermven@ukr.net

Head of the Department of Pharmacology and Internal Medicine No 3 named after M.M. Berezhnytskyi Ivano-Frankivsk National Medical University.
Scientific interest: information technologies in medicine.

http://orcid.org/0000-0002-5794-8754

Ph.D. Liudmyla Vasylevska-Skupa
e-mail: lpvasylevska@gmail.com

Associated professor of Vinnytsia Mychailo Kotsiubynskyi State Pedagogical University.
Scientific interest: information technologies in medicine, pedagogy.

http://orcid.org/0000-0002-1989-7175

Ph.D. Aliya Kalizhanova
e-mail: kalizhanova_aliya@mail.ru

Candidate of physical and mathematical sciences, professor, University of Power Engineering and Telecommunications, the chief researcher of the Institute of Information and Computational Technologies of the Ministry of Education and Science CS of the Republic of Kazakhstan.
Scientific interests: mathematical modeling of systems, models of transport systems network analysis, optimization methods, technologies for developing sensor systems for signals receive – transmit, mathematical modeling of Bragg fiber gratings.

http://orcid.org/0000-0002-5979-9756

M.Sc. Nazerka Mukanova
e-mail: mukanova0124@gmail.com

Master of Pedagogical Sciences, teacher of the highest category of computer science of gymnasium No. 159 named after Y. Altynsarin, a prize-winner of several national and international competitions, her scientific articles have been published in several domestic and international publications, and she is a participant in various international teaching-methodical pedagogical conferences.
Scientific interest: information technologies in medicine.

http://orcid.org/0009-0002-7945-7187