Predicting the risk of surgical complications based on multiparametric neural network clustering at revascularization of main arteries of the lower limbs

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Abstract

To propose a method for predicting the complications of surgical interventions through the use of multiparameter neural network clustering, followed by the development of a scale for stratification of the surgical risk complications. Analysis of examination results of 411 patients with obliterating atherosclerosis of the main arteries of the lower limbs was performed. For a more in-depth analysis 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. The proposed scale of the surgical risk stratification of treatment the main arteries of the lower extremities in the postoperative period takes into account the multifactorial clinical-anamnestic and laboratory-instrumental studies. Considering the combination of factors that characterize the state of organs and systems, influence the choice and method of reconstructive surgery. Based on the data of neural network clustering, the level of possible postoperative complications of surgery on the main arteries of the lower extremities was determined, followed by four levels of risk factors development: 31-40 very high risk, high risk 21-30, moderate 11-20, and low - 1–10.

Keywords 1

predicting the risk factors, neural network clustering, risk scale, obliterating atherosclerosis, revascularization, vascular reconstruction.

1. Introduction

Application of information methods and computer modeling in modern conditions makes it possible to significantly improve the quality and provide a comprehensive approach to the choice of surgical intervention, especially in the field of vascular surgery, which requires a large amount of information and parameters analysis. [1,5] A large number of studies have been aimed at solving prevention of complications, taking into account patient's parameters and developing relevant prevention risk scales [7]. However, the problem of their usage in practical medicine and comprehensive consideration of numerous risk factors is still being solved [8, 9]. At the same time, the development of a unified scale of possible risks of surgical intervention has become extremely important. The prediction of combined complications in patients with vascular pathology and the use of neural network technology for their detection have remained especially applicable [10, 11].

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2. Main Part

To form a multi-parameter neural network clustering followed by the development of a risk stratification scale for surgical complications, we have performed analysis of the examination indicators of 411 patients with obliterating atherosclerosis of the main arteries of lower limbs.

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

The obtained results of clinical observations, laboratory and instrumental studies have been processed by variational mathematical statistics method. To process of statistical data, we used Microsoft Excel (2013) package. In cases of normal distribution, statistical significance of the difference between the arithmetic avarage 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 a more in-depth analysis of combined changes in the indicators of groups in observational studies and in order to optimize the prediction of the risk of developing complications in the postoperative period, we have performed a neural network clustering using NeuroXL Classifier add-in for the Microsoft Excel program. The NeuroXL Classifier program (developed by the AnalyzerXL company) implements self-organizing neural networks that process categorization by studying trends and interconnections within groups. The key advantages of NeuroXL Classifier are simplicity of mastering and usage; in-depth knowledge in the field of neural networks is optional; integration with Microsoft Excel; provision of 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. Results and Discussions

We have analyzed clinical observations results, laboratory and instrumental studies, which we entered in the neural network clustering system for processing.

3.1. Average values of indicators

Besides, we have analyzed anamnestic, and clinical and laboratory indicators of 72 patients (group 1). Open surgical interventions (subgroup 1a) have been used to treat 44 patients (61.1%), and endovascular interventions (subgroup 1b) – to treat 28 patients (38.9%). The average age of patients in the first group was (67.06±1.14) years old. 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. Among other indicators, the following were taken into account: lesions of extracranial arteries ((54.14±5.87) %), diabetes ((30.56±5.43) %), stroke in history ((5.56±2.70) %), myocardial infarction in history ((23.61±5.01) %), pathology of the gastrointestinal tract ((15.28±4.24) %), respiratory failure ((12.5±3.90) %), diseases of the cardiovascular system ((95.83±2.35) %), malignant process in history ((1.39±1.38) %), conduction anesthesia ((13.89±4.08) %), epidural anesthesia ((55.56±5.86) %), mechanical ventilation ((1.39±1.38) %), presence of pulmonary hypertension ((9.72±3.49) %) and level revascularization ((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) %), myocardial infarction ((1.39±1.38) %), pseudoaneurysm ((2.78±1.94) %) and suppuration conduit ((4.17±2.35) %). It should be noted 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 have studied general blood analysis and biochemical indicators and coagulogram indicators of all subgroups of patients. The results of the study are shown in Table 1.

Table 1

Indicators of general blood analysis, biochemical indicators and coagulogram indicators of patients with open and endovascular 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.

We have also carried out analysis of ultrasound examination indicators of 47 patients (2nd group) who underwent open and endovascular surgical interventions. All the patients were diagnosed with an insignificant stenosis at the level of the aorta/iliac segment. However, a significant stenosis/occlusion at the level of the aorto-iliac segment was not detected. The patency of the femoral segment was

identified in (44.68±7.25)% cases, the patency of the deep femoral artery – in (89.36±4.50)% cases, and the patency of the popliteal segment – in (68.10±6.80)% cases. We have detected patency at the level of the tibial arteries at the level of the posterior tibial artery in (53.19±7.29)% of patients, the anterior tibial artery in (68.09±6.80)% of patients, 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) %.

3.2. Cluster Analysis

In order to establish combined changes of the parameters study, the most significant for predicting the risk of complications in the postoperative period, we have performed a neural network clustering of the indicators of the research. 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 clinical and anamnestic examination (Fig. 1) was carried out on the basis of the following indicators: age (1), unhealthy habits (2), body mass index (3), extracranial arteries injury (4), decompensated diabetes (5), uncompensated diabetes (6), stroke in anamnesis (7), myocardial infarction in anamnesis (8), pathology of the gastrointestinal tract (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 segment (16), myocardial infarction (17), pseudoaneurysm (18), suppuration of the prosthesis (19) and C - indicator of complications in the postoperative 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.

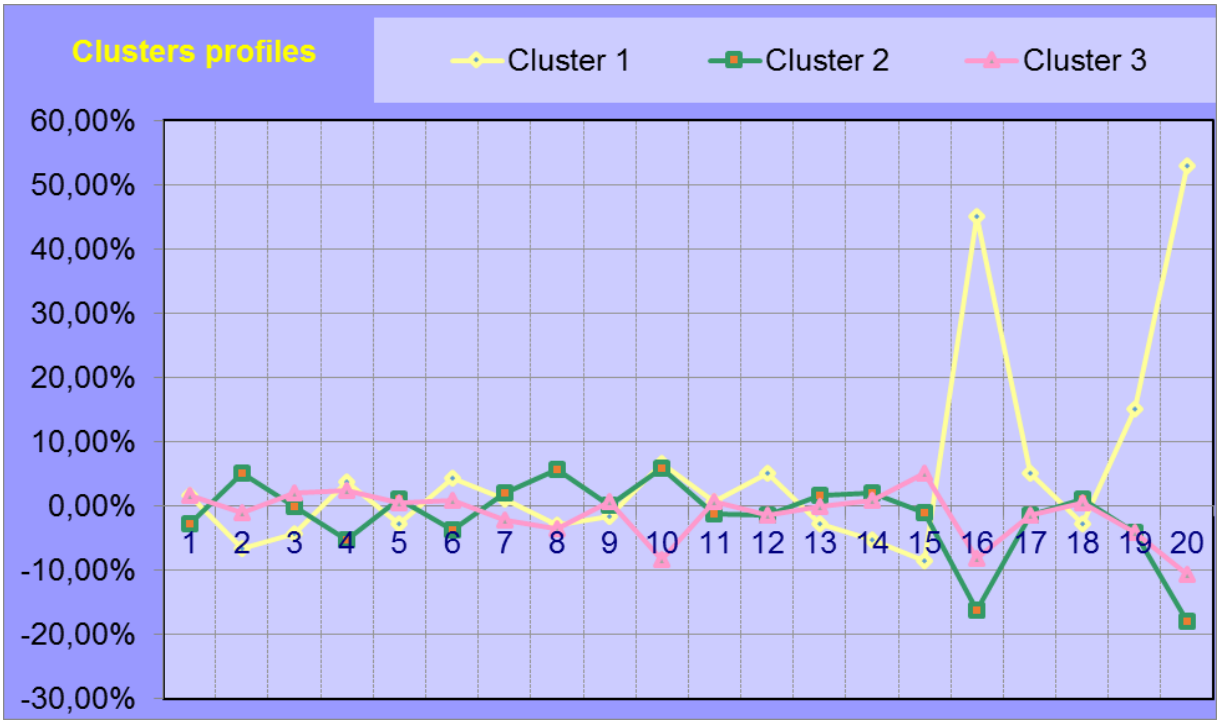

Figure 1: The results of clustering of patients' anamnestic indicators.

According to the research, the patients of the 1st cluster have the highest level of complications in the postoperative period. With the help of cluster portrait, we found out that this cluster has shown the highest age indicators (1.6%), lesions of extracranial arteries (3.8%), diabetes in the sub- and decompensation 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.

Besides, a neural network clustering of the results of laboratory-instrumental research (Fig. 2) has been performed based on a number of indicators: erythrocytes (1), hemoglobin content (2), color index (3), leukocytes (4), eosinophils (5), rod-shaped neutrophils (6), segmented neutrophils (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), prothrombin time (22), Prothrombin according to Kwik (23), INR (24), thrombin time (25), fibrinogen (26), ejection fraction (27), allo-graft (28), deep fundoplasty (29), autovenous graft (30), hybrid surgery (31), stenting (32), balloon angioplasty (33), reconstruction segment thrombosis (34)), myocardial infarction (35), pseudoaneurysm (36), suppuration of the prosthesis (37), and C – is an indicator of complications in the postoperative period (38).

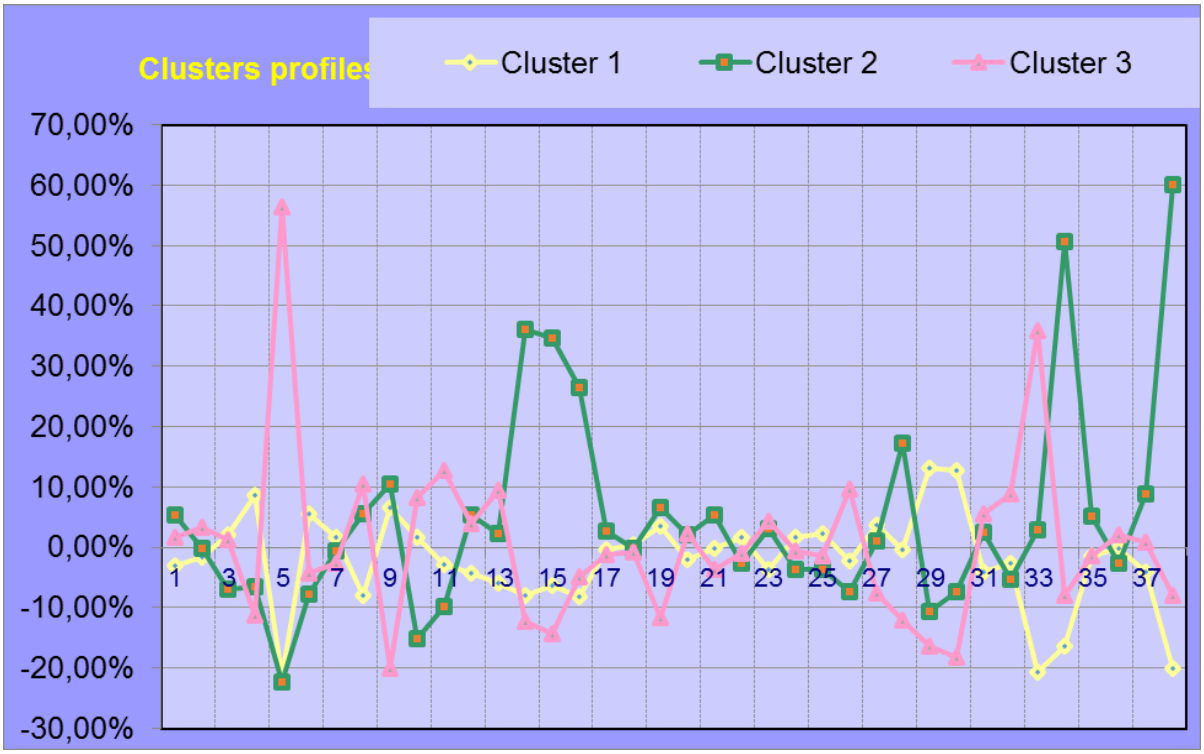

Figure 2: Results of indicators clustering of laboratory-instrumental examination of patients

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

The highest value of the complications indicator in the postoperative period was found out in the 2nd cluster. With the help of a cluster portrait, we have come to conclusion that the 2nd cluster includes the highest number of erythrocytes (5.4%), monocytes (10.5%), creatinine levels (5.4%), AST (36.1%), ALT (34.7%), bilirubin (26.6%), potassium (2.7%), 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.

We have also performed a neural network clustering of the ultrasound study results (Fig. 3) based on the following indicators: ultrasound of the aorto-iliac segment (1), ultrasound of the femoral-popliteal segment (2), hemodynamically insignificant stenosis at the level of the aorto-iliac segment (3) , hemodynamically significant stenosis/occlusion at the level of the aorto-iliac segment (4), patency of the femoral segment (5), patency of the deep femoral artery (6), patency of the popliteal segment (7), patency of the posterior tibial artery (8), patency of the anterior tibial artery (9), patency of the peroneal artery (10), ankle-brachial index (11), sPO2 before surgery (12), sPO2 after surgery (13), level of revascularization (14), thrombosis of the reconstruction segment (15), myocardial infarction (16)), embolism (17), pseudoaneurysm (18), suppuration of the prosthesis (19) and C is an indicator of complications in the postoperative period (20).

As indicated in Figure 3, the highest indicator value of complications in the postoperative 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 femoral segment patency (-16.1%), peroneal artery patency (-1.3%), as well as the ankle-brachial index (-2.5%). The posterior tibial artery patency value (-2.1%) and anterior tibial artery patency value (-2.3%) in the 3rd cluster was lower compared to the 1st cluster.

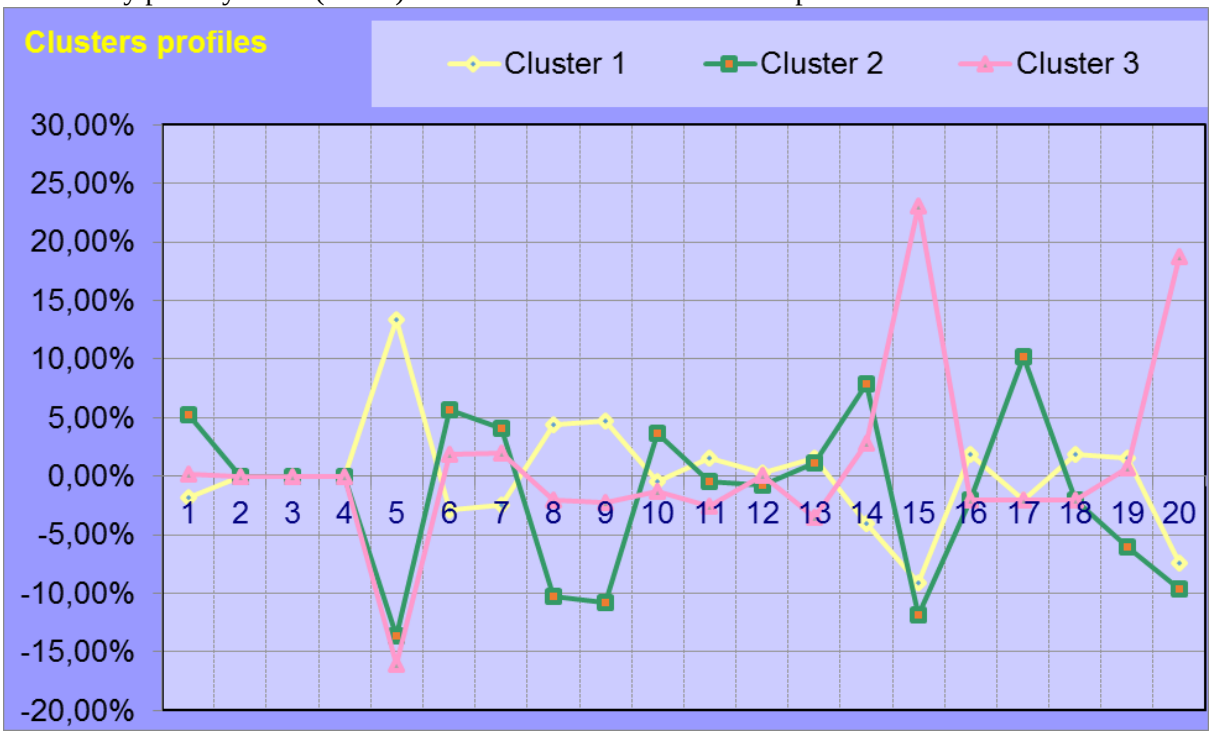

Figure 3: Results of clustering of ultrasound examination indicators.

3.3. Risk scale

Thus, based on the results of neural network clustering, we have identified groups of anamnestic, laboratory, and ultrasound examination indicators, combined changes of which are the most significant for predicting the risk of complications in the postoperative period. The obtained results of neural network clustering have been included into the NeuroXL Classifier program in order to create a scale for determining the risk of postoperative complications. At the same time, the limit values of their indicators are determine on the basis of values defined by patients clustering.

The coefficients value for the indicators was set as the ratio of their fractions in the specified cluster to the minimum fraction of the indicator. Its coefficient was defined as 1.0. Thus, in the group of anamnestic indicators, the indicator of cardiovascular system diseases had the smallest fraction (0.70%) in the cluster with the largest number of complications. This indicator is considered to be a unit. Accordingly, the next-highest fraction of stroke (1.07%) exceeded the previous one by 1.5, so its coefficient was 1.5. Other coefficients of anamnestic indicators, as well as laboratory indicators and ultrasound examination indicators, which are defined on the basis of clustering as the most important factors for predicting, were determined in a similar way.

It should be noted that by adding to the scale indicators, that are not allocated to the most important groups for prediction based on clustering, but are the risk factors for the development of complications according to the results of other studies, a minimum coefficient of 1.0 was defined.

To unify the definition of risk levels, all coefficient values were converted into 10-point scales according to the research directions with formation of scales for anamnestic (Table 2), laboratory (Table 3) indicators, indicators of symptomatic ultrasound examination (Table 4) and contralateral ultrasound examination (Table 5) of patients' limbs. The maximum number was 40 points, respectively.

Indicators of all clustering analysis, such as anamnestic, laboratory, ultrasound examination of the symptomatic and contralateral limbs indicators, have been included into the NeuroXL Classifier

program in order to define the values of their points. Names of some indicators, including ultrasound, have been adapted to facilitate the use in the vascular surgery department.

Table 2

Values of coefficients and scores for anamnestic indicators of patients with open and endovascular 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
Atherosclerotic carotid disease	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 myocardial infarction	1,0	0,3
Respiratory failure	9,5	2,8
Pulmonary hypertension	1,0	0,3
Diseases of the cardiovascular system	1,0	0,3
Heart failure with reduced left ventricular ejection fraction ≤ 49%	1,0	0,3
Pathology of the gastrointestinal tract	1,0	0,3
History of oncological diseases	1,0	0,3

Table 3

Values of coefficients and scores for laboratory indicators of patients with open and endovascular 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
K	≥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

Values of coefficients and scores for indicators of ultrasound examination of the symptomatic limbs of patients with open and endovascular surgical interventions.

Indicator	Coefficient	Score
Stenosis in the range of 51-70% at the level of the aorto/iliac segment	1,0	0,4
Stenosis ≥ 71% or occlusion at the level of the aorto-iliac segment	1,0	0,4
Stenosis ≥ 71% or occlusion at the level of the femoral segment	12,4	5,3
Stenosis ≥ 71% or occlusion at the level of the deep femoral artery	1,0	0,4
Stenosis ≥ 71% or occlusion at the level of the a.poplitea	1,0	0,4
Stenosis/occlusion of a. tibialis posterior	1,6	0,7
Stenosis/occlusion of a. tibialis anterior	1,8	0,8
Stenosis/occlusion of peroneal artery	1,0	0,4
Ankle-brachial index ≤ 0,53	1,9	0,8
sPO2 before surgery ≤ 83,4	1,0	0,4

Table 5

Values of coefficients and points for ultrasound examination indicators of the contra-lateral limbs of patients with open and endovascular surgical interventions

Indicator	Coefficient	Score
Stenosis in the range of 51-70% at the level of the aorto/iliac segment	1,0	0,4
Stenosis ≥ 71% or occlusion at the level of the aorto-iliac segment	1,0	0,4
Stenosis ≥ 71% or occlusion at the level of the femoral segment	12,4	5,3
Stenosis ≥ 71% or occlusion at the level of the deep femoral artery	1,0	0,4
Stenosis ≥ 71% or occlusion at the level of the a.poplitea	1,0	0,4
Stenosis/occlusion of a. tibialis posterior	1,6	0,7
Stenosis/occlusion of a. tibialis anterior	1,8	0,8
Stenosis/occlusion of peroneal artery	1,0	0,4
Ankle-brachial index ≤ 0,53	1,9	0,8
sPO2 before surgery ≤ 83,4	1,0	0,4

Table 6

Cumulative 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
Atherosclerotic carotid disease	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 myocardial infarction	0,3
Respiratory failure	2,8
Pulmonary hypertension	0,3
Diseases of the cardiovascular system	0,3
Heart failure with reduced left ventricular ejection fraction ≤ 49%	0,3
Pathology of the gastrointestinal tract	0,3
History of oncological diseases	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
Stenosis in the range of 51-70% at the level of the aorto/iliac segment	0,4
Stenosis ≥ 71% or occlusion at the level of the aorto-iliac segment	0,4
Stenosis ≥ 71% or occlusion at the level of the femoral segment	5,3

Stenosis ≥ 71% or occlusion at the level of the deep femoral artery	0,4
Stenosis ≥ 71% or occlusion at the level of the a.poplitea	0,4
Stenosis/occlusion of a. tibialis posterior	0,7
Stenosis/occlusion of a. tibialis anterior	0,8
Stenosis/occlusion of peroneal artery	0,4
Ankle-brachial index ≤ 0,53	0,8
sPO2 before surgery ≤ 83,4	0,4
Ultrasound examination indicators of contralateral limb	
Indicator	Score
Stenosis in the range of 51-70% at the level of the aorto/iliac segment	0,4
Stenosis ≥ 71% or occlusion at the level of the aorto-iliac segment	0,4
Stenosis ≥ 71% or occlusion at the level of the femoral segment	5,3
Stenosis ≥ 71% or occlusion at the level of the deep femoral artery	0,4
Stenosis ≥ 71% or occlusion at the level of the a.poplitea	0,4
Stenosis/occlusion of a. tibialis posterior	0,7
Stenosis/occlusion of a. tibialis anterior	0,8
Stenosis/occlusion of peroneal artery	0,4
Ankle-brachial index ≤ 0,53	0,8
sPO2 before surgery ≤ 83,4	0,4

According to the obtained results of the scoring system for defining the risk of postoperative complications, we have developed a scale of the level of risk of complications in the postoperative period of patients with diseases of the main arteries that underwent open and endovascular surgical interventions (Table 7). Accordingly, we have defied the risk of the development of postoperative complications, in the case of aggregate points value for all directions of our research: a very high risk - 31-40, a high risk - 21-30, a medium risk - 11-20, and a low risk - 1-10.

Table 7

Cumulative scoring system for assessing the risk of developing complications.

Total points in all areas of research

Risk rate	Total points
Low risk	1–10
Moderate risk	11–20
High risk	21–30
Very high risk	31–40

The following is a suggested range of scales for defining postoperative complications: SVS Wifi (2019), Finnvasc (2007), Prevent III (2006), BASIL (2010), ERICVA (2016), Caprini (1991), GCS (1974) [16]. Each of them takes into account separate criteria of the pathology of organs and systems and their influence on the main pathology.

The suggested scale of risk stratification of the development of complications of operative treatment of main arteries of the lower extremities in the postoperative period takes into account the multifactorial nature of clinical, anamnestic and laboratory-instrumental studies. Consideration of the combination of factors that characterize the state of organs and systems affects the choice and method of reconstructive surgery.

4. Conclusions

In order to predict possible postoperative complications of surgical interventions into the great vessels of the lower limbs, we have defined a level of risk of developing complications by processing them by neural network clustering of indicators of clinical, anamnestic and laboratory-instrumental studies, followed by the NeuroXL Classifier processing program.

Based on the determined level of possible postoperative complications of surgery on the main arteries of the lower limbs, we have defined four levels of risk of developing complications: 31-40 – a very high risk, 21-30 – a high risk, 11-20 – a moderate risk, and 1-10 – a low risk.

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