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INTRAOPERATIVE NEUROPHYSIOLOGICAL MONITORING IN PATIENTS WITH DELAYED CEREBRAL ISCHEMIA AFTER CLIPPING OF RUPTURED ARTERIAL ANEURYSMS

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Aim. Research of significant changes in parameters (SCP) by intraoperative neurophysiological monitoring (IONM) during clipping of ruptured cerebral aneurysms in patients with delayed cerebral ischemia (DCI) in the postoperative period.
Materials and methods. The study included 16 patients, 7 (43.8 %) men and 9 (56.2 %) women, aged 51.1 ± 9.3 years, who underwent clipping of ruptured cerebral aneurysms for the period 2016–2021, in which the neurological deficit (ND) remained at the preoperative level on the first postoperative day, but increased by the end of hospitalization. In order to study the factors leading to the development of DCI, 2 groups were identified with transient SCP according to IONM: with the development of DCI – 7 patients out of the above 16 patients, including 3 men (42.9 %) and 4 women (57.1 %), aged 49.6 ± 8.5 years; and control group – 19 patients, including 9 men (47.4 %) and 10 women (52.6 %), aged 46.2 ± 10.9 years, in whom ND did not increase on the first postoperative day and by the time of discharge. The groups did not differ significantly in age, sex, aneurysm location, rupture period, and baseline ND.
Results. In patients with DCI, in 9 cases (56.2 %), during the operation, SCP from the side of somatosensory evoked potentials (SSEP) and transcranial motor evoked potentials (TcMEP) was not registered, in 7 cases (43.8 %) transient SCP was registered, of which 3 patients (42.8 %) had TcMEP and SSEP, in 2 patients (28.6 %) – only TcMEP and in 2 patients (28.6 %) – only SSEP. In the control group, transient SCR of TcMEPs and SSEPs were registered in 4 patients (21.6 %), only TcMEPs – in 9 patients (47.4 %), only SSEPs – in 6 patients (31.6 %).
When comparing two groups of patients with transient SCR (DCI-group and control group), a statistically significant predominance was revealed in the first group of patients with severity 3 according to the Hunt–Hess scale (42.9 % *vs* 5.2 %), while in the second group patients of severity 1 and 2 prevailed (94.8 % *vs* 57.2 %) ($p < 0.05$). When analyzing the data of ultrasonic duplex scanning of extra- and intracranial arteries in both groups, a statistically significant increase in peak systolic blood flow velocity in the middle cerebral artery was revealed (in the group with DCI before surgery – 100 (80–139) cm/s, after surgery – 175 (139–278) cm/s ($p = 0.001$), in the control group before surgery – 100 (100–118) cm/s, after surgery – 150 (116–194) cm/s ($p = 0.0001$)), as well as the Lindegaard index (in the group with DCI before surgery – 2.5 ± 0.7, after surgery – 3.5 ± 1.1 ($p = 0.01$), in the control group before surgery – 2.1 ± 0.3, after surgery 2.9 ± 1.1 ($p = 0.0002$)), but the differences between the groups were not statistically significant ($p = 0.092$).
Conclusion. At this stage, it cannot be unequivocally stated that transient SCP according to IONM may be one of the risk factors for the development of DCI after clipping of ruptured cerebral aneurysms. However, patients with transient SCR according to IONM, whose severity at admission is estimated at 3 points on the Hunt–Hess scale, are statistically significantly more likely to develop DCI.

Keywords: intraoperative neurophysiological monitoring, transcranial motor evoked potentials, somatosensory evoked potentials, delayed cerebral ischemia

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BACKGROUND

Aneurysmal subarachnoid hemorrhage (SAH) is characterized by blood extravasation into the subarachnoid space due to rapture of an intracranial arterial aneurysm and presents a type of hemorrhagic stroke associated with high mortality and disablement [1].

Delayed cerebral ischemia (DCI) is appearance of focal neurologic deficits or depression of the level of consciousness by 2 or more points per the Glasgow scale for more than 1 hour manifesting on day 3 and later after aneurysmal SAH or at day 2 or later after aneurysm occlusion, as well as detection of infarction area using spiral computed tomography (SCT) or magnetic resonance imaging (MRI) of the brain in the 6 weeks after aneurysmal SAH or at the last examination before death in the first 6 weeks, or during autopsy (but if it is absent per SCT or MRI performed between 24 and 48 hours after early aneurysm occlusion) not associated with other causes [2]. DCI is considred one of the leading causes of unfavorable SAH outcomes. Overall DCI incidence in patients with aneurysmal SAH is 29 (20–40) %, and it has not been decreasing in the last 20 years [1, 3, 4].

Despite developments in DCI pathogenesis research, the pathological mechanisms and risk factors of this phenomenon are not completely clear. According to the current understanding of DCI, it is a dynamically developing multifactorial process. The discrepancy between increased requirement of the brain tissue in oxygen, on the one hand, and decreased or absent increase in cerebral blood flow, on the other, plays the key role in DCI pathogenesis (see Figure) [5, 6].

Understanding of the precise mechanisms leading to DCI development is important for development of new treatment approaches [3]. To avoid unreasonably long stay in the intensive care unit, preventative and therapeutic treatment of DCI should be directed primarily at patients with the highest risk. Therefore, it can be useful to differentiate patients with aneurysmal SAH in moderately sever condition into groups with low and high risk of DCI [7].

To this date, a lot of data on clinical, anamnestic, instrumental (including radiological, ultrasound, electrophysiological), as well as biochemical and genetic predictors of DCI have been accumulated [7–9]. However, intraoperative factors of DCI risk require further investigation.

Intraoperative neurophysiological monitoring (IONM) plays a significant role in evaluation of regional cerebral perfusion in the pathologically affected blood supply system, as well as evaluation of the condition of functionally crucial areas of the brain. The literature describes cases of DCI development without significant changes in transcranial motor evoked potentials (TcMEP) and somatosensory evoked potentials (SSEP) during surgery.

In 2017, F. Ghavami et al. published a report on a case of permanent loss of SSEP cortical response in a patient during X-ray endovascular occlusion of a fusiform partially thrombosed aneurysm of the P2 segment of the posterior cerebral artery. On day 2 after surgery, the patient had transient weakness in the left arm which regressed after controlled increase of mean arterial pressure. On day 3 after cancellation of inotropic support and transfer to a general ward, the patient developed marked left-sided hemiparesis. MRI showed an area of ischemia in the right optic thalamus. In this case, significant changes in SSEP indicated decreased cerebral blood flow which did not manifest clinically due to controlled increase of mean arterial blood pressure during surgery. Clinical manifestations developed only after cancellation of inotropic support which worsened focal ischemia [10].

In the available literature, we did not find any descriptions of DCI development in the postoperative period in combination with transient significant changes in TcMEPs and/or SSEP during surgery.

Aim. To study significant changes in parameters (SCP) detected by intraoperative neurophysiological monitoring (IONM) during clipping of ruptured cerebral aneurysms in patients with delayed cerebral ischemia (DCI) in the postoperative period.

MATERIALS AND METHODS

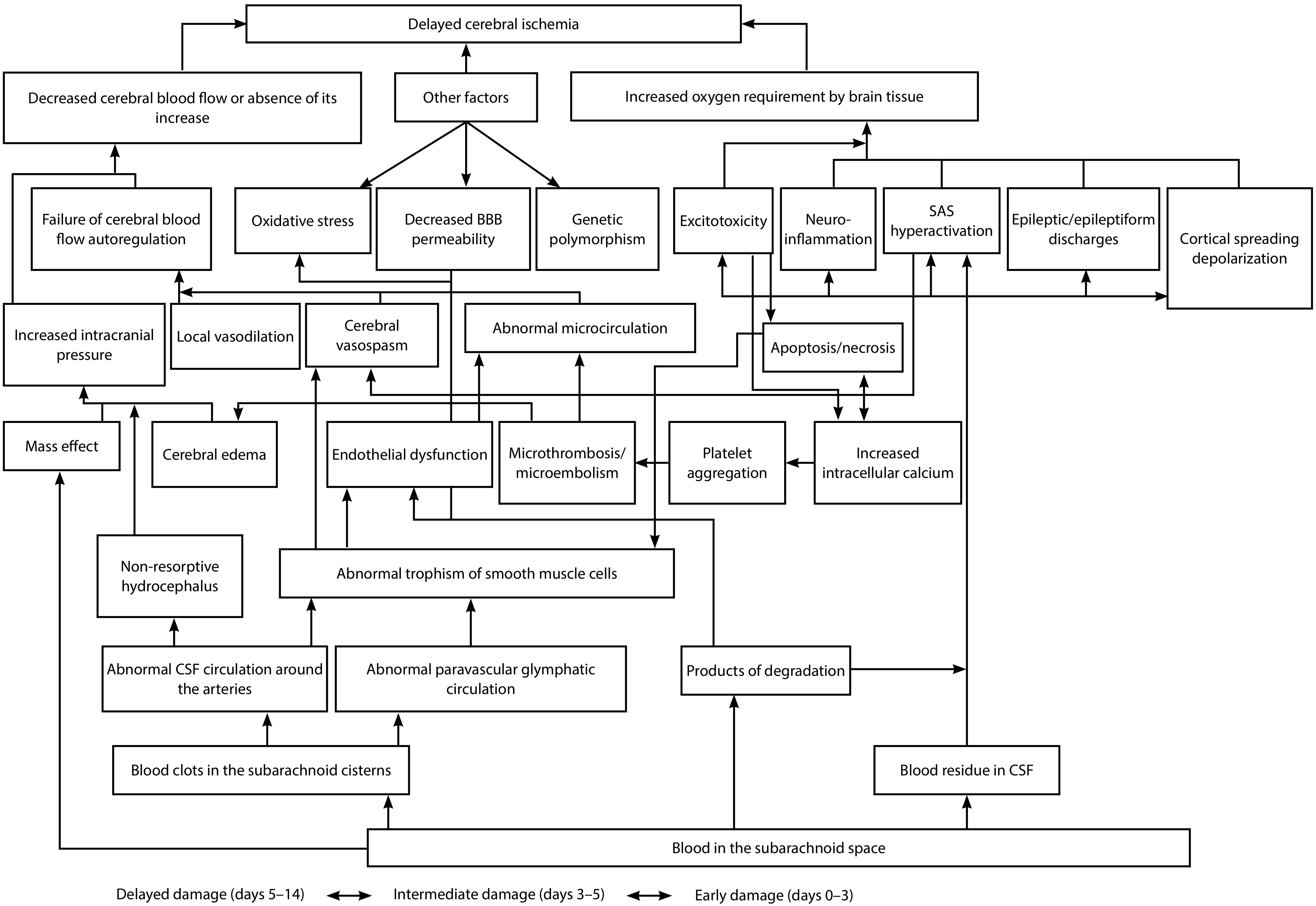
The retrospective study included 16 patients (7 (43.8 %) men and 9 (56.2 %) women) aged 51.1 ± 9.3 years who underwent surgeries to treat ruptured aneurysms of cerebral vessels using IONM at the Neurosurgery Division of the Irkutsk "Mark of Honor" Order Regional Clinical Hospital between 2016 and 2021 and in whom on the 1st postoperative day neurologic deficit (ND) remained on the preoperative level but increased at the end of hospitalization.

The criteria for inclusion in the study were clinical DCI criteria: development of focal neurologic symptoms and/or depression of the level of consciousness by 2 or more points per the Glasgow scale for more than 1 hour manifesting on day 2 or later after clipping of a ruptured aneurysm of cerebral vessel.

Exclusion criteria: 1) only instrumental signs of vasospasm per transcranial Doppler ultrasound or presence of hypodense zones per SCT but absence of clinical manifestations of DCI; 2) other causes of new ND and/or depressed level of consciousness detected through clinical evaluation, neuroimaging, and laboratory tests.

Among the patients, 5 (31.2 %) had aneurysms of the anterior cerebral/anterior communicating artery, 9 (56.3 %) had aneurysms of the internal carotid/middle cerebral artery, 2 (12.5 %) had multiple aneurysms. SCT angiography showed normal structure of the circle of Willis in 4 (25.0 %) cases; in 12 cases (75.0 %) it was incomplete: in 8 due to hypo- and aplasia of the anterior communicating arteries, in 4 cases due to hypo- and aplasia of the posterior communicating artery.

In all 16 patients, ruptured aneurysms were clipped; in the acute period in 12 (75 %) patients, in the subacute period in 4 (25 %) patients.



Key points of the delayed cerebral ischemia pathogenesis (according to [3, 6, 9, 11, 12]). SAS – sympatho-adrenal system; CSF – cerebrospinal fluid; BBB – blood-brain barrier

Table 1. *Comparative characteristics of patients' groups with transient significant response changes, according to intraoperative neurophysiological monitoring data*

Parameter	DCI group (*n* = 7)	Control group (without increasing of ND) (*n* = 19)	*p*
Age, years	49.6 ± 8.5	46.2 ± 10.9	0.899
Sex *n* (%): male female	 3 (42.9) 4 (57.1)	 9 (47.4) 10 (52.6)	0.350
Length of stay in hospital, days	16.7 ± 6.3	18.6 ± 8.4	0.796
Localization of aneurysm, *n* (%): anterior circulation middle circulation multiple	 4 (57.1) 2 (28.6) 1 (14.3)	 13 (68.4) 6 (31.6) 0	0.615
Period of rupture *n* (%): acute subacute remote	 6 (85.7 %) 1 (14.3 %) 0	 15 (78.9) 3 (15.8) 1 (5.3)	0.831
Severity on the Hunt–Hess scale, *n* (%): I II III	 3 (42.9) 1 (14.3) 3 (42.9)	 6 (31.6) 12 (63.2) 1 (5.2)	0.026*
Severity of SAH on the Fischer scale, *n* (%): I II III IV	 1 (14.2) 2 (28.6) 2 (28.6) 2 (28.6)	 3 (15.7) 4 (21.1) 8 (42.1) 4 (21.1)	0.179
NIHSS, score: initial final	 1 (0–10) 5 (0.5–31.0)	 1 (0–2) 0 (0–0)	 0.074 0.037**
Temporary clipping of aneurysm, *n* (%): yes no	 5 (71.4) 2 (28.6)	 14 (73.7) 5 (26.3)	0.939
Продолжительность временного клипирования, с Temporary clipping duration, s	263.5 (151.25–480.0)	150 (106.5–235.0)	0.091

**Statistically significant differences according to the χ^2 criterion; **statistically significant differences according to the Mann–Whitney test.*
Note. *DCI – delayed cerebral ischemia; ND – neurological deficit; SAC – subarchnoid hemorrhage; NIHSS – National Institutes of Health Stroke Scale.*

Evaluation of the severity of SAH in patients with ruptured aneurysms per the Hunt–Hess scale was the following: grade I – in 6 (37.5 %) patients, grade II – in 3 (18.7 %), grade III – in 7 (43.8 %). SAH grade per the Fischer scale: I – in 2 (12.5 %) patients, II – in 3 (18.7 %), III – in 5 (31.3 %), IV – in 6 (37.5 %).

Temporary clipping of the parent artery lasting on average 200 s (115–395 s) was performed in 8 (47.1 %) cases; among them, in 3 (37.5 %) cases the artery was clipped multiple times, in 5 (62.5 %) cases one time.

ND severity was evaluated prior to surgery during hospitalization and on day 3 (1–13) from the moment of rupture, day 1 after surgery, day 6 (3–16) after rupture, at discharge, day 25 (17–31) after rupture using the National Institute of Health Stroke Scale (NIHSS).

To study the factors leading to DCI development in patients with transient SCP per IONM, we formed a control group of 19 patients (9 men (47.4 %) and 10 (52.6 %) women) aged 46 (41.0–54.5) years who also had transient SCP during surgery. TcMEP changes were observed in 9 (47.4 %) patients, SSEP changes in 6 (31.6 %) patients, both TcMEP and SSEP changes in 4 (21.6 %) patients, but in all patients of the control group ND did not increase on day 1 after surgery and at the time of discharge.

All patients underwent high-resolution duplex scan of the extracranial parts of the brachiocephalic arteries and transcranial Doppler ultrasonography (TCD) per the standard technique using portable ultrasound systems Sonosite M-turbo (Fujifilm SonoSite Inc., Japan) and Sonoscape S8 (SonoScape Co. Ltd., China) with electronic broadband multi-frequency probes with scanning frequency between 5 and 9 MHz and 1–4 MHz broadband array probes, respectively. During TCD of the extracranial parts of the brachiocephalic arteries, internal carotid arteries in the extracranial sectors (cervical parts, C1 segments per A. Bouthillier) were visualized and located. During ultrasound in 2D gray scale mode and color and spectral Doppler modes, patency of the carotid arteries was evaluated. At the linear part without areas of physiological and pathological turbulence, peak systolic velocity (PSV) was measured. TCD allowed to visualize and locate color maps of flows in the middle cerebral arteries (segments M1 per A. Bouthillier). Along the whole available length, PSV was measured. For further calculations, maximal measured PSV was used.

Lindegaard ratio (LR) was calculated as the ratio between maximal PSV in the middle cerebral artery and PSV in the ipsilateral internal carotid artery.

Duplex sonography was performed daily prior to surgery and in the postoperative period until the patient was transferred from the intensive care unit to specialized unit. Examination for the postoperative period included maximal values of PSV and LR. Time of deterioration per TCD was the day after surgery when signs of vasospasm were first registered: PSV increase to 120 cm/s and above, LR increase to 3.0 and above, as well as interhemispheric asymmetry in PSV by 30 % or more.

Intraoperative neurophysiological monitoring of TcMEP and/or SSEP was performed using 4-channel neuromonitor Viking Quest 11.0 (Nicolet Biomedical, USA).

During clipping of aneurysms of the anterior circulation, SSEP from the lower limbs (in response to stimulation of the tibial nerve) and TcMEP from the upper and lower limbs on 2 sides were measured. During clipping of aneurysms of the middle circulation, SSEP from the contralateral upper limb (in response to median nerve stimulation) and TcMEP from the contralateral upper and lower limbs were measured. In case of multiple aneurysms, SSEP and TcMEP from the upper and lower limbs on both sides were measured.

During SSEP registration, parameter changes were considered significant if full loss of N20–P25 cortical component or its amplitude decrease by 50 % or more from the baseline registered at the base level of anesthetic depth after completion of trephination prior to dura mater dissection were observed.

During TcMEP registration, parameter changes were considered significant if full loss of M-response or its amplitude decrease by 50 % or more not restored by 20 mA increase in stimulus or (in case of initial use of maximal stimulus) through facilitation were observed.

The above-described parameter changes were considered permanent if they developed at any stage of the surgery and persisted at the time of its completion; they were considered transient if at the end of surgery they returned to the baseline or acceptable values.

In all patients, endotracheal anesthesia, intravenous anesthesia (based on propofol infusion at dose 0.5–4 mg/kg/h) without or with inhalation anesthetics in a small concentration (sevoflurane 0.2 MAC) were used. Analgesic component was provided by continuous intravenous fentanyl infusion at mean dose 5–12 μg/kg/h. Muscle relaxation was created by rocuronium only during trachea intubation at dose 0.5 mg/kg, at other stages of anesthesia and surgery muscle relaxants were not used.

If TcMEP and/or SSEP SCP developed, neuroprotection measures were taken including irrigation with warm physiological solution, intravenous bolus administration of 2000 mg citicoline, increase of systemic blood pressure, papaverine application to the wound, changes in mechanical ventilation (increased oxygen concentration in the breathing mixture, increased positive pressure at the end of exhale).

Statistical data processing was performed using online calculators from the http://www.medstatistic.ru/, https://www.jamovi.org web resources and Microsoft Excel software. Comparison of quantitative characteristics between groups was performed using Student's test for normal distributions or Mann–Whitney test for non-normal distributions. For determination of normality, Shapiro–Wilk test was used. Distribution was considered normal at $p \geq 0.05$. Intergroup comparison per quantitative characteristics was performed using Fisher's exact test and χ^2-test. Dynamics in the groups were studied using Student's test and McNemar test. All differences were considered significant at $p < 0.05$. Quantitative data in cases of non-normal distribution are presented as Me (Q_1–Q_3) where Me is median, Q_1 is the first quartile, Q_3 is the third quartile; in cases of normal distribution, as M ± σ, where M is mean, σ is standard deviation. Qualitative characteristics are presented as absolute and relative frequencies.

RESULTS

In patients with DCI mean score per the NIHSS prior to surgery was 1 (0–5), on day 1 after surgery – 1 (0–4.5), at the end of hospitalization – 7 (1.0–26.5).

Death occurred in 4 (25.0 %) cases, severe ND was observed in 1 (6.25 %) case, moderate ND – in 6 (37.5 %) cases, mild ND – in 5 (31.25 %) cases. In 2 (12.5 %) patients, ND was transient, in 14 (87.5 %) permanent.

Control SCT in 8 (50.0 %) cases showed ischemic lesions; in 5 (31.25 %) cases, ischemic lesions with secondary hemorrhagic transformation, in 3 (18.75 %) cases, focal pathology was not found.

IONM in patients with DCI in 9 (56.2 %) cases showed no SCP in SSEP and TcMEP, in 7 (43.8 %) cases transient SCP were registered, among them in 3 (42.8 %) patients of both TcMEP and SSEP, in 2 (28.6 %) patients only of TcMEP, in 2 (28.6 %) patients only of SSEP. In 3 (42.8 %) cases, SCP appeared after constant clipping, in 2 (28.6 %) cases at the stage of temporary clipping, and in 2 (28.6 %) cases during aneurysm mobilization.

TCD prior to surgery in 11 (68.75 %) patients showed blood flow characteristics in the reference range. In 5 (31.25 %) patients, signs of vasospasm were observed requiring watchful waiting, and surgeries were performed after normalization of blood flow characteristics.

ND level increased on average on day 3 (2.0–4.5) after surgery which corresponds to worsening TCD characteristics on day 2 (2.0–4.5).

Thus, the group of interest – with transient SCP per IONM and subsequent DCI development – consists of 7 patients including 3 (42.9 %) men and 4 (57.1 %) women

Table 2. *Characteristics of transient significant neurophysiological response changes during operation in the delayed cerebral ischemia group vs control group*

Parameter	DCI group (*n* = 7)	Control group (without increasing of ND) (*n* = 19)	*p*
Modality of TSR, *n* (%): TcMEP SSEP TcMEP + SSEP	 2 (28.6) 2 (28.6) 3 (42.8)	 9 (47.4) 6 (31.6) 4 (21.6)	0.511
Time of worsening, min	7 (5–10)	10 (7.5–12.0)	0.762
Period of worsening, *n* (%): aneurysm mobilization temporary clipping after final clipping several periods	 2 (28.6) 2 (28.6) 3 (42.8) 0	 3 (15.8) 5 (26.3) 9 (47.4) 2 (10.5)	0.773

***Note.** DCI – delayed cerebral ischemia; ND – neurological deficit; TcMEP – transcranial motor evoked potentials; SSEP – somatosensory evoked potentials.*

Table 3. *Ultrasound duplex scanning (USDS) parameter value in patients with transient significant response changes, according to intraoperative neurophysiological monitoring data, in the group with delayed cerebral ischemia and in the control group*

Parameter	DCI group (*n* = 7)	Control group (without increasing of ND) (*n* = 19)	*p*
USDS normal values *n* (%): before surgery after surgery USDS signs of angiospasm, *n* (%): before surgery after surgery	 4 (57.1) 0 (0)* 3 (37.5) 7 (100)**	 19 (100) 7 (36.8)* 0 (0) 12 (63.2)**	 >0.05 >0.05
Day of USDS data worsening	2 (1.5–2.5)	3 (2–4)	>0.05
Lindegaard index: before surgery after surgery	 2.5 ± 0.7 3.5 ± 1.1	 2.1 ± 0.3 2.9 ± 1.1	 0.08 0.09
Peak systolic blood flow velocity in middle cerebral artery, cm/s: before surgery after surgery	 100 (80–139) 175 (139–278)	 100 (100–118) 150 (116–194)	 0.81 0.092

**Statistically significant decrease in the number of patients with normal linear blood flow velocity by ultrasound, according to the McNemar criterion (p <0.001).*
Statistically significant increase in the number of patients with angiospasm by ultrasound, according to the McNemar criterion (p <0.01).

aged 49.6 ± 8.5 years. Comparison of this group with the control group did not show significant differences in age (Student's test, $p = 0.899$), sex (χ^2-test, $p = 0.350$), aneurysm location (χ^2-test, $p = 0.615$), rupture period (χ^2-test, $p = 0.831$), and baseline ND level (Mann–Whitney test, $p = 0.074$) (Table 1).

At the end of hospitalization, ND per the NIHSS was significantly higher in the DCI group (score 7 (10–26.5)) compared to the control group (score 0 (0–0)) (Mann–Whitney test, $p = 0.037$, $p < 0.05$).

Comparison of the 2 groups showed significant differences in SAH severity per the Hunt–Hess scale: the DCI group contained more patients with grade III SAH (42.9 % *versus* 5.2 %), the control group with grade II SAH (63.2 % *versus* 14.3 %) (χ^2-test, $p = 0.026$, $p < 0.05$). However, there were no differences in SAH severity per the Fischer scale (χ^2-test, $p = 0.179$). No significant differences in the number of patients who underwent temporary clipping of the parent artery (χ^2-test, $p = 0.939$) or duration of temporary clipping (Mann–Whitney test, $p = 0.091$) were found.

In terms of neurophysiological characteristics, there were no significant differences in the modalities for which SCP were observed (χ^2-test, $p = 0.511$), operative time when they were observed (χ^2-test, $p = 0.773$) or duration of amplitude decrease by 50 % or more (Mann–Whitney test, $p = 0.762$ (Table 2).

Analysis of TCD data of the groups showed significant increase in the number of patients with signs of vasospasm in the postoperative period, and the control group initially did not contain any patients with signs of vasospasm (in the DCI group, vasospasm prior to surgery was observed in 37.5 % of patients, after surgery in 100 % of patients; in the control group prior to surgery, vasospasm was not observed (0 % of patients), after surgery it was observed in 63.2 % of patients (McNemar test, $p < 0.01$)). In both groups, significant PSV increase in the middle cerebral arteries was observed (in the DCI group prior to surgery: 100 (80–139) cm/s, after surgery: 175 (139–278) cm/s (Mann–Whitney test, $p = 0.001$); in the control group prior to surgery: 100 (100–118) cm/s, after surgery: 150 (116–194) cm/s (Mann–Whitney test, $p = 0.0001$)), as well as an increase in LR (in the DCI group prior to surgery: 2.5 ± 0.7, after surgery: 3.5 ± 1.1 (Student's test, $p = 0.01$); in the control group prior to surgery: 2.1 ± 0.3, after surgery: 2.9 ± 1.1 (Student's test, $p = 0.0002$)) without significant differences between the groups. In the postoperative period, PSV in the middle cerebral arteries and LR were higher in the DCI group compared to the control group, but the difference was not statistically significant (Mann–Whitney test, $p = 0.092$; Student's test, $p = 0.071$ respectively; $p > 0.05$) (Table 3).

Statistically significant increase in the number of patients with angiospasm by ultrasound, according to the McNemar criterion ($p < 0.01$).

DISCUSSION

In our study, 46.2 % of patients with DCI had intraoperative transient SCP in TcMEP and SSEP in the form of decreased amplitude by 50 % or more with mean duration of 7 (5–10) minutes. This fact was not previously described in literature, so we made an assumption that this phenomenon plays an important role in DCI pathogenesis. In recent retrospective clinical trials, model of carotid endarterectomy showed that SCP per IONM can indicate decreased cerebrovascular reserve – ability of circulation to increase blood flow in response to various physiological and pharmacological irritants which is the key link in DCI pathogenesis and is a risk factor of late strokes [13]. Reversibility of SCP is caused both by switching on of physiological compensatory mechanisms and a complex of treatment measures during surgery.

According to the literature data, positive prognostic value of ND development on day 1 after surgery for transient loss of TcMEP is 31 %; transient or complete loss of N20 cortical component of SSEP from the upper limbs was prognostically even less favorable (odds ratio 7.55) than critical amplitude decrease and latency increase at the end of surgery (odds ratio 5.63) [14].

However, transient SCP per IONM do not always predict DCI, and absence of transient SCP per IONM in more than half of the cases shows that their absence does not guarantee that the patient won't develop ND later. We suggest that the presence of transient SCP per IONM in some cases can serve as a marker of decreased cerebrovascular reserve which in the presence of other pathogenetic factors can lead to delayed ND increase in the postoperative period. However, currently we cannot state this as a fact due to low number of observations.

Considering multifactorial nature of DCI (see Figure), from the whole sample of patients with delayed ND increase we selected a group with transient SCP per IONM. Comparison of the 2 groups with transient SCP per IONM – with DCI and without ND increase – showed statistically significant predominance of patients with grade III SAH severity per the Hunt–Hess scale in the 1st group, while in the 2nd group most patients had grade I and II SAH. There were no significant differences per the Fischer scale. Therefore, patients with grade III SAH severity per the Hunt–Hess scale require longer observation in the intensive care unit even in stable condition in the postoperative period.

In both groups, TCD showed significant increase in PSV and LR in the postoperative period on days 3–4 to the level of moderate vasospasm per A.R. Shakhnovich»s classification (PSV – 120–200 cm/s). Additionally, in the DCI group higher absolute PSV (175 (139–278) cm/s) and LR (3.5 ± 1.1) values were observed in the postoperative period compared to the control group (PSV 150 (116–194) cm/s, LR 2.9 ± 1.1). However, these differences were not statistically significant. Highly likely, that they did not reach significance due to small sample sizes. This fact allows to assume that in all patients with transient SCP per IONM, similar pathogenic mechanisms are at play including to a greater or lesser degree decreased cerebrovascular reserve which in time reaches clinical significance in patients with higher PSV values approaching level of severe vasospasm. Pathophysiology of this phenomenon cannot be fully explained by retrospective data, further clinical and experimental multicenter trials are necessary.

CONCLUSION

Currently, it is impossible to univocally state that transient SCP per IONM are one of the risk factors of DCI development after clipping of ruptured cerebral arterial aneurysms. Confirmation of this hypothesis requires further study of intraoperative risk factors of DCI development. However, patients with transient and permanent SCP per IONM and grade III SAH severity per the Hunt–Hess scale significantly more frequently develop DCI compared to patients with grade I or II SAH severity. Therefore, these patients require longer observation in the intensive care unit due to the high risk of delayed ND increase.

REFERENCES

1. Zhang Y.B., Zheng F., Stavrinou L. et al. Admission serum iron as an independent risk factor for postoperative delayed cerebral ischemia following aneurysmal subarachnoid hemorrhage: a propensity-matched analysis. Brain Sci 2022;12(9):1183. DOI: 10.3390/brainsci12091183
2. Vergouwen M.D., Vermeulen M., van Gijn J. et al. Definition of delayed cerebral ischemia after aneurysmal subarachnoid hemorrhage as an outcome event in clinical trials and observational studies: proposal of a multidisciplinary research group. Stroke 2010;41(10):2391–5. DOI: 10.1161/STROKEAHA.110.589275
3. Budohoski K.P., Guilfoyle M., Helmy A. et al. The pathophysiology and treatment of delayed cerebral ischaemia following subarachnoid haemorrhage. J Neurol Neurosurg Psychiatry 2014;85(12):1343–53. DOI: 10.1136/jnnp-2014-307711
4. Rigante L., van Lieshout J.H., Vergouwen M.D. et al. Time trends in the risk of delayed cerebral ischemia after subarachnoid hemorrhage: a meta-analysis of randomized controlled trials. Neurosurg Focus 2022;52(3):E2. DOI: 10.3171/2021.12.FOCUS21473
5. Scherschinski L., Catapano J.S., Karahalios K. et al. Electroencephalography for detection of vasospasm and delayed cerebral ischemia in aneurysmal subarachnoid hemorrhage: a retrospective analysis and systematic review. Neurosurg Focus 2022;52(3):E3. DOI: 10.3171/2021.12.FOCUS21656
6. Suzuki H., Kawakita F., Asada R. Neuroelectric mechanisms of delayed cerebral ischemia after aneurysmal subarachnoid hemorrhage. Int J Mol Sci 2022;23(6):3102. DOI: 10.3390/ijms23063102
7. Rautalin I., Juvela S., Martini M.L. et al. Risk factors for delayed cerebral ischemia in good-grade patients with aneurysmal subarachnoid hemorrhage. J Am Heart Assoc 2022;11(23):e027453. DOI: 10.1161/JAHA.122.027453
8. Castillo J.L., Reyes S.P., Gutiérrez R. et al. [Quantitative electroencephalogram for prediction of delayed ischemia in subarachnoid haemorrhage. Report of one case (In Spanish)]. Rev Med Chil 2021;149(9):1377–81. DOI: 10.4067/S0034-98872021000901377
9. Sinkin M.V., Kaimovsky I.L., Komoltsev I.G. et al. Electroencephalography in acute stroke. Zhurnal nevrologii i psikhiatrii im. S.S. Korsakova = S.S. Korsakov Journal of Neurology and Psychiatry 2020;120(8–2):10–16. (In Russ.).
10. Ghavami F., Choudhri O., Marks M., López J.R. Intraoperative neurophysiologic monitoring (IONM) changes associated with a case of delayed thalamic infarct: implications for postoperative management. J Clin Neurosci 2018;47:139–42. DOI: 10.1016/j.jocn.2017.10.035
11. Surgery of cerebral aneurysms. Ed. by V.V. Krylov. In three volumes. Vol. I. Moscow, 2011. 432 p. (In Russ.).
12. Dodd W.S., Laurent D., Dumont A.S. et al. Pathophysiology of delayed cerebral ischemia after subarachnoid hemorrhage: a review. J Am Heart Assoc 2021;10(15):e021845. DOI: 10.1161/JAHA.121.021845
13. Domenick Sridharan N., Chaer R.A., Thirumala P.D. et al. Somatosensory evoked potentials and electroencephalography during carotid endarterectomy predict late stroke but not death. Ann Vasc Surg 2017;38:105–12. DOI: 10.1016/j.avsg.2016.07.064
14. Kashkoush A.I., Jankowitz B.T., Nguyen C. et al. Perioperative stroke after cerebral aneurysm clipping: risk factors and postoperative impact. J Clin Neurosci 2017;44(10):188–95. DOI: 10.1016/j.jocn.2017.06.030

Authors' contributions

N.A. Bobriakov: developing the research design, performing intraoperative neuromonitoring, obtaining data for analysis, analysis of the obtained data, reviewing of publications on the topic of the article, article writing;
S.I. Petrov, A.G. Moskalev: performing operations, supervision of patients, instrumental diagnostics, obtaining data for analysis, analysis of the obtained data, scientific editing, scientific advice;
E.V. Sereda: performing operations, supervision of patients, instrumental diagnostics, obtaining data for analysis, analysis of the obtained data, article writing, scientific editing, scientific advice;
A.A. Ponomarev: performing operations, assisting in surgery, instrumental diagnostics, supervision of patients, obtaining data for analysis, analysis of the obtained data;
I.Yu. Kazankov: developing the research design, performing operations, assisting in surgery, instrumental diagnostics, supervision of patients, obtaining data for analysis, analysis of the obtained data;
E.Yu. Sedova: instrumental diagnostics, obtaining data for analysis, analysis of the obtained data, article writing;
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