Multiparametric neural network clustering in prediction the risk of surgical complications after revascularization on great arteries of the lower extremities

Boryslav Selskyi[a], Andriy Sverstiuk[a,b], Petro Selskyi[a], Sviatoslav Kostiv[a] and Ihor Venher[a]

[a]*I. Horbachevsky Ternopil National Medical University, Maidan Voli, 1, Ternopil, 46002, Ukraine*
[b]*Ternopil National Ivan Puluj Technical University, Rus'ka str. 56, Ternopil, 46001, Ukraine*

Abstract

We propose a method for predicting complications of surgical intervention using multiparameter neural network clustering, subsequently, a hierarchical scale was developed of surgical risk complications. We analyzed the examination results of 397 patients with occlusive atherosclerosis of the great arteries of the lower limbs. To optimize the prediction of the risk of postoperative sequela, neural network clustering was performed on 119 patients applying the software NeuroXL Classifier for a more detailed analysis of the changes in the results of each group. The proposed measure of surgical risk stratification for postoperative treatment of the great arteries of the lower extremities takes into account multifactorial clinical-anamnestic factors and laboratory instrumentation. It's characteristic combination of factor's in condition of an organ or system influences reconstructive surgery selection and methods based on neural network clustering data, the level of potential postoperative sequela of surgery on the great arteries of the lower extremity was perform, followed by four levels of risk factor expression: very high risk 31-40, high risk 21-30, moderate 11-20, low risk 1-10.

Keywords

Risk scale, atherosclerosis, neural network clustering, limb revascularization, surgical complications

1. Introduction

The use of nova neural methods and computer modeling in the modern context, especially in the region of vascular surgery, can significantly improve the quality of the huge amount of information parameter's analysis required and provide's a comprehensive approach to the best surgical choice [1, 2]. Numerous studies have been conducted with the aim of solving the prevention of complications by taking into account patient parameters and developing relevant preventive risk measures [3]. However, the problems of using them in practice and of comprehensively considering a multitude of risk factors remain unresolved [4]. While, the development of a uniform scale to assess the possible risks of surgical interventions has become very important. The prediction of huge part of complications in patients with vascular damage and the applying of neural network techniques for their detection remain particularly applicable [5, 6].

In [7], the approach to forecasting in endocrinology with the selection and justification of the most important factors is considered. Prediction of the risk of developing hypothyroidism and diffuse non-toxic goiter in patients with type 2 diabetes mellitus is considered in works [8, 9]. An example of the use of multivariate regression analysis to assess the severity of Lyme borreliosis is given in works [10, 11].

ITTAP'2023: 3rd International Workshop on Information Technologies: Theoretical and Applied Problems, November 22–24, 2023, Ternopil, Ukraine
EMAIL: selskyi_bp@tdmu.edu.ua l (A.1); sverstyuk@tdmu.edu.ua (A.2); selskyy@tdmu.edu.ua (A.3); kostivsj@tdmu.edu.ua (A.4); vengerik@tdmu.edu.ua (A.5)
ORCID: 0000-0001-6787-4843 (A.1); 0000-0001-8644-0776 (A.2); 0000-0001-9778-2499 (A. 3); 0000-0002-7963-5425 (A.4); 0000-0003-0170-1995 (A5)

Prediction and cluster analysis of informative features in cardiodiagnostic systems [12, 13], results of measurements by biosensors [14] and immunosensors [15, 16] are interesting and promising studies. The clustering technology of neural networks for the recognition of cartographic images is presented in [17].

2. Materials and methods

The results of clinical observations, instrumental and laboratory studies have been processed by variational mathematical statistics method. To process the data, we used Microsoft Excel (2016) package. In example of normal distribution, statistical significance of the difference between the arithmetic average was defined with the help of Student's test (T-Test), and in the case of non-normal distribution – with the help of Mann-Whitney non-parametric test (U-Test) at $p<0.05$.

For more detailed analysis 119 patients of co-changes to optimize the group's measures in observational studies and the predict the risk of developing postoperative complications, we have used a neural network clustering using NeuroXL Classifier for the Microsoft Excel. NeuroXL Classifier (developed by AnalyzerXL) implements a self-organizing neural network, which handles classification by studying trends and interconnections within groups.

The main advantages of the k-means method are its simplicity and speed of execution. The k-means method is more convenient for clustering a large number of observations than the hierarchical cluster analysis method (in which dendograms become overloaded and lose visibility). The principle of the algorithm consists in finding such cluster centers and sets elements of each cluster in the presence of some function F(°), which expresses the quality of the current division of the set into k clusters, when the total squared deviation of the elements of the clusters from the centers of these clusters will be the smallest.

The following notation describes the linkages used by the various methods:

- Cluster r is formed from clusters p and q.
- n_r is the number of objects in cluster r.
- x_{ri} is the ith object in cluster r.
- Single linkage, also called nearest neighbor, uses the smallest distance between objects in the two clusters.

$$d(\mathrm{r},\mathrm{s}) = \min(\mathrm{dist}(\mathrm{x_{ri}},\mathrm{x_{sj}})), \mathrm{i} \in (\mathrm{i},\dots,\mathrm{n}_r), \mathrm{j} \in (1,\dots,\mathrm{n}_s)$$

- Complete linkage, also called farthest neighbor, uses the largest distance between objects in the two clusters.

$$d(\mathrm{r},\mathrm{s}) = \max\left(\mathrm{dist}\left(\mathrm{x_{ri}},\mathrm{x_{sj}}\right)\right), \mathrm{i} \in (\mathrm{i},\dots,\mathrm{n}_r), \mathrm{j} \in (1,\dots,\mathrm{n}_s)$$

- Average linkage uses the average distance between all pairs of objects in any two clusters.

$$d(\mathrm{r},\mathrm{s}) = \frac{1}{\mathrm{n}_r\mathrm{n}_s}\sum_{i=1}^{\mathrm{n}_r}\sum_{j=1}^{\mathrm{n}_s}\mathrm{dist}(\mathrm{x_{ri}},\mathrm{x_{sj}})$$

- Centroid linkage uses the Euclidean distance between the centroids of the two clusters.

$$d(\mathrm{r},\mathrm{s}) = \|\bar{\mathrm{x}}_\mathrm{r} - \bar{\mathrm{x}}_\mathrm{s}\|_2,$$

where

$$\bar{\mathrm{x}}_\mathrm{r} = \frac{1}{\mathrm{n}_r}\sum_{i=1}^{\mathrm{n}_r}\mathrm{x_{ri}}$$

• Median linkage uses the Euclidean distance between weighted centroids of the two clusters.

$$d(\mathrm{r},\mathrm{s}) = \|\widetilde{\mathrm{x}_\mathrm{r}} - \widetilde{\mathrm{x}_\mathrm{s}}\|_2,$$

d(r,s)=‖‖˜xr−˜xs‖‖2,

where $\tilde{x}_r$ and $\tilde{x}_s$ are weighted centroids for the clusters r and s. If cluster r was created by combining clusters p and q, $\tilde{x}_r$ is defined recursively as

$$\widetilde{\mathrm{x}_\mathrm{r}} = \frac{1}{2}\left(\tilde{x}_p + \tilde{x}_q\right)$$

• Ward's linkage uses the incremental sum of squares, that is, the increase in the total within-cluster sum of squares as a result of joining two clusters. The within-cluster sum of squares is defined as the sum of the squares of the distances between all objects in the cluster and the centroid of the cluster. The sum of squares metric is equivalent to the following distance metric $d(r,s)$, which is the formula linkage uses.

$$d(r,s) = \sqrt{\frac{2n_r n_s}{(n_r+n_s)}}\|\bar{x}_r - \bar{x}_s\|_2,$$

where

- o $\|\quad\|_2$is the Euclidean distance.
- o $\bar{x}_r$ and $\bar{x}_s$ are the centroids of clusters r and s.
- o n_r and n_s are the number of elements in clusters r and s.

In some references, Ward's linkage does not use the factor of 2 multiplying nrns. The linkage function uses this factor so that the distance between two singleton clusters is the same as the Euclidean distance.

• Weighted average linkage uses a recursive definition for the distance between two clusters. If cluster r was created by combining clusters p and q, the distance between r and another cluster s is defined as the average of the distance between p and s and the distance between q and s.

$$d(r,s) = \frac{(d(p,q) + d(q,s))}{2}$$

A linkage is the distance between two clusters.

The general advantages of NeuroXL Classifier are simplicity of usage; in-depth knowledge in the region of neural networks is optional; integration with Microsoft Excel; providing justified neural network technology for high accuracy classification; determination of interconnections and trends that cannot be defined by traditional statistical methods [1, 2, 3, 4].

3. Main Part

To model a neural network clustering followed by the development of a surgical risk scale, we have performed analysis of the indicators of 397 patients with atherosclerosis of the great arteries of lower limbs. For a more in-depth analysis 119 patients of the combined changes in the performance of the studied groups in order to optimize the prediction of the risk of complications in the postoperative period, neural network clustering was performed by using the software NeuroXL Classifier.

To determine the nature and prevalence of atherosclerotic lesions of the arterial bed of great arteries of lower extremities and to examine patiens, we used ultrasound SonoScape S8 Exp (China) and tomographic computer study Siemens Brilliance CT64 (Germany) with contrasting of vascular segment. With angiography of the main vessels of the lower extremities in the conditions of the endovascular operating room with X-ray we used angiograph Siemens Axiom Artis (Germany).

4. Results and Discussions

Laboratory and instrumental studies, clinical observations results were analyzed, which we entered in the neural network clustering system for calculation.

4.1. Average values of indicators

Anesthesiological and laboratory indices of 72 patients were analyzed (group 1). Open surgical interventions (subgroup 1a) have been used to treat 44 patients (61.1%), endovascular and hybrid interventions (subgroup 1b) – to treat 28 patients (38.9%). The body mass index (BMI) in patients of this examination group was 23.39±0.39, (50.0±5.89)% of patients led unhealthy lifestyle. The average age of patients in the first group was (67.06±1.14) years old. Other indicators, were taken into account: diabetes ((30.56±5.43) %), respiratory failure ((12.5±3.90) %), pathology of the gastrointestinal tract ((15.28±4.24) %), lesions of extracranial segment ((54.14±5.87) %), stroke in history ((5.56±2.70) %), diseases of the cardiovascular system ((95.83±2.35) %), myocardial infarction in history ((23.61±5.01) %), malignant process in history ((1.39±1.38) %), conduction anesthesia ((13.89±4.08) %), mechanical ventilation ((1.39±1.38) %), epidural anesthesia ((55.56±5.86) %), presence of pulmonary hypertension ((9.72±3.49) %) and revascularization level ((5.56±2.70) %).

(25±5.10)% of patients (subgroup 1c) suffered from side-effects, such as thrombosis of the reconstruction segment ((19.44±4.66) %), pseudoaneurysm ((2.78±1.94) %), myocardial infarction ((1.39±1.38) %) and suppuration conduit ((4.17±2.35) %). It should be memorize that the average age ((67.5±1.74) years old and BMI (22.64±0.89) of the patients in this subgroup were not significantly different from the similar indicators of the patients of the first group of our study ($p>0.05$).

We studied biochemical, coagulation and general blood analyses picture indices for all subgroups of patients. The results are shown in Table 1.

Table 1

Biochemical, coagulation and general blood analyses of patients with open, endovascular and hybrid surgical interventions (M ± m)

Indicators	1 group (n – 72)	1a subgroup (n – 44)	1b subgroup (n – 28)	1c subgroup (n – 18)
Erythrocytes, $^{*}10^{12}$/l	4.38±0,06	4.32±0,05	4.48±0,08	4.50±0,28
Hemoglobin, g/dl	128.80±2,41	127.30±2,92	131.18±4,18	125.72±4,97
Color index	0.90±0,01	0.91±0,01	0.89±0,01	0.84±0,05
Leukocytes, $^{*}10^{9}$ /l	7.85±0,39	8.16±0,54	7.35±0,54	7.23±0,64
Eosinophils, %	3.26±0,76	2.73±0,36	4.09±1,87	2.72±0,48
Rod-shaped neutrophils, %	6.58±0,50	6.75±0,73	6.32±0,60	6.22±0,77
Segmented neutrophils, %	64.58±1,11	65.66±1,39	62.89±1,82	65.67±1,85
Lymphocytes, %	22.92±1,19	21.43±1,60	25.25±1,67	22.89±1,89
Monocytes, %	3.50±0,33	3.77±0,44	3.07±0,49	3.56±0,74
ESR, mm/hour	18.17±2,06	16.75±2,68	20.39±3,22	16.22±3,51
Glucose, mmol/l	6.23 ± 0,14	5.78 ± 0,10	6.94± 0,18**	5.59± 0,35*
Creatinine, µmol/l	75.46±2,33	70.44±2,64	83.34±3,93**	79.28±3,93
Urea, mmol/l	5.99±0,24	5.65±0,28	6.54±0,43	6.61±0,67
AST, u/l	20.34±1,85	21.29±2,83	18.86±1,73	25.18±6,95
ALT, u/l	20.14±1,34	21.15±1,85	18.56±1,83	24.59±4,30

Bilirubin, μmol/l	9.81±0,59	9.13±0,70	10.89±1,04	11.31±1,71
K, mmol/l	5.79±1,10	6.54±1,80	4.61±0,14**	5.00±0,25
Na, mmol/l	138.14±0,41	138.91±0,55	136.93±0,53**	138.22±0,77
LDL, mmol/l	3.26±0,14	3.47±0,18	2.92±0,21	3.42±0,28
HDL, mmol/l	1.26±0,05	1.20±0,06	1.35±0,08	1.30±0,11
Cholesterol, mmol/l	4.56±0,14	4.64±0,20	4.43±0,20	4.74±0,28
Fibrinogen, g/l	4.56±0,18	4.43±0,22	4.77±0,34	4.59±0,39
Prothrombin time, sec.	11.65±0,15	11.81±0,22	11.40±0,18	11.43±0,22
Prothrombin according to Kwik, %	96.58±2,15	94.31±2,86	100.17±3,16	99.31±3,88
INR, index	0.99±0,02	0.99±0,03	0.99±0,02	0.96±0,02
Trombin time, sec.	11.11±0,14	11.28±0,19	10.83±0,21	10.86±0,37

Remark 1. * – p<0.05 compared to the 1st group.

Remark 2. ** – p<0.005 compared to the 2nd group.

Ultrasound indices were also analyzed in 47 patients (group2) who survive after open, endovascular and hybrid operation. All patients were diagnosed with minor stenosis at the level of the aorto/iliac segment. However, no significant stenosis/obstruction at the level of the aorto-iliac segment was found. The passability of the femoral segment was identified in (44.68±7.25)% cases, the passability of the deep femoral artery – in (89.36±4.50)% cases, passability of the superficial femoral artery – in (34,04±6,91) and the passability of the popliteal segment – in (68.10±6.80)% cases. We have detected passability of the anterior tibial artery in (68.09±6.80)%, posterior tibial artery in (53.19±7.29)% and the peroneal artery in (80.85 ±5.74) % of patients. The ankle-brachial index (ABI) was (0.53±0.02) %. The average sPO2 index before surgery was (83.40±0.81) %, and sPO2 after surgery – (92.21±1.10) %.

4.2. Cluster Analysis

To establish the most important parameter study composite changes to predict the risk of afteroperative complications, we performed neural network clustering of the study's indicators. At the same time, the rate of complications (C) in the postoperative period for each patient was defined: "1" in case of absence of complications, and "2" – in case of presence of some complications. Neural network clustering of the results of the anamnestic and clinical examination (Fig. 1) was carried out on the basis of the following indicators: age (1), unhealthy habits (2), body mass index (3), injury of extracranial segment (4), diabetes decompensated (5), diabetes uncompensated (6), stroke in anamnesis (7), myocardial infarction in anamnesis (8), gastrointestinal pathology (9), respiratory failure (10), cardiovascular diseases (11), oncology in anamnesis (12), pulmonary hypertension (13), reduced ejection fraction (14), mid-range reduced ejection fraction (15), thrombosis of the reconstruction part (16), myocardial infarction (17), pseudoaneurysm (18), suppuration of the prosthesis (19) and C – indicator of complications in the afteroperative period (20).

Figure 1 shows the results of the indicators clustering program performance. The 1st cluster includes 20.83% of patients, 2nd – 36.11% patients, and 3rd – 43.06% patients.

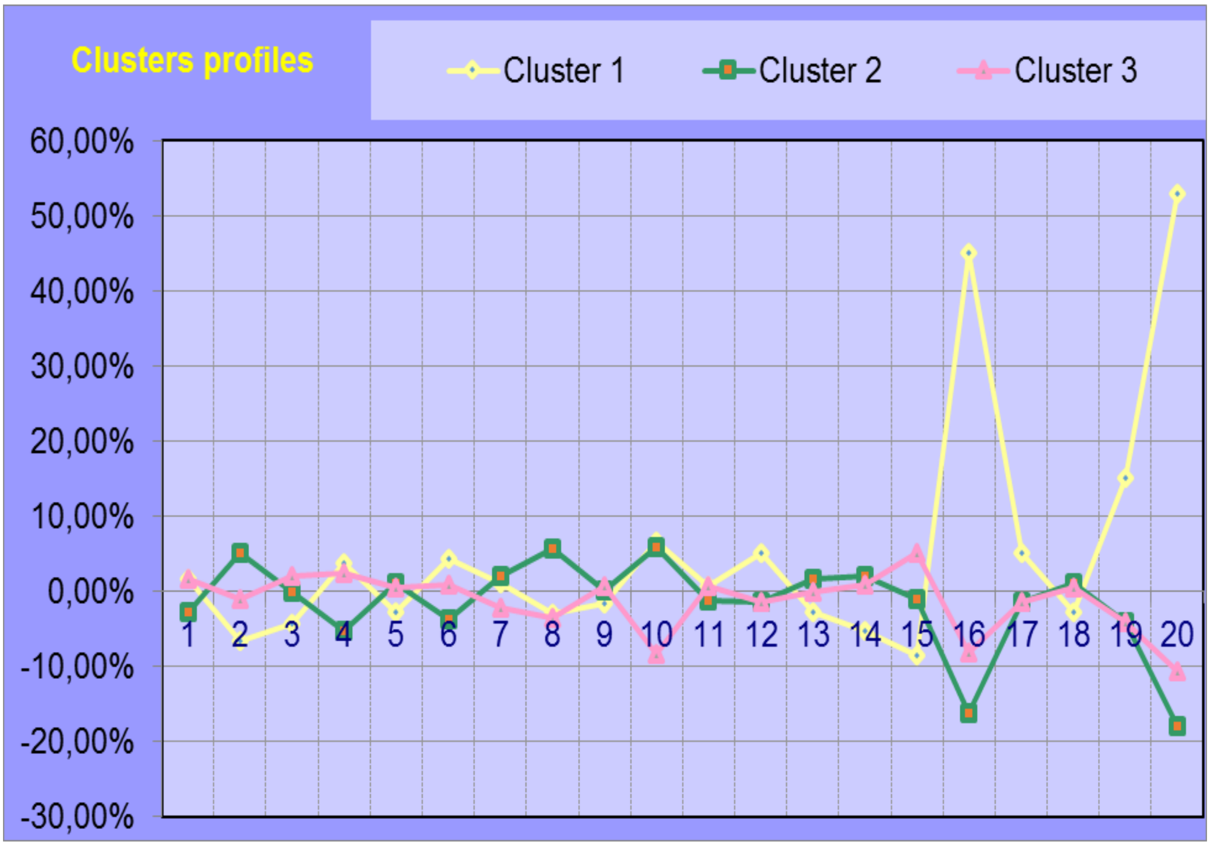

Figure 1: Results after clustering of patients anamnestic indicators

According to the survey, patients in the first cluster have the highest number of postoperative complications. With the help of cluster portraits, this cluster was found to have the highest age index. (1.6%), injury of extracranial arteries (3.8%), diabetes in the de- and subcompensation stages (4.4%) and respiratory failure (6.7%), as compared to other clusters. The rate of stroke in the anamnesis (1.1%) exceeded the similar rate in the 3rd cluster, and the rate of diseases of the cardiovascular system (0.7%) – exceeded the rate in the 2nd cluster.

A neural network clustering of the results of instrumental-laboratory research (Fig. 2) has been performed based on a number of indicators: erythrocytes (1), content of hemoglobin (2), color index (3), leukocytes (4), eosinophils (5), neutrophils rod-shaped (6), neutrophils segmented (7), lymphocytes (8), monocytes (9), ESR (10), glucose (11), creatinine (12), urea (13), AST (14), ALT (15), bilirubin (16), K (17), Na (18), LDL (19), HDL (20), cholesterol (21), time of prothrombin (22), Kwik prothrombin (23), INR (24), time of thrombin (25), fibrinogen (26), fraction ejection (27), allo-graft (28), fundoplasty of deep artery (29), autovenous graft (30), hybrid surgery (31), stenting (32), balloon angioplasty (33), thrombosis of reconstruction segment (34)), infarction of myocardium (35), pseudoaneurysm (36), prosthesis suppuration (37), and C – is an indicator of complications in the postoperative period (38).

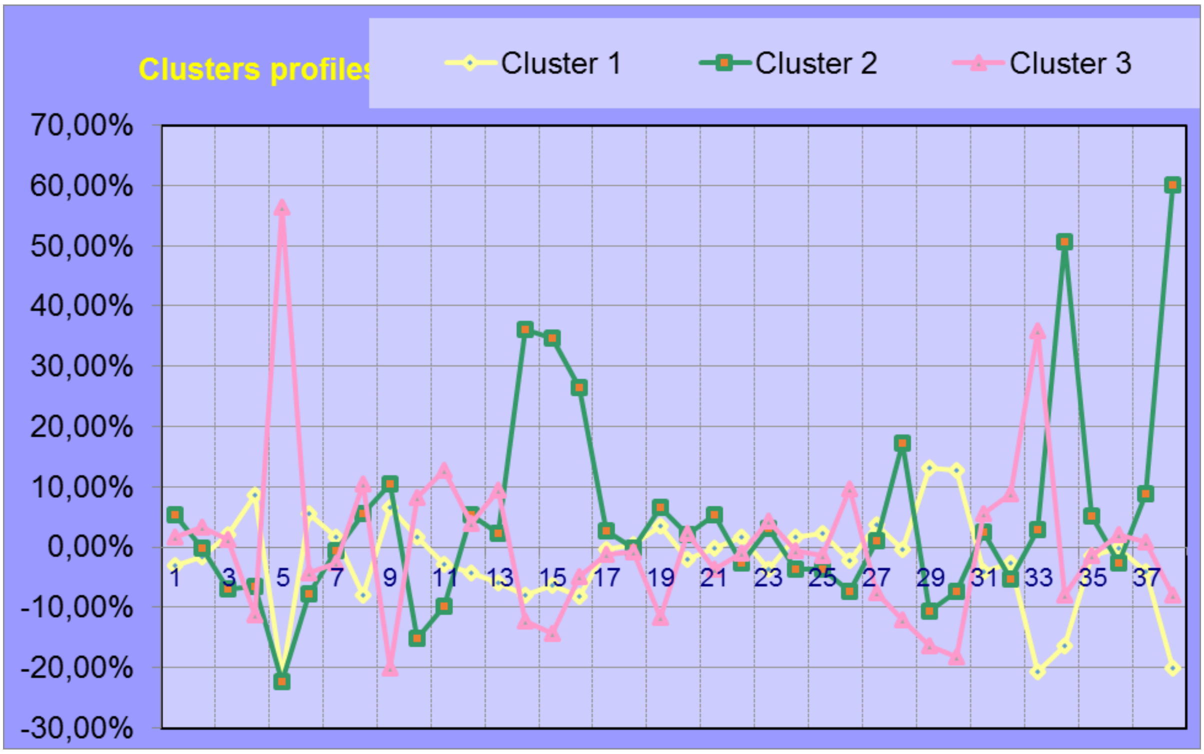

Figure 2: Results of clustering of indicators program performance. 1st cluster includes 51.39% of patients, 2nd – 20.83%, and 3rd cluster – 27.78%.

Figure 2 illustrates the results of clustering of indicators program performance. 1st cluster includes 51.39% of patients, 2nd – 20.83%, and 3rd cluster – 27.78%.

The biggest value of the complications parameter in the afteroperative period was found out in the 2nd cluster. With cluster portrait, we have come to result that the 2nd cluster includes the highest number of monocytes (10.5%), erythrocytes (5.4%), AST (36.1%), ALT (34.7%), potassium (2.7%), creatinine levels (5.4%), bilirubin (26.6%), low-density lipoproteins (6.6%), and cholesterol (5.34%). Indicators of urea (2.2%) and prothrombin according to Kwik (3.1%) exceeded those in the 1st cluster.

Clustering of ultrasound results with neural networks was also performed in greater depth than in previous studies (Fig. 3) based on the following indicators: aorto-iliac segment ultrasound (1), femoral-popliteal segment ultrasound (2), stenosis at the level of the aorto-iliac segment hemodynamically insignificant (3) , stenosis/occlusion at the level of the aorto-iliac segment hemodynamically significant (4), femoral segment patency (5), deep femoral artery patency (6), superficial femoral artery patency (7), popliteal segment patency (8), posterior tibial artery patency (9), anterior tibial artery patency (10), peroneal artery patency (11), ankle-brachial index (12), before surgery sPO2 (13), after surgery sPO2 (14), revascularization level (15), thrombosis of the reconstruction segment (16), infarction of myocardium (17), embolism (18), pseudoaneurysm (19), prosthesis suppuration (20) and C is an indicator of complications in the afteroperative period (21).

As shown in Figure 3, the highest indicator value of complications in the afteroperative period was found in the 3rd cluster. With the help of a cluster portrait, it can be determined that this cluster also had the lowest values of patency in femoral segment (-17.1%), patency of superficial segment (-15,5%), peroneal artery patency (-4,2%), as well as the ankle-brachial index (-1.5%). The patency of posterior tibial artery value (-4,3%) and patency of anterior tibial artery value (-4,8%) in the 3rd cluster was lower compared to the 1st cluster.

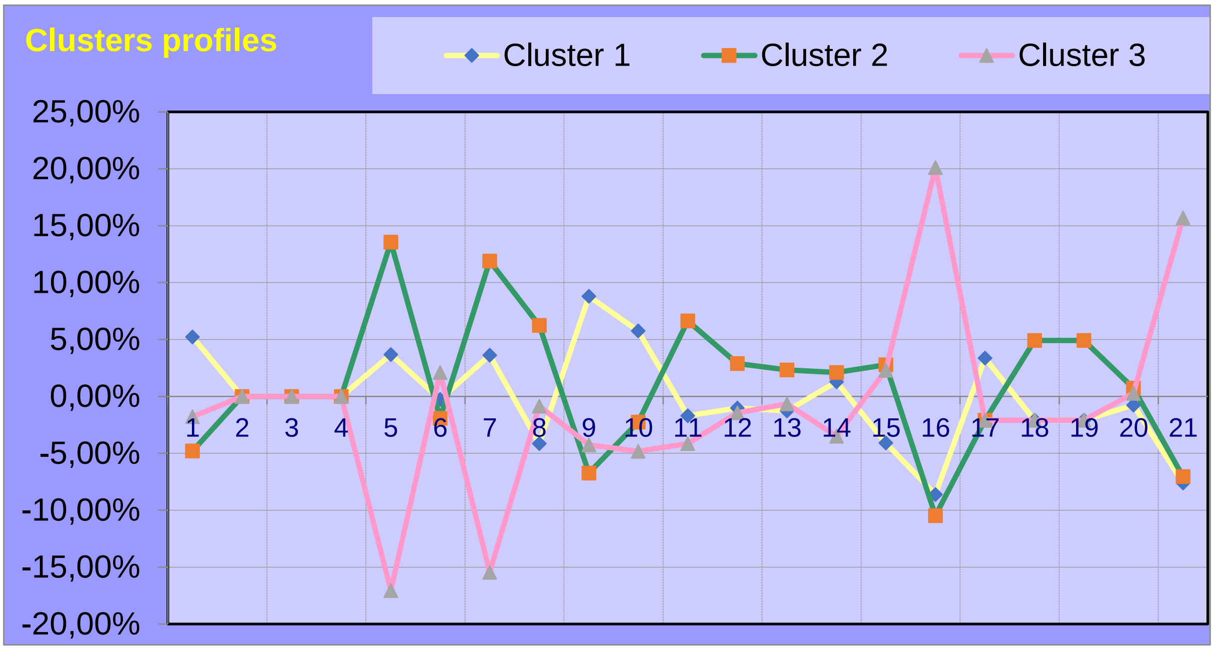

Figure 3: The biggest indicator value of complications in the afteroperative period was found in the 3rd cluster. On this cluster portrait, it can be noted that this cluster also had the lowest values of patency in femoral segment (-17.1%), patency of superficial segment (-15,5%), patency of peroneal artery (-4,2%), as well as the ankle-brachial index (-1.5%).

4.3. Risk scale

Based on the results of clustering by neural networks, we identified the groups of anatomic, laboratory, and ultrasound indicators that are most important for predict the risk of postoperative complications. The resulting neural network clustering results were incorporated into the NeuroXL Classifier program to create a scale to determine the risk of afteroperative complications. At the same time, the limits of the indicator are determined based on the values defined by the patient clustering.

The coefficient value of the indicator was set as the ratio of the percent age of the indicator in a given cluster to the minimum percent age of the indicator. The coefficient was set at1.0. As a result, the cluster with the highest number of complications had the smallest percentage (0.70%) of indicators of cardiovascular disease. This indicator isused as the unit of measure. Thus, the next highest percentage of stroke (1.07%) exceeded the previous percentage by 1.5, resulting in a coefficient of 1.5. The coefficients for the other anesthesia, laboratory, and ultrasound indices were also defined as the most important predictors based on clustering and determined in a similar manner. Note that although the prediction based on clustering did not assign to the most important groups, adding indicators that are risk factors for the development of complications according to the results of other studies to the scale resulted in a minimum coefficient of 1.0.

To unify the definition of risk levels, all coefficient values formed a scale of anamnestic (Table 2), examination (Table 3), symptomatic ultrasound (Table 4), and contralateral ultrasound (Table 5) indices of the patient's extremities, which were converted to a 10-point scale according to the direction of the study. Each had a maximum score of 40 points. All clustering analysis indices, e.g., anesthesia, examination, and ultrasonography indices for the symptomatic and contralateral limbs, are included in the NeuroXL Classifier program to define their point values. The names of some indicators, including ultrasound, have been changed to facilitate their use in vascular surgery.

Table 2 shows coefficients and point values for anamnestic indicators of patients with open and endovascular surgical interventions.

Table 2

Coefficients and scores values for anamnestic indicators of patients with open and endovascular/hybrid surgical interventions

Indicator	Coefficient	Score
Age ≥ 65 years	2,3	0,7
Bad Habits	1,0	0,3
Body mass index ≥ 22,6	1,0	0,3
Carotid disease atherosclerotic genesis	5,4	1,6
Diabetes (in the stage of compensation)	1,0	0,3
Diabetes (in the stage of sub- and decompensation)	6,2	1,8
History of stroke	1,5	0,4
History of infarction of miocardium	1,0	0,3
Failure of respiratory tract	9,5	2,8
Pulmonary hypertension	1,0	0,3
Diseases of the cardiovascular system (cardiosclerosis, heart failure I-II stage, coronary heart disease,)	1,0	0,3
Heart failure with reduced left ventricular ejection fraction ≤ 49%	1,0	0,3
Gastrointestinal tract pathology	1,0	0,3
Oncological diseases history	1,0	0,3

Table 3 shows coefficients and scores values for laboratory indicators of patients with open and endovascular surgical interventions.

Table 3

Scores and coefficients values for laboratory indicators of patients with open endovascular and hybrid surgical interventions

Indicator	Value	Coefficient	Score
Erythrocytes	≥4,5	2,5	0,4
Monocytes	≥3,6	4,8	0,8
Creatinine	≥79,3	2,5	0,4
Urea	≥6,6	1,0	0,1
AST	≥25,2	16,4	2,6
ALT	≥24,6	15,8	2,5
Bilirubin	≥11,3	12,1	1,9
К	≥5,0	1,2	0,2
LDL	≥3,4	3,0	0,5
Cholesterol	≥4,7	2,4	0,4
Thrombin time	≥99,3	1,4	0,2

Table 4 shows coefficients and scores values for indicators of ultrasound examination of the symptomatic limbs of patients with open and endovascular surgical interventions.

Table 4

Scores and coefficients values for indicators of ultrasound examination of the symptomatic limbs of patients with open endovascular and hybrid surgical interventions

Indicator	Coefficient	Score
51-70% stenosis in the aorto/iliac segment	1,0	0,1
≥ 71% stenosis or occlusion in the aorto-iliac segment	1,0	0,1
≥ 71% stenosis or occlusion of the femoral segment	26,7	3,4
≥ 71% stenosis or occlusion of the deep femoral artery	1,0	0,1
≥ 71% stenosis or occlusion of the superficial femoral artery	24,1	3,0
≥ 71% stenosis or occlusion of the a.poplitea	1,3	0,2
Stenosis/occlusion of a. tibialis posterior	6,7	0,9
Stenosis/occlusion of a. tibialis anterior	7,5	1,0
Stenosis/occlusion of peroneal artery	6,5	0,8
Ankle-brachial index ≤ 0,53	2,3	0,3
sPO2 before surgery ≤ 83,4	1,0	0,1

Table 5 shows coefficients and points values for ultrasound examination indicators of the contra-lateral limbs of patients with open and endovascular surgical interventions.

Table 5

Points and coefficients values for ultrasound examination indicators of the contra-lateral limbs of patients with open endovascular/hybrid surgical interventions

Indicator	Coefficient	Score
51-70% stenosis in the aorto/iliac segment	1,0	0,1
≥ 71% stenosis or occlusion in the aorto-iliac segment	1,0	0,1
≥ 71% stenosis or occlusion of the femoral segment	26,7	3,4
≥ 71% stenosis or occlusion of the deep femoral artery	1,0	0,1
≥ 71% stenosis or occlusion of the superficial femoral artery	24,1	3,0
≥ 71% stenosis or occlusion of the a.poplitea	1,3	0,2
Stenosis/occlusion of a. tibialis posterior	6,7	0,9
Stenosis/occlusion of a. tibialis anterior	7,5	1,0
Stenosis/occlusion of peroneal artery	6,5	0,8
Ankle-brachial index ≤ 0,53	2,3	0,3
sPO2 before surgery ≤ 83,4	1,0	0,1

Table 6 shows scoring system for assessing the risk of developing complications.

Table 6
Scoring system for assessing the risk of developing complications.

Anamnestic parameters	
Indicator	Score
Age ≥ 65 years	0,7
Bad Habits	0,3
Body mass index ≥ 22,6	0,3
Carotid disease atherosclerotic genesis	1,6
Diabetes (in the stage of compensation)	0,3
Diabetes (in the stage of sub- and decompensation)	1,8
History of stroke	0,4
History of infarction of miocardium	0,3
Failure of respiratory tract	2,8
Pulmonary hypertension	0,3
Diseases of the cardiovascular system (cardiosclerosis, heart failure I-II stage, coronary heart disease,)	0,3
Heart failure with reduced left ventricular ejection fraction ≤ 49%	0,3
Gastrointestinal tract pathology	0,3
Oncological diseases history	0,3

Laboratory indicators	
Indicator	Score
Erythrocytes ≥ 4,5 $^{*}10^{12}$ /l	0,4
Monocytes ≥ 3,6 %	0,8
Creatinine ≥ 79,3 μmol/l	0,4
Urea ≥ 6,6 mmol/l	0,1
AST ≥ 25,2 u/l	2,6
ALT ≥ 24,6 u/l	2,5
Bilirubin ≥ 11,3 μmol/l	1,9
K ≥ 5,0 mmol/l	0,2
LDL ≥ 3,4 mmol/l	0,5
Cholesterol ≥ 4,7 mmol/l	0,4
Thrombin time ≥ 99,3 %	0,2

Ultrasound examination indicators of symptomatic limb

Indicator	Score
51-70% stenosis in the aorto/iliac segment	0,1
≥ 71% stenosis or occlusion in the aorto-iliac segment	0,1
≥ 71% stenosis or occlusion of the femoral segment	3,4
≥ 71% stenosis or occlusion of the deep femoral artery	0,1
≥ 71% stenosis or occlusion of the superficial femoral artery	3,0
≥ 71% stenosis or occlusion of the a.poplitea	0,2
Stenosis/occlusion of a. tibialis posterior	0,9
Stenosis/occlusion of a. tibialis anterior	1,0
Stenosis/occlusion of peroneal artery	0,8
Ankle-brachial index ≤ 0,53	0,3
sPO2 before surgery ≤ 83,4	0,1

Ultrasound examination indicators of contralateral limb

Indicator	Score
51-70% stenosis in the aorto/iliac segment	0,1
≥ 71% stenosis or occlusion in the aorto-iliac segment	0,1
≥ 71% stenosis or occlusion of the femoral segment	3,4
≥ 71% stenosis or occlusion of the deep femoral artery	0,1
≥ 71% stenosis or occlusion of the superficial femoral artery	3,0
≥ 71% stenosis or occlusion of the a.poplitea	0,2
Stenosis/occlusion of a. tibialis posterior	0,9
Stenosis/occlusion of a. tibialis anterior	1,0
Stenosis/occlusion of peroneal artery	0,8
Ankle-brachial index ≤ 0,53	0,3
sPO2 before surgery ≤ 83,4	0,1

Based on the results obtained from the scoring system to define the risk of postoperative complications, we scaled the risk level of postoperative complications in patients with main artery disease undergoing open endovascular and hybrid surgery (Table 7). Thus, the risk of developing postoperative complications was defined as the total score of all directions of our study: low risk 1 to 10points, moderate 11 to 20points, high risk 21 to 30points, and very high risk 31 to 40 points.

Table 7 shows cumulative scoring system (total points in all areas of research) for assessing the risk of developing complications.

Table 7

Scoring system (all areas of research total points) for assessing the risk of developing complications.

Risk rate	**Total points**
Risk are low	1–10
Risk are moderate	11–20
Risk are high	21–30
Risk are very high	31–40

The following is a suggested range of scales for defining postoperative complications: SVS WIfI (2019), GLASS (2019), EuroSCORE II (2012), CRAB/2YLE (2013), TASC II (2007), Caprini (1991) [18, 19, 20]. Each considers individual criteria for the pathology of organs and their impact on major pathologies.

The proposed measure of risk stratification for the development of afteroperative complications from surgical treatment of the great arteries of the lower extremity takes into account the multifactorial nature of clinical, laboratory, and experimental measurement studies [21, 22, 23]. Consideration of the combination of risk factors that shown the condition of the organ or system influences the choice and method of reconstructive treatment [24, 25, 26].

4.4. Development web page based on a scoring system for assessing the risk of developing postoperative complications

Based on the results of the scoring system for determining the risk of afteroperative complications [27, 28, 29], the web page was developed fig. 4, for ease of use on any device in Ukrainian and English with a visualized scale, where you need to put a check mark under the selected sign and an automatic calculation of parameters will take place with an illustration of the actual result for a patient with diseases of the magistral arteries of the lower limbs [30, 31], within risk are low 1–10, risk are moderate 11-20, risk are high 21-30 and 31-40 risk are very high

Figure 4: Webpage by applying neural network clustering in the assessment of the risk of developing postoperative complications of surgical interventions on the magistral arteries of the lower extremities considering anamnestic/laboratory indicators

Figure 5 shows neural network clustering in the assessment of the risk of developing postoperative complications of surgical interventions on the great arteries of the lower extremites considering ultrasound exam (indicators of symptomatic and contralateral limb) [32, 33].

Ultrasound examination indicators of symptomatic limb

- [x] Stenosis in the range of 51-70% at the level of the aorto/iliac segment
- [x] Stenosis ≥ 71% or occlusion at the level of the aorto-iliac segment
- [ ] Stenosis ≥ 71% or occlusion at the level of the femoral segment
- [x] Stenosis ≥ 71% or occlusion at the level of the deep femoral artery
- [x] Stenosis ≥ 71% or occlusion at the level of the superficial femoral artery
- [ ] Stenosis ≥ 71% or occlusion at the level of the a.poplitea
- [ ] Stenosis/occlusion of a. tibialis posterior
- [ ] Stenosis/occlusion of a. tibialis anterior
- [x] Stenosis/occlusion of peroneal artery
- [ ] Ankle-brachial index ≤ 0,53
- [ ] sPO2 before surgery ≤ 83,4

Ultrasound examination indicators of contralateral limb

- [ ] Stenosis in the range of 51-70% at the level of the aorto/iliac segment
- [ ] Stenosis ≥ 71% or occlusion at the level of the aorto-iliac segment
- [ ] Stenosis ≥ 71% or occlusion at the level of the femoral segment
- [ ] Stenosis ≥ 71% or occlusion at the level of the deep femoral artery
- [ ] Stenosis ≥ 71% or occlusion at the level of the superficial femoral artery
- [x] Stenosis ≥ 71% or occlusion at the level of the a.poplitea
- [ ] Stenosis/occlusion of a. tibialis posterior
- [x] Stenosis/occlusion of a. tibialis anterior
- [ ] Stenosis/occlusion of peroneal artery
- [x] Ankle-brachial index ≤ 0,53
- [x] sPO2 before surgery ≤ 83,4

Total points in all areas of research

17.2

Low risk: 1–10
Moderate risk: 11–20
High risk: 21–30
Very high risk: 31–40

Figure 5: Neural network clustering in the assessment of the risk of developing postoperative complications of surgical interventions on the great arteries of the lower extremites considering ultrasound exam (indicators of symptomatic and contralateral limb).

5. Conclusions

In order to predict the likelyhood of postoperative complications from surgical intervention on the magistral arteries of the lower extremity, risk levels for the development of complications were defined by clustering the indices of clinical, anesthetic, and laboratory equipment tests in a neural network and processing them with the NeuroXL Classifier program.

Four levels of risk of developing complications were defined based on the level of determination of the likelihood of afteroperative complications of surgery on the great arteries of the lower extremities: risk are low 1–10, risk are moderate 11-20, risk are high 21-30 and 31-40 risk are very high.

Acknowledgements

There were no external sources of funding and support. No fees or other compensation were paid. The authors who participated in this study declared that they have no conflict of interest regarding this manuscript.

6. References

[1] C. Bishop (1996) “Neural networks,” Handbook of Neural Computation [Preprint]. Available at: https://doi.org/10.1201/9781420050646.ptb6.

[2] Du K. Clustering: A neural network approach. Neural Networks. 2010;23(1):89-107. doi: 10.1016/j.neunet.2009.08.007.

[3] J. Granton, D. Cheng. Risk stratification models for cardiac surgery. Semin Cardiothorac Vasc Anesth. 2008;12(3):167–174.

[4] H. Geissler, P. Hölzl, S. Marohl, F. Kuhn-Régnier, U. Mehlhorn, M. Südkamp, et al. Risk stratification in heart surgery: comparison of six score systems. Eur J Cardiothorac Surg. 2000;17(4):400–406.

[5] V. Martsenyuk, P. Selskyi, V. Tvorko. Analiz rezultativ obstezhennia patsiientiv z hipertenziieiu na osnovi koreliatsiinykh pokaznykiv ta bahatoparametrychnoi neiromerezhevoi klasteryzatsii z metoiu optymizatsii prohnozuvannia perebihu zakhvoriuvannia na pervynnomu rivni. Medical Informatics and Engineering. 2013;(2). doi: 10.11603/mie.1996-1960.2013.2.1720. [In Ukrainian].

[6] P. Selskyi, A. Sverstiuk, A. Slyva, B. Selskyi. Prediction of the progression of endometrial hyperplasia in women of premenopausal and menopausal age based on an analysis of clinical and anamnestic indicators using multiparametric neural network clustering // Family medicine & Primary Care Review. – 2023. – Vol. 25, № 2. – p. 184-189.

[7] O. Chukur, N. Pasyechko, A. Bob, A. Sverstiuk. Prediction of climacteric syndrome development in perimenopausal women with hypothyroidism. Prz Menopauzalny. 2022. 12; 21 (4): 236–241. doi: 10.5114/ pm.2022.123522.

[8] V. Musiienko, M. Marushchak, A. Sverstuik, A. Filipyuk, I. Krynytska. Prediction Factors For The Risk Of Hypothyroidism Development In Type 2 Diabetic Patients. Pharmacology On Line. 2021. 3: 585–594. 14.

[9] V. Musiienko, A. Sverstiuk, A. Lepyavko, L. Mazur, S. Danchak, N. Lisnianska. Prediction factors for the risk of diffuse non-toxic goiter development in type 2 diabetic patients. Pol. Merkur Lekarski. 2022. 19; 50 (296): 94–98. PMID: 35436270.

[10] S. Nykytyuk, A. Sverstiuk, S. Klymnyuk, D.Pyvovarchuk, Y. Palaniza. Approach to prediction and receiver operating characteristic analysis of a regression model for assessing the severity of the course Lyme borreliosis in children. Reumatologia 2023; 61, 5: 345–352.

[11] S. Nykytyuk, A. Sverstiuk, D. Pyvovarchuk, S. Klymnyuk, A multifactorial model for predicting severe course and organ and systems damage in Lyme borreliosis in children. Modern pediatrics. 2023. No. 2(130). C. 6-16.

[12] S. Lupenko, I. Lytvynenko, A. Sverstiuk, A. Horkunenko, B. Shelestovskyi, Software for statistical processing and modeling of a set of synchronously registered cardio signals of different physical nature. CEUR Workshop Proceedings, 2021, 2864, pp. 194–205.

[13] V. Martsenyuk, A. Sverstiuk, A. Klos-Witkowska, A. Horkunenko, S. Rajba, Vector of diagnostic features in the form of decomposition coefficients of statistical estimates using a cyclic random process model of cardiosignal. Proceedings of the 2019 10th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS 2019, 1, pp. 298–303. doi: 10.1109/IDAACS.2019.8924398.

[14] V. Martsenyuk, A. Klos-Witkowska, A. Sverstiuk, Stability Investigation of Biosensor Model Based on Finite Lattice Difference Equations. Springer Proceedings in Mathematics and Statistics, 2020, 312, pp. 297–321. doi: 10.1007/978-3-030-35502-9_13.

[15] V. Martsenyuk, A. Sverstiuk, I. Gvozdetska, Using Differential Equations with Time Delay on a Hexagonal Lattice for Modeling Immunosensors. Cybernetics and Systems Analysis, 2019, 55(4), pp. 625–637. doi: 10.1007/s10559-019-00171-2.

[16] V. Martsenyuk, I. Andrushchak, P. Zinko, A. Sverstiuk, On application of latticed differential equations with a delay for immunosensor modeling. Journal of Automation and Information Sciences, 2018, 50(6), pp. 55–65.

[17] V. Zhukovskyy, S. Shatnyi, N. Zhukovska, A. Sverstiuk, Neural network clustering technology for cartographic images recognition. EUROCON 2021 - 19th IEEE International Conference on Smart Technologies, Proceedings, 2021, pp. 125–128. doi: 10.1109/EUROCON52738.2021.9535544.

[18] M.A. Cronin et al. Completion of the updated Caprini risk assessment model (2013 version). Clinical and Applied Thrombosis/Hemostasis 2019. Volume 25: 1-10. DOI: 10.1177/1076029619838052

[19] Management of peripheral arterial disease (PAD). TransAtlantic Inter-Society Consensus (TASC). Section D: chronic critical limb ischaemia // Eur. J. Vasc. Endovasc. Surg. — 2000. — Vol. 19, suppl. A. — P. S144–243.

[20] Z. Zhao, S. Voros, Y. Weng, F. Chang. Tracking-by-detection of surgical instruments in minimally invasive surgery via the convolutional neural network deep learning-based method. Computer Assisted Surgery. 2017;22(sup1):26-35. doi: 10.1080/24699322.2017.1378777.
[21] A. Filiberto, T. Loftus, C. Elder, S. Hensley, A. Frantz, P. Efron et al. Intraoperative hypotension and complications after vascular surgery: A scoping review. Surgery. 2021;170(1):311-317. doi: 10.1016/j.surg.2021.03.054.
[22] D. Harris, A. Herrera, C. Drucker, R. Kalsi, N. Menon, S. Toursavadkohi et al. Defining the burden, scope, and future of vascular acute care surgery. Journal of Vascular Surgery. 2017;66(5):1511-1517. doi:10.1016/j.jvs.2017.04.060.
[23] L. Dominioni, A. Imperatori, N. Rotolo, F. Rovera. Risk Factors for Surgical Infections. Surgical Infections. 2006;7(supplement 2):s-9-s-12. doi.10.1089/sur.2006.7.s2-9.
[24] H. Hentati, C. Lim, C. Salloum, D. Azoulay. Authors' Reply: Risk Factors for Mortality and Morbidity in Elderly Patients Presenting with Digestive Surgical Emergencies. World Journal of Surgery. 2018;42(12):4129-4129. doi: 10.1007/s00268-018-4701-z.
[25] F. Sobczak, P. Pais-Roldán, K. Takahashi. Decoding the brain state-dependent relationship between pupil dynamics and resting state fMRI signal fluctuation. eLife. 2021;10. doi: 10.7554/elife.68980.
[26] I. Venher, S. Kostiv, B. Selskiy, I. Faryna, M. Orlov, N. Tsiupryk, D. Kovalskiy. Levels of coagulation factors during intraoperative state of patients treated with open and endovascular revacularization of occluded tibial arteries. Georgian Medical News. -2022. – Vol. 323, № 2. – P. 11-17.
[27] B. Fritz, G. Marbach, F. Civardi, S. Fucentese, C. Pfirrmann. Deep convolutional neural network-based detection of meniscus tears: comparison with radiologists and surgery as standard of reference. Skeletal Radiology. 2020;49(8):1207-1217. doi: 10.1007/s00256-020-03410-2.
[28] I. Kobza, Y. Yarema, R. Zhuk, D. Fedoriv. Rekonstruktyvni operatsii na arteriiakh stopy v likuvanni krytychnoi ishemii nyzhnikh kintsivok.. UMJ Heart & Vessels. 2018;0(1):37-39. doi: 10.30978/hv2018137. [In Ukrainian].
[29] C. Hicks, A. Najafian, A. Farber, M. Menard, M. Malas, J. Black, and C. Abularrage, 2016. Below-knee endovascular interventions have better outcomes compared to open bypass for patients with critical limb ischemia. Vascular Medicine, 22(1), pp.28-34. doi: 10.1177/1358863x16676901.
[30] F. Gentile, G. Lundberg and R. Hultgren, 2016. Outcome for Endovascular and Open Procedures in Infrapopliteal Lesions for Critical Limb Ischemia: Registry Based Single Center Study. European Journal of Vascular and Endovascular Surgery, 52(5), pp.643-649. doi: 10.1016/j.ejvs.2016.07.013.
[31] M. Matsagkas, G. Kouvelos, E. Arnaoutoglou, N. Papa, N. Labropoulos and A. Tassiopoulos, 2011. Hybrid Procedures for Patients With Critical Limb Ischemia and Severe Common Femoral Artery Atherosclerosis. Annals of Vascular Surgery, 25(8), pp.1063-1069. doi: 10.1016/j.avsg.2011.07.010.
[32] I. Venher, S. Kostiv, D. Kovalskiy, B. Selskyi, O. Kostiv, O. Zarudna, O. Dobrovanov, D. Dmytriev, K. Dmytriev, 2022. Endovascular technologies: reconstruction of deep femoral artery and revascularization of stenotic-occlusive process of infrainguinal arterial bed. Lekarsky obzor, 71(2), pp-55-59.
[33] M. Abualhin, M. Gargiulo, C. Bianchini Massoni, R. Mauro, A. Morselli-Labate, A. Freyrie, G. Faggioli and A. Stella, 2019. A prognostic score for clinical success after revascularization of critical limb ischemia in hemodialysis patients. Journal of Vascular Surgery, 70(3), pp.901-912. doi: 10.1016/j.jvs.2018.11.034.