

ORIGINAL STUDIES ORIGINALNI NAUČNI RADOVI

OUTCOMES AND COMPLICATIONS OF OPEN SURGICAL CAROTID ARTERY REVASCULARIZATION IN RELATION TO CLINICAL PRESENTATION OF THE DISEASE

ISHODI I KOMPLIKACIJE OTVORENE HIRURŠKE REVASKULARIZACIJE KAROTIDNE ARTERIJE U ODNOSU NA KLINIČKU MANIFESTACIJU BOLESTI

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Abstract

Introduction. Open surgical carotid artery revascularization remains the gold standard for the treatment of carotid atherosclerotic disease. The aim of this study was to analyze atherosclerotic risk factors in patients undergoing open surgical carotid revascularization and to evaluate intraprocedural factors associated with periprocedural complications. **Material and Methods.** This retrospective study included 125 patients treated at the University Clinical Center of Vojvodina between 2023 and 2024. Data were collected from medical records at the Clinic for Vascular and Endovascular Surgery. **Results.** Patients were categorized as asymptomatic ($n = 89$) and symptomatic ($n = 36$). The study population consisted of 63% men and 37% women. An incomplete Circle of Willis was observed in 24% of patients (16% in the asymptomatic group and 44% in the symptomatic group), demonstrating a significant association with disease stage ($p = 0.001$). Unstable plaques were detected in 15% of asymptomatic and 36.1% of symptomatic patients ($p = 0.023$). An incomplete Circle of Willis was significantly associated with the occurrence of hyperperfusion syndrome ($p = 0.012$) and intraoperative hypertension ($p < 0.001$). **Conclusion.** Age, cardiac comorbidities, plaque morphology, and completeness of the Circle of Willis are associated with the clinical stage of extracranial cerebrovascular disease. Intraoperatively, hemodynamic instability, carotid plaque length, clamp duration, and total procedure time were associated with an increased risk of procedural complications.

Key words: Cerebrovascular Disorders; Endarterectomy, Carotid; Surgical Procedures, Operative; Postoperative Complications; Treatment Outcome; Plaque, Atherosclerotic; Atherosclerosis; Risk Factors

Introduction

Open surgical carotid artery revascularization, or carotid endarterectomy (CEA), remains the gold

Sažetak

Uvod. Otvorena hirurška revaskularizacija predstavlja zlatni standard lečenja karotidne aterosklerotske bolesti. Cilj rada bila je analiza faktora rizika ateroskleroze kod ispitanika nakon otvorene hirurške revaskularizacije karotidnih arterija; analiza uticaja intraproceduralnih faktora na periproceduralne komplikacije. **Materijal i metode.** Retrospektivna studija obuhvatala je 125 ispitanika lečenih u Univerzitetskom kliničkom centru Vojvodine u periodu 2023–2024. godine. Podaci su prikupljeni iz medicinske dokumentacije Klinike za vaskularnu i endovaskularnu hirurgiju. **Rezultati.** Ispitanici su podeljeni na one bez simptoma (asimptomatske) ($n = 89$) i one sa simptomima (simptomatske) ($n = 36$). Ukupno 63% je bilo muškog, a 37% ženskog pola. Inkompletna Vilisov šestougao utvrđen je kod 24% ispitanika (16% asimptomatskih i 44% simptomatskih), uz značajnu razliku u odnosu na klinički stadijum ($p = 0,001$). Nestabilan plak bio je prisutan kod 15% asimptomatskih i 36,1% simptomatskih ispitanika ($p = 0,023$). Hiperperfuzioni sindrom bio je povezan sa inkompletnim Vilisovim šestouglom ($p = 0,012$) i intraoperativnom hipertenzijom ($p < 0,001$). **Zaključak.** Starost, kardiološka bolest, morfologija plaka i kompletnost Vilisovog šestougla značajno koreliraju sa stadijumom ekstrakranijalne cerebrovaskularne bolesti. Intraoperativno, hemodinamička nestabilnost, dužina plaka, trajanje klemo i trajanje intervencije povezani su sa proceduralnim komplikacijama.

Ključne reči: cerebrovaskularna bolest; karotidna endarterektomija; operativne hirurške procedure; postoperativne komplikacije; ishod lečenja; aterosklerotski plak; ateroskleroza; faktori rizika

standard for the treatment of both symptomatic and asymptomatic carotid atherosclerotic disease [1]. In approximately 60-80% of cases, atherosclerotic lesions of the extracranial carotid arteries lead to re-

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Abbreviations

BMI	– body mass index
CAS	– carotid artery stenting
CEA	– carotid endarterectomy
CoW	– Circle of Willis
COPD	– chronic obstructive pulmonary disease
DM	– diabetes mellitus
EEA	– eversion endarterectomy
HLP	– hyperlipoproteinemia/hyperlipidemia
HPS	– cerebral hyperperfusion syndrome
HTA	– arterial hypertension
PAOD	– peripheral arterial occlusive disease
TEA	– conventional endarterectomy
TIA	– transient ischemic attack
UKCV	– University Clinical Center of Vojvodina

duced cerebral blood flow, thereby creating an opportunity for preventive surgical intervention [2].

Contemporary approaches to carotid artery disease and stroke – particularly ischemic stroke – emphasize the importance of timely intervention as the most critical factor in preventing irreversible neuronal damage [3]. The incidence of stroke continues to increase in both elderly and younger populations and remains associated with high mortality and a substantial socioeconomic burden. Current therapeutic strategies include preventive, pharmacological, and surgical approaches [4,5].

Preventive strategies can be divided into primary prevention – focused on identifying and modifying risk factors such as smoking, physical inactivity, and poor dietary habits – and secondary prevention, which aims to reduce the risk of stroke recurrence in patients with a history of stroke or transient ischemic attacks (TIA) [6,7].

Pharmacological therapy targets comorbid conditions that contribute to the development or progression of carotid atherosclerosis. Commonly used medications include antiplatelet agents such as aspirin and clopidogrel, statins, and anticoagulants such as warfarin or heparin [8].

Endovascular revascularization techniques include carotid artery stenting (CAS), which represents a less invasive alternative to open surgery and is typically reserved for patients considered to be at higher surgical risk [9].

Open surgical revascularization through CEA restores hemodynamically adequate carotid flow [10]. CEA can be performed using either the eversion endarterectomy (EEA) technique or the conventional technique (TEA), with or without the use of a shunt, depending on the surgeon's preference [10].

The aim of this study was to analyze the type and frequency of atherosclerotic risk factors in patients undergoing open surgical carotid revascularization according to the clinical stage of extracranial cerebrovascular disease, and to evaluate the impact of intraprocedural factors on the occurrence of periprocedural complications.

Material and Methods

This retrospective study included 125 patients who underwent open surgical carotid revascularization at the University Clinical Center of Vojvodina (UKCV) between January 2023 and December 2024. Data were obtained from the medical records of the Clinic for Vascular and Endovascular Surgery, UKCV, Novi Sad, including electronic database, operative reports, clinical and radiological documentation, and discharge summaries.

All procedures were performed by vascular surgeons. Postoperatively, patients were monitored in the intensive care unit and subsequently transferred to the surgical ward. Patients with an uncomplicated postoperative course were discharged on the fourth postoperative day.

Inclusion criteria were: age >18 years; carotid artery stenosis of 70-99% with an indication for open surgical revascularization; and absence of focal neurological deficits (including ischemic stroke, transient ischemic attack, or amaurosis fugax) attributable to the ipsilateral carotid artery within the preceding six weeks.

Exclusion criteria included: occlusion of the carotid artery planned for treatment; severe or unstable comorbid conditions; extreme preoperative blood pressure values; symptomatic patients with typical carotid-related neurological symptoms within the preceding six weeks; significant intracranial vascular pathology; and incomplete medical documentation.

During surgery, carotid clamp duration was recorded and plaque morphology was documented. Heparin was administered at a dose of 100 IU/kg [11]. Protamine was not routinely used.

The following procedural complications were analyzed: new-onset neurological deficit, myocardial infarction or death, bleeding and wound hematoma, hemodynamic instability (hypotension or hypertension, tachycardia, bradycardia), arrhythmia, delirium, hyperperfusion syndrome, cranial nerve injury, and carotid artery thrombosis occurring within 30 days.

Hyperperfusion syndrome (HPS) was defined as the occurrence of clinical manifestations such as migraine-like headache, ophthalmalgia, facial neuralgia, seizures, and focal neurological deficits resulting from cerebral edema or intracranial hemorrhage [12].

Descriptive and comparative statistical analyses were performed between the asymptomatic and symptomatic patient groups. Categorical variables were analyzed using the chi-square test, while continuous variables were assessed using the independent samples t-test. Significance was defined as $p < 0.05$.

Table 1. Prevalence of risk factors in the sample

Risk Factor	Overall Prevalence (%)	Asymptomatic Group (%)	Symptomatic Group (%)
Diabetes mellitus	34	29	44
Hyperlipidemia	71	73	67
Hypertension	97	99	92
Chronic kidney disease	5.2	2.3	5.6
Peripheral arterial occlusive disease	20.8	19	25
Chronic obstructive pulmonary disease	13	11.2	16.7
Cardiac arrhythmia	17.6	18	17
Cardiac disease	30	36	14
Obesity	9.6	11.2	5.6

Table 2. Postoperative complications

Complication	Total (%)	Asymptomatic (%)	Symptomatic (%)
Hematoma	3.2	5.6	11.1
Infection	0.8	0	2.8
Thrombosis	1.6	1.1	2.8
Stroke	2.4	1.1	5.6
Transient ischemic attack	4	2.2	8.3
Hyperperfusion syndrome	12	10.1	16.7
In-hospital mortality	0.8	0	2.8
Acute myocardial infarction	0.8	0	2.8
Delirium	2.4	3.4	0
Postprocedural hypertension	20	15.7	30.6
Postprocedural hypotension	5.6	5.6	5.6
Arrhythmia	2.4	1.1	5.6
Cranial nerve injury	8	7.9	8.3

Results

Between January 2023 to December 2024, open surgical carotid revascularization was performed in 225 patients at UKCV. Of these, 125 patients who met the inclusion criteria were enrolled in the study to ensure group homogeneity. Patients were categorized as asymptomatic ($n = 89$) or symptomatic ($n = 36$).

The study population included 79/125 (63%) men and 46/125 (37%) women. No statistically significant association was found between sex and the clinical stage of the disease ($\chi^2(1) = 0.094$; $p = 0.759$).

Patient age ranged from 47 to 81 years, with a mean age of 64 ± 7 years. Asymptomatic patients were significantly older (66 ± 6.43 years) than symptomatic patients (64 ± 7.27 years; $p < 0.001$).

The most common risk factors are presented in **Table 1**. Chi-square analysis revealed a statistically significant difference according clinical stage for cardiac disease, which was more frequent observed in asymptomatic subjects ($\chi^2(1) = 4.997$; $p = 0.025$).

The right carotid artery was treated in 50.4% of patients and the left carotid artery in 49.6%, with no statistically significant difference between the groups.

An incomplete Circle of Willis (CoW) was identified in 24% of patients (16% of asymptomatic and 44% of symptomatic patients), demonstrating a statistically significant association with the clinical stage of the disease ($\chi^2(1) = 10.066$; $p = 0.001$).

Unstable plaque morphology was present in 21.6% of patients: 15% of asymptomatic and 36.1% of symptomatic patients ($\chi^2(1) = 5.141$; $p = 0.023$). The mean plaque length of internal carotid artery was significantly greater in symptomatic subjects ($p < 0.001$).

Postoperative complications are summarized in **Table 2**, while comparative analyses of selected complications are presented in **Tables 3-6**. Carotid thrombosis occurring within 30 days was significantly associated with the severity of contralateral carotid stenosis ($p = 0.021$) (**Table 3**). Hyperperfusion syndrome showed a significant association with incomplete CoW ($p = 0.012$) and intraoperative hypertension ($p < 0.001$) (**Table 4**). Postoperative hypertension was significantly associated with intraoperative hypertension ($p < 0.001$), whereas postoperative hypotension was associated with preoperative hypertension ($p = 0.005$) and intraoperative hypotension ($p = 0.010$) (**Table 5**). Postoperative arrhythmia

Table 3. Thrombosis within 30 days – comparative variables (selected)

Variable	Chi-square	df	p
Sex	0.122	1	0.727
Diabetes mellitus	0.067	1	0.795
ECST stenosis (contralateral)	7.689	2	0.021*
Operative technique	0.404	2	0.817

ECST = European Carotid Surgery Trial; *p <0.05

Table 4. Hyperperfusion syndrome – comparative variables (selected)

Variable	Chi-square	df	p
Sex	0.313	1	0.576
Diabetes mellitus	0.805	1	0.370
Incomplete Circle of Willis	6.317	1	0.012*
Intraoperative hypertension	17.526	1	<0.001*

*p <0.05

Table 5. Postoperative hypotension with comparative variables

Postoperative hypotension	χ^2	df	p
Gender	0.000	1.000	1.000
DM	0.000	1.000	1.000
HLP	0.000	1.000	1.000
HTA	7.954	1.000	0.005*
Nicotinismus	0.203	2.000	0.903
CRI	0.372	1.000	0.542
PAOD	0.000	1.000	1.000
COPD	0.213	1.000	0.645
Heart rhythm disorder	0.559	1.000	0.455
Cardiac disease	0.133	1.000	0.715
Obesity BMI +35	0.052	1.000	0.820
Side of the carotid artery	0.000	1.000	1.000
Asymptomatic/symptomatic	0.000	1.000	1.000
Anticoagulant therapy	0.213	1.000	0.645
Medication administration	0.218	2.000	0.897
Is CoW complete	0.000	1.000	1.000
ECST grade of treated carotid stenosis	0.000	1.000	0.983
ECST grade of contralateral carotid stenosis	1.194	2.000	0.551
Contralateral carotid occlusion	0.000	1.000	1.000
Plaque type	0.000	1.000	0.991
Type of operative technique	1.287	2.000	0.525
Anesthesia	0.993	1.000	0.319
Intraoperative hypotension	6.598	1.000	0.010*
Intraoperative hypertension	0.317	1.000	0.574
Intraoperative bradycardia HR below 40/min	0.000	1.000	1.000
Tachycardia intraoperative HR over 100/min	0.000	1.000	1.000
Javid's shunt	0.381	1.000	0.537
Dose of heparin	0.330	1.000	0.566
Protamine	0.025	1.000	0.873

DM – diabetes mellitus; HLP – hyperlipoproteinemia; HTA – arterial hypertension; Nicotinismus-smoking; CRI – chronic renal insufficiency; PAOD – peripheral arterial occlusive disease; COPD – chronic obstructive pulmonary disease, BMI – body mass index; CoW-Willis hexagon; HR – heart rate

was significantly associated with the operative technique used (p = 0.010) (**Table 6**).

Table 6. Postoperative arrhythmia with comparative variables

Postoperative rhythm disorder-arrhythmia	χ^2	df	p
Gender	0.000	1.000	1.000
DM	0.000	1.000	1.000
HLP	0.000	1.000	1.000
HTA	0.000	1.000	1.000
Nicotinismus	0.455	2.000	0.797
CRI	0.000	1.000	1.000
PAOD	0.000	1.000	1.000
COPD	0.041	1.000	0.839
Heart rhythm disorder	0.000	1.000	1.000
Cardiac disease	0.000	1.000	1.000
Obesity BMI +35	0.000	1.000	1.000
Side of the carotid artery	1.334	1.000	0.248
Asymptomatic/symptomatic	0.674	1.000	0.412
Anticoagulant therapy	0.041	1.000	0.839
Medication administration	1.790	2.000	0.409
Is CoW complete	0.000	1.000	1.000
ECST grade of treated carotid stenosis	0.000	1.000	0.989
ECST grade of contralateral carotid stenosis	0.847	2.000	0.655
Contralateral carotid occlusion	0.000	1.000	1.000
Plaque type	0.044	1.000	0.834
Type of operative technique	9.237	2.000	0.010*
Anesthesia	0.000	1.000	1.000
Intraoperative hypotension	1.139	1.000	0.286
Intraoperative hypertension	0.000	1.000	1.000
Intraoperative bradycardia HR below 40/min	0.000	1.000	1.000
Tachycardia intraoperative HR over 100/min	0.000	1.000	1.000
Javid's shunt	0.000	1.000	1.000
Dose of heparin	0.506	1.000	0.477
Protamine	0.000	1.000	1.000

DM – diabetes mellitus; HLP – hyperlipoproteinemia; HTA – arterial hypertension; Nicotinismus-smoking; CRI – chronic renal insufficiency; PAOD – peripheral arterial occlusive disease; COPD – chronic obstructive pulmonary disease, BMI – body mass index; CoW-Willis hexagon; HR – heart rate

Discussion

The age distribution observed in our study (47-81 years; mean 64 ± 7 years) is consistent with contemporary literature indicating that clinically significant carotid stenosis most frequently manifests in the seventh decade of life [13,14]. Interestingly, asymptomatic patients in our cohort were significantly older than symptomatic patients ($p < 0.001$), suggesting that carotid atherosclerosis may progress gradually in older individuals without acute neurological manifestations. This observation highlights the importance of preventive screening in elderly populations.

The predominance of male patients (63%) corresponds with the well-established epidemiological profile of carotid artery disease [15]. Although sex was not significantly associated with the clinical stage of the disease ($p = 0.759$), consistent with findings

reported by Schmid et al. [16], it remains an important demographic variable in cardiovascular risk stratification.

Analysis of risk factors revealed a high prevalence of systemic atherosclerotic conditions in the study population, including diabetes mellitus (34%), hyperlipidemia (71%), and hypertension (97%). Notably, cardiac disease was significantly more prevalent in asymptomatic subjects ($p = 0.025$). This finding, also reported by Pastori et al. [17], suggests that patients with established cardiac disease should undergo routine carotid screening even in the absence of neurological symptoms, in order to reduce the risk of ischemic stroke.

A central aspect of our study was the analysis of anatomical variations of the CoW. An incomplete CoW was identified in 24% of patients, with a significantly higher prevalence among symptomatic individuals

(44% vs. 16%; $p = 0.001$). Reported rates of CoW completeness vary widely in the literature (3.5-63%) [18]. Nevertheless, our findings support the hypothesis that incomplete collateral circulation may increase the risk of neurological symptoms and ischemic events due to limited compensatory cerebral blood flow.

Plaque morphology also proved to be an important determinant of clinical presentation. Unstable plaques were significantly more common in symptomatic patients (36.1% vs. 15%; $p = 0.023$), supporting the well-established concept that such plaques are more prone to rupture and distal embolization [20]. Furthermore, plaque length was significantly greater in symptomatic patients ($p < 0.001$), in agreement with Ball et al. [21], suggesting that greater atherosclerotic burden is associated with increased risk of cerebral ischemia.

Regarding intraoperative factors, the use of an intraluminal shunt in 32% of patients (42% of symptomatic patients) reflects our institutional strategy aimed at maximizing cerebral protection during carotid cross-clamping. This rate is somewhat higher than that reported by several international centers. Postprocedural hemodynamic disturbances, particularly peak systolic pressure variations, were strongly influenced by intraoperative hemodynamic status. HPS observed in 12% of patients, was significantly associated with intraoperative hypertension ($p < 0.001$) and incomplete CoW ($p = 0.012$). Although the incidence of HPS in our cohort exceeds the rates reported in meta-analyses (0-3%) [22], the observed relationship with CoW anatomy and blood pressure control is consistent with existing literature [23,24].

Cranial nerve injury, observed in 8% of patients, most frequently involved the recurrent laryngeal

nerve, while postoperative delirium occurred in 2.4% of patients. These complications underscore the importance of continued refinement of surgical techniques and anesthetic management. Our results suggest that plaque length may increase the risk of nerve injury [25], whereas the use of EEG-guided anesthesia has been proposed as a strategy to reduce postoperative delirium.

Finally, carotid thrombosis within 30 days (1.6%) as significantly associated with the severity of contralateral carotid stenosis ($p = 0.021$), highlighting the importance of evaluating global cerebral perfusion status undergoing carotid revascularization. Interestingly, patients who developed this complication were younger on average, cohort finding that warrants further investigation, as similar associations have rarely been reported in the available literature.

Conclusion

The analysis of comorbidities and preoperative factors indicates that age, cardiac disease, plaque morphology, and the completeness of the Circle of Willis are significantly associated with the clinical stage of extracranial cerebrovascular disease. Furthermore, evaluation of intraoperative variables demonstrates that hemodynamic instability, operative technique, clamp duration, and internal carotid artery plaque length are significantly associated with the occurrence of procedural complications. Overall, open surgical carotid revascularization remains highly effective treatment modality for carotid occlusive disease, achieving favorable outcomes with low rates of periprocedural morbidity and mortality.

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