Research Article

https://doi.org/10.23934/2223-9022-2023-12-3-386-396

Predicting the Development of Thrombosis of the Femoral-Popliteal Bypass in the Long-Term Follow-Up Period

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AIM OF STUDY The development of a program for predicting thrombosis with subsequent amputation of a limb in the long-term period after femoral-popliteal bypass (FPB).

MATERIAL AND METHODSThis is a retrospective open comparative study performed from January 10, 2016 to December 25, 2019 at Research Institute – Professor S.V. Ochapovsky Regional Clinical Hospital No. 1 of the Ministry of Health of the Krasnodar Territory, Krasnodar, which included 473 patients who underwent FPB. Depending on the type of bypass, five groups were formed: Group 1 (n=266), reversed vein (great saphenous vein (GSV); Group 2 (n=59), autovenous vein (GSV), prepared in situ; Group 3 (n=66), autovenous vein (GSV), prepared ex situ; Group 4 (n=9) synthetic graft (Jotec, Germany); Group 5 (n=73), veins of the upper limb (forearm and shoulder). In all cases of observation, multislice computed tomography with angiography revealed an extensive (25 cm or more) atherosclerotic occlusive lesion of the superficial femoral artery, corresponding to type D according to the transatlantic consensus (TASC II). The long-term follow-up period was 16.6±10.3 months.

RESULTS During the hospital postoperative period, all complications developed in groups 1, 2, 3 and 5. However, no significant intergroup statistical differences were found. In the long-term follow-up period, according to the mortality rate (group 1: 4.6%; group 2: 1.7%; group 3: 4.6%; group 4: 0%; group 5: 2.8%; p=0.78), myocardial infarction (group 1: 1.9%; group 2: 0%; group 3: 1.5%; group 4: 0%; group 5: 0%; p=0.62), ischemic stroke (group 1: 0.8%; group 2: 1.7%; group 3: 1.5%; group 4: 0%; group 5: 0%; p=0.8) and bybass thrombosis (group 1: 14.5%; group 2: 19.3%; group 3: 18.5%; group 4: 44.4%; group 5: 19.7%; p=0.16), no significant intergroup differences were identified. However, the largest number of limb amputations (group 1: 4.2%; group 2: 5.3%; group 3: 9.2%; group 4: 22.2%; group 5: 1.4%; p=0.03) and the maximum composite endpoint (sum of all complications) (group 1: 26.0%; group 2: 28.1%; group 3: 35.4%; group 4: 66.7%; group 5: 23 .9%; p=0.05) were observed after the use of a synthetic graft.
Using “random forest” analysis, a model and computer program was created that allows, the risk (low, medium, high) of developing bypass thrombosis to be assessed interactively, based on clinical, anamnestic, demographic and perioperative data, with subsequent amputation after FPB in the long-term follow-up period.

CONCLUSIONS Revascularization strategy for patients with extended atherosclerotic lesions of the femoropopliteal segment should be determined individually and only by a multidisciplinary council. The conduit of choice for femoral-popliteal bypass surgery is an autovenous graft. Synthetic prostheses can only be used in the absence of the latter. To identify a group of patients with a high risk of thrombosis of the femoral-popliteal bypass and limb amputation in the long-term follow-up period, the created risk stratification program for the development of these complications can be used. Precision supervision of these patients in the postoperative period will make it possible to prevent these adverse events in time.

Keywords: femoral-popliteal bypass, reverse autovein, autovein “in situ”, autovein “ex situ”, autovein of the upper limb, synthetic graft, Jotec, risk stratification, bypass thrombosis, amputation

For citation Zakeryaev AB, Vinogradov RA, Sukhoruchkin PV, Butayev SR, Bakhishev TE, Derbilov AI, et al. Predicting the Development of Thrombosis of the Femoral-Popliteal Bypass in the Long-Term Follow-Up Period. Russian Sklifosovsky Journal of Emergency Medical Care. 2023;12(3):386–396. https://doi.org/10.23934/2223-9022-2023-12-3-386-396 (in Russ.)

Conflict of interest Authors declare lack of the conflicts of interests

Acknowledgments, sponsorship The study had no sponsorship

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ACVA – acute cerebrovascular accident
CHF – chronic heart failure
CILE – chronic ischemia of the lower extremities
CKD – chronic kidney disease
COPD – chronic obstructive pulmonary disease
DM – diabetes mellitus
GSV – great saphenous vein
FC – functional class
FPB – femoral-popliteal bypass
MFA – multifocal atherosclerosis
MI – myocardial infarction
PICS – post-infarction cardiosclerosis
SFA – superficial femoral artery

INTRODUCTION

Femoral-popliteal bypass (FPS) is the operation of choice in the presence of extensive lesions of the femoropopliteal segment [1–3]. The entire arsenal of autovenous, synthetic and biological shunts for implementing this type of reconstruction makes it possible to significantly achieve confident success of revascularization [4–6]. However, the effectiveness of surgical treatment can only be assessed by analyzing the long-term outcomes of operations [1–5].

Long-term operation of a particular shunt allows one to maintain the ability to work and quality of life for each patient [1–5]. Therefore, timely identification of the cohort of patients who are at risk of shunt dysfunction is an extremely urgent problem. In this regard, it should be noted that today there are no methods that can solve this problem [1–3]. One of the options that was proposed by N.N. Burkov et al. showed high efficiency in predicting shunt occlusion [7]. The method was based on calculating the probability of a given event using special software decision support [7]. However, the inability to routinely use this development was due to the need to enter information about the chromosomal spectrum of certain hereditary parallels from the patient's genetic passport [7]. This analysis is expensive and is not performed as part of preparing patients for FPB [1–3, 7]. Thus, the development of a new method for predicting shunt dysfunction, universal for different types of autovenous and synthetic conduits, is an extremely urgent task.

The purpose of this study was to develop a program for predicting shunt thrombosis with subsequent amputation of a limb in the long-term period after FPB.

MATERIAL AND METHODS

This is a retrospective open comparative study for the period from January 10, 2016 to December 25, 2019 at the Research Institute – S.V. Ochapovsky Regional Clinical Hospital No. 1(Krasnodar) included 473 patients who underwent FPB. Depending on the type of bypass, five groups have been formed:

Group 1 (n =266), reversed vein (great saphenous vein, GSV);

Group 2 (n =59), autovenous vein (GSV), prepared "in situ";

Group 3 (n =66), autovenous vein (GSV), prepared "ex situ";

Group 4 (n =9), synthetic prosthesis (Jotec, Germany);

Group 5 (n =73), veins of the upper limb.

To assess the severity of the lesion, the following classifications were used: Fontaine–Pokrovsky (*https://racvs.ru/clinic/files/2016/Diseases-lower-limb-arteries.pdf*), WiFi (*https://sudact.ru/law/klinicheskie-rekomendatsii-sakharnyi-diabet-1-tipa-u_1/prilozhenie-g/prilozhenie-g4/*), Rutherford (*https://racvs.ru/clinic/files/2016/Diseases-lower-limb-arteries.pdf*).

In all cases, multislice computed tomography and (or) angiography revealed an extensive (25 cm or more) atherosclerotic occlusive lesion of the superficial femoral artery (SFA), corresponding to type D according to the transatlantic consensus (TASC II) [1–3].

The choice of the method of revascularization and the type of shunt was made by a multidisciplinary council consisting of a vascular surgeon, endovascular surgeon, cardiologist, resuscitator, and anesthesiologist.

The "ex situ" GSV was prepared as follows: the GSV was isolated from the saphenofemoral junction in the distal direction to the required length and removed from the wound. Next, a valvotomy was performed through the proximal end of the GSV. The valvulotome was then removed and a metal cannula was inserted. Through it, using a syringe, saline solution at room temperature with unfractionated heparin was injected into the lumen of the GSV, simulating blood flow, and the quality of the valvotomy was checked. The shunt was carefully prepared with ligation of the branches and suturing of defects in the vein wall.

Inclusion criteria: the presence of extensive atherosclerotic occlusive lesions of the SFA (25 cm or more), the absence of decompensated comorbid disease (diabetes, chronic heart failure, etc.).

Non-inclusion criteria: the disease that limits the follow-up of the patient in the long-term follow-up period.

During the hospital observation period, the following types of complications were assessed: death, myocardial infarction (MI), shunt thrombosis, bleeding type 3b and higher (requiring wound revision) according to the Bleeding Academic Research Consortium (BARC) scale, postoperative wound infection, limb amputation, acute cerebrovascular accident (ACVA), combined end point (sum of all listed complications).

In the long-term follow-up period (16.6±10.3 months), the following types of complications were assessed: death, shunt thrombosis, limb amputation, MI, stroke, combined end point (the sum of all listed complications). In this case, if a fatal outcome occurred or amputation of a revascularized limb was performed, the patient was excluded from the sample.

All patients signed written consent for the use of their data in scientific research. The work was carried out in accordance with the standards of good clinical practice (Good Clinical Practice) and the principles of the Declaration of Helsinki, it did not contradict the Federal Law of the Russian Federation of November 21, 2011 No. 323-FZ "On the fundamentals of protecting the health of citizens in the Russian Federation", the order of the Ministry of Health of the Russian Federation dated April 1, 2016 N 200n "On approval of the rules of good clinical practice."

Statistical analysis. The type of distribution was determined using the Kolmogorov–Smirnov test. Group comparisons were performed using the Pearson and Kruskal–Wallis chi-square tests. Differences were assessed as significant at $p < 0.05$. The research results were processed using the Graph Pad Prism application package (www.graphpad.com).

According to clinical and anamnestic characteristics, the groups were completely comparable. The majority were male and elderly. Every third person suffered from diabetes, every tenth person had a history of myocardial infarction and (or) stroke; in the overwhelming percentage of cases, chronic obstructive pulmonary disease (COPD) and chronic heart failure (CHF) were diagnosed (Table 1).

Table 1

Clinical and anamnestic characteristics

Index	Group 1	Group 2	Group 3	Group 4	Group 5	R
	n=266	n=59	n=66	n=9	n=73	
Age, M±m , years	63.0±7.9	63.0±8.4	63.9±6.8	63.6±5.3	62.9±7.1	0.45
Male gender, n (%)	240 (90.2)	53 (89.8)	56 (84.8)	6 (66.7)	67 (91.8)	0.14
Diabetes, n (%)	89 (33.4)	22 (37.3)	28 (42.4)	2 (22.2)	20 (27.4)	0.35
Diabetes insulin dependent, n (%)	34 (12.8)	7 (11.8)	10 (15.1)	2 (22.2)	6 (8.2)	0.64
COPD, n (%)	221 (83.1)	46 (77.9)	51 (77.3)	7 (77.8)	55 (75.3)	0.54
CKD, n (%)	10 (3.7)	0	2 (3.0)	0	5 (6.8)	0.3
History of stroke, n (%)	25 (9.4)	4 (6.8)	5 (7.6)	1 (11.1)	5 (6.8)	0.92
PICS, n (%)	27 (10.1)	6 (10.2)	8 (12.1)	0	11 (15.1)	0.61
Angina pectoris FC I–II, n (%)	52 (19.5)	13 (22.0)	18 (27.3)	2 (22.2)	19 (26.0)	0.61
Overweight, n (%)	129 (48.5)	27 (45.8)	35 (53.0)	2 (22.2)	28 (38.3)	0.22
Obesity grade I, n (%)	39 (14.7)	11 (18.6)	13 (19.7)	2 (22.2)	21 (28.8)	0.09
Obesity II degree, n (%)	12 (4.5)	3 (5.1)	2 (3.0)	1 (11.1)	2 (2.7)	0.76
CHF II FC according to NYHA, n (%)	249 (93.6)	53 (89.8)	64 (97.0)	9 (100)	71 (97.3)	0.28
MFA (subclinical) with damage to three arterial territories	11 (4.1)	1 (1.7)	1 (1.5)	1 (11.1)	4 (5.5)	0.46

Notes: MFA – multifocal atherosclerosis, PICS – post-infarction cardiosclerosis, COPD – chronic obstructive pulmonary disease, CKD – chronic kidney disease, CHF – chronic heart failure, FC – functional class

The groups were not comparable in terms of the severity of chronic lower limb ischemia (CLI) according to the Fontaine-Pokrovsky classification. Grade IIB was most often diagnosed in groups 2 and 5, grade III in the 3rd group, and grade IV in the 1st, 3rd, 4th groups. According to the Rutherford classification, class 2 was more often observed in groups 2 and 5, class 3 in groups 1 and 3, class 4 in groups 1 and 3. The groups did not differ in grades 5 and 6 (Table 2).

According to WiFi classification, significant intergroup differences were identified in component I, 2 points (the lowest indicator in the 2nd group), I – 3 points (the highest indicator in the 2nd group), fI — 0 points (the highest indicator in the 5th group), fI — 1 point (the lowest indicator in the 5th group) (Table 3).

Table 2

The severity of chronic ischemia of the lower extremities according to current classifications

Index	Group 1	Group 2	Group 3	Group 4	Group 5	R
	n=266	n=59	n=66	n=9	n=73	
Classification of chronic ischemia of the lower extremities according to Fontaine-Pokrovsky						
IIB, n (%)	139 (52.2)	35 (59.3)	27 (41.0)	4 (44.4)	56 (76.7)	0.0003 p_{1-5} : 0.0002 p_{2-3} : 0.04 p_{2-5} : 0.03 p_{3-5} : <0.0001 p_{4-5} : 0.05
III, n (%)	57 (21.4)	10 (16.9)	22 (33.3)	1 (11.1)	7 (9.6)	0.01 p_{1-3} : 0.05 p_{1-5} : 0.02 p_{2-3} : 0.04 p_{3-5} : 0.0007
IV, n (%)	69 (25.9)	13 (22.0)	17 (25.7)	4 (44.4)	9 (12.3)	0.07 p_{1-5} : 0.01 p_{3-5} : 0.05 p_{4-5} : 0.03
Rutherford classification						
2, n (%)	80 (30.1)	30 (50.8)	19 (28.8)	3 (33.3)	50 (68.5)	<0.0001 p_{1-2} : 0.002 p_{1-5} : <0.0001 p_{2-3} : 0.01 p_{2-5} : 0.04 p_{3-5} : <0.0001 p_{4-5} : 0.03
3, n (%)	64 (24.1)	5 (8.5)	14 (21.2)	2 (22.2)	8 (10.9)	0.02 p_{1-2} : 0.008 p_{1-5} : 0.01 p_{2-3} : 0.04
4, n (%)	53 (19.9)	10 (16.9)	16 (24.2)	0	5 (6.8)	0.03 p_{1-5} : 0.008 p_{3-5} : 0.004
5, n (%)	65 (24.4)	12 (20.3)	17 (25.7)	4 (44.4)	9 (12.3)	0.09
6, n (%)	4 (1.5)	1 (1.7)	0	0	0	0.67

Table 3
Distribution of patients according to WiFi classification

Index	Group 1	Group 2	Group 3	Group 4	Group 5	R
	n=266	n=59	n=66	n=9	n=73	
W — 0 points, n (%)	200 (75.2)	45 (76.3)	49 (74.2)	7 (77.8)	64 (87.7)	0.23
W — 1 point, n (%)	30 (11.3)	9 (15.2)	9 (13.6)	1 (11.1)	6 (8.2)	0.75
W — 2 points, n (%)	32 (12.0)	3 (5.1)	8 (12.1)	1 (11.1)	3 (4.1)	0.19
W - 3 points, n (%)	4 (1.5)	1 (1.7)	0	0	0	0.67
I - 0 points, n (%)	2 (0.7)	1 (1.7)	1 (1.5)	0	1 (1.4)	0.94
I — 1 point, n (%)	10 (3.7)	2 (3.4)	1 (1.5)	1 (11.1)	3 (4.1)	0.66
I — 2 points, n (%)	164 (61.6)	21 (35.6)	44 (66.7)	6 (66.7)	47 (64.4)	0.002 p_{1-2}: 0.0004 p_{2-3}: 0.0007 p_{2-4}: 0.002 p_{2-5}: 0.002
I — 3 points, n (%)	90 (33.8)	35 (59.3)	20 (30.3)	2 (22.2)	22 (30.1)	0.002 p_{1-2}: 0.003 p_{2-3}: 0.001 p_{2-4}: 0.04 p_{2-5}: 0.0008
fI — 0 points, n (%)	194 (72.9)	45 (76.3)	43 (65.1)	4 (44.4)	65 (89.0)	0.003 p_{1-5}: 0.004 p_{2-4}: 0.04 p_{2-5}: 0.05 p_{3-5}: 0.0007 p_{4-5}: 0.0005
fI — 1 point, n (%)	46 (17.3)	9 (15.2)	21 (31.8)	3 (33.3)	4 (5.5)	0.001 p_{1-3}: 0.008 p_{1-5}: 0.01 p_{2-3}: 0.03 p_{3-5}: <0.0001 p_{4-5}: 0.005
fI — 2 points, n (%)	26 (9.8)	4 (6.8)	2 (3.0)	2 (22.2)	4 (5.5)	0.16
fI — 3 points, n (%)	0	0	0	0	0	–

The groups were comparable in the frequency of performing FPB above and below the knee joint gap (Table 4).

Table 4
Intraoperative indicators

Index	Group 1	Group 2	Group 3	Group 4	Group 5	R
	n =266	n =59	n =66	n =9	n =73	
FPB above the knee joint gap, n (%)	183 (68.8)	35 (59.3)	37 (56.1)	4 (44.4)	50 (68.5)	0.14
FPB below the knee joint gap, n (%)	83 (31.2)	23 (39.0)	29 (44.0)	5 (55.5)	23 (31.5)	0.14

Notes: FPBh - femoral-popliteal bypass

RESULTS

During the hospital postoperative period, all complications developed in groups 1, 2, 3 and 5. However, there were no significant differences in the incidence of death (group 1: 0%; group 2: 0%; group 3: 1.5%; group 4: 0%; group 5: 0%; p = 0.18), MI (group 1: 0.4%; group 2: 0%; group 3: 0%; group 4: 0%; group 5: 0%; p = 0.94), shunt thrombosis (group 1: 3, 0%; group 2: 6.8%; group 3: 4.5%; group 4: 0%; group 5: 8.2%; p = 0.29), bleeding (group 1: 1.5%; group 2: 3.4%; group 3: 3.0%; group 4: 0%; group 5: 0%; p = 0.52), postoperative wound infections (group 1: 1.5%; group 2: 3.4%; group 3: 0%; group 4: 0%; group 5: 4.1%; p = 0.36), limb amputation (group 1: 1.9%; group 2: 3.4%; group 3: 1.5%; group 4: 0%; group 5: 2.7%; p = 0.91) was not detected (Table 5).

Table 5
Hospital Complications

Index	Group 1	Group 2	Group 3	Group 4	Group 5	R
	n=266	n=59	n=66	n=9	n=73	
Fatal outcome, n (%)	0	0	1 (1.5)	0	0	0.18
MI, n (%)	1 (0.4)	0	0	0	0	0.94
Stroke, n (%)	0	0	0	0	0	–
Shunt thrombosis, n (%)	8 (3.0)	4 (6.8)	3 (4.5)	0	6 (8.2)	0.29
Bleeding type 3 b and higher, BARC scale, n (%)	4 (1.5)	2 (3.4)	2 (3.0)	0	0	0.52
Postoperative wound infection, n (%)	4 (1.5)	2 (3.4)	0	0	3 (4.1)	0.36
Limb amputation, n (%)	5 (1.9)	2 (3.4)	1 (1.5)	0	2 (2.7)	0.91
Composite endpoint, n (%)	22 (8.3)	10 (16.9)	7 (10.6)	0	5 (6.8)	0.19

Notes: MI - myocardial infarction, BARC - Bleeding Academic Research Consortium

In the long-term follow-up period, according to the frequency of death (group 1: 4.6%; group 2: 1.7%; group 3: 4.6%; group 4: 0%; group 5: 2.8%; p = 0 .78), MI (group 1: 1.9%; group 2: 0%; group 3: 1.5%; group 4: 0%; group 5: 0%; p = 0.62), stroke (group 1: 0.8%; group 2: 1.7%; group 3: 1.5%; group 4: 0%; group 5: 0%; p = 0.8) and shunt thrombosis (group 1: 14, 5%; group 2: 19.3%; group 3: 18.5%; group 4: 44.4%; group 5: 19.7%; p = 0.16) no significant intergroup differences were identified. However, the largest number of limb amputations (group 1: 4.2%; group 2: 5.3%; group 3: 9.2%; group 4: 22.2%; group 5: 1.4%; p = 0.03) and the maximum composite endpoint (group 1: 26.0%; group 2: 28.1%; group 3: 35.4%; group 4: 66.7%; group 5: 23.9%; p =0.05) after using a synthetic prosthesis (Table 6).

Table 6
Long-term complications

Index	Group 1	Group 2	Group 3	Group 4	Group 5	R
	n=261	n=57	n=65	n=9	n=71	
Fatal outcome, n (%)	12 (4.6)	1 (1.7)	3 (4.6)	0	2 (2.8)	0.78
MI, n (%)	5 (1.9)	0	1 (1.5)	0	0	0.62
Stroke, n (%)	2 (0.8)	1 (1.7)	1 (1.5)	0	0	0.8
Shunt thrombosis, n (%)	38 (14.5)	11 (19.3)	12 (18.5)	4 (44.4)	14 (19.7)	0.16
Limb amputation, n (%)	11 (4.2)	3 (5.3)	6 (9.2)	2 (22.2)	1 (1.4)	0.03 p_{4-5}: 0.03
Composite endpoint, n (%)	68 (26.0)	16 (28.1)	23 (35.4)	6 (66.7)	17 (23.9)	0.05 p_{1-4}: 0.01 p_{4-5}: 0.01

Notes: MI – myocardial infarction

To solve the classification problem (it is necessary to determine whether the patient belongs to any of two classes: "Shunt thrombosis" and (or) "Limb amputation") two methods were used: Gaussian Naive Bayes classifier and "random forest" (https://neurohive. io/ru/osnovy-data-science/ansamblevye-metody-begging-busting-i-steking/). Due to the fact that they are numeric, we transformed string categorical features into qualitative ones. According to the first classifier, below is a code fragment for training a model to predict whether a patient belongs to the "Shunt Thrombosis" class and outputting the results of the trained model in the form of an error matrix (Confusion matrix) consisting of 4 quadrants:

0-0 — during testing, the model showed a "0" result where there should have been a "0" (true negative result);

0-1 — during testing, the model showed a "0" result where there should have been a "1" (false negative result);

1-0 — during testing, the model showed a result of "1" where there should have been a "0" (false positive result);

1-1 — during testing, the model showed a result of "1" where there should have been a "1" (true positive result).

Fragment code For training models : #Training data train_data = td train_data = train_data.dropna() feature_train = train_data['xx'] label_train = train_data.drop(['xx','zz'], axis = 1) train_data.shape #891 x 28 .

According to the analysis of the error matrix (Confusion matrix), the prediction accuracy is quite low, 38%, the model gives a large number of false positive values (Fig. 1).

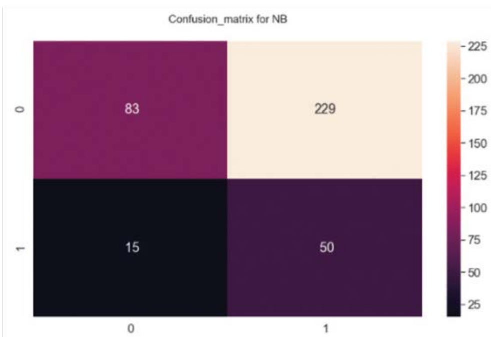

Fig. 1. Confusion matrix for the first model

Next, similar calculations were carried out with the "random" model forests. Below given fragment code programs : *##Random forest clf = RandomForestClassifier(criterion='entropy', n_estimators=700, min_samples_split=10, min_samples_leaf=1, max_features='auto', oob_score=True, random_state=1, n_jobs=-1) x_train, x_test, y_train, y_test = train_test_split(label_train, feature_train, test_size=0.2) clf.fit(x_train, np.ravel(y_train)) print("RF Accuracy: "+repr(round(clf.score(x_test, y_test) * 100, 2)) + "%")*. From the result of the analysis of the error matrix (Confusion matrix), it follows that this model gives a much more accurate result, 88%. In this case, false positive results are completely absent, but a fairly large number of false negative ones are still present (Fig. 2).

Based on the above data, only the random forest model was used for further calculations. Since the historical data is quite small for the model with the available number of features (476 records for 35 features), the number of the latter was reduced, leaving only those that occur in at least 10% of positive observations. The following is the program code that returns a trimmed data array and a set of trimmed fields: *def drop_low_volume_columns(td, volume, col): if col == 'xx': td = td.drop('zz', axis=1) elif col == 'zz': td=td.drop('xx', axis=1) x = td[td[col] == 1] su = x.sum() mass = [] header = list(td) for key in header: if su[key] < su[col] * volume / 100 : mass.append(key) td = td.drop(mass, axis=1) return td, mass*. Using this function, the random forest model described above was recalculated. From the result of the analysis of the error matrix (Confusion matrix), it follows that false negative results have disappeared, and the accuracy of the model has increased by 5% (Fig. 3).

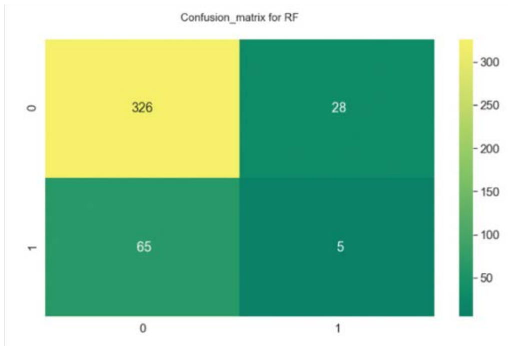

Fig. 2. Confusion matrix for the second model

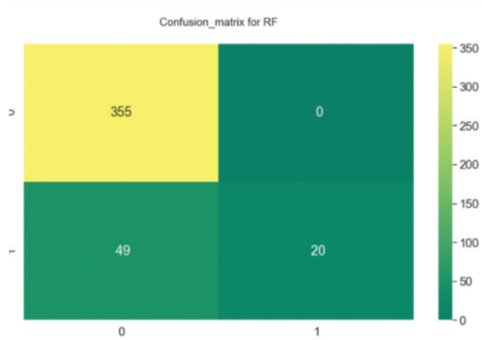

Fig. 3. Confusion matrix for the third model

Thus, this model was used to create a computer program that makes it possible to interactively, based on clinical, anamnestic, demographic and perioperative data, assess the risk (low, medium, high) of developing shunt thrombosis with subsequent amputation after FPB in the long-term follow-up period (Fig. 4).

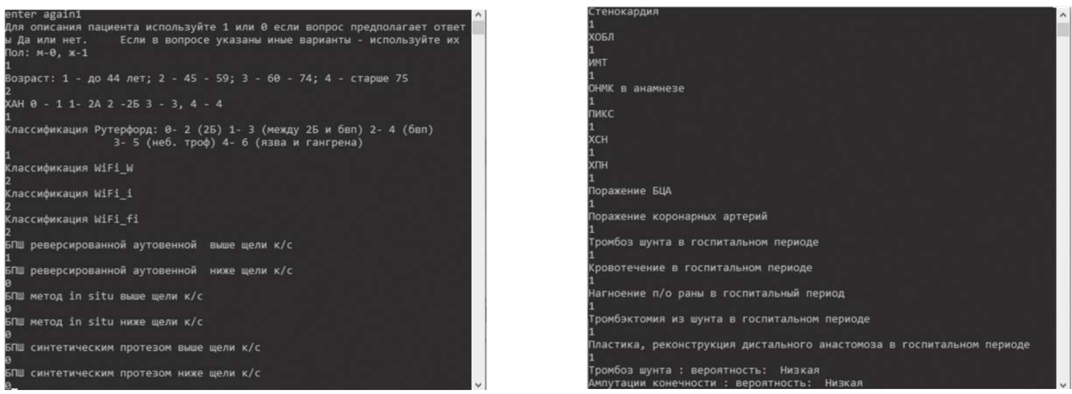

Fig. 4. Program interface for predicting the likelihood of developing thrombosis of the femoral-popliteal bypass and amputation of the lower limb in the long-term follow-up period

DISCUSSION

The results of our study demonstrated that a personalized approach to choosing a revascularization strategy and type of shunt for BSP is the most justified. This tactic is accompanied by the absence of an intergroup statistically significant increase in all complications in the hospital postoperative period, which reached minimal levels (Table 4). However, at the long-term follow-up stage, a high incidence of shunt thrombosis with subsequent amputation of the limb was noted when using a synthetic prosthesis (Table 5). The results obtained do not contradict the world literature, according to which this type of conduits is characterized by a high tendency to dysfunction already in the mid-term postoperative period [12–14]. In our study, the use of the latter was due to the lack of a suitable autovenous graft for the implementation of FPB, which also does not contradict current recommendations [1–3].

Timely identification and further observation of patients with a high risk of developing thrombosis of the esophageal spinal cord and, as a consequence, limb amputation is an urgent task of modern angiosurgery [1–3, 6]. Today, there are several interactive calculators that can predict the development of certain complications. The internationally recognized EuroScore II and STS Score have proven themselves as tools for accurate risk stratification of adverse cardiovascular events in the postoperative period [15–19]. At the same time, their wide versatility allows them to be used for all cardiovascular surgery, and not just for FPB, which also reduces the specificity for this particular revascularization method [15–19]. Plus, their action is primarily aimed at predicting the immediate results of operations, limiting the possibility of stratifying the risk of long-term outcomes [15–19]. But the most important disadvantage of EuroScore II and STS Score in this context is that they are not able to determine the likelihood of shunt thrombosis after FPB [15–19]. Thus, their use for this purpose becomes impossible.

In Russian angiology in recent years, a trend has emerged towards the creation of interactive calculators for stratifying the risk of postoperative complications for each specific surgical pathology. So, A.A. Khalafyan et al. have developed several programs that allow not only to calculate the probability of developing adverse cardiovascular outcomes after interventions on the carotid region, but also to differentiate the safest revascularization tactics for each individual patient [20, 21]. In turn, R.A. Vinogradov et al. created similar software for carotid endarterectomy, which showed high efficiency in real clinical practice [22, 23]. In a study by R.S. Tarasov et al. software decision support was proposed for choosing one of four open and hybrid revascularization strategies for patients with combined atherosclerotic lesions of the carotid and coronary arteries. This tool also made it possible to calculate the probability of developing complications for each specific tactic in the hospital and long-term postoperative periods [24, 25]. However, despite the growing interest of domestic science in the collaboration of practical and mathematical components, the only attempt to create such interactive calculators for FPB was made by N.N. Burkov et al. [7]. But for the above reasons and as a result of a narrow focus towards only biological prostheses, this development has not become widespread [7].

The result of the analysis of the data that we obtained as part of this study was the creation of a program for stratifying the risk of shunt thrombosis and limb amputation in patients after FPB in the late postoperative period. For the first time, a tool has appeared in the arsenal of a multidisciplinary council that allows one to calculate the likelihood of these complications when using both synthetic prostheses and different options for autovenous grafts. However, further prospective testing in real clinical practice is required for routine use of this software.

CONCLUSION

The revascularization strategy for patients with extensive atherosclerotic lesions of the femoropopliteal segment should be determined individually and only by a multidisciplinary council.

The conduit of choice for femoral popliteal bypass surgery is an autovenous graft. Synthetic prostheses can only be used in the absence of the autovenous graft.

To identify a cohort of patients at high risk of femoropopliteal shunt thrombosis and limb amputation in the long-term follow-up period, a created risk stratification program for the development of these complications can be used.

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Received on 01/14/2022
Review completed on 02/15/2022
Accepted on 06/27/2023