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Disorders of Sensory Analysers after Ligation of Major Neck Vessels

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Abstract. The aim of the study is to identify functional changes in sensory analysers following surgical ligation of cervical vessels. The observational cohort study was conducted at the I. K. Akhunbaev Kyrgyz State Medical Academy (Bishkek) from January 2024 to June 2025 and included 42 patients, in whom, sensory analyser functions were assessed by using a combination of subjective complaints and objective clinical or instrumental examinations, together with indicators of regional and cerebral haemodynamics after surgical ligation of major neck vessels. The study showed that, in the postoperative period, disorders of sensory analyser functions were detected in 66.7% of the patients. The maximum frequency of disorders was recorded on day 5 and amounted to 35.7% for the vestibular analyser, 28.6% for the auditory analyser, and 21.4% for the visual analyser. By day 14, the frequency of disorders decreased to 14.3–21.4%, and, after 1 month, persisted in only 7.1–11.9% of those examined, reflecting the predominantly reversible nature of the changes. Regional haemodynamics were accompanied by a decrease in the blood flow velocity in the common carotid artery from 78.4±11.6 to 61.2±13.8 cm/s and an increase in vascular resistance from 0.62±0.06 to 0.74±0.08 against the background of compensatory enhancement of the blood flow in the vertebral arteries to 48.6±9.4 cm/s. Simultaneously, a decrease in the blood flow velocity in the middle cerebral artery from 56.3±8.7 to 47.1±9.2 cm/s was noted. Correlation analysis revealed associations between haemodynamic parameters and vestibular disorders after 1 month (r=-0.48), more pronounced in traumatic indications and ligation of the common carotid artery. The obtained results confirmed the transient nature of sensory disorders after the ligation of major neck vessels and their close relationship with early haemodynamic changes. The data can be used by vascular surgeons, otorhinolaryngologists and neurologists to optimise postoperative monitoring, predict functional outcomes, and individualise rehabilitation measures.

Keywords: cerebral perfusion, haemodynamics, vestibular disorders, postoperative period, visual acuity, hearing, arteries.

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Jutimo organų sutrikimai po pagrindinių kaklo kraujagyslių ligavimo

Santrauka. Tyrimo tikslas – nustatyti jutimo organų funkcinius pokyčius po kaklo kraujagyslių chirurginio ligavimo. Stebėjimo kohortinis tyrimas buvo atliktas I. K. Akhunbaevo Kirgizijos valstybinėje medicinos akademijoje (Biškekas) nuo 2024 m. sausio iki 2025 m. birželio, tyrimo imtis – 42 pacientai, kurių jutimo organų funkcijos buvo vertinamos remiantis subjektyvių skundų ir objektyvių klinikinių bei instrumentinių tyrimų duomenimis, taip pat regioninės ir smegenų hemodinamikos rodikliais po pagrindinių kaklo kraujagyslių chirurginio ligavimo. Tyrimas parodė, kad pooperaciniu laikotarpiu jutimo organų funkcijų sutrikimai buvo nustatyti 66,7 % pacientų. Didžiausias sutrikimų dažnis užfiksuotas penktą dieną ir siekė 35,7 % pusiausvyros, 28,6 % klausos ir 21,4 % regos atvejų. Iki keturioliktos dienos sutrikimų dažnis sumažėjo iki 14,3–21,4 %, o po vieno mėnesio išliko tik 7,1–11,9 % tiriamųjų, tai rodo, kad pokyčiai daugiausia buvo grįžtamieji. Pakitus bendrajai organizmo ar tam tikro regiono kraujotakai, kartu sulėtėjo ir kraujo tėkmės pagrindine kaklo arterija, kuri maitina smegenis ir veido audinius, greitis nuo 78,4±11,6 iki 61,2±13,8 cm/s ir kraujagyslių pasipriešinimas padidėjo nuo 0,62±0,06 iki 0,74±0,08, esant kompensaciniam kraujo tėkmės padidėjimui stuburo arterijose iki 48,6±9, 4 cm/s. Tuo pačiu sumažėjo kraujo srauto greitis vidurinėje smegenų arterijoje nuo 56,3±8,7 iki 47,1±9,2 cm/s. Koreliacijos analizė atskleidė ryšį tarp hemodinaminių parametrų ir pusiausvyros sutrikimų po vieno mėnesio (r = -0,48), kuris buvo ryškesnis trauminių indikacijų atveju ir užrišus bendrąją miego arteriją. Gauti rezultatai patvirtino jutimo sutrikimų po pagrindinių kaklo kraujagyslių ligavimo praeinantį pobūdį ir jų glaudų ryšį su ankstyvaisiais hemodinamikos pokyčiais. Remdamiesi šiais duomenimis kraujagyslių chirurgai, otorinolaringologai ir neurologai gali siekti optimizuoti pooperacinę stebėseną, prognozuoti funkcinius rezultatus ir taikyti individualias reabilitacijos priemones.

Raktažodžiai: smegenų perfuzija, hemodinamika, pusiausvyros sutrikimai, pooperacinis laikotarpis, regos aštrumas, klausa, arterijos.

Introduction

Ligation of major neck vessels is a forced surgical solution in cases of tumour invasion, traumatic injuries and complex vascular complications; however, it inevitably leads to changes in regional and cerebral haemodynamics. Impaired blood supply to the brain and peripheral structures can affect the functioning of sensory analysers, in particular, the visual, auditory and vestibular systems, as well as the integrative processes of sensory processing. Of significant importance is the fact that sensory disorders are often latent or delayed in nature and are not always detected in the early postoperative period. Insufficient certainty in assessing such changes complicates the prediction of functional consequences, the justification of surgical tactics and the formation of postoperative follow-up algorithms, which is accompanied by a persistent decrease in daily activity and the preservation of functional limitations.

Cerebral haemodynamic disturbance during ligation or occlusion of major neck vessels is considered a fundamental pathogenetic mechanism for the development of metabolic and functional disorders of the central nervous system. In an experimental study by A. Ghazi [1], it was shown that early metabolic dysfunction after carotid artery occlusion exacerbates cognitive and motor impairments, and the severity of energy deficit determines the duration and severity of post-ischaemic consequences. In a clinical-physiological work by A. Baubekov et al. [2], it was demonstrated that revascularisation of the carotid arteries leads to significant changes in gas exchange and metabolic parameters of the brain, thus reflecting the restoration of the energy supply to the neuronal tissue. The obtained data confirm the pathogenetic significance of major carotid blood flow in maintaining adequate cerebral perfusion and functional stability of the brain. The surgical experience in treating patients with multiple atherosclerotic lesions of the carotid arteries, presented by X. Alidjanov et al. [3], demonstrated that combined stenoses significantly limit the cerebral blood flow and create conditions for the formation of chronic hypoperfusion. The authors showed that the absence of a

timely reconstruction of major vessels is associated with the progression of neurological deficit and worsening of the functional prognosis.

Experimental and clinical studies have made it possible to detail the mechanisms of adaptation of cerebral circulation in carotid insufficiency. In the work of O. Harmatina et al. [4], it was shown that chronic unilateral occlusion of the common carotid artery leads to a pronounced restructuring of the arterial blood flow in the vessels of the head and neck with a change in the direction and distribution of perfusion. The scientists demonstrated that such haemodynamic shifts form prerequisites for subsequent functional disorders due to prolonged perfusion imbalance. In a clinical study by G. Madjidova et al. [5], cerebral arterial insufficiency was considered as a multifactorial syndrome, including cognitive and sensory disorders against the background of chronic reduction of cerebral blood flow. The obtained data underscore the diagnostic significance of a comprehensive assessment of haemodynamic and functional indicators in prolonged brain ischaemia. Morphological aspects of vascular pathology were analysed in detail by Y. Dogalbayev et al. [6], who established that dolichoarteriopathies of the internal carotid artery disrupt the laminar blood flow and alter the local haemodynamic conditions. The authors showed that the identified structural anomalies are associated with clinically significant neurological manifestations and are amenable to correction with timely surgical intervention.

The tactical choice in lesions of the major neck vessels has a decisive influence on the functional prognosis and the state of sensory analysers. In a retrospective analysis by M. Sarshayev et al. [7], it was shown that endovascular interventions for atherosclerotic lesions of the cerebral arteries contribute to the stabilisation of cerebral perfusion and improvement of clinical outcomes. The researchers emphasised that restoration of the blood flow reduces the severity of ischaemia-induced functional disorders, including disturbances of higher cortical and sensory functions. In the work of Z. Kutuev [8], it was substantiated that the choice between ligation and reconstruction of major vessels is a key factor in shaping the neurological prognosis in vascular injuries. It was shown that preservation or restoration of the blood flow reduces the risk of persistent sensory disorders caused by chronic ischaemia of the central nervous system structures. The systematisation of postoperative complications presented by A. Lupyr et al. [9] revealed a high sensitivity of sensory analysers to changes in the regional haemodynamics after surgical interventions in the neck area. The authors indicated that, even in the absence of gross neurological deficit, disturbances of auditory and visual functions may reflect subclinical cerebral hypoperfusion. Additional information on the limits of compensation of cerebral circulation is provided in the study by M. Luyken et al. [10], which analysed the dynamics of cerebral oxygenation and vascular reactivity under conditions of long-term adaptation. The obtained results expand the understanding of the functional vulnerability of sensory systems when the perfusion reserve is reduced, which has direct implications for assessing the consequences of ligation of major neck vessels.

Despite the availability of some data on the haemodynamic and neurological consequences of ligation of major neck vessels, information on the nature and severity of changes in the function of sensory analysers in the postoperative period remained insufficiently systematised. The aim of this study was to assess changes in the functional state of sensory analysers in patients after ligation of major neck vessels under conditions of cohort observation. To achieve the aim of the study, the following tasks were formulated: to identify changes in the functions of the visual, auditory and vestibular analysers in the postoperative period; to analyse the relationship of sensory disorders with indicators of regional and cerebral haemodynamics; and to determine the features of functional changes depending on the clinical characteristics of patients and the extent of surgical intervention.

Materials and Methods

Design and Study Base

The study had an observational cohort design and was aimed at assessing the dynamics of the functional state of sensory analysers in the postoperative period without altering the treatment tactics. The study base was the I. K. Akhunbaev Kyrgyz State Medical Academy (Bishkek, Kyrgyz Republic), Department of Otorhinolaryngology, based at the National Hospital, in whose Department of Otorhinolaryngology and Head and Neck Surgery, surgical treatment and postoperative follow-up of patients were carried out. The study was conducted from 1 January 2024 to 30 June 2025, which amounts to 18 months. This time interval was chosen as methodologically justified for forming a homogeneous cohort of patients operated on for comparable clinical indications while using unified diagnostic and surgical approaches; we also sought to ensure a sufficient volume of clinical observations within the cohort design.

Characteristics of the Study Cohort

The study included 42 surgical patients who underwent ligation of major neck vessels. The patients were aged from 29 to 68 years; the mean age was 48.6±9.7 years. The patient age was analysed at a descriptive level when interpreting the dynamics of functional changes in sensory analysers. In the gender structure of the sample, males predominated with 26 (61.9%) individuals, while females comprised 16 (38.1%) patients, which reflected the characteristics of the patient population with traumatic and oncological lesions of the neck vessels. Functional differences related to gender factors were not analysed within the framework of this study. Indications for surgical ligation of major neck vessels were the following: penetrating and blunt traumatic injuries of the neck vessels; vascular wall invasion in malignant tumours of the head and neck (squamous cell carcinoma of the larynx, oropharynx, hypopharynx); iatrogenic vascular injuries occurring during surgical interventions; complicated vascular anomalies requiring emergency or planned surgical resolution.

To implement a comparative analysis, all patients were divided into groups according to several clinical criteria, including the nature of the pathological process, the urgency of the surgical intervention, as well as the level and extent of ligation of major neck vessels. According to the nature of the pathology, two clinical groups were formed: the first comprised patients with traumatic injuries of major neck vessels (n=24), whereas, the second group was made up of patients with tumour invasion of the vascular wall in malignant neoplasms of the head and neck (n=18). Taking into account the urgency of the surgical intervention, all observations were additionally stratified into an emergency surgery group, which included 19 patients, and a planned surgical intervention group, which included 23 patients. Depending on the level of vessel ligation, the patients were distributed into subgroups with ligation of the common carotid artery (n=17) and ligation of branches of the external carotid artery (n=25). The formation of groups was carried out retrospectively based on the analysis of the operating protocols and medical documentation, and no reallocation of patients between the groups was performed during the study. The analysis of functional changes in sensory analysers with different extents of surgical intervention was primarily descriptive in nature and was aimed at identifying the direction, structure and temporal dynamics of changes in the postoperative period, without calculating integral quantitative indicators of the degree of severity of disorders.

The baseline demographic and clinical characteristics of the study cohort are summarised in Table 1.

Table 1. Baseline clinical and demographic characteristics of the study cohort (n=42)

Characteristic	Value
Age, years, M±SD (range)	48.6±9.7 (29–68)
Male, n (%)	26 (61.9%)
Female, n (%)	16 (38.1%)
Nature of pathology	
Traumatic injury of major neck vessels, n (%)	24 (57.1%)
Tumour invasion of the vascular wall, n (%)	18 (42.9%)
Urgency of surgical intervention	
Emergency surgery, n (%)	19 (45.2%)
Planned surgery, n (%)	23 (54.8%)
Level of vessel ligation	
Common carotid artery, n (%)	17 (40.5%)
Branches of the external carotid artery, n (%)	25 (59.5%)

Note: M – mean value; SD – standard deviation.
Source: compiled by the authors based on the study cohort data.

Inclusion criteria: performance of surgical ligation of major neck vessels for traumatic, oncological or vascular indications; age 18 years and older; absence of clinically significant visual, auditory and vestibular function impairments before surgery; stable general condition in the postoperative period; ability of the patient to perform functional tests; written voluntary consent to participate in the study. Exclusion criteria: presence of pronounced sensory disorders diagnosed before surgery; previous strokes or transient ischaemic attacks in the medical history; severe chronic neurological diseases; decompensated cardiovascular, endocrine or somatic conditions; previous operations on the vessels of the head and neck; postoperative complications preventing functional examination; patient's refusal to further participate in the study. During the cohort observation, no dropout of participants was registered. All patients included in the study completed the stipulated examination protocol and were accounted for in the statistical data processing.

Methods for Assessing the Function of Sensory Analysers

Baseline indicators of the functions of the visual, auditory and vestibular analysers were recorded prior to surgical intervention in all cases where the patient's clinical condition allowed examination without delaying surgical treatment. In emergency indications for surgery (traumatic injuries of neck vessels), the baseline level of sensory functions was determined by using information contained in the patient's medical documentation (outpatient record, extracts from previous medical examinations), as well as from the results of a brief clinical-neurological and otorhinolaryngological examination performed in the preoperative period to an extent that did not impede the provision of emergency surgical care (such cases numbered 9 (21.4%)). Surgical intervention was not postponed for the sake of conducting complete functional testing.

Postoperative disorders of the sensory analysers were identified by using a combined diagnostic approach that included both subjective patient-reported complaints and objective clinical or instrumental assessment. Subjective symptoms were recorded during clinical examination, while visual, auditory and vestibular dysfunctions were evaluated by using the corresponding functional and instrumental methods described below. Thus, the assessment of postoperative sensory disorders was based on the integrated interpretation of subjective and objective findings rather than on patient complaints or instrumental measurements alone.

Assessment of the function of the visual analyser included recording subjective visual complaints, as well as determination of visual acuity and ophthalmological examination. Visual acuity was determined separately for each eye with and without correction by using Sivtsev–Golovin tables; the results were recorded indicating Vis OD (visual acuity of the right eye) and Vis OS (visual acuity of the left eye). For an approximate assessment of visual fields, the confrontation perimetry method was used; when indicated, computer perimetry was performed on a *Humphrey Field Analyzer* 3 automated perimeter (*Carl Zeiss Meditec*, Germany). To assess the condition of the fundus, direct ophthalmoscopy was performed by using a *HEINE Beta 200* ophthalmoscope (Germany) with descriptive recording of the condition of the optic disc and retinal vessels, which made it possible to identify signs of ischaemic and vascular changes. The examination was performed by an ophthalmologist with a current specialist certificate and at least 5 years of clinical work experience.

The function of the auditory analyser was assessed on the basis of clinical and audiological examination. Complaints of hearing loss, tinnitus, asymmetry of auditory perception and deterioration of speech intelligibility were initially recorded. Otoscopy was performed by using a *Welch Allyn* otoscope (USA) to exclude pathology of the external auditory canal and tympanic membrane. For the primary assessment of the auditory function, Rinne and Weber tuning fork tests were used at a frequency of 512 Hz. Quantitative assessment of the auditory function was carried out by pure-tone threshold audiometry with determination of air and bone conduction thresholds in the frequency range of 0.25–8 kHz using an *Interacoustics AC40* clinical audiometer (Denmark). The degree and nature of hearing loss were determined from audiogram data. When indicated, impedancemetry was additionally performed with recording of tympanograms and acoustic reflexes on an *Interacoustics AT235* analyser (Denmark). Audiological and otorhinolaryngological examination was conducted by an otorhinolaryngologist with specialised medical education, current authorisation for clinical practice, and practical experience working in the specialty in a hospital setting.

Assessment of the function of the vestibular analyser was carried out on the basis of analysis of subjective complaints and data from clinical otoneurological examination. Episodes of dizziness, balance disorders, provoking factors and accompanying vegetative manifestations were recorded. Clinical examination included assessment of spontaneous nystagmus, performance of coordination tests and tests of static-locomotor stability. To identify peripheral and central vestibular disorders, positional tests, the clinical Head Impulse Test (rapid passive head rotation to assess the adequacy of the vestibulo-ocular reflex), as well as functional Romberg and tandem walking tests were used. The clinical Head Impulse Test was applied in the postoperative period provided the postoperative wound was stable, there was no pain syndrome, and with limitation of the amplitude of passive head rotation to physiologically acceptable values (≈10–15°). The obtained data were recorded descriptively, indicating the presence, severity and persistence of the identified disorders. Assessment of the function of the vestibular analyser and recording of the obtained data were carried out by an otorhinolaryngologist with specialised training in otoneurology and authorisation for clinical practice in the specialty.

Dynamic follow-up was conducted according to an identical diagnostic algorithm at all control points. Repeated assessment of the functions of sensory analysers was performed on day 5, day 14 and 1 month after surgical intervention. The choice of these time points was determined by the need to record early and subacute functional changes during the period of postoperative state stabilisation and the formation of compensatory reactions. The control point at 1 month was considered as the stage of completion of early postoperative adaptation and stabilisation of neurosensory functions.

Assessment of Haemodynamic Parameters

Regional haemodynamics were assessed by means of ultrasound duplex scanning of extracranial neck vessels. Assessment of the vascular bed encompassed the common (CCA), internal and ex-

ternal carotid arteries along with the vertebral arteries. Ultrasound examination was performed by using a *GE Logiq P7* diagnostic system (*GE Healthcare*, USA), equipped with a linear transducer at a frequency of 7–12 MHz. During the study, indicators of the peak systolic blood flow velocity and end-diastolic velocity in the CCA were recorded, as well as the resistance index (RI), characterising the state of peripheral vascular resistance. Additionally, the peak systolic blood flow velocity in the vertebral arteries was assessed, which made it possible to judge the redistribution of the regional blood supply after surgical intervention. Assessment of cerebral haemodynamics was carried out by means of transcranial Dopplerography using a *DWL Doppler Box X* ultrasound device (Compumedics Germany GmbH, Germany). The study was conducted through standard acoustic windows with analysis of the blood flow in the middle cerebral artery (MCA), anterior cerebral artery (ACA) and posterior cerebral artery (PCA). Mean linear blood flow velocities in these arteries were recorded, as well as the pulsatility index (PI), which was used as an indirect indicator of the state of cerebral perfusion and cerebral autoregulation.

Baseline haemodynamic parameters were recorded in the preoperative period in patients with planned surgical intervention. In cases of emergency ligation of major neck vessels, baseline parameters were established by using data from ultrasound examination performed upon admission, or on the basis of information from the last objective vascular examination reflected in the medical documentation. Repeated haemodynamic measurements were performed synchronously with the assessment of sensory analyser functions at the same control points (on day 5, day 14 and 1 month after surgery) by using identical methods and measurement parameters, which ensured comparability of the results over time. Ultrasound examinations and interpretation of haemodynamic parameters were performed by a functional diagnostics physician with current authorisation to conduct ultrasound vascular examinations and practical experience in the field of vascular diagnostics.

Method and Instruments for Surgical Ligation of Major Neck Vessels

Ligation of major neck vessels was performed by using an open surgical method under direct visual control. Surgical access was achieved through a standard neck incision with layered dissection of soft tissues and isolation of the neurovascular bundle. For mobilisation and temporary control of the vessel, atraumatic vascular instruments were used, including DeBakey and Satinsky vascular clamps, allowing controlled occlusion without pronounced traumatisation of the vascular wall. Isolation and handling of vessels were carried out by using DeBakey blunt-tipped dissectors, as well as anatomical and microsurgical forceps. Ligation of major vessels was performed by using non-absorbable polypropylene suture material – Prolene (*Ethicon*, *Johnson & Johnson*, USA) of calibre 3/0–4/0, depending on the diameter of the vessel. Ligatures were applied proximal and distal to the zone of the pathological process, followed by the visual control of the adequacy of haemostasis. When necessary, additional haemostatic control was achieved by using electrosurgical coagulation. The tactics of the intervention were oriented towards gentle tissue handling and limiting impact on adjacent anatomical structures. The nature and extent of the performed surgical intervention were recorded on the basis of data from the operating protocol and used for descriptive interpretation of the features of postoperative functional changes.

Statistical Analysis Methods

For processing the results of the study, a set of descriptive and analytical statistical approaches was used. Quantitative data were summarised by using mean values (M) and standard deviations (SD), whilst qualitative indicators were analysed by absolute and relative frequencies (%). To analyse the dynamics of quantitative indicators, Student's t-test for paired samples or the Wilcoxon test was applied, depending on the nature of the data distribution, which was assessed by using the Shapiro-

Wilk test. Relationships between haemodynamic parameters and the functions of sensory analysers were analysed by correlation analysis using Pearson or Spearman coefficients. Statistical significance of differences and correlations was assessed at a significance level of $p<0.05$. Data processing was performed by using the *IBM SPSS Statistics* software package, version 28.0 (*IBM Corp*., USA).

Ethical Standards

During the conduct of the study, the ethical principles set forth in the Declaration of Helsinki [11] were observed, as well as the provisions of Good Clinical Practice [12]. The research protocol was reviewed and approved by the Local Bioethics Committee of the I. K. Akhunbaev Kyrgyz State Medical Academy (Protocol No. 3 of 28 December 2023). All patients were informed about the aims, methods and possible risks of the study and provided written voluntary informed consent to participate. Confidentiality of personal data was ensured in accordance with applicable ethical and legal requirements at all stages of the research.

Results

Dynamics of the Functional State of Sensory Analysers in the Postoperative Period

In the postoperative period, the patients exhibited temporary disturbances of sensory functions, the nature and dynamics of which varied depending on the analyser involved and the stage of observation. The most pronounced functional shifts were recorded in the early period after surgical intervention, followed by a tendency towards partial or complete regression. The obtained results made it possible to characterise the dynamics of disturbances of visual, auditory, and vestibular functions in comparison with the preoperative level (Table 2).

Table 2. Dynamics of indicators of the sensory analyser function in the postoperative period (n=42)

Indicator	Before surgery	Day 5	Day 14	After 1 month
Visual analyser				
Visual acuity Vis OD, M±SD	1.0±0.0	0.86±0.14*	0.91±0.11*	0.96±0.08
Visual acuity Vis OS, M±SD	1.0±0.0	0.84±0.16*	0.90±0.12*	0.95±0.09
Patients with decreased visual acuity, n (%)	0 (0%)	9 (21.4%)	6 (14.3%)	3 (7.1%)
Auditory analyser				
Mean hearing threshold (better ear), dB, M±SD	18.2±4.1	26.5±7.34*	23.1±6.4*	20.4±5.2
Patients with sensorineural hearing loss, n (%)	0 (0%)	12 (28.6%)	8 (19.0%)	4 (9.5%)
Complaints of tinnitus, n (%)	0 (0%)	10 (23.8%)	7 (16.7%)	3 (7.1%)
Vestibular analyser				
Patients with dizziness, n (%)	0 (0%)	15 (35.7%)	9 (21.4%)	5 (11.9%)
Positive positional tests, n (%)	0 (0%)	11 (26.2%)	7 (16.7%)	3 (7.1%)
Impaired stability (Romberg test), n (%)	0 (0%)	13 (31.0%)	8 (19.0%)	4 (9.5%)

Note: M – mean value; SD – standard deviation; * – differences are statistically significant compared with the preoperative level ($p<0.05$).
Source: compiled by the authors based on the results of the study.

Analysis of the indicators presented in Table 2 showed that the most pronounced changes in the functions of sensory analysers were recorded in the early postoperative period – on day 5 after surgical intervention. During this period, a decrease in the function of the visual analyser was recorded

in 21.4% of the patients, which was accompanied by a reduction in visual acuity indicators. The mean value of Vis OD decreased from 1.0±0.0 to 0.86±0.14, and Vis OS to 0.84±0.16. At the same time, the identified changes were predominantly functional in nature and were not accompanied by gross ophthalmoscopic signs of organic damage to the optic nerve or retina. In the subsequent follow-up periods, a tendency towards restoration of visual functions was noted. By day 14 after surgery, the mean visual acuity indicators had increased (Vis OD – 0.91±0.11; Vis OS – 0.90±0.12), and the proportion of patients with a reduced vision decreased to 14.3%. One month after surgical intervention, reduced visual acuity persisted in only 7.1% of those examined, whilst the mean Vis values approached the baseline level. The obtained data indicate the transient nature of visual disturbances and the high capacity of the visual analyser for functional compensation under conditions of haemodynamic stabilisation.

More pronounced and persistent changes were identified on the part of the auditory analyser. In the early postoperative period, sensorineural hearing loss was recorded in 28.6% of the patients. This was confirmed by an increase in the mean hearing threshold in the better ear from 18.2±4.1 dB to 26.5±7.3 dB on day 5 after surgery. Simultaneously, 23.8% of those examined complained of tinnitus, which indicated functional involvement of cochlear structures under conditions of altered blood supply. During the follow-up, auditory function indicators demonstrated partial recovery. By day 14, the mean hearing threshold had decreased to 23.1±6.4 dB, and the frequency of sensorineural disorders decreased to 19.0%. One month after the surgery, hearing disorders persisted in 9.5% of the patients, whilst the mean hearing threshold was 20.4±5.2 dB. Despite the positive dynamics, the auditory analyser was characterised by slower and incomplete recovery compared to the visual analyser, which is associated with the high sensitivity of the cochlear apparatus to ischaemic influences.

Functional changes on the part of the vestibular analyser were most pronounced in nature. Already on day 5 after the surgery, complaints of dizziness and balance disorders were noted in 35.7% of the patients. Positive positional tests were recorded in 26.2%, and stability disorders in the Romberg test in 31.0% of those examined. These data indicate the high vulnerability of the vestibular system to changes in regional and cerebral haemodynamics occurring after ligation of major neck vessels. Subsequently, a gradual regression of vestibular disorders was observed. By day 14, the frequency of dizziness decreased to 21.4%, and, after 1 month, it persisted in 11.9% of the patients. Similar dynamics were noted according to functional test data: positive positional tests and stability disorders were recorded, respectively, in 7.1% and 9.5% of those examined 1 month after the surgery. Despite the pronounced positive dynamics, vestibular disorders demonstrated the greatest resistance to recovery compared to other sensory systems.

A comparative analysis of the results across different analysers revealed an unequal response of sensory systems to the surgical intervention and the haemodynamic shifts caused by it. In the early postoperative period, functional disorders of the vestibular and auditory analysers predominated, whilst the visual analyser was involved to a lesser extent. In 66.7% of the patients in whom sensory disorders were identified in the early postoperative period, their regression was observed during the first month. Thus, ligation of major neck vessels is accompanied by the development of temporary functional disorders of sensory analysers, the maximum severity of which is observed in the early period after surgical intervention. The persistence of residual disorders in some patients after 1 month underscores the clinical significance of early and systematic sensory monitoring in the postoperative period and justifies the need for a comprehensive assessment of sensory functions when analysing the functional outcomes of such interventions.

Changes in Regional and Cerebral Haemodynamics after Ligation of the Major Vessels of the Neck

In the postoperative period, quantitative changes in the indicators of regional and cerebral blood flow were recorded in the examined patients, reflecting the vascular system response to ligation of the major vessels of the neck. The dynamics of velocity and resistance parameters of circulation differed depending on the anatomical localisation of the studied vessels and the observation period. A comparison of the obtained values with preoperative parameters made it possible to characterise the features of haemodynamic changes presented in Table 3.

Table 3. Postoperative dynamics of regional and cerebral haemodynamics (n=42)

Indicator	Before surgery	Day 5	Day 14	After 1 month
Extracranial blood flow				
Peak systolic velocity in the CCA, cm/s, M±SD	78.4±11.6	61.2±13.8*	68.9±12.4*	74.1±11.9
End-diastolic velocity in the CCA, cm/s, M±SD	21.6±4.9	15.3±5.1*	18.4±4.6*	20.2±4.8
Resistance index in the CCA, M±SD	0.62±0.06	0.74±0.08*	0.69±0.07*	0.64±0.06
Peak systolic velocity in the vertebral arteries, cm/s, M±SD	41.8±7.9	48.6±9.4*	45.2±8.6*	42.7±7.8
Cerebral haemodynamics				
Mean linear velocity in the MCA, cm/s, M±SD	56.3±8.7	47.1±9.2*	51.8±8.9*	54.6±8.5
Mean linear velocity in the ACA, cm/s, M±SD	49.2±7.4	43.6±7.8*	46.9±7.2*	48.1±7.5
Mean linear velocity in the PCA, cm/s, M±SD	44.7±6.8	50.3±8.1*	47.6±7.3*	45.8±6.9
Vascular resistance index (PI), M±SD	0.89±0.07	1.02±0.09*	0.96±0.08*	0.91±0.07

Note: CCA – common carotid artery; MCA – middle cerebral artery; ACA – anterior cerebral artery; PCA – posterior cerebral artery; PI – pulsatility index; M – mean value; SD – standard deviation; * – differences statistically significant compared with the preoperative level ($p<0.05$).
Source: compiled by the authors based on the results of the study.

At the level of extracranial blood flow, the most pronounced changes were recorded on day 5 after surgical intervention. In the early postoperative period, a decrease in the peak systolic velocity in the common carotid artery to 61.2±13.8 cm/s was noted compared to the preoperative level of 78.4±11.6 cm/s, reflecting the sharp restriction of the linear blood flow due to the exclusion of the major vascular bed. A similar trend was noted for the end-diastolic velocity, which decreased to 15.3±5.1 cm/s, accompanied by a significant increase in the resistance index to 0.74±0.08. These changes reflected an increase in the peripheral vascular resistance and redistribution of the blood flow in the early postoperative period. By day 14 after the surgery, partial normalisation of the extracranial parameters was noted. The peak systolic velocity in the common carotid artery increased to 68.9±12.4 cm/s, and the resistance index decreased to 0.69±0.07; however, these parameters retained statistically significant differences from the baseline values. This indicates ongoing adaptive processes aimed at stabilising regional circulation. One month after the surgery, the main indicators of the extracranial blood flow approached the preoperative level, and statistically significant differences for most parameters were not detected, which indicates the completion of the early stage of haemodynamic compensation. Particular attention was merited by the dynamics of the blood flow in the vertebral arteries. On day 5 after the ligation of major neck vessels, a significant increase in the peak systolic velocity in the vertebral arteries was noted, to 48.6±9.4 cm/s compared to the baseline level (41.8±7.9 cm/s). This phenomenon reflects the involvement of the vertebrobasilar territory in the processes of collateral blood supply and compensatory redistribution of cerebral perfusion. By

day 14, the blood flow velocity in the vertebral arteries had decreased, and, after 1 month, it returned to values comparable to the preoperative ones, which confirms the transient nature of the identified changes.

Changes in cerebral haemodynamics demonstrated a similar phasic pattern. The most pronounced shifts were recorded in the middle cerebral artery territory, where the mean linear blood flow velocity on day 5 after the surgery decreased to 47.1±9.2 cm/s compared to the baseline level of 56.3±8.7 cm/s. Simultaneously, an increase in the pulsatility index to 1.02±0.09 was noted, which indicated an increase in the vascular resistance and a relative decrease in the cerebral perfusion in the early postoperative period. In the territories of the anterior and posterior cerebral arteries, the changes were less pronounced but unidirectional in nature. In the early postoperative period, the anterior cerebral artery was characterised by a decrease in the mean velocity parameters, whilst, in the posterior cerebral artery, a short-term increase in the blood flow velocity to 50.3±8.1 cm/s was observed. This fact testified to the redistribution of the cerebral blood flow with activation of the posterior parts of the cerebral blood supply, which correlated with the increased role of the vertebrobasilar system under conditions of an altered carotid inflow. By day 14 after the surgery, cerebral haemodynamic parameters showed a tendency towards normalisation; however, statistically significant differences from the baseline level persisted, especially in vascular resistance indicators. One month after surgical intervention, the mean linear blood flow velocities and vascular resistance indices in most cases did not differ from the preoperative values, which reflects the stabilisation of cerebral perfusion and the completion of early compensatory processes [13–15].

The obtained data show that the most critical period was the initial 5 days after surgery, characterised by a decrease in the carotid blood flow, an increase in vascular resistance and activation of alternative pathways of cerebral perfusion. The subsequent dynamics reflect the gradual compensation of haemodynamic disturbances, which created a pathophysiological basis for interpreting the sensory disorders identified in the previous subsection and their regression during the first month after surgical intervention.

Relationship of Functional Disorders of Sensory Analysers with Haemodynamic Parameters

Data analysis revealed a statistically significant relationship between the parameters of regional and cerebral circulation and the dynamics of the functional state of sensory analysers in the postoperative period. The nature of the identified correlations indicated an unequal sensitivity of sensory systems to changes in the blood supply after ligation of major neck vessels. The most pronounced and stable relationships were characteristic of the vestibular analyser, whilst the auditory analyser occupied an intermediate position, and the visual analyser demonstrated minimal dependence on the haemodynamic parameters.

Analysis of the vestibular function indicators revealed a close association between the parameters of the cerebral blood flow and the severity of clinical manifestations of balance disorders. The most pronounced inverse relationship was found between the velocity parameters of the blood flow in the posterior cerebral artery and the frequency of vestibular disorders ($r=-0.48$; $p<0.01$). This testifies that a decrease in perfusion in the vertebrobasilar territory was directly reflected in the functional state of the vestibular structures, including the brainstem nuclei and associated pathways. Additionally, a positive correlation identified between the pulsatility index in the posterior cerebral artery and the severity of vestibular disorders ($r=0.41$; $p<0.05$) indicated the adverse effect of an increased vascular resistance on the mechanisms of central balance compensation.

Significant correlations of vestibular disorders were also noted with indicators of regional haemodynamics. The frequency of dizziness and stability disorders increased with a decrease in the peak

systolic blood flow velocity in the common carotid artery (r=-0.39; $p<0.05$). This fact indicates the systemic nature of haemodynamic rearrangements after ligation of major neck vessels, in which, a decrease in the blood inflow through extracranial vessels could indirectly reduce cerebral perfusion, especially under conditions of limited compensatory capabilities [16,17].

Functional changes in the auditory analyser also demonstrated statistically significant, but less pronounced, correlations with the blood flow parameters. An increase in hearing thresholds was associated with a decrease in the mean linear blood flow velocity in the middle cerebral artery (r=-0.36; $p<0.05$) and the posterior cerebral artery (r=-0.31; $p<0.05$). This indicates the ischaemic vulnerability of the auditory analyser, whose blood supply is partially provided by structures sensitive to a decrease in cerebral perfusion. Simultaneously, an increase in the resistance index in the common carotid artery correlated with deterioration of the auditory function (r=0.29; $p<0.05$), which reflects the influence of extracranial haemodynamic factors on the formation of sensorineural hearing disorders. However, the lower strength of correlations compared to the vestibular analyser testifies to a higher capacity of the auditory system for functional compensation in the early postoperative period.

Correlations between the haemodynamic parameters and the function of the visual analyser were predominantly weak in nature [18]. Statistically significant positive relationships were identified between the visual acuity and the blood flow indicators in the common carotid and anterior cerebral arteries (r=0.28–0.29; $p<0.05$). At the same time, parameters of the posterior cerebral artery, which play a key role in the blood supply to the visual cortex, did not demonstrate significant correlations with visual indicators. This could reflect the preservation of collateral circulation and effective autoregulation of perfusion of the visual analyser, which reduced the severity of functional disorders even in the presence of regional haemodynamic changes. Summary data of the correlation analysis are presented in Table 4, which clearly illustrate the differences in the strength and direction of relationships between the blood flow parameters and the functions of sensory analysers at 1 month after the surgery.

Table 4. Correlation of haemodynamics and sensory functions 1 month after surgery

Haemodynamic indicators	Visual analyser	Auditory analyser (hearing threshold, dB)	Vestibular analyser
Peak systolic velocity in the CCA	r=0.28*	r=-0.34*	r=-0.39*
Resistance index in the CCA	r=-0.31*	r=0.29*	r=0.41*
Mean linear velocity in the MCA	r=0.26*	r=-0.36*	r=-0.33*
Mean linear velocity in the ACA	r=0.29*	r=-0.27	r=-0.30*
Mean linear velocity in the PCA	r=0.21	r=-0.31*	r=-0.48**
Pulsatility index (PI) in the PCA	r=-0.24	r=0.34*	r=0.41*

Note: CCA – common carotid artery; MCA – middle cerebral artery; ACA – anterior cerebral artery; PCA – posterior cerebral artery; PI – pulsatility index; * – $p<0.05$; ** – $p<0.01$.
Source: authors' own calculations based on correlation analysis.

The comparative analysis of the identified correlations made it possible to establish a hierarchy of the sensitivity of sensory analysers to haemodynamic changes: the vestibular analyser proved to be the most dependent on the indicators of cerebral and regional perfusion, the auditory analyser was moderately dependent, and the visual analyser was the least sensitive. The identified differences were due to the specifics of the vascular supply of the sensory systems and the unequal severity of compensatory reactions in the postoperative period.

Thus, the results of the correlation analysis confirmed the presence of pathophysiologically substantiated relationships between changes in haemodynamics and the functional state of the sensory

analysers. The obtained data indicate the key role of haemodynamic factors in the formation of postoperative sensory disorders and underscore the necessity of a comprehensive assessment of the blood flow when interpreting the functional outcomes of the ligation of major neck vessels.

Features of Functional Changes with Different Extents of Surgical Intervention

Analysis of the study results showed that the nature and severity of functional changes in sensory analysers after the ligation of major neck vessels varied depending on the clinical characteristics of the patients and the parameters of the surgical intervention. Analysis of the results revealed the presence of regular differences in the dynamics of sensory functions, associated with the type of pathological process, the urgency of the surgical intervention and the level of vascular ligation in the postoperative period.

When comparing patients operated on for traumatic indications and patients with tumour invasion of neck vessels, differences were identified in the structure and temporal characteristics of sensory disorders. In the group of traumatic vascular injuries, more pronounced functional changes predominated in the early postoperative period, which was probably associated with the combined impact of acute blood loss, traumatic damage to the surrounding tissues and the forced urgency of the surgical intervention. In these patients, transient vestibular disorders and subjective complaints of dizziness were more frequently recorded, which reflected the features of acute haemodynamic rearrangement. At the same time, in the dynamics of the follow-up, a tendency towards faster recovery of the sensory functions was noted in the majority of patients in this group, which could be due to the absence of a long-term chronic vascular exposure before the surgery.

In the group of patients with oncological indications, functional changes in sensory analysers were less acute but more prolonged in nature. In these cases, disorders were more often identified in the subacute period after the surgery and were characterised by greater resistance to regression during the first month of the follow-up. This feature could be associated with the preceding chronic impact of the tumour process on regional circulation, as well as with the greater extent and complexity of the surgical intervention. The obtained data indicate a difference in the mechanisms of formation of sensory disorders in traumatic and tumour lesions of neck vessels.

The features of functional changes depending on the level and extent of the ligation of major vessels required separate analysis. Functional disorders of sensory analysers manifested more pronouncedly with the ligation of the common carotid artery, whereas interventions on branches of the external carotid artery were accompanied by less significant changes. In these cases, combined disorders of the auditory and vestibular analysers were more frequently recorded, which reflects a more significant impact on total cerebral perfusion. The ligation of branches of the external carotid artery was accompanied by predominantly local and less pronounced functional changes, which, in most cases, were reversible in nature.

The urgency of the surgical intervention also influenced the postoperative dynamics of sensory functions. In patients who underwent emergency ligation of the major neck vessels, early functional disorders were more frequently identified, which was associated with the impossibility of full preoperative compensation and adaptation of cerebral circulation [19,20]. At the same time, in planned interventions, changes in sensory analysers were characterised by lesser severity and more favourable dynamics, which reflected the role of preoperative adaptation and compensatory mechanisms.

Age-related features of the patients were considered within the framework of descriptive analysis. In the patients of the older age groups, a tendency towards slower regression of identified functional disorders was observed, especially on the part of the auditory and vestibular analysers. This feature could be associated with age-related changes in the vascular wall and a decrease in the reserve capabilities of cerebral circulation [21–23]. At the same time, the obtained data did not allow consider-

ing age as an independent risk factor, but only indicated its modifying influence on the dynamics of recovery.

Data analysis testified to the key role of clinical factors and parameters of surgical intervention in the formation of sensory disorders in the postoperative period. This underscores the advisability of individualised interpretation of functional changes in sensory analysers, while taking into account the clinical context and the extent of the surgical impact.

Discussion

The conducted study showed that the ligation of major neck vessels is accompanied by the development of transient functional disorders of sensory analysers, mainly in the early postoperative period. The severity of changes decreased over the course of the follow-up, which indicates the formation of compensatory mechanisms. The vestibular analyser proved to be the most sensitive to haemodynamic shifts, whilst visual and auditory disorders were less pronounced and generally reversible in nature. The identified relationships with blood flow parameters suggested a possible association between haemodynamic alterations and the observed sensory changes.

After the ligation of major neck vessels, sensory disorders were most pronounced in the early postoperative period and showed progressive regression during the follow-up, with vestibular dysfunction being the most frequent and persistent manifestation. Similar functional complications after surgical interventions in the neck area were described by H. Jeyarajan and S. McCammon [24], who established the predominance of reversible sensory disorders associated with temporary changes in regional perfusion and postoperative neurovascular dysfunction. The data presented by these authors were consistent with the tendency towards a gradual recovery of sensory functions as haemodynamics stabilised, as identified in the present study. The predominant involvement of the vestibular analyser corresponded to the provisions set forth by D. Kaski et al. [25], where the high sensitivity of the balance system to short-term changes in the cerebral blood flow was demonstrated. The scientists noted that even moderate haemodynamic shifts could cause clinical manifestations of dizziness and instability without the formation of persistent organic damage.

The identified auditory disorders and their partial regression were consistent with the results of M. Soliman et al. [26], who demonstrated the vascular nature of audiological symptoms after interventions on neck vessels. The researchers showed that such manifestations, including tinnitus and hearing loss, are predominantly functional in nature and diminish with the restoration of regional blood supply. The obtained data also found confirmation in the work of V. Gray et al. [27], where the influence of carotid hypoperfusion on balance and coordination disorders was established even in the absence of pronounced neurological deficit. These observations were consistent with the high frequency of vestibular disorders recorded in the early postoperative period. At the same time, the less pronounced and rapidly regressing visual disorders partially diverged from the results of L. István et al. [28], who identified persistent microvascular changes in the retina in chronic carotid artery pathology. This divergence may be related to the acute nature of the haemodynamic changes and the preservation of autoregulation mechanisms of the visual analyser in the analysed cohort.

The haemodynamic findings demonstrated a transient reduction in carotid and cerebral blood flow accompanied by an increased vascular resistance in the early postoperative period, followed by a gradual return of the main parameters towards baseline values [29,30]. A similar directionality of disturbances in cerebral clearance and slowing of perfusion processes after intervention on cervical structures was experimentally demonstrated by S. Luo et al. [31], who showed that intervention in the cervical lymphatic pathways led to impaired metabolite clearance and exacerbation of neurological outcomes. The results of the present study were consistent with these findings, since

the increase in peripheral vascular resistance combined with a short-term decrease in velocity parameters of the blood flow could contribute to transient impairment of cerebral microcirculation in the early postoperative period. The role of the cervical vascular-lymphatic pathways as a functional module influencing the state of the central nervous system was also confirmed by W. Jiang et al. [32], who showed the involvement of the "brain – cervical lymph nodes" signalling axes in enhancing neuroinflammatory reactions after injury. In the context of the presented results, the identified haemodynamic shifts may have been associated with conditions favouring the activation of similar mechanisms and could potentially contribute to the high severity of early functional disorders and their relative reversibility as perfusion recovered.

The obtained data were consistent with the generalised observations of M. Piegza et al. [33], according to which, interventions on the carotid arteries are accompanied by changes in cerebral haemodynamics and functional parameters, especially in the early period, with subsequent stabilisation. At the same time, in contrast to studies devoted to reconstructive operations, the present study showed that, even with the ligation of a major vessel, compensatory mechanisms could ensure that the velocity parameters of the blood flow approach the baseline level within one month. The connection of vascular disorders at the cervical level with clinical manifestations, including cephalgic and vegetative symptoms, was discussed in detail by W. Wang et al. [34], who considered cervical vascular disorders as a trigger for functional neurological manifestations. The changes in velocity and resistive parameters of the blood flow in the extra- and intracranial territories identified in the conducted study corresponded to this concept and extended it, demonstrating quantitative characteristics of these shifts over time after surgical intervention. The interpretation of the obtained results fits into the understanding of the role of the glymphatic system in neurovascular pathology, formulated by T. Krings et al. [35]. The decrease in linear blood flow velocities and the increase in pulsatility indices in the early postoperative period could potentially limit the efficiency of glymphatic clearance, whilst the restoration of haemodynamic parameters by 1 month created prerequisites for the normalisation of drainage and compensatory processes.

Correlation analysis indicated that the association with haemodynamic parameters was strongest for the vestibular function, moderate for the auditory function and comparatively weak for the visual function. This pattern suggests a greater sensitivity of the vestibular analyser to changes in the cerebral blood flow [36,37]. The identified dependence between the blood flow parameters and the vestibular function was consistent with the concept of glymphatic and lymphatic brain clearance set forth by Z. He and J. Sun [38]. The authors showed that impairment of vascular pulsation and perfusion gradients limits the efficiency of brain drainage mechanisms, which contributes to the persistence of functional disorders even after the stabilisation of macrocirculatory haemodynamics. The obtained data partially corresponded with the results presented by W. Dorigo et al. [39], where the persistence of functional disorders of the cranial nerves and the vestibulocochlear system after carotid artery interventions was demonstrated in the absence of gross ischaemic complications. In contrast to these results, reversible functional disorders without signs of structural damage predominated in the present work, which may help explain the moderate strength of the identified correlations.

Experimental results by T. Chotirungsan et al. [40] confirmed the high sensitivity of the sensorimotor and vestibular functions to unilateral exclusion of the carotid blood flow. The researchers established that, even in the absence of necrotic tissue changes, perfusion disturbances led to persistent functional shifts, which was consistent with the correlations found between the blood flow parameters and vestibular symptomatology. Additional confirmation of the identified relationships is presented in the study by S. Miyake et al. [41], where impairment of the vestibulo-ocular reflex suppression was considered a sensitive marker of reduced cerebral perfusion. The demonstrated

dependence between the parameters of posterior cerebral circulation and vestibular dysfunction corresponded to the results of the present study and extended the clinical interpretation in patients after the ligation of major neck vessels. Data from L. Gil et al. [42] complemented the obtained results, indicating that carotid artery ligation compared to reconstructive interventions was associated with more pronounced functional, but not always structural, neurological disorders. The work emphasised that such changes were predominantly transient in nature and mediated by haemodynamic rearrangement, which is fully consistent with the correlations identified in the present study.

The side of vascular intervention may also influence the spatial pattern of postoperative haemodynamic changes. Recent perfusion studies have demonstrated that unilateral carotid occlusion or stenosis is associated with more pronounced reduction of the cerebral blood flow in the ipsilateral hemisphere, although compensatory collateral circulation may also modify perfusion in the contralateral hemisphere [43,44]. These haemodynamic asymmetries could potentially contribute to differences in visual, auditory and vestibular functional responses depending on the vascular territory involved; however, the available evidence does not support a consistent predominance of adverse effects after either right- or left-sided intervention. In the present study, outcomes were not analysed separately according to the right or left side of vessel ligation; therefore, no conclusions regarding side-specific differences in the sensory function can be drawn. Further studies with stratification by the side of intervention and assessment of collateral cerebral circulation are required to clarify this relationship.

The results of the study showed that the severity and dynamics of sensory disorders after the ligation of major neck vessels varied according to the clinical context and the extent of the intervention: in traumatic indications, early transient disorders with rapid regression predominated, whereas, in oncological vascular invasion, the changes were less acute but more prolonged in nature; the ligation of the common carotid artery was accompanied by more pronounced combined disorders compared to interventions on branches of the external carotid artery. The results of the present study correlated with the data of J. Asensio et al. [45], indicating that, in penetrating lesions of the common and internal carotid arteries, the severity of neurological complications largely depended on the urgency of the surgical intervention and the degree of loss of the major blood flow. The authors' study emphasised that the absence of preoperative compensation in emergency operations increases the risk of functional disorders, which corresponds to the higher frequency of early sensory disorders identified in this work in traumatic patients. A similar position was taken by L. Jenkins and J. Rezende-Neto [46], who indicated that emergency interventions on neck vessels were associated with more pronounced physiological destabilisation and limited adaptive capabilities of the cerebral circulation. The differences between emergency and planned ligations obtained in the present study were consistent with this interpretation and extended its clinical context through the analysis of sensory analysers as sensitive indicators of haemodynamic rearrangement.

The role of the extent and level of vascular exclusion correlated with the data from X. Wang et al. [47], who showed that, even when unilateral cerebral perfusion is ensured in conditions of major vascular interventions, the degree of functional consequences depends on the length and anatomical significance of the excluded segment. In the conducted study, the more pronounced disorders observed with the ligation of the common carotid artery were consistent with this principle, although a causal relationship cannot be established from the present observational data. The comparison of traumatic and oncological patients was consistent with the results of K. Sun et al. [48], demonstrating that, in carotid artery tumour invasion, functional outcomes are determined by the duration of the preoperative vascular impact and the complexity of surgical tactics. The prolonged nature of sensory disorders in the oncological group in this study did not contradict their findings. At the same time, data from S. Okochi et al. [49], obtained in a neonatal cohort, indicated a high

plasticity of cerebral compensatory mechanisms after carotid artery ligation or reconstruction. In contrast to these results, in the adult cohort of the present study, the recovery was slower and more variable in nature, which underscores the significance of age and clinical background as modifying, but not independent, risk factors.

The obtained results demonstrated the regular nature of postoperative sensory and haemodynamic changes after the ligation of major neck vessels and were consistent with data from other scientific experimental and clinical studies. The identified transience of disorders, the phasic nature of haemodynamic rearrangement and the leading role of compensatory mechanisms of cerebral circulation correspond to the published concepts of vascular adaptation and neurosensory vulnerability in carotid interventions. The obtained data supplement existing knowledge, while clarifying the clinical determinants and temporal characteristics of functional recovery.

Conclusions

The conducted study demonstrates that the ligation of major neck vessels was associated with the development of transient disorders of sensory analyser functions in 66.7% of the patients, reflecting the response of neurosensory systems to changes in the regional and cerebral perfusion. The maximum severity of disorders was recorded on day 5 after the surgery. The most vulnerable proved to be the vestibular analyser (35.7%), whilst auditory (28.6%) and visual (21.4%) disorders were identified less frequently and were less pronounced in nature. The gradual regression of symptoms with a decrease in the frequency of disorders by the 1st month of the follow-up (to 7.1–11.9%) testified to the predominantly functional nature of the changes and the activation of compensatory mechanisms of cerebral circulation.

Haemodynamic shifts in the postoperative period were phasic in nature. In the early period, a decrease in linear blood flow velocities in the carotid territory and the middle cerebral artery was noted (in the CCA – from 78.4±11.6 to 61.2±13.8 cm/s; in the MCA – from 56.3±8.7 to 47.1±9.2 cm/s), accompanied by an increase in vascular resistance (PI to 1.02±0.09). Simultaneously, a compensatory increase in the blood flow in the vertebral and posterior cerebral arteries was recorded, reflecting a redistribution of perfusion with the involvement of the vertebrobasilar territory. By day 14, the changes were partially levelled out, and, after 1 month, most parameters approached the baseline values, which indicated the completion of the early stage of adaptation.

Correlation analysis demonstrated associations of sensory disorders with changes in the regional and cerebral blood flow. The most pronounced dependencies were characteristic of the vestibular analyser (with parameters of the vertebrobasilar blood flow: r=-0.48; $p<0.01$; with the pulsatility index: r=0.41; $p<0.05$). The auditory analyser demonstrated moderate correlations (r=-0.31…-0.36), whilst the visual analyser showed minimal dependence on the haemodynamic parameters. The severity and duration of the disorders depended on the clinical context and the extent of the intervention: in traumatic indications, early but rapidly regressing disorders predominated, whereas, in tumour invasion of vessels, the changes were more prolonged in nature. Ligation of the common carotid artery, emergency surgery and older age were associated with less favourable recovery dynamics.

A limitation of the study was that the dynamic follow-up was confined to the early postoperative period, which did not allow for the analysis of possible long-term functional outcomes. Additional limitations include the single-centre design, the relatively small sample size and the absence of a control group. These factors may limit the generalisability of the findings and, together with the observational nature of the study, preclude definitive conclusions regarding causal relationships between haemodynamic changes and postoperative sensory disorders. In further research, it is recom-

mended to extend the follow-up period and to include control points at 3 and 6 months after the surgery, involve larger multicentre cohorts and appropriate control groups, while supplementing the protocol with standardised instrumental and questionnaire-based methods, in order to clarify the persistence/reversibility of sensory disorders and the factors determining their long-term prognosis.

Author contributions

S. B.: Conceptualization, Methodology, Investigation, Formal Analysis, Data Curation, Writing – Original Draft Preparation, Writing – Review & Editing.
E. A.: Methodology, Investigation, Validation, Writing – Review & Editing.
H. U.: Investigation, Data Curation, Visualization, Writing – Original Draft Preparation.
I. A.: Methodology, Formal Analysis, Writing – Review & Editing.
M. Z.: Supervision, Project Administration, Validation, Writing – Review & Editing.

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