VIA MEDICA

ORIGINAL ARTICLE

Acta Angiol
Vol. 28, No. 1, pp. 8–15
Doi: 10.5603/AA.2022.0004

ISSN 1234–950X
e-ISSN 1644–3276

Proximal vertebral artery surgery. Results of treatment of ischemia of the rhombencephalon (hindbrain). Simultaneous carotid and vertebral artery operating procedures

Magda Czajkowska[2], Barbara Wolf[1], Grzegorz Oszkinis[3], Andrzej Dorobisz[1]

[1]Medical UniversityPiastów Śląskich, Wroclaw, Poland

[2]The Department of Pharmacy of the Regional Blood Donation Centre in Wroclaw, Poland

[3]Department of General and Vascular Surgery, Institute of Medical Sciences, University of Opole, Poland

Abstract

Introduction: *Surgical treatment of hindbrain ischemia is becoming the accepted surgical procedure in cases of stenosis of extracranial segments of vertebral arteries in the course of advanced atherosclerotic lesions in their initial segments (V1) or caused by external compression of these arteries in the canal formed by the transverse processes of cervical vertebrae. The latter is referred to as vertebrobasilar insufficiency (VBI). The transposition of the left vertebral artery to the common carotid artery in cases where stent graft implantation is necessary with coverage of the subclavian artery and possible blood supply disorders of both the hindbrain and the spinal cord has become important.*

Material and methods: *In the Department of Vascular Surgery at the Medical University in Wrocław, in 58 out of 76 patients treated for ischemia of the hindbrain, the procedures were performed in the distal vertebral artery. The authors present the diagnosis of 18 patients treated surgically for stenosis or kinking of vertebral arteries in their first segment.*

Results: *In 12 cases, the procedure was performed with simultaneous unblocking of significantly narrowed left internal carotid artery. The material includes patients operated on between 1994 and 2018, most of whom had a good or very good outcome with zero mortality.*

Conclusions: *Our results allow for a conclusion that proximal anastomosis of the common carotid and vertebral arteries is an effective method of treatment of vertebrobasilar insufficiency resulting both from atherosclerotic lesions of the vertebral arteries and their kinking. The qualification for the procedure is relatively difficult and must be based on angiography, whereas non-invasive methods are not fully reliable and should be, therefore, treated as auxiliary. We believe, however, that with increasing experience, ultrasound methods will also allow for a proper assessment. Unfavorable results of stenting, especially of vertebral arteries, demonstrated in our study, indicate the necessity to rely on surgical treatment.*

Key words: vertebral artery surgery, diagnosis, concomitant carotid artery endarterectomy procedures

Acta Angiol 2022; 28, 1: 8–15

Address for correspondence: Andrzej Dorobisz, Medical University Piastów Śląskich, Pasteura 1, 50–629 Wrocław, Poland , e-mail: andrzej.dorobisz@umw.edu.pl

Introduction

Cerebral ischemia caused by lesions of the vertebral and basilar arteries is much less frequently diagnosed than syndromes originating in the carotid artery vascularization area. Cerebral strokes in the vascularization area of these arteries account for about 15% of all ischemic cerebral strokes and their number shows an increasing trend. The essential role in cerebral blood supply is played by internal carotid arteries supplying 80–85% of the blood, while the remaining portion is supplied by vertebral arteries. The normal cerebral flow is calculated at 700-900 ml of blood per minute, which is 1/5 of the minute stroke volume of the heart. This amount of blood carries approx. 500–600 ml/min of oxygen and 75–100 mg/min of glucose, which allows to supply the brain with about 30 watts of energy per day, obtained from the combustion of glucose [1, 2]. The cerebral blood flow time from the common carotid artery to the jugular vein is calculated at 7–9 sec. The flow velocity in the vertebral arteries is slightly lower — it is about 10 sec. However, the contact time of a given blood volume in the cerebral capillaries is only about 0.5–1.0 sec. [1, 2].

The hindbrain is supplied by two vertebral arteries with a small cross-section of 3 to 5 mm, forming the first branches of the subclavian arteries. The vertebral arteries (VA) run their characteristic winding course starting from the subclavian arteries through the canal opened by the transverse processes of the cervical vertebrae from the height of the 6th vertebra to the 2nd vertebra, which means practically to the height of the skull base.

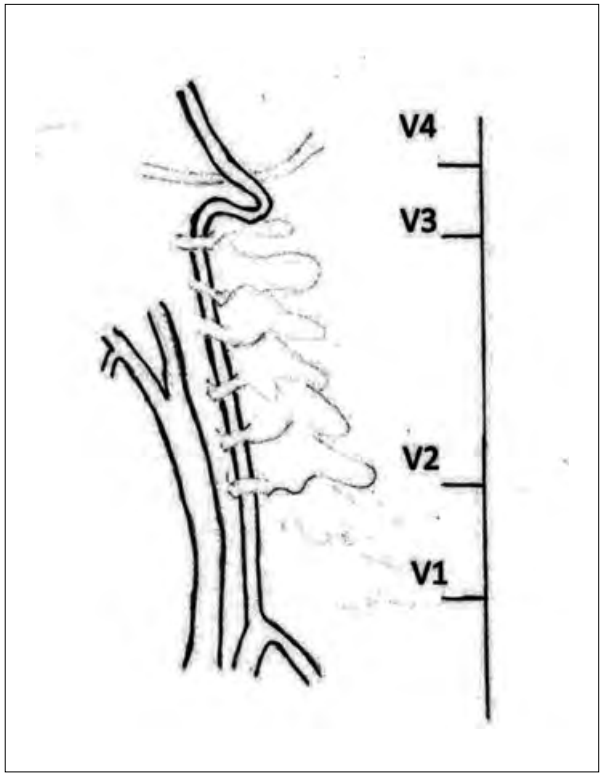

Figure 1. The course of the vertebral artery and its segmentation

Due to the anatomy and from the pathophysiological point of view, the course of each of them is divided into four segments (V1–V4) (Fig. 1). Vertebral arteries are often asymmetric, they narrow gradually, and in 25% of the population they differ in diameter. Hypoplasia in segment V1 is defined as a diameter ≤ 2.5 mm, while ultrasound examination shows a significant decrease in flow velocity compared to the opposite side and an increase in the ipsilateral flow resistance index [3].

Historically, intra-arterial angiography was the "gold standard" in the diagnosis of lesions in both the common carotid (CCA) and internal carotid (ICA) arteries, and in VA. However, because of the potential for angiography-associated stroke, it has been replaced with noninvasive imaging, particularly contrast-enhanced MR (angio MR) and contrast-enhanced CT (angio CT). Both methods allow visualization of the entire vertebrobasilar system. These examination techniques make it possible to detect simultaneously the extracranial and intracranial lesions of the ACC, ACI, and VA, as well as stenosis in the basilar artery. Angio MR provides better visualization of the vertebrobasilar system, especially the proximal VA, than non-contrast MR techniques [4]. A study comparing angio CT, angio MR, and ultrasound for the "gold standard" of endovascular angiography concluded that digital angiography with the use of the new techniques has high sensitivity and specificity and that these methods are superior to ultrasound [5].

The stenotic changes in the form of atherosclerosis or kinking are most common in the first segment, i.e. from the vertebral artery exit to its entry into the canal formed by the transverse processes. In the second segment of VA, stenosis is caused mainly by external compression due to degenerative changes in the vertebrae or disc hernias. The main pathology within the third segment is VA kinks. The terminal segments of VA and the basilar artery are more frequently affected by atherosclerotic lesions. Compared with carotid artery lesions, kinks in these arteries are found in the distal parts of the ICA, whereas atherosclerotic lesions in carotid arteries are most frequent in the CCA division and the proximal segment of the ICA (more than 80%). The posterior and anterior cerebral circulations interconnect in the circle of Willis, which is efficient only in 50% of the population [6].

The vertebrobasilar system supplies blood to centers located in the brainstem, cerebellum, occipital lobes, and (in most patients) inferior temporal lobes and most of the thalamus. When chronic VA stenosis oc-

curs, nonspecific and diverse complaints are diagnosed relatively late [1, 7]. The most common ones include dizziness, binocular visual disturbances, eye movement disturbances, and complete loss of vision (cortical blindness). Less commonly, hemianopia, tinnitus, alternate sensory disturbances, and numbness of the upper extremities are reported. The most characteristic symptoms are sudden, repeated limb movements with falling to the knees with consciousness preserved, so-called "drop attacks", and gait disturbances. The most characteristic symptoms include sudden recurring lower limb floppiness with falling to the knees while maintaining consciousness (so-called "drop attacks") and gait disturbances caused by balance disorders, most often with deviation in the direction in which the hearing is impaired (as under the influence of alcohol). The explanation for these complaints is not simple and often requires the consultation of specialists in ENT, cardiology, and rheumatology [8–10].

In a series of 407 patients with posterior circulation stroke, the most common symptoms included dizziness (47%), unilateral limb weakness (41%), dysarthria (31%), headache (28%), and nausea with vomiting (27%). In another study, the most common symptoms included unilateral limb weakness (38%), gait ataxia (31%), unilateral limb ataxia (30%), dysarthria (28%), and nystagmus (24%) [11]. Chronic vertebrobasilar events may also include symptoms that can be attributed to classic ischemia in terms of anterior cerebral circulation disorders, including unilateral limb weakness or numbness.

Acute incidents in the form of posterior cerebral circulation strokes are much easier to diagnose, though a high percentage ends in death.

In non-invasive diagnostics, a very helpful examination is Doppler ultrasound performed to assess the morphology of lesions and the velocity and direction of flow, as well as to evaluate functional changes in different head positions, especially when the patient may have characteristic symptoms.

Indicators of hemodynamically significant VA stenosis include an increase in flow velocity at the site of stenosis (PSV ≥ 120 cm/s and EDV ≥ 40 cm/s), a marked decrease in velocity downstream of the stenosis, and asymmetry between right and left VA (> 15%), consistent with Doppler imaging. In contrast, retrograde (reflex) flow is indicative of subclavian artery stealth syndrome.

Visualization of the VA outflow from the subclavian artery is not always possible for anatomical reasons. Frequent changes in the caliber of the arteries also make an unambiguous diagnosis difficult. However, VA diameter and flow direction can always be assessed and hypoplasia, stenosis, or vessel occlusion can be distinguished.

On ultrasound, VA is most easily visualized in segment II by initially obtaining a longitudinal section of the CCA and then varying the probe angle toward the anteroposterior plane. The assessment of flow in this segment with head turns provides important information, though it is not always diagnostically sufficient [12].

Magnetic resonance imaging shows greater sensitivity than Computed Tomography without contrast in imaging ischemia and/or infarcts in the lateral segment of the CNS, especially in the brainstem. In identifying infarcts, especially small ones, in the brainstem or cerebellum, the resolution of MRI is higher compared to CT due to its lower susceptibility of the former to artifacts.

Diffusion-weighted imaging (DWI) is recognized as the most sensitive and specific method to observe a stroke minutes after its onset [13].

Indications for treatment

Making a decision regarding invasive treatment in the area of vertebral arteries is difficult. A frequently obscure disease pattern and complex nature of symptoms require detailed multispecialty diagnostics. The risk of stroke in patients with asymptomatic VA stenosis is significantly lower than in patients with symptomatic VA stenosis. The annual risk of stroke was 0.2% in patients with isolated asymptomatic VA stenosis and 0.8% in those with symptomatic VA lesions. The prognosis changes markedly with concomitant carotid artery stenosis.

Indications for treatment are facilitated when lesions are present in both vertebral arteries. It should be noted that blood supply disorders in hindbrain circulation are particularly dangerous and often lead to the patient's death. This has been confirmed by cases of fatal embolism and thrombosis after Blalock surgery.

Conservative treatment

There are virtually no randomized trials regarding the conservative treatment of vertebral arteries. Patients with asymptomatic VA stenosis are routinely given antiplatelet drugs and may be put on statin therapy, similar to patients treated for carotid artery lesions [14].

Surgical treatment

In their 1958 paper, Crawford, DeBakey, and Filds reported four cases of surgical treatment of basilar artery insufficiency. A year later Cate and Scott described the technique of transclavicular access to the vertebral artery for endarterectomy. At the same time, however, reports were dominated by carotid artery surgery and treatment of cases of subclavian artery steal syndrome. The growing experience led to an interesting report by

De Weese in 1973. He discovered that in patients with non-classical symptoms of carotid artery insufficiency, a good surgical result is achieved only in 13% of cases. He put forward a hypothesis that the reason for the lack of good surgical outcome is vertebrobasilar insufficiency. Similar observations began to proliferate and in Polish literature, they were reported by A. Dorobisz.

Even though vertebral artery surgeries are, in a way, challenging, there is a need to perform them in clinical practice. This is a direct result of the increasing number of catastrophic strokes, also in young people after cervical spinal trauma, especially those arising in an overstretched mechanism leading to dissection and thrombotic changes in the vertebral arteries [15].

The first reports on vertebral artery surgery date back to the 19th century: in 1831 Dietrich was the first to propose vertebral artery ligation in the occipital region, whereas in 1833 Velpeau suggested ligation in its proximal segment. In 1853 Maisonneuve ligated the injured vertebral artery at the level of the 6th cervical vertebra. The patient died due to septic embolism one month after the procedure. In 1864, A. Smythe selectively ligated the vertebral artery due to the subclavian artery aneurysm. In 1881 Fenger observed cessation of breathing after ligation of the vertebral artery, and 7 years later, R. Matas successfully ligated the vertebral artery because of an aneurysm between the axis and the atlas vertebrae. In 1882 Alexander from Liverpool ligated vertebral arteries unilaterally and bilaterally to treat epilepsy. In 1946 Elkin and Harris published a report on the ligation of vertebral arteries in 10 cases of arteriovenous fistulas. A year later, However and French reported that ligation of the vertebral artery even on only one side could result in the patient's death due to slowing of blood flow and thrombosis of the basilar artery [16]. In 1959, DeBakey described a method of treating ischemia of the posterior cerebellum, which consisted in inserting a saphenous vein and anastomosing it between the subclavian and vertebral arteries. Technically very difficult, this method allows to achieve good results. VA anastomosis was first performed by Crawford in 1958 and Cate in 1959. However, these procedures led to early thrombosis of the vertebral artery, which can be explained by the small caliber of the vessel. In 1972, Edwards performed a side-to-side anastomosis of the vertebral and common carotid arteries. This procedure is also technically difficult and in clinical follow-up the results were poor, which led to the eventual abandonment of these procedures. In 1976, Cormier described the technique of end-to-side anastomosis of the vertebral artery with the common carotid artery (Fig. 2A). It is now the most commonly performed procedure with very good and durable results [16].

Early post-surgery complication rates are low — up to 2.5% for proximal VA reconstruction, with perioperative mortality rates of 0–4% [16].

Studies suggest the need for early intervention in symptomatic patients. The literature of the subject had often reflected a belief that acute neurological events, such as vertebrobasilar events, had a better prognosis than events in the carotid artery blood supply area. As

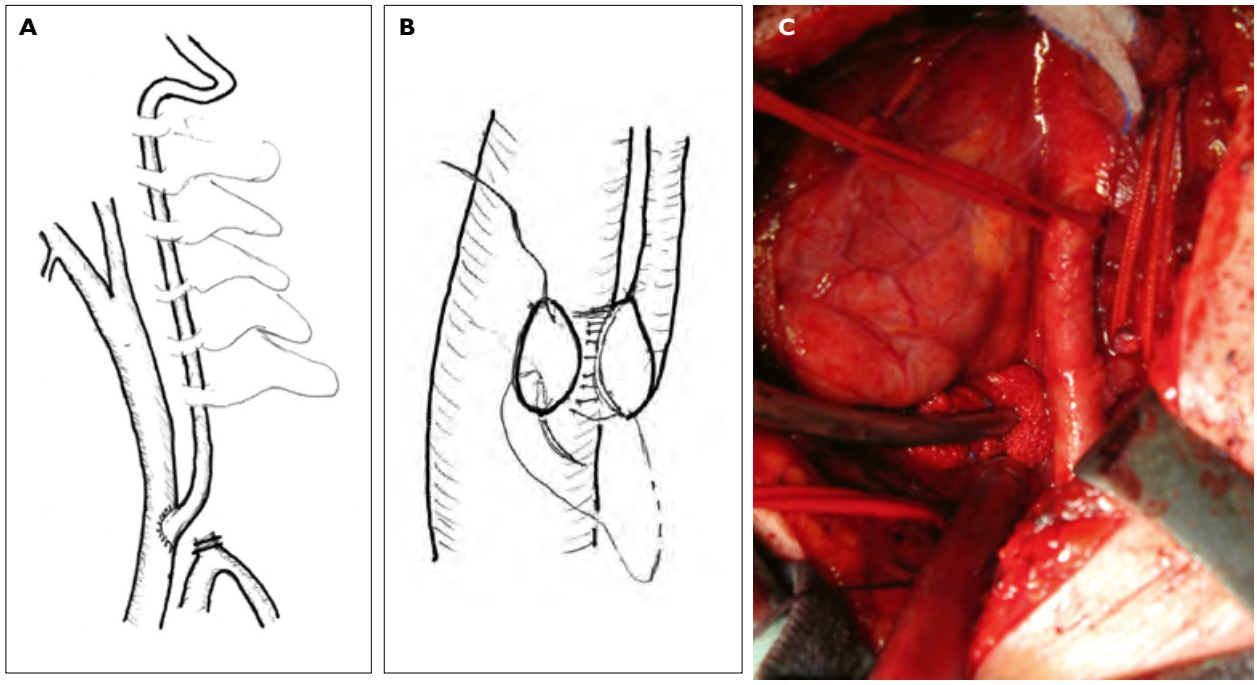

Figure 2A–C. Proximal anastomosis of VA with CCA using P.J. Comier's method

a result, patients were less rigorously screened and did not always receive intensive secondary prevention. However, recent studies suggest that VA stenosis is associated with higher rates of early and recurrent stroke in comparison with symptomatic carotid artery lesions. Evidence from numerous centers suggests that the 90-day risk of recurrent stroke is 7% in patients with no hemodynamically significant VA stenosis, 16% in patients with significant extracranial stenosis in the VA, and 33% in patients with intracranial or basilar artery stenosis. Therefore, the evidence suggests that any intervention in symptomatic patients should be undertaken early after the onset of symptoms [17–19].

Since stenosis of the first vertebral artery segment is most often caused by atherosclerotic lesions or kinking, a detailed morphological and hemodynamic assessment of the carotid arteries is necessary during the qualification for surgery [20, 21].

Material and methods

Between 1994 and 2018, 76 patients diagnosed with vertebrobasilar insufficiency (44 men, 32 women), including 18 patients with vertebral artery stenosis in the first segment, were surgically treated in the Department of Vascular, General, and Transplant Surgery, at Wroclaw Medical University. The remaining patients underwent surgery for a typical vertebrobasilar syndrome with lesions in the 2nd and 3rd segments. The patients' age was between 42 and 65 years (Fig. 3).

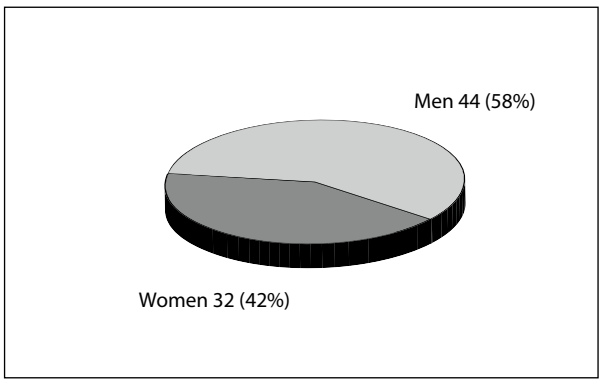

Figure 3. Gender of patients, n (%)

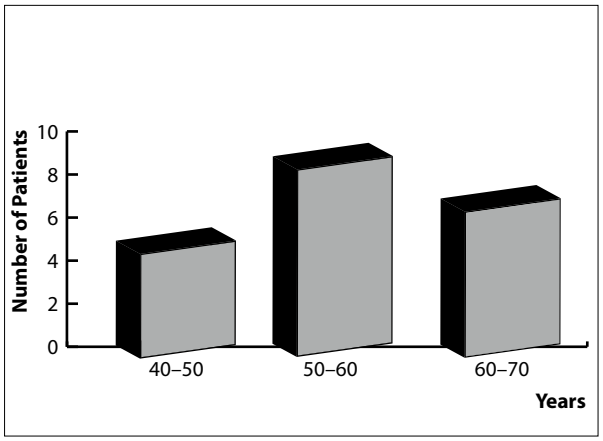

Figure 4. The age of the patients ranged from 42 to 65 years

Results

In the first group of 18 patients, 12 cases revealed coexisting symptomatic stenosis of the internal carotid artery (ICA). In this group, due to concomitant symptoms in the anterior and posterior collateral pathways in the circle of Willis, neurological consultations and an extended panel of examinations resulted in the decision to perform simultaneous surgery to unblock the internal carotid artery and to displace (implant) the vertebral artery into the common carotid artery.

The largest group consisted of patients aged less than 60 years (Fig. 4).

The neurological symptoms presented by the patients are summarized in Table 1.

Table 1. Neurological symptoms presented by patients with proximal VA stenosis

Symptom	n = 18
Dizziness	18
Bilateral visual disturbances	18
Periodic nausea	18
Drop attack	16
Double vision on turning the head	15
Sensory disturbances of the face	10
Visual acuity disorders	12
TIA with unilateral hemiparesis	12

All patients with hemodynamically active internal carotid artery stenosis showed symptoms of transient cerebral ischemic attacks, mostly transient hemiparesis and unilateral visual disturbances.

Angiographic and angio-CT findings in the vertebral and carotid arteries are presented in Table 2.

Table 2. Anatomical changes found in angiography and/or angio-CT

Anatomical changes found	n
Cerebellar stroke	9
Closure of one vertebral artery and stenosis of the other one	10
Bilateral significant vertebral artery stenosis	4
Unilateral lesions on the left vertebral artery	4
Concomitant significant left ICA stenosis	12

All patients reported concomitant multiple neurological symptoms. The most common included headaches, dizziness, balance disorders, periodic nausea, falls with preserved consciousness (drop attacks), skin sensory disturbances, and particularly facial burning and visual disturbances in the form of double vision and

blurred vision. In 9 cases, the patients were treated for a cerebellar stroke and a diagnosed Wallenberg syndrome.

The qualification for surgery was performed in two stages. During the first stage, the general and neurological examination was followed by cervical spine radiography to discover lesions likely to cause compression of the vertebral arteries running in the transverse process channel (degenerative changes, discopathies). This was followed by duplex Doppler examinations carried out to visualize abnormalities of flow through the vertebral arteries (atheromatous stenosis, kinking, occlusions, and abnormalities of flow during head turns). They were performed functionally in the head position in which the patients presented symptoms of insufficiency of the basilar artery and to visualize the carotid arteries. The next examination was meant to determine the blood flow through the vertebral and basilar arteries using the Transcranial Doppler. Measurements were taken in two head positions: straight ahead and in the position in which symptoms of vertebrobasilar insufficiency were present. It was characteristic and significant that during the examination, only half of the patients managed to induce symptoms of hindbrain ischemia [1].

The outpatient evaluation of vertebral artery lesions is not straightforward. Out of 250 patients referred for outpatient diagnostics, 76 were qualified for surgery on the basis of all standard examinations performed. In 18 patients, lesions were found in the first segment of the vertebral artery, while in the remaining patients — in the second and third segments. During hospitalization, the patients underwent Transcranial Doppler, head CT (or MRI), and angiography (including functional CT with head turns). Half of the patients showed changes in head angio-CT in the form of a history of cerebellar stroke and atrophic changes in the posterior cerebellum. Angiographic changes were found in all cases, 21 of which showed occlusion of one vertebral artery and stenotic changes in the other. The remaining cases showed bilateral stenotic lesions, often accompanied by hypoplasia of one of the arteries.

Surgical procedures for the first segment of the vertebral artery are undoubtedly more difficult technically than procedures to revascularize the carotid artery, This is clearly the main reason why surgery to treat symptomatic stenosis is less frequently undertaken. The procedure should be performed with the use of loupes and under general anesthesia. Access is gained from a similar incision as for the carotid artery, i.e. along with the sternocleidomastoid muscle, and often requires its partial transection. The view is obtained between the common carotid artery and the internal jugular vein. Once the lymphatic duct is exposed, it should be carefully ligated to avoid lymphothorax, which is often difficult to treat. After ligation of the vertebral veins, the vertebral artery is exposed as the first shunt of the subclavian artery. Once the common carotid artery (CCA) and internal carotid artery (ICA) (and vertebral and subclavian arteries for safety reasons) are captured in surgical loops, several types of procedures can be performed, including the transposition to the CCA, reimplantation of VA into the subclavian artery, or insertion of a saphenous vein insert from the VA to the subclavian artery. At this stage, the common carotid artery and its division were always palpated for safety reasons after clamping the internal carotid artery. In 12 cases, significant narrowing of the internal carotid artery was confirmed. The ICA was revascularized using the flow shunt. In all patients, the VA was sutured to the side of the CCA.

When significant stenosis of the ICA was discovered, the first procedure involved its revascularization. A long flow drain was inserted from ICA to the aortic arch. This was followed by the revascularization of the division of the CCA into the ICA and this stage of the procedure was completed by suturing the artery and inserting a patch. Subsequently, the vertebral artery was cut off at the subclavian artery and its distal end was sewn end-to-side to the common carotid artery. Towards the end of the suturing procedure, the flow drain was removed and the retrograde outflow from the carotid arteries was controlled following the principles of clamp removal similar to the endarterectomy of the ICA alone. After removing the flow drain, the vascular suture was completed. The blood flow was first directed to the external carotid artery, then to the vertebral artery, and finally to the internal carotid artery to avoid the possibility of microembolism. In procedures limited to the implantation of the VA, the flow drain was also placed in the CCA, although it was shorter and reached distally half of the ACC length.

Table 3. Early results of surgical treatment

	Cessation of symptoms	Improvement	No improvement	Deterioration
No history of stroke		8	1	0
A history of cerebellar stroke	9	8 (90%)	0	0

Table 4. Distant results of surgical treatment

	Cessation of symptoms	Improvement	No improvement	Deterioration
No history of stroke	9	9	0	0
A history of cerebellar stroke	9	7 (80%)	2	0

Treatment outcomes

Early treatment results (up to 4 weeks after surgery) are shown in Table 3.

Nine patients without cerebrovascular lesions and nine patients after an ischemic stroke were operated for insufficient cerebrovascular circulation. Preoperative angiographic examination revealed atherosclerotic lesions of the arteries in 14 patients, while in four patients ischemia was a result of kinking of vertebral arteries (Table 4).

Further follow-up was conducted on an outpatient basis, with the shortest period of follow-up being three years. Follow-up examinations included not only the history and neurological examination but also USG-DD-ultrasound of cephalic arteries. In this group, a very good (complete remission of symptoms) or good (partial remission of symptoms) postoperative effect was achieved in 16 cases. Patients reported complete remission of extremely bothersome symptoms of the disease. Those with previous cerebellar strokes reported partial remission of symptoms, while all patients reported reduced but still persistent dizziness and periodic facial burning as an expression of sensory disturbances. This group of patients showed a significant increase in the comfort of life, with complete resolution of visual disturbances. In two cases, the symptoms persisted. The lack of improvement may be attributed to the established neurological changes. No new neurological symptoms developed as a perioperative complication in any case, nor did any patient die of other causes. In all patients, an ultrasound examination showed normal patency of anastomoses of the vertebral artery with the common carotid artery. There was no evidence of internal carotid artery restenosis.

Conclusions

According to the presented data, the efficacy of arterial revascularization can be described as high. The long-term follow-up (up to nine years) showed a good effect or clinical improvement in almost all cases; a poor early result (no improvement) was obtained in one case. The efficacy of proximal vertebral artery anastomoses, especially the preserved patency, confirms the good surgical outcome. A very good result obtained in 12 patients with concomitant internal carotid artery stenosis indicates the feasibility and high safety of combined procedures. Anastomosis of the common carotid artery and vertebral artery has resulted in the complete remission of neurological symptoms.

Our results allow for a conclusion that proximal anastomosis of the common carotid and vertebral arteries is an effective method of treatment of vertebrobasilar insufficiency resulting both from atherosclerotic lesions of the vertebral arteries and their kinking. The qualification for the procedure is relatively difficult and must be based on angiography, whereas non-invasive methods are not fully reliable and should be, therefore, treated as auxiliary. We believe, however, that with increasing experience, ultrasound methods will also allow for a proper assessment. Unfavorable results of stenting, especially of vertebral arteries, demonstrated in our study, indicate the necessity to rely on surgical treatment [22, 23].

Conflict of interest

None.

References:

1. Huber P. Stenosierende und oblitierende zerebrale Gefässprozesse. In: Diethelm L, Henck F, Olssen S, Strand S, Vieten H, Zuppinger A. ed. Handbuch der medizinischen radiologie. Springer Verlag, Berlin – Heidelberg 1981: 571.
2. Lübbers DW. Physiologie der Gehirndurchblutung. In: Gänschirt HW. ed. Der Hirnkreislauf. Thieme Verlag, Stuttgart 1972.
3. Hua Y, Meng XF, Jia LY, et al. Color Doppler imaging evaluation of proximal vertebral artery stenosis. AJR Am J Roentgenol. 2009; 193(5): 1434–1438, doi: 10.2214/AJR.09.2624, indexed in Pubmed: 19843764.
4. Khan S, Cloud GC, Kerry S, et al. Imaging of vertebral artery stenosis: a systematic review. J Neurol Neurosurg Psychiatry. 2007; 78(11): 1218–1225, doi: 10.1136/jnnp.2006.111716, indexed in Pubmed: 17287234.
5. Yurdakul M, Tola M. Doppler criteria for identifying proximal vertebral artery stenosis of 50% or more. J Ultrasound Med. 2011; 30(2): 163–168, doi: 10.7863/jum.2011.30.2.163, indexed in Pubmed: 21266553.
6. Pitts FW. Variations of collateral circulation in internal carotid occlusion. Comparison of clinical and x-ray findings. Neurology. 1962; 12: 467–471, doi: 10.1212/wnl.12.7.467, indexed in Pubmed: 14038389.
7. Parkinson D. Collateral circulation of cavernous carotid artery. Can J Surg. 1964; 7: 251–268, indexed in Pubmed: 14176972.

8. Piton J, Caille M. Anastomoses carotido–carotidiennes chez l humane. J Radiol Elekreol. 1971; 52: 447.
9. Schechter MM, Zingesser LH. The radiology of basilar thrombosis. Radiology. 1965; 85: 23–32, doi: 10.1148/85.1.23, indexed in Pubmed: 14303067.
10. Szapiro J. Z zagadnienia fizjopatologii krążenia krwi w mózgu. Łódzkie Tow. Nauk. 1960.
11. Searls DE, Pazdera L, Korbel E, et al. Symptoms and signs of posterior circulation ischemia in the new England medical center posterior circulation registry. Arch Neurol. 2012; 69(3): 346–351, doi: 10.1001/archneurol.2011.2083, indexed in Pubmed: 22083796.
12. Khan S, Cloud GC, Kerry S, et al. Imaging of vertebral artery stenosis: a systematic review. J Neurol Neurosurg Psychiatry. 2007; 78(11): 1218–1225, doi: 10.1136/jnnp.2006.111716, indexed in Pubmed: 17287234.
13. Khan S, Rich P, Clifton A, et al. Noninvasive detection of vertebral artery stenosis: a comparison of contrast-enhanced MR angiography, CT angiography, and ultrasound. Stroke. 2009; 40(11): 3499–3503, doi: 10.1161/STROKEAHA.109.556035, indexed in Pubmed: 19762707.
14. Compter A, van der Worp HB, Algra A, et al. Second Manifestations of ARTerial disease (SMART) Study Group. Prevalence and prognosis of asymptomatic vertebral artery origin stenosis in patients with clinically manifest arterial disease. Stroke. 2011; 42(10): 2795–2800, doi: 10.1161/STROKEAHA.110.612903, indexed in Pubmed: 21852605.
15. Carney AL. Vertebral Artery Surgery: Historial Development Basic Concepts of Brain Hemodynamics and Clinical Experiens of 102 cases. In: Advances in Neurology, vol. 30. Diagnosis and Treatment of Brain Ischemia. Raven Press, New York, 1981, 250.
16. Dorobisz A. Badania nad skutecznością chirurgicznego leczenia niedokrwienia mózgu. In: Wrocław, Akad. Med., 1996; 109. Rozprawy Habilitacyjne Akademii Medycznej we Wrocławiu; 4/1996.
17. Gulli G, Marquardt L, Rothwell PM, et al. Stroke risk after posterior circulation stroke/transient ischemic attack and its relationship to site of vertebrobasilar stenosis: pooled data analysis from prospective studies. Stroke. 2013; 44(3): 598–604, doi: 10.1161/STROKEAHA.112.669929, indexed in Pubmed: 23386676.
18. Kieffer E, Praquin B, Chiche L, et al. Distal vertebral artery reconstruction: long-term outcome. J Vasc Surg. 2002; 36(3): 549–554, doi: 10.1067/mva.2002.126092, indexed in Pubmed: 12218980.
19. Berguer R, Morasch M, Kline R. A review of 100 consecutive reconstructions of the distal vertebral artery for embolic and hemodynamic disease. Journal of Vascular Surgery. 1998; 27(5): 852–859, doi: 10.1016/s0741-5214(98)70265-4.
20. Dorobisz AT. Langzeitergebnisse der operativen Behandlung des vertebrobasilären Syndroms. Zentralblatt für Chirurgie. 2006; 131(1): 3–7, doi: 10.1055/s-2006-921406.
21. Writing Group: A.R. Naylor and all, Editor's Choice – Management of Atherosclerotic Carotid and Vertebral Artery Disease: 2017 Clinical Practice Guidelines of the European Society for Vascular Surgery (ESVS). 2018; 55(1): 3–81.
22. Gargiulo G, Sannino A, Stabile E, et al. New cerebral lesions at magnetic resonance imaging after carotid artery stenting versus endarterectomy: an updated meta-analysis. PLoS One. 2015; 10(5): e0129209, doi: 10.1371/journal.pone.0129209, indexed in Pubmed: 26017678.
23. Stayman AN, Nogueira RG, Gupta R. A systematic review of stenting and angioplasty of symptomatic extracranial vertebral artery stenosis. Stroke. 2011; 42(8): 2212–2216, doi: 10.1161/STROKEAHA.110.611459, indexed in Pubmed: 21700936.