Zeitschrift für
Gefäßmedizin

Bildgebende Diagnostik • Gefäßbiologie • Gefäßchirurgie • Hämostaseologie • Konservative und endovaskuläre Therapie • Lymphologie • Neurologie • Phlebologie

Treatment of vertebrobasilar insufficiency in a neurosurgical hospital // Studienergebnisse zur Behandlung der vertebrobasilaren Insuffizienz in einer neurochirurgischen Klinik

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Zeitschrift für Gefäßmedizin 2021;

18 (2), 14-22

Offizielles Organ der Österreichischen Gesellschaft für Phlebologie und dermatologische Angiologie

Offizielles Organ des Österreichischen Verbandes für Gefäßmedizin

Offizielles Organ der Österreichischen Gesellschaft für Internistische Angiologie (ÖGIA)

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ERWO PHARMA

Treatment of vertebrobasilar insufficiency in a neurosurgical hospital

B. S. Dzhilkashiev[1,2], G. I. Antonov[1], G. E. Chmutin[1], Z. U. Zokhidov[1]

Abstract: This article presents the treatment outcomes for 100 patients with vertebrobasilar insufficiency (VBI) associated with tortuosity of the V1 segment of the VA, who were divided into 2 groups: surgical (n = 50) and conservative treatment (n = 50). Together with conventional diagnostic methods used to clarify the tactics of surgical treatment (Doppler ultrasonography, contrast-enhanced multi-spiral computed tomography) a proposed method to determine VA reactivity and impaired blood flow in the VBS is a key method for the prediction of clinical outcomes following surgery on the VBS arteries. Cerebral angiography is recommended in all patients before surgery on the VBS arteries, in order to determine the state of the intracranial part of the vertebral and main arteries, as outflow paths, and to determine collateral compensation in the VBS. Further use of reconstructive techniques on the V1 segment of the VA show better distant clinical outcomes. Tortuosity resection in the V1 segment of the VA is most effective in the immediate postoperative period and is used in patients with multiple lesions of the arteries as the first stage to increase the resistance of the brain to ischemia in subsequent reconstructive surgery. The use of conservative treatment in patients with concomitant lesions of the VBS is possible. Immediate outcomes are satisfactory.

Key words: types of reconstructive surgery, preoperative preparation of patients, nature and localization of arterial lesions, clinical improvement in the patient's condition, modern instrumental examination

Zusammenfassung: Studienergebnisse zur Behandlung der vertebrobasilaren Insuffizienz in einer neurochirurgischen Klinik. Dieser Artikel präsentiert die Behandlungsergebnisse von 100 Patienten mit vertebrobasilarer Insuffizienz (VBI) im Zusammenhang mit Tortuosität des V1-Segments der VA, die in zwei Gruppen unterteilt wurden: chirurgische (n = 50) und konservative Behandlung (n = 50). Zusammen mit herkömmlichen Diagnosemethoden zur Klärung der Taktik der chirurgischen Behandlung (Doppler-Sonographie, kontrastverstärkte Mehrspiral-Computertomographie) ist eine vorgeschlagene Methode zur Bestimmung der VA-Reaktivität und der Beeinträchtigung des Blutflusses in der VBS eine Schlüsselmethode für die Vorhersage der klinischen Ergebnisse nach einer Operation an den VBS-Arterien. Die zerebrale Angiographie wird bei allen Patienten vor der Operation an den VBS-Arterien empfohlen, um den Zustand des intrakraniellen Bereichs der Wirbel- und Hauptarterien als Abflusswege und die Kollateralkompensation in der VBS zu bestimmen. Die weitere Verwendung von Rekonstruktionstechniken im V1-Segment der VA zeigt bessere klinische Ergebnisse. Die Tortuositätsresektion im V1-Segment der VA ist in der unmittelbaren postoperativen Phase am effektivsten und wird bei Patienten mit multiplen Läsionen der Arterien als erste Methode verwendet, um die Resistenz des Gehirns gegen Ischämie bei nachfolgenden rekonstruktiven Operationen zu erhöhen. Die Anwendung einer konservativen Behandlung bei Patienten mit begleitenden VBS-Läsionen ist möglich. Unmittelbare Ergebnisse sind zufriedenstellend. **Z Gefäßmed 2021; 18 (2): 14–22.**

Schlüsselwörter: Rekonstruktive Chirurgie, präoperative Vorbereitung von Patienten, Art und Lokalisation von arteriellen Läsionen, klinische Verbesserung des Zustands des Patienten, moderne instrumentelle Untersuchung

Abbreviations:

CAD: coronary heart disease

CV: cerebrovascular

CVA: cerebrovascular accident

DEP: dyscirculatory encephalopathy

FC: functional class

VA: vertebral artery

VBF: venous blood flow

VBS: vertebrobasilar system

Introduction

It is known that the success of the treatment of many brain diseases dramatically depends on the introduction of surgical technologies that offer reliable vasotopic characteristics of pathological changes in the arteries and their further radical correction with differentiated use of reconstructive surgery, which makes this type of research more urgent. Over the past decades, the possibility of surgical treatment of the clinical manifestations of cerebral stroke, in particular vertebrobasilar, has been theoretically justified, however, surgical interventions for tortuosity of the V1 segment of the VA are rarely used and are based mainly on single studies, therefore the potential of reconstructive surgery is not fully realized [1, 2].

A variety of reconstructive interventions for VA stenosis is associated with persistent disability and maladaptation, which significantly impairs the quality of life of such patients of predominantly working age, making them inferior in the social and labour sphere and burdensome in everyday life. Resistance of the manifestations of this disease to conventional drugs in most cases makes the treatment ineffective. The use of vascular-active, anticoagulant, antiplatelet agents and neuroprotectors in the comprehensive therapy of cerebrovascular insufficiency has exhausted its potential and does not result in a significant improvement in treatment outcomes.

Unstable results of surgical treatment of the VA stenosis are due to the lack of an optimal diagnostic algorithm that would determine the nature, degree and level of vascular lesion and the role of various components of vasoconstriction in the choice of surgical technique. A system of indications for surgical treatment of tortuosity of the V1 segment of the VA and differentiated use of various technologies for reconstructive surgery and prediction of its results are not adequately addressed. The purpose of this article is to present the outcomes of the differential surgical treatment of stenosis of the V1 segment of the VA as the basis for medical technology that provides improved

Received: April 24, 2020; accepted: May 12, 2020

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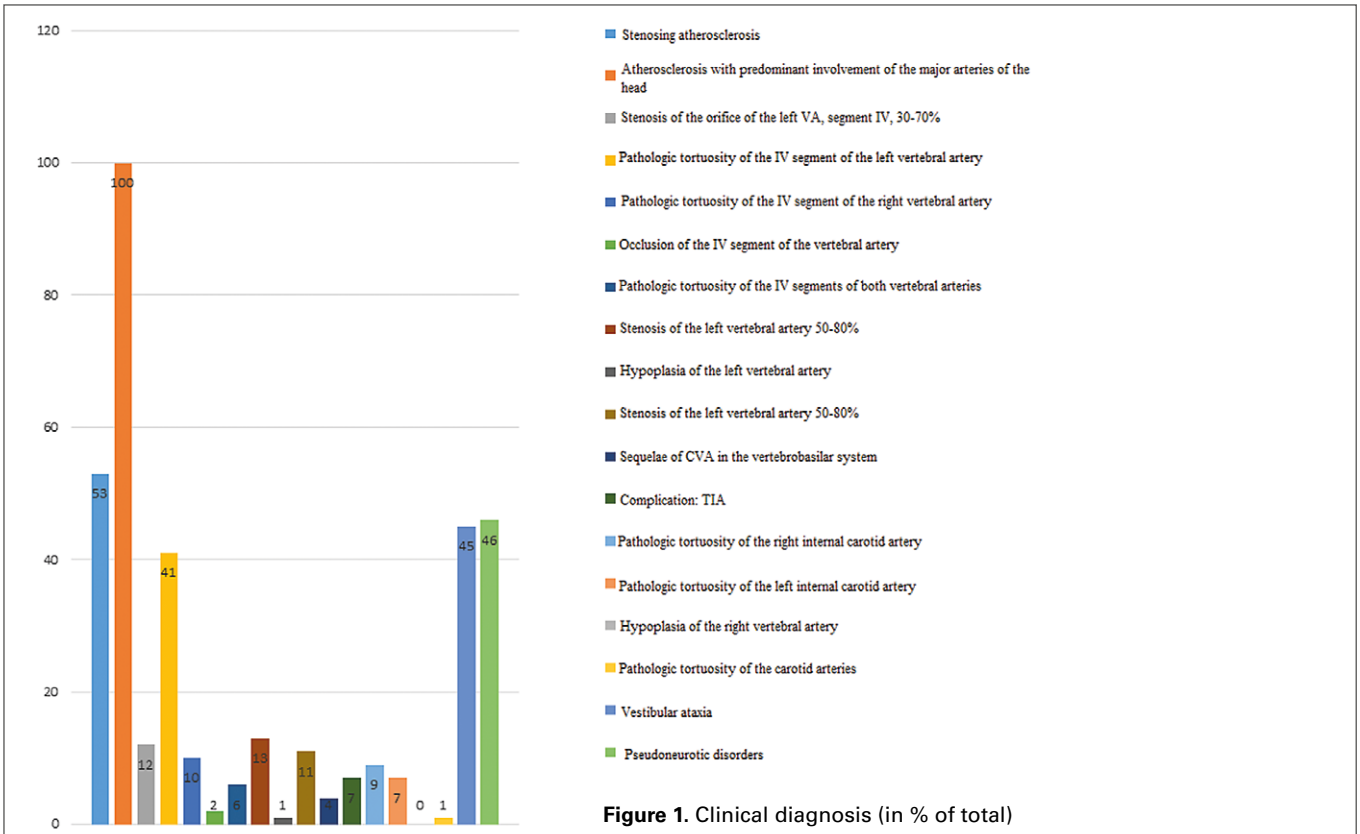

Figure 1. Clinical diagnosis (in % of total)

treatment outcomes for patients with cerebrovascular diseases of the VBS.

Manifestations of VBI of the V1 segment of the VA result from a imbalance between oxygen demand of the brain and energy substrates supplied by the blood, on the one hand, and a sharp decrease in cerebral perfusion combined with insufficient compensatory capabilities of the collateral circulation in the sector, on the other hand. A degree of ischemic damage is primarily due to the depth and duration of a decrease in cerebral blood flow [3–5]. A part of the brain with a blood flow level < 10–15 ml within 6 minutes from the onset of ischemia becomes irreversibly damaged. For several hours, the area of focal infarction is surrounded by ischemic but living tissue (penumbra area), where the metabolism is preserved and rather functional, than organic changes are observed.

When VBI of the V1 segment of the VA is diagnosed, the success of the treatment of ischemic brain lesions largely depends on the use of emergency surgical techniques, which include modern instrumental examination and reconstructive surgery. Despite widely recognized effectiveness of surgical interventions in VA stenosis, they are still used in individual, situational indications for the V1 segment of the VA; the theoretical base for the surgical treatment of stenosis of the arteries of the vertebrobasilar system in this segment is not sufficiently developed, and the lack of standard technologies for its implementation makes the final outcome unstable.

Materials and Methods

The examination and treatment data of 100 patients who were treated at the FSBI A.A. Vishnevsky CMCH No. 3 of the Ministry of Defense of Russia from 2009 to 2019 inclusive. The study design is a single-center, retrospective-prospective, cohort, controlled clinical study. Vertebral-basilar insufficiency was confirmed and various significant stenosis/occlusions of the V1 segment of the arteries were observed in all patients. The baseline clinical diagnosis of pathological tortuosity of the vertebral arteries was established and recorded in the patients' record forms. The clinical diagnosis has the following distribution in percent. The structure of the identified lesions is shown in Figure 1.

The structure of the lesions presented in Figure 1 indicates the accuracy of the clinical diagnosis based on the combined clinical picture. Gender and age factors were excluded, as the distribution of 100 patients by sex and age created a comprehensive picture of the examination and accuracy of the results based on the data from sampling characteristics. The mean age of the

Table 1. Concomitant diseases identified.

Concomitant diseases	Number of events
Stage 1 hypertension	1
Stage 2 hypertension	34
Stage 3 hypertension	10
Stage 2 DEP	42
Stage 3 DEP	7
Stage 1 DEP	1
Osteochondrosis spinal	32
Osteochondrosis mixed	0
Parkinson's disease	2
CAD, FC I angina of effort	1
CAD, FC II angina of effort	26
CAD, FC III angina of effort	3

patients was 72.2 years and indicated an increased risk of the disease at the age from 45 to 89 years. 58% of the patients were men and 42% – women. In 50% of patients, DEP was observed in the VBS (Stage 2 DEP – 42 patients, Stage 3 DEP – 7 patients, Stage 1 DEP – 1 patient), 7% had a history of TIA in the VBS, and 4% had a history of CVA in the VBS. 98% of patients had some concomitant pathologies. The structure of concomitant pathologies is presented in Table 1.

Patient assignment to groups and subgroups

Depending on the leading lesion in any arterial segment participating in the blood supply to the VBS, in the presence of stenosis/occlusions of the V1 segment of the VA, all 100 patients were divided into 2 groups: the Surgical Treatment Group (n = 50) and the Conservative Treatment Group (n = 50). During the study, isolated carotid endarterectomies were performed in the patients with vertebrobasilar insufficiency; the elements of reconstructive surgery were used; hybrid interventions on the arteries of the vertebrobasilar system were performed. The number of reconstructive interventions performed in the Surgical Treatment Group is presented in Table 2.

At the same time, in the surgery group additional angioplasty, stenting of the right vertebral artery, left scalenotomy, left carotid endarterectomy, resection of the pathological loop and correction of the left vertebral artery were performed.

Methods of examination

The indications for hospitalization in 100 patients included: 1) significant clinical symptoms of VBI; 2) for the Surgical Treatment Group, lack of clinical efficacy of drug therapy under the supervision of a neurologist for at least 6 months. After patient admission at the hospital, both to consider surgical treatment and to determine the type of surgery, the clinical phase of the examination was performed [6–8]. The presence of VBI syndrome in a patient was established only when the obligatory combination of discoordination, vestibular ataxia, auditory and visual disorders was observed. Objective neurological symptoms indicated a focal lesion of the brain stem structures (Fig. 2).

Total severity of various manifestations of VBI and their changes before and after surgery was evaluated using the Hofferberth scale.

Treatment Methods

All patients were treated at the FSBI A.A. Vishnevsky CMCH No. 3 of the Ministry of Defense of Russia as scheduled. Surgery techniques, including the choice of suture material, are strictly regulated in the clinic. Preoperative preparation of the patients was carried out taking into account the nature of the identified concomitant pathology, as well as the volume of the upcoming surgical intervention. Regardless of the type of concomitant pathology, all patients were prescribed antiplatelet agents and sedatives during the preoperative period [9–11]. In cases of severe dizziness, patients were prescribed betahistine hydrochloride at a dose of 16–32 mg daily. Concomitant pathologies were corrected by a cardiologist, pulmonologist and endocrinologist.

During the postoperative period, the patients were examined on day 10, 1 and 3 years after surgery and later. The examinations included a general clinical and neurological examination with

Table 2. Number of operations performed

Treatment method	Number of operations	Subgroups	
"Surgery" Group (n = 50)			
I. anastomosis	6	Left carotid-vertebral anastomosis	6
II. tortuosity resection	35	Tortuosity resection with correction and reimplantation of the right vertebral artery orifice	3
		Resection of the left vertebral artery from the orifice, left carotid-vertebral anastomosis	2
		Tortuosity resection with correction and plastic surgery of the left vertebral artery orifice	24
		Tortuosity resection in the V1 segment of the left vertebral artery	5
		Resection of the right vertebral artery, plastic surgery of the orifice, reimplantation into right subclavian artery	1
III. Arteriolysis	3	Arteriolysis, sympathectomy, arteriopexy of left VA and SCA	1
		Arteriolysis, sympathectomy of the V1 segment of the right vertebral artery	1
		Arteriolysis. Periarterial sympathectomy of the left vertebral artery	1
IV. X-ray-guided endovascular stenting	1	X-ray-guided endovascular stenting of the left vertebral artery orifice. Reconstruction of the arterial lumen.	1
V. Plastic surgery	1	Plastic surgery of the right vertebral artery orifice	1
Additional methods	2	Angioplasty, stenting of the right vertebral artery orifice	2
	1	Left scalenotomy.	1
	1	Left eversion carotid endarterectomy. Tortuosity resection with correction of the left vertebral artery	1
Total			100 % n = 50

identification of VBI symptoms and their changes. Persistence, reduction or absence of subjective symptoms, as well as objective neurological data were studied. In addition, the condition of anastomosis area and functional characteristics of blood flow through the brachiocephalic vessels were determined using instrumental methods. The clinical picture and treatment methods in each subgroup will be further discussed:

1. Anastomosis (n = 6).
2. Tortuosity resection (n = 35).
3. Reconstructive surgery on the V1 segment of the vertebral artery according to the type of combinations:
   Type III. Arteriolysis
   Type IV. Endovascular stenting
   Type V. Plastic surgery
   Additional methods

Results and Discussion

For the selection of the patients with VBI symptoms for surgical treatment, all 50 patients were examined according to a single developed algorithm. First, other diseases having similar to VBI clinical symptoms, were excluded. Then a topical diagnosis was established, i.e. the nature and localization of the damage to the arteries. CT scan angiography or CT contrast angiography was performed to assess the outflow pathways through the intracranial arteries – the 4th segment of the VA and the main artery [12–15]. The procedures of this study allowed us to determine the presence or absence of a tortuosity in the venous blood flow in the posterior type (absence of PCA), to determine the type of collateral compensation and to establish indications for a specific type of surgical treatment in all patients with VBI. In all patients with VBI symptoms and V1 segment of the VA involvement, a statistical analysis of blood flow parameters was performed before and after surgery.

At the same time, significant differences were determined in the reactivity index (RI) ($p < 0.05$) depending on the persistence or disappearance of VBI symptoms. In the group of patients after surgery, favourable outcomes, i.e. reduction or disappearance of VBI symptoms, were observed in those patients who demonstrated an increase in the reactivity index up to 0.3 or more (RI more than 30%) after surgery. Poor outcomes, i.e. deterioration or recurrence of VBI symptoms, were observed in the patients who had reactivity index lower than 0.3 (RI lower than 30%) after surgery. The data is presented in Figure 3.

To determine the VA reactivity and blood flow insufficiency, a specific method was used. The proposed method included color Doppler mapping of the VA in the supine position. Linear and volumetric blood flow rates were recorded for the V1 segment of the VA from the approach at the angle of the mandible, mean rate was calculated and a 30 second breath-holding test was performed. The VA reactivity index was calculated using the following formula:

RI = Y2 – VI / V2*100%

Where IR – reactivity index

VI – mean blood flow rate before test

V2 – mean blood flow rate after test.

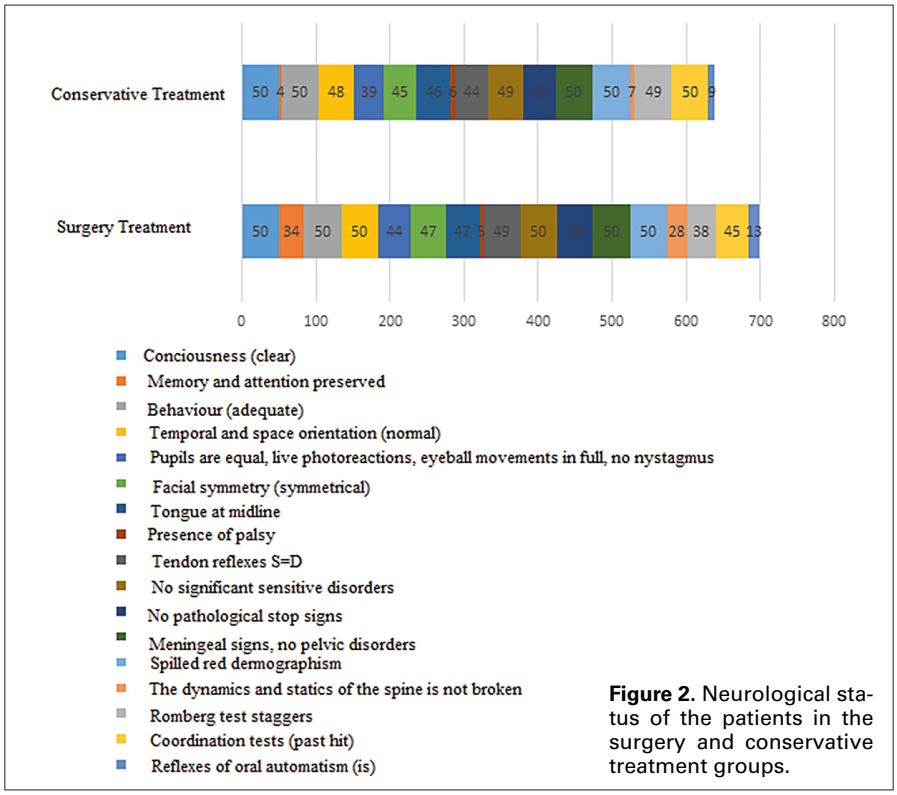

Figure 2. Neurological status of the patients in the surgery and conservative treatment groups.

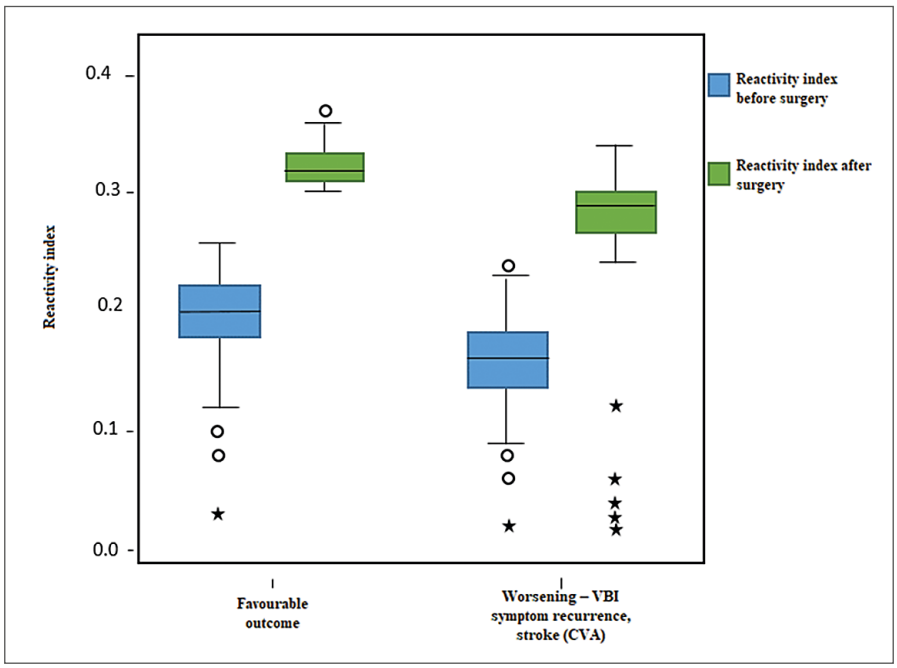

Figure 3. The VA reactivity index depending on VBI symptoms before and after surgery.

Table 3. Blood flow characterization in the V1 segment of VA depending on the baseline form of VBI

	DEP VBI 1	TIA VBS 2	CVA VBS 3	Control group (conservative treatment)
Age at the time of surgery	59.06 ± 8.28	69.12 ± 7.70	70.27 ± 7.60	76.12 ± 7.70
Duration from the onset of the disease to surgery	4.61 ± 2.97	4.80 ± 2.84	3.97 ± 2.27	–
Blood flow to VA, ml/min	62.13 ± 20.60	62.70 ± 22.18	63.13 ± 17.09	62.98 ± 29.11
Blood flow after VA, ml/min	117.79 ± 23.99	116.57 ± 17.54	115.92 ± 17.48	120.88 ± 23.54
Increased blood flow of VA, ml/min	54.56 ± 22.63	55.96 ± 19.73	52.80 ± 17.73	55.96 ± 19.73
Total blood flow for both VAs before surgery/treatment, ml/min	207.81 ± 22.33	210.16 ± 29.81	216.16 ± 23.37	220.11 ± 28.82
Total blood flow for both VAs after surgery/treatment, ml/min	262.76 ± 36.29	264.08 ± 42.62	271.36 ± 23.99	234.18 ± 14.32
Increased total blood flow for both VAs	54.96 ± 30.80	53.92 ± 36.21	55.20 ± 24.96	14.07 ± 28.87
Increased total blood flow for both VAs	59.79 ± 23.41	61.13 ± 25.75	56.19 ± 23.09	53.65 ± 25.65
Reactivity index before surgery/treatment	0.181 ± 0.043	0.171 ± 0.070	0.197 ± 0.038	0.198 ± 0.020
Reactivity index after surgery/treatment	0.298 ± 0.068	0.296 ± 0.080	0.314 ± 0.026	0.215 ± 0.082
Increased reactivity index	0.117 ± 0.051	0.125 ± 0.076	0.116 ± 0.042	0.017 ± 0.072

Table 4. Characterization of blood flow in the V1 segment of VA depending on the type of operation

Parameter	Transposition of VA to CCA n = 67 M ± SD	Anastomosis M ± SD	Tortuosity resection M ± SD	Reconstructive surgery M ± SD
Age at the time of surgery	60.45 ± 8.66	69.97 ± 7.33	76.46 ± 8.05	70.09 ± 6.94
Duration from the onset of the disease to surgery	4.73 ± 3.28	4.53 ± 2.73	4.50 ± 1.80	3.69 ± 1.99
Blood flow to VA, ml/min	65.08 ± 18.34	58.12 ± 19.10	75.11 ± 21.52	57.48 ± 15.83
Blood flow after VA, ml/min	120.83 ± 20.62	111.52 ± 18.38	118.71 ± 24.63	113.95 ± 17.21
Increased blood flow along VA, ml/min	55.18 ± 23.42	52.14 ± 16.38	46.29 ± 18.19	56.48 ± 17.30
Total blood flow for both VAs before surgery, ml/min	214.27 ± 22.59	209.35 ± 25.63	212.96 ± 26.24	211.49 ± 24.24
Total blood flow for both VAs after surgery, ml/min	271.33 ± 26.23	252.74 ± 52.29	271.14 ± 30.37	268.91 ± 20.25
Increased total blood flow for both VAs	59.26 ± 23.20	57.00 ± 21.46	58.18 ± 27.29	57.42 ± 23.43

The VA was examined from the opposite side and the reactivity index was calculated; the volumetric blood flow rates for both VAs were summed. Results with similar values of the reactivity index were obtained in the patients during distributions to the groups depending on the baseline form of VBI (Tab. 3). To control the results obtained, the data from the conservative treatment group is used, 50 patients who received pharmacotherapy during the observation period and were not operated on.

An increase in the reactivity index of more than 0.3 (RI over 30%) was also observed in most patients after all types of operations on the V1 segment of the VA, while the type of operation performed did not affect this change (Tab. 4).

When analyzing the volumetric blood flow rates, it was observed that among the operated patients, a decrease in the VBI clinic was observed in patients with an increase in the total volumetric blood rate in VA more than 250 ml/min ($p < 0.05$). This circumstance has been identified in most patients with various forms of VBI. An increase in total volumetric blood flow of more than 250 ml/min was observed in most patients after various types of operations on 1st segment of VA. Favorable outcomes consisting in a decrease or disappearance of VBI symptoms were observed in most patients with an increase in total volumetric blood flow by VA of 250 ml/min or more, and unfavorable outcomes were a deterioration or return of VBI symptoms, in patients with a total volumetric blood flow after VA of less than 250 ml/min and in all patients of the control group.

Surgery outcomes in the anastomosis group in the patients with vertebral-basilar insufficiency

Treatment outcomes in the patients of subgroup I were evaluated 10 days, 1 year, 3 years after surgery and later. Follow-up examinations included a consultation with a neurologist and triplex ultrasound mapping of the brachiocephalic arteries. Improvements after surgery were achieved in 4 (83.3%) patients of the total number of patients in subgroup I. Changes in clinical symptoms are presented in Figure 4.

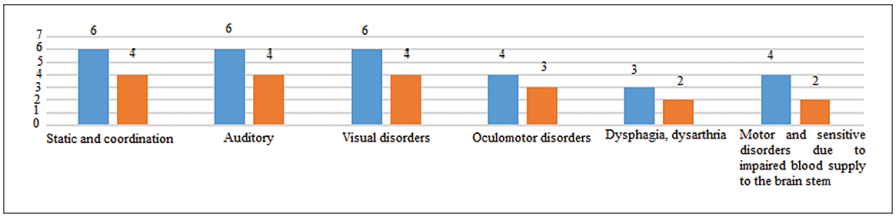

Figure 4. Clinical symptoms of VBI in patients of subgroup I (n = 6, $p < 0.05$)

The most persistent were auditory disorders. Despite the improvement in the

form of a subjective decrease in the severity of tinnitus, impaired auditory acuity or impaired speech intelligibility. The mean score on the Hofferberth scale after surgery decreased from 15.2 ± 4.21 to 11.6 ± 2.56 ($p < 0.05$). Changes in the severity of VBI symptoms in points are presented in Table 5.

One year after "Anastomosis" surgery, clinical improvements persisted in 4 (83.3%) patients. Three years after surgery, clinical improvements were observed 2 (33.3%) patients only. Depending on the non-tortuosity of the posterior venous blood flow, improvements after surgery were not similar in different groups of patients. So, improvements after surgery on day 10 with a decrease in VBI symptoms was observed in 3 (75%) patients in group I.A (non-tortuous venous blood flow) and in 1 (50%) patient in the group I.B (tortuous venous blood flow). The effects of non-tortuosity of the posterior venous blood flow on the efficacy of "Anastomosis" surgery were statistically significant in the patients with VBI symptoms. Treatment outcomes were significantly better in the patients with non-tortuous venous blood flow (sig < 0.001) (Fig. 5).

In addition, the patients with a history of hypertension and the disease of more than 5 years had significantly worse outcomes than the patients without hypertension or history of the disease less than 5 years. To study the combined effects of various risk factors on the treatment outcomes 3 years after surgery, various multidimensional methods were used. First, a model of multiple logistic regression with step-by-step inclusion of predictors was built [16, 17].

The analyzed factors included: age at the time of surgery, disease duration from onset to surgery, type of "Anastomosis" surgery, VBI clinical form, non-tortuous venous blood flow, presence of hypertension, diabetes mellitus and rhythm disturbances. The characteristics of the risk factors for clinical deterioration 3 years after surgery using multivariate logistic regression are presented in Table 6. It should be noted that the chance of clinical deterioration is 13-fold higher in the patients from group I.B, compared to the patients from group I.A ($p < 0.001$).

Among other risk factors, a history of hypertension for more than 5 years increases the risk of clinical deterioration 2.67-fold ($p < 0.05$); a history of diabetes mellitus for more than 3 years increases the risk more than 26-fold ($p < 0.001$). According to the results of this study, the factors that affect the anastomosis outcomes in the patients with VBI with statistical significance, are the closure of the posterior venous blood flow, a history of CVA in the VBS, a history of hypertension lasting more than 5 years and diabetes mellitus lasting

Table 5. Change in the severity of VBI symptoms after "anastomosis" surgery

Severity	Hofferberth average point			
	Before operation	After 10 days	After 1 year	After 3 years
Mild	4.83	1.17	2.21	2.19
Moderate	15.4	11.3	12.1	12.4
Severe	25.3	18.5	20.2	20.4

Table 6. Characterization of risk factors for deterioration during the 3-year observation period by multivariate logistic regression.

Model predictor (risk factor)	Predictor grades	Odds ratio (95% CI)	P
Untwisted venous blood flow	Group 1.A. (closed VBF) – ref	1	–
	Group 1.B (open VBF)	13.43 (5.70–31.66)	< 0.001
Hypertension	Hypertension period up to 5 years – ref	1	–
	No hypertension	0.14 (0.01–1.34)	0.088
	Hypertension period more than 5 years	2.67 (1.42–5.02)	0.002
Diabetes mellitus	No DM	1	–
	DM up to 3 years or tablets	1.73 (0.91–3.26)	0.092
	DM more than 3 years or insulin	26.44 (6.67–104.90)	< 0.001
Rhythm disorders	No rhythm disorders – ref	1	–
	Rhythm disorders	0.54 (0.05–1.78)	0.076

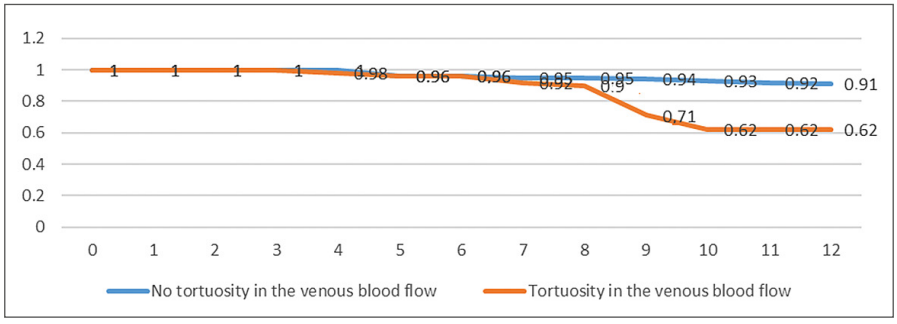

Figure 5. Cumulative survival curves without clinical deterioration in the patients following "Anastomosis" in groups I.B and I.B

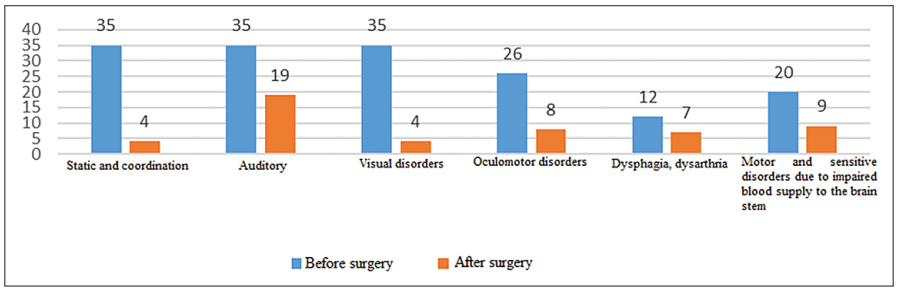

Figure 6. Changes in clinical symptoms in the patients from subgroup II after surgery on the V1 segment of the VA

more than 3 years, and administration of insulin. At the same time, rhythm disturbance does not have statistically significant effects on surgery outcomes in the patients with VBI symptoms.

Tortuosity resection results

In the early postoperative period, clinical improvements were observed in 32 (91.4%) patients in subgroup II. Changes in the clinical symptoms in the patients from subgroup II after surgery on the V1 segment of the VA are presented in Figure 6.

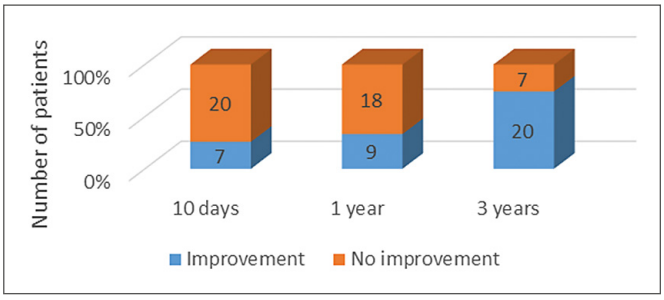

Figure 7. Treatment outcomes in the patients from group IIA.1 (tortuosity resection with correction) and IIA.2 (vertebral arteriotomy from the orifice, carotid-vertebral anastomosis)

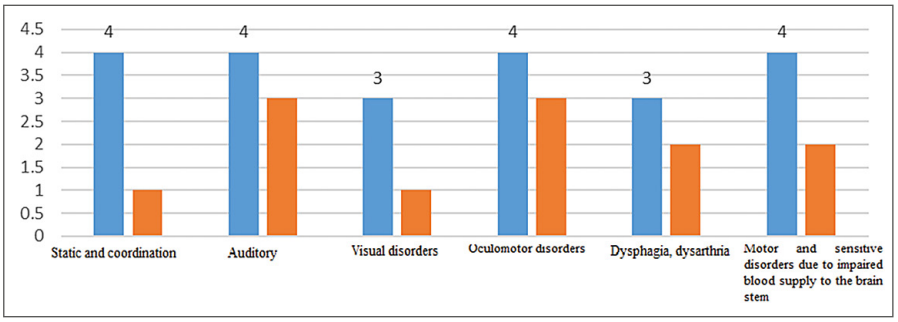

Figure 8. Changes in the clinical symptoms of VBI in the patients from the "Additional operations" group.

Table 7. Statistical indicators of clinical improvement after operations on the V1 segment of VA

		II.B.1 and II.A.2		II.B.1 and II.A.1		II.A.2 and II. A.1	
		chi²	p	chi²	p	chi²	p
10 days	Improvement	0.00	0.946	53.0	< 0.001	214.9	< 0.001
1 year	Improvement	3.2	0.072	66.1	< 0.001	178.8	< 0.001
3 years	Improvement	24.8	< 0.001	61.7	< 0.001	305.1	< 0.001

The mean score on the Hofferberth scale (1990) in the early postoperative period decreased from 18.7 ± 5.14 to 3.1 ± 2.17 ($p < 0.05$). In group IIA.1 (tortuosity resection with correction), clinical improvements were achieved only in 1 patient during the early postoperative period. During the follow-up period of 3 years, another 2 patients reported recurrence of the symptoms. The outcomes of the patients from group IIA.1 (tortuosity resection with correction) are presented in Figure 7.

In group IIA.2 (vertebral arteriotomy from the orifice, carotid-vertebral anastomosis), the patients showed good immediate outcomes. Clinical improvements were observed in 22 patients. A one-year follow-up showed 3 patients with thrombosis in the reconstruction area with symptom recurrence, but without CVA. Another 3 patients demonstrated recurrences of VBI symptoms. During follow-up periods of up to 3 years, another 7 patients reported recurrences of VBI symptoms, but without pathologies in the reconstruction area and no restenosis.

In the patients of group II.B.1 (resection of the V1 segment of the VA from the orifice, carotid-vertebral anastomosis, n = 3), 100% angiographic and clinical successes were observed in the early postoperative period and one-year follow-up. However, after 3 years of follow-up, 1 patient had restenosis in the stent with symptom recurrence. Therefore, clinical improvements persisted in 66.6% of patients only after 3 years of follow-up.

The statistical analysis of the clinical outcomes of surgery after 3 years of follow-up and their comparison showed that the clinical outcomes in the patients of group II.A.1 (tortuosity resection with correction) were significantly worse than the outcomes in the patients in groups II.A.2 and II.B.1 (vertebral arteriotomy from the orifice, right and left carotid-vertebral anastomosis). The comparison of the outcomes in groups II.A.2 and II.B.1 (vertebral arteriotomy from the orifice, right and left carotid-vertebral anastomosis) showed no statistically significant differences after 1-year follow-up, but after 3 years of follow-up, group II.A.2 (vertebral arteriotomy from the orifice, left carotid-vertebral anastomosis) showed a statistically significantly greater number of clinical improve-

Table 8. Comparative evaluation of the results of surgery methods

		Angioplasty, stenting of the right vertebral artery orifice		Left scalenotomy		Left eversion carotid endarterectomy. Tortuosity resection with correction of the left vertebral artery		chi²	p	p FEM (Fisher's exact method)
		Absolute value (quantity)	Ratio to 1, in%	Absolute value (quantity)	Ratio to 1, in%	Absolute value (quantity)	Ratio to 1, in%			
	Improvement	1	100%	1	100%	2	100%	2.265	0.132	0.098
10 days	No improvement	0		0		0				

Table 9. Comparative evaluation of the results of the methods of operations III on the V1 segment of VA

		Group III.A		Group III.B		Group III.C		chi²	p	pТМФ
		Absolute value (quantity)	Ratio to 1, in%	Absolute value (quantity)	Ratio to 1, in%	Absolute value (quantity)	Ratio to 1, in%			
	Improvement	3	100%	1	100%	1	100%	2.265	0.132	0.098
10 days	No improvement	0		0		0				
1 year	Improvement	2	66.6%	1	100%	1	100%	1.212	0.271	0.217
	No improvement	1	33.3%	0		0				
3 years	Improvement	2	66.6%	1	100%	0	100%	0.587	0.443	0.364
	No improvement	1	33.3%	0		1	100%			

ments compared to group II.B.1 (right vertebral arteriotomy from the orifice, carotid-vertebral anastomosis). Statistical calculations are presented in Table 7.

The analysis of the VA surgery outcomes was performed in two stages. First, the factors affecting the 3-year outcomes were analyzed, then the factors for a longer follow-up period. A separate analysis of open surgeries only identified the following risk factors:

- Age at the time of surgery: each year increases the risk of complications 1.06-fold (95% CI: 1.01–1.10), and every 5 years – 1.31-fold (95% CI: 1.04–1.65)
- VA lesion: the risk of complications is 2-fold lower in subtotal stenosis compared to occlusion, OR = 0.47 (95% CI: 0.22–1.00).

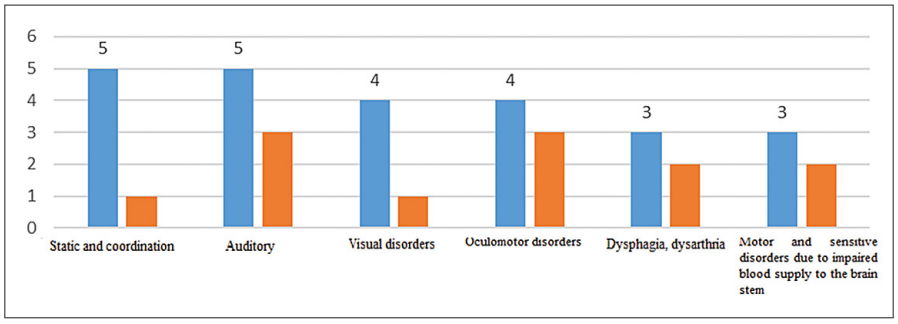

Figure 9. Changes in clinical symptoms of VBI in the patients of subgroup III after surgery on the V1 segment of the VA.

Therefore, after the study, clinical improvements were achieved after 3 years of follow-up in 22 (81.5%) patients from subgroup II with pathologies of the V1 segment of the VA and VBI symptoms. We shall also discuss the treatment outcomes in the "Additional operations" group of patients. Despite favourable outcomes obtained, a long-term follow-up is not possible due to the deaths of the patients (mean age in this group of patients exceeded 82 years) (Tab. 8, Fig. 8).

Overall Outcomes

In the early postoperative period, clinical improvements were achieved in 5 (100%) patients of subgroup III. The most persistent were auditory disorders. Even with a subjective decrease in the severity of tinnitus, a decrease in auditory acuity or impaired speech intelligibility persisted in some patients. The mean score on the Hofferberth scale in the early postoperative period decreased from 20.8 ± 3.19 to 3.7 ± 1.47 ($p < 0.05$).

Differences in the changes in the scores in groups III.A, III.B and III.C were not statistically significant ($p>0.05$). Comparison of the VA reconstructive surgery outcomes are presented in Table 9.

The analysis of the risk factors for adverse clinical events in patients is presented in Table 10.

The exponential regression coefficients, interpreted as odds ratios, show that the risks of an unfavorable outcomes increased after 3 years of follow-up after reconstructive operations in group III. All other factors reduced the risks of non-improvement (where the OR is less than 1). The forecast quality at the cut-off point of 0.3: sensitivity – 70.7%, specificity – 85.3%. Therefore, of 5 patients from subgroup III, persistent clinical improvements in the early postoperative period were achieved in 100% of patients, which persisted after 1 year of follow-up in 80% of patients, and after 3 years of follow-up in 40% of patients. Of note, these patients did not experience any clinical improvement before surgery after a long course of pharmacotherapy followed-up by a neurologist.

In the patients from the Conservative Treatment control group (n = 50), clinical improvement was observed in 40%. The follow-up period was 3–5 years. In 2 patients, restenosis of the VA segment was observed 3 years later. During dynamic neurological examinations, a slight clinical improvement was observed in all patients, manifested in a decrease or disappear-

Table 10. Characterization of risk factors for deterioration during the 3-year observation period for operations III on the V1 segment of VA

Model Predictors	Odds ratio (95% CI)	p
Total blood flow for both VAs before surgery, ml/min	0.97 (0.95–0.99)	0.008
Reactivity index before surgery	0.13 (0.04–0.46)	0.001
Operation performed		
Subgroup III.A.1 (Arteriolysis)	1	–
Subgroup III.A.2 (X-ray-guided endovascular stenting of orifice)	7.25 (1.56–33.76)	0.012
Subgroup III.A.3 (Plastic surgery)	0.73 (0.15–3.42)	0.686

ance of static and coordination, auditory and visual disorders. During dynamic neurological examinations, a persistent clinical improvement was observed in 2 patients, which lasted for more than 3 years.

Overall results of surgical treatment in the patients with tortuosity of the vertebral artery in the V1 segment

Using a developed algorithm for the selection of patients for surgery and performing interventions in 50 out of 100 patients with VBI symptoms, who received ineffective pharmacotherapy for 6 months or more, we achieved clinical improvements after surgery in 80% of patients. Clinical improvements persisted in 75% of patients after 1 year of follow-up, and in 68% of patients after 3 years of follow-up. The analysis of long-term results shows favourable clinical outcomes after reconstructive surgery in the patients with VBI symptoms. The long-term favourable outcomes of pharmacotherapy do not reach 40%.

Conclusions

1.) Along with traditional diagnostic methods necessary to clarify the strategy of surgical treatment (Doppler ultrasonography, contrast-enhanced multi-spiral computed tomography), the proposed method for determination of the VA reactivity and blood flow insufficiency in the VBS is a key method for the selection and prediction of the clinical outcomes of surgery on the VBS arteries. Cerebral angiography is recommended in all patients before surgery on the VBS arteries, in order to determine the state of the intracranial part of the vertebral and main arteries, as outflow paths, and to determine collateral compensation in the VBS.

2.) An isolated carotid endarterectomy in patients with vertebral-basilar insufficiency results in clinical improvements in most patients. In patients with a long history of diabetes mellitus and hypertension, this intervention does not lead to clinical improvement.

3.) The reconstruction of the V1 segment of the vertebral artery is clinically justified. This surgical transposition results in the restoration of physiological main blood flow and the best early and long-term outcomes. During this intervention, it is possible to perform endarterectomy from the orifice of the vertebral and internal thoracic arteries.

4.) Reconstructive techniques for the V1 segment of the VA show better long-term clinical results. The use of tortuosity resection of the V1 segment of the VA is most effective in the early postoperative period and is indicated in patients with multiple lesions of the arteries as the first stage to increase the resistance of the brain to ischemia in subsequent reconstructive interventions.

5.) The use of conservative treatment in patients with concomitant lesions of the VBS is possible. Early outcomes are satisfactory.

Conflict of Interest

The authors confirm, that they have no conflicts of interest to disclose.

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