GEORGIAN MEDICAL NEWS

ISSN 1512-0112

NO 4 (349) Апрель 2024

ТБИЛИСИ - NEW YORK

ЕЖЕМЕСЯЧНЫЙ НАУЧНЫЙ ЖУРНАЛ

Медицинские новости Грузии

საქართველოს სამედიცინო სიახლენი

GEORGIAN MEDICAL NEWS

Monthly Georgia-US joint scientific journal published both in electronic and paper formats of the Agency of Medical Information of the Georgian Association of Business Press. Published since 1994. Distributed in NIS, EU and USA.

GMN: Georgian Medical News is peer-reviewed, published monthly journal committed to promoting the science and art of medicine and the betterment of public health, published by the GMN Editorial Board since 1994. GMN carries original scientific articles on medicine, biology and pharmacy, which are of experimental, theoretical and practical character; publishes original research, reviews, commentaries, editorials, essays, medical news, and correspondence in English and Russian.

GMN is indexed in MEDLINE, SCOPUS, PubMed and VINITI Russian Academy of Sciences. The full text content is available through EBSCO databases.

GMN: Медицинские новости Грузии - ежемесячный рецензируемый научный журнал, издаётся Редакционной коллегией с 1994 года на русском и английском языках в целях поддержки медицинской науки и улучшения здравоохранения. В журнале публикуются оригинальные научные статьи в области медицины, биологии и фармации, статьи обзорного характера, научные сообщения, новости медицины и здравоохранения. Журнал индексируется в MEDLINE, отражён в базе данных SCOPUS, PubMed и ВИНИТИ РАН. Полнотекстовые статьи журнала доступны через БД EBSCO.

GMN: Georgian Medical News – საქართველოს სამედიცინო სიახლენი – არის ყოველთვიური სამეცნიერო სამედიცინო რეცენზირებადი ჟურნალი, გამოიცემა 1994 წლიდან, წარმოადგენს სარედაქციო კოლეგიისა და აშშ-ის მეცნიერების, განათლების, ინდუსტრიის, ხელოვნებისა და ბუნებისმეტყველების საერთაშორისო აკადემიის ერთობლივ გამოცემას. GMN-ში რუსულ და ინგლისურ ენებზე ქვეყნდება ექსპერიმენტული, თეორიული და პრაქტიკული ხასიათის ორიგინალური სამეცნიერო სტატიები მედიცინის, ბიოლოგიისა და ფარმაციის სფეროში, მიმოხილვითი ხასიათის სტატიები.

ჟურნალი ინდექსირებულია MEDLINE-ის საერთაშორისო სისტემაში, ასახულია SCOPUS-ის, PubMed-ის და ВИНИТИ РАН-ის მონაცემთა ბაზებში. სტატიების სრული ტექსტი ხელმისაწვდომია EBSCO-ს მონაცემთა ბაზებიდან.

WEBSITE

www.geomednews.com

К СВЕДЕНИЮ АВТОРОВ!

При направлении статьи в редакцию необходимо соблюдать следующие правила:

1. Статья должна быть представлена в двух экземплярах, на русском или английском языках, напечатанная через **полтора интервала на одной стороне стандартного листа с шириной левого поля в три сантиметра**. Используемый компьютерный шрифт для текста на русском и английском языках - **Times New Roman** (**Кириллица**), для текста на грузинском языке следует использовать **AcadNusx.** Размер шрифта - **12**. К рукописи, напечатанной на компьютере, должен быть приложен CD со статьей.

2. Размер статьи должен быть не менее десяти и не более двадцати страниц машинописи, включая указатель литературы и резюме на английском, русском и грузинском языках.

3. В статье должны быть освещены актуальность данного материала, методы и результаты исследования и их обсуждение.

При представлении в печать научных экспериментальных работ авторы должны указывать вид и количество экспериментальных животных, применявшиеся методы обезболивания и усыпления (в ходе острых опытов).

4. К статье должны быть приложены краткое (на полстраницы) резюме на английском, русском и грузинском языках (включающее следующие разделы: цель исследования, материал и методы, результаты и заключение) и список ключевых слов (key words).

5. Таблицы необходимо представлять в печатной форме. Фотокопии не принимаются. **Все цифровые, итоговые и процентные данные в таблицах должны соответствовать таковым в тексте статьи**. Таблицы и графики должны быть озаглавлены.

6. Фотографии должны быть контрастными, фотокопии с рентгенограмм - в позитивном изображении. Рисунки, чертежи и диаграммы следует озаглавить, пронумеровать и вставить в соответствующее место текста **в tiff формате**.

В подписях к микрофотографиям следует указывать степень увеличения через окуляр или объектив и метод окраски или импрегнации срезов.

7. Фамилии отечественных авторов приводятся в оригинальной транскрипции.

8. При оформлении и направлении статей в журнал МНГ просим авторов соблюдать правила, изложенные в «Единых требованиях к рукописям, представляемым в биомедицинские журналы», принятых Международным комитетом редакторов медицинских журналов - http://www.spinesurgery.ru/files/publish.pdf и http://www.nlm.nih.gov/bsd/uniform_requirements.html
В конце каждой оригинальной статьи приводится библиографический список. В список литературы включаются все материалы, на которые имеются ссылки в тексте. Список составляется в алфавитном порядке и нумеруется. Литературный источник приводится на языке оригинала. В списке литературы сначала приводятся работы, написанные знаками грузинского алфавита, затем кириллицей и латиницей. Ссылки на цитируемые работы в тексте статьи даются в квадратных скобках в виде номера, соответствующего номеру данной работы в списке литературы. Большинство цитированных источников должны быть за последние 5-7 лет.

9. Для получения права на публикацию статья должна иметь от руководителя работы или учреждения визу и сопроводительное отношение, написанные или напечатанные на бланке и заверенные подписью и печатью.

10. В конце статьи должны быть подписи всех авторов, полностью приведены их фамилии, имена и отчества, указаны служебный и домашний номера телефонов и адреса или иные координаты. Количество авторов (соавторов) не должно превышать пяти человек.

11. Редакция оставляет за собой право сокращать и исправлять статьи. Корректура авторам не высылается, вся работа и сверка проводится по авторскому оригиналу.

12. Недопустимо направление в редакцию работ, представленных к печати в иных издательствах или опубликованных в других изданиях.

При нарушении указанных правил статьи не рассматриваются.

REQUIREMENTS

Please note, materials submitted to the Editorial Office Staff are supposed to meet the following requirements:

1. Articles must be provided with a double copy, in English or Russian languages and typed or compu-ter-printed on a single side of standard typing paper, with the left margin of **3** centimeters width, and **1.5** spacing between the lines, typeface - **Times New Roman** (**Cyrillic**), print size - **12** (referring to Georgian and Russian materials). With computer-printed texts please enclose a CD carrying the same file titled with Latin symbols.

2. Size of the article, including index and resume in English, Russian and Georgian languages must be at least 10 pages and not exceed the limit of 20 pages of typed or computer-printed text.

3. Submitted material must include a coverage of a topical subject, research methods, results, and review.

Authors of the scientific-research works must indicate the number of experimental biological species drawn in, list the employed methods of anesthetization and soporific means used during acute tests.

4. Articles must have a short (half page) abstract in English, Russian and Georgian (including the following sections: aim of study, material and methods, results and conclusions) and a list of key words.

5. Tables must be presented in an original typed or computer-printed form, instead of a photocopied version. **Numbers, totals, percentile data on the tables must coincide with those in the texts of the articles.** Tables and graphs must be headed.

6. Photographs are required to be contrasted and must be submitted with doubles. Please number each photograph with a pencil on its back, indicate author's name, title of the article (short version), and mark out its top and bottom parts. Drawings must be accurate, drafts and diagrams drawn in Indian ink (or black ink). Photocopies of the X-ray photographs must be presented in a positive image in **tiff format**.

Accurately numbered subtitles for each illustration must be listed on a separate sheet of paper. In the subtitles for the microphotographs please indicate the ocular and objective lens magnification power, method of coloring or impregnation of the microscopic sections (preparations).

7. Please indicate last names, first and middle initials of the native authors, present names and initials of the foreign authors in the transcription of the original language, enclose in parenthesis corresponding number under which the author is listed in the reference materials.

8. Please follow guidance offered to authors by The International Committee of Medical Journal Editors guidance in its Uniform Requirements for Manuscripts Submitted to Biomedical Journals publication available online at: http://www.nlm.nih.gov/bsd/uniform_requirements.html
http://www.icmje.org/urm_full.pdf
In GMN style for each work cited in the text, a bibliographic reference is given, and this is located at the end of the article under the title "References". All references cited in the text must be listed. The list of references should be arranged alphabetically and then numbered. References are numbered in the text [numbers in square brackets] and in the reference list and numbers are repeated throughout the text as needed. The bibliographic description is given in the language of publication (citations in Georgian script are followed by Cyrillic and Latin).

9. To obtain the rights of publication articles must be accompanied by a visa from the project instructor or the establishment, where the work has been performed, and a reference letter, both written or typed on a special signed form, certified by a stamp or a seal.

10. Articles must be signed by all of the authors at the end, and they must be provided with a list of full names, office and home phone numbers and addresses or other non-office locations where the authors could be reached. The number of the authors (co-authors) must not exceed the limit of 5 people.

11. Editorial Staff reserves the rights to cut down in size and correct the articles. Proof-sheets are not sent out to the authors. The entire editorial and collation work is performed according to the author's original text.

12. Sending in the works that have already been assigned to the press by other Editorial Staffs or have been printed by other publishers is not permissible.

Articles that Fail to Meet the Aforementioned Requirements are not Assigned to be Reviewed.

ავტორთა საყურადღებოდ!

რედაქციაში სტატიის წარმოდგენისას საჭიროა დავიცვათ შემდეგი წესები:

1. სტატია უნდა წარმოადგინოთ 2 ცალად, რუსულ ან ინგლისურ ენებზე,დაბეჭდილი სტანდარტული ფურცლის 1 გვერდზე, 3 სმ სიგანის მარცხენა ველისა და სტრიქონებს შორის 1,5 ინტერვალის დაცვით. გამოყენებული კომპიუტერული შრიფტი რუსულ და ინგლისურენოვან ტექსტებში - **Times New Roman (Кириллица)**, ხოლო ქართულენოვან ტექსტში საჭიროა გამოვიყენოთ **AcadNusx.** შრიფტის ზომა – 12. სტატიას თან უნდა ახლდეს CD სტატიით.

2. სტატიის მოცულობა არ უნდა შეადგენდეს 10 გვერდზე ნაკლებს და 20 გვერდზე მეტს ლიტერატურის სიის და რეზიუმეების (ინგლისურ, რუსულ და ქართულ ენებზე) ჩათვლით.

3. სტატიაში საჭიროა გაშუქდეს: საკითხის აქტუალობა; კვლევის მიზანი; საკვლევი მასალა და გამოყენებული მეთოდები; მიღებული შედეგები და მათი განსჯა. ექსპერიმენტული ხასიათის სტატიების წარმოდგენისას ავტორებმა უნდა მიუთითონ საექსპერიმენტო ცხოველების სახეობა და რაოდენობა; გაუტკივარებისა და დაძინების მეთოდები (მწვავე ცდების პირობებში).

4. სტატიას თან უნდა ახლდეს რეზიუმე ინგლისურ, რუსულ და ქართულ ენებზე არანაკლებ ნახევარი გვერდის მოცულობისა (სათაურის, ავტორების, დაწესებულების მითითებით და უნდა შეიცავდეს შემდეგ განყოფილებებს: მიზანი, მასალა და მეთოდები, შედეგები და დასკვნები; ტექსტუალური ნაწილი არ უნდა იყოს 15 სტრიქონზე ნაკლები) და საკვანძო სიტყვების ჩამონათვალი (key words).

5. ცხრილები საჭიროა წარმოადგინოთ ნაბეჭდი სახით. ყველა ციფრული, შემაჯამებელი და პროცენტული მონაცემები უნდა შეესაბამებოდეს ტექსტში მოყვანილს.

6. ფოტოსურათები უნდა იყოს კონტრასტული; სურათები, ნახაზები, დიაგრამები - დასათაურებული, დანომრილი და სათანადო ადგილას ჩასმული. რენტგენოგრამების ფოტოასლები წარმოადგინეთ პოზიტიური გამოსახულებით **tiff** ფორმატში. მიკროფოტოსურათების წარწერებში საჭიროა მიუთითოთ ოკულარის ან ობიექტივის საშუალებით გადიდების ხარისხი, ანათალების შეღებვის ან იმპრეგნაციის მეთოდი და აღნიშნოთ სურათის ზედა და ქვედა ნაწილები.

7. სამამულო ავტორების გვარები სტატიაში აღინიშნება ინიციალების თანდართვით, უცხოურისა – უცხოური ტრანსკრიპციით.

8. სტატიას თან უნდა ახლდეს ავტორის მიერ გამოყენებული სამამულო და უცხოური შრომების ბიბლიოგრაფიული სია (ბოლო 5-8 წლის სიღრმით). ანბანური წყობით წარმოდგენილ ბიბლიოგრაფიულ სიაში მიუთითეთ ჯერ სამამულო, შემდეგ უცხოელი ავტორები (გვარი, ინიციალები, სტატიის სათაური, ჟურნალის დასახელება, გამოცემის ადგილი, წელი, ჟურნალის №, პირველი და ბოლო გვერდები). მონოგრაფიის შემთხვევაში მიუთითეთ გამოცემის წელი, ადგილი და გვერდების საერთო რაოდენობა. ტექსტში კვადრატულ ფჩხილებში უნდა მიუთითოთ ავტორის შესაბამისი N ლიტერატურის სიის მიხედვით. მიზანშეწონილია, რომ ციტირებული წყაროების უმეტესი ნაწილი იყოს 5-6 წლის სიღრმის.

9. სტატიას თან უნდა ახლდეს: ა) დაწესებულების ან სამეცნიერო ხელმძღვანელის წარდგინება, დამოწმებული ხელმოწერითა და ბეჭდით; ბ) დარგის სპეციალისტის დამოწმებული რეცენზია, რომელშიც მითითებული იქნება საკითხის აქტუალობა, მასალის საკმაობა, მეთოდის სანდოობა, შედეგების სამეცნიერო-პრაქტიკული მნიშვნელობა.

10. სტატიის ბოლოს საჭიროა ყველა ავტორის ხელმოწერა, რომელთა რაოდენობა არ უნდა აღემატებოდეს 5-ს.

11. რედაქცია იტოვებს უფლებას შეასწოროს სტატია. ტექსტზე მუშაობა და შეჯერება ხდება საავტორო ორიგინალის მიხედვით.

12. დაუშვებელია რედაქციაში ისეთი სტატიის წარდგენა, რომელიც დასაბეჭდად წარდგენილი იყო სხვა რედაქციაში ან გამოქვეყნებული იყო სხვა გამოცემებში.

აღნიშნული წესების დარღვევის შემთხვევაში სტატიები არ განიხილება.

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Содержание:

GEORGIAN MEDICAL NEWS
No 4 (349) 2024

EFFECT OF DIRECT SURGICAL REVASCULARIZATION ON CEREBRAL HEMODYNAMICS AND STROKE DEVELOPMENT IN PATIENTS WITH MOYAMOYA DISEASE

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Abstract.

Decreased cerebral blood flow (CBF) leads to impaired cerebral hemodynamics, which causes an increased risk of stroke. Revascularization has been shown to improve CBF in patients with moyamoya disease. The study is devoted to the retrospective study of clinical features and cerebral hemodynamic characteristics of 17 patients with moyamoya disease before, during and after surgical treatment using extracranial-intracranial (EC-IC) bypass by STA-MCA type. Patients underwent superficial temporal artery-middle cerebral artery bypass surgeries. All patients were carried out by DSA, MSCT-angiography, and MSCT-perfusion imagine (MSCTPI) before and 6 months after surgery. The hemodynamic parameters during MSCTPI, changes in cerebral vascular pattern, and clinical outcomes were evaluated. Cerebral blood flow and mean transit time (MTT) were measured using MSCT-perfusion imaging to identify areas of hypoperfusion. Intraoperative indocyanine green (ICG) analysis was performed to assess local cerebral hemodynamics before and after the creation of the STA-MCA bypass. Results showed that hemodynamics improved significantly on the surgery side after revascularization. After STA-MCA bypass CBF increased and MTT reduced by almost 2 times compared to the level before the bypass. The modified Rankin Scale scores demonstrated an improvement in the neurological status of patients following surgical revascularization. Thus, STA-MCA-type surgical revascularization significantly improved cerebral perfusion parameters and reduced the risk of stroke in patients with moyamoya disease. MSCTPI can serve as an effective and noninvasive method for monitoring cerebral hemodynamics in these patients. Intraoperative ICG angiography is a safe method that can display hemodynamic characteristics in the surgical area.

Key words. Moyamoya disease, neuroimaging, intraoperative intravenous indocyanine green angiography, extra-intracranial microvascular bypass.

Introduction.

Moyamoya disease (MMD) is a chronic, progressive, occlusive-stenotic disease of the cerebral vessels of unknown etiology that involves gradual hyperplasia of smooth muscle cells with the concomitant development of critical stenoses or occlusions of proximal cerebral vessels [1]. This process results in compensatory distal vasodilation and the formation of an abnormal network of vessels in the basal brain regions, known as moyamoya vessels. Critical stenotic lesions of the internal carotid arteries (ICA) are one of the causes of cerebral ischemia in MMD, resulting in a progressive decrease in blood flow to the brain. MMD was first described by Japanese neurosurgeons Takeuchi and Shimizu in 1957 [2]. The Ministry of Health and Welfare of Japan defines four types of MMD: ischemic, hemorrhagic, epileptic, and 'other'. Patients with MMD with moderate arterial hypotension and/or hyperventilation have a very high risk of cerebral stroke. In cases of arterial hypertension, there is also an increased risk of intracerebral hemorrhage due to the fragility of anastomotic vessels [1]. Clinical symptoms in most patients are determined by the following causes: cerebral ischemia (transient ischemic attacks, seizures, stroke) and a compensatory response to progressive ischemic brain damage. These include headache, which may be associated with dilated transdural collaterals, or intracerebral hemorrhage resulting from ruptured moyamoya vessels. As a rule, the ischemic course of the disease is predominant in childhood and the hemorrhagic course in adults [2]. MMD is more commonly diagnosed in young patients. Prolonged hypoperfusion due to the progression of the disease and insufficiency of collateral circulation can lead to irreversible brain damage. This can result in the development of multiple ischemic strokes and intracerebral hemorrhages, ultimately causing severe disability and a poor prognosis [3].

The progression of the disease increases the risk of cerebrovascular disorders, which may require surgical treatment. The treatment of MMD is determined by the aggressiveness of its progression. Collateral circulation provides some alternative means of maintaining cerebral perfusion, but this compensation is usually inadequate and/or unbalanced [4]. The goal of MMD treatment is to ensure adequate collateral blood flow, which can significantly reduce the risk of stroke. Currently, the most effective treatment for MMD is surgery to reduce the risk of stroke by restoring adequate cerebral blood flow (CBF) [5,6]. There are three types of surgical treatment for MMD: direct revascularization of the brain using extra-intracranial bypass, indirect revascularization by placing vascularized tissue over the cerebral cortex, and combined revascularization. Any of these techniques aims to supplement or restore cerebral blood flow in the area of hypoperfusion. They are recommended to improve cerebral blood flow and brain perfusion, reduce the risk of stroke, and improve neurocognitive functioning [7,8]. The most common method of restoring blood flow in MMD is surgical revascularization by creating an extra-intracranial microanastomosis between the superficial temporal artery and the cortical branch of the middle cerebral artery (EICMA by the STA-MCA bypass) [9].

Radiological diagnostics, including visualization of the moyamoya vascular network and decreased brain perfusion, is important in establishing the diagnosis of the disease [10]. Cerebral blood flow can be assessed by various neuroimaging techniques, including single-photon emission computed tomography and magnetic resonance perfusion imaging.

Multislice computed tomographic perfusion imaging (MSCTPI) of the brain is one of the modern techniques that allow rapid and qualitative determination of indicators of cerebral hemodynamics in these areas of the brain, provides the necessary data to predict the course of the disease, determines appropriate treatment strategies, resolve the issue of surgical revascularization, and allows monitoring of blood supply to the brain in the early and extended postoperative periods.

Our study aims to analyze the possibilities and results of surgical revascularization of moyamoya disease by forming an extra-intracranial microanastomosis of the STA-MCA bypass using neuroimaging methods in different stages of surgical treatment.

Materials and Methods.

The analysis is based on the results of a retrospective study conducted as part of the research projects of the State Institution «Romodanov Neurosurgery Institute, National Academy of Medical Sciences of Ukraine» (2016–2024 pp.): «To determine the effectiveness of surgical revascularization in patients with cerebral vascular disease» (State registration number No0116U001037); «To study the peculiarities of ischemic brain damage manifestations during surgical treatment of cerebrovascular diseases and ways of their correction» (State registration number No0122U000332).

Patient selection. A retrospective analysis of the results of the examination and surgical treatment of 17 moyamoya disease patients (7 males and 10 females, between 16 and 70 years old) who were undergoing examination and treatment in the Emergency Department of Vascular Neurosurgery of the State Institution «Romodanov Neurosurgery Institute, National Academy of Medical Sciences of Ukraine» from 2016 to 2023.

The study was approved by the Ethics and Bioethics Committee of the State Institution «Romodanov Neurosurgery Institute, National Academy of Medical Sciences of Ukraine». All patients were informed about the study procedures and gave written informed consent by the World Medical Association's Declaration of Helsinki for the Ethical Principles of Scientific Medical Research Involving Human Subjects (1964-2008), the European Society Directive 86/609 on the Participation of Human Subjects in Biomedical Research, and the Order of the Ministry of Health of Ukraine as amended by No. 690 of 23.09.2009.

Inclusion criteria for the study were: 1 - Diagnosis of MMD according to recommendations [11]; 2 – Age between 16 and 70 years old; 3 – Results of previous studies of cerebral digital subtraction angiography (DSA) and MSCTPI of the brain (if available); 4 – Stable preoperative condition, absence of acute cerebrovascular disease (no new cerebral hemorrhage or ischemic stroke, frequent transient ischemic attacks (TIAs) (> 2 times per week); 5 – Absence or previous results of surgical revascularization for CBF reconstruction (STA-MCA bypass); 6 – Consent to monitoring cerebral perfusion and informed consent to process study results.

Exclusion criteria for the study were: 1 – Detection of concomitant cerebrovascular disease such as aneurysms or vascular malformations during angiographic examination in patients with MMD; 2 – Acute period of stroke; 3 – Inability to conduct research due to constitutional peculiarities such as cognitive impairment or mental disorders; 4 – The study's quality is substandard or does not meet standard visualization practices; 5 – Missing patient clinical data and refusal to process test results.

Patients underwent a comprehensive clinical examination that included neuropsychological testing, Doppler ultrasound of head and neck vessels, multislice spiral computed tomography (MSCT), and MSCT perfusion imaging of the brain, as well as cerebral digital subtraction angiography before and after surgery. All patients diagnosed with MMD exhibited severe symptoms, as shown in Table 1. The modified Rankin Scale (mRS) was assessed during hospitalization and at follow-up. The moyamoya vessels were assessed following the angiographic staging of MMD by the Suzuki and Takaku classification [12].

Table 1. *Clinical characteristics of the patients with moyamoya disease.*

Characteristics	**All cases**
No. of patients	17
No. of hemispheres [a]	22
Age (years) [b]	35.06±10.42
Sex [a]	
Male	7 (41.2%)
Female	10 (58.8%)
Premorbid history [a]	
Hypertension	14 (82.4%)
Headache	17 (100%)
Amaurosis (геміанопсія)	2 (11.8%)
Diabetes	3 (17.6%)
CHD	2 (11.8%)
Smoker	2 (11.8%)
Damage to the cerebral hemispheres [a]	
Bilateral	5 (29.4%)
Right	4 (23.5%)
Left	8 (47.1%)
Clinical symptoms onset [a]	
TIA	17 (100%)
Ischemia	16 (94.1%)
Hemorrhage	1 (5.9%)
Preoperative mRS score [a]	
0	0 (0%)
1	0 (0%)
2	15 (88.2%)
3	1 (5.9%)
4	1 (5.9%)
Surgical side [a]	
Right	6 (35.3%)
Left	11 (64.7%)
Postoperative stroke in acute phase	
TIA	1 (5.9%)
Ischemia	0 (0%)
Hemorrhage	0 (0%)
Postoperative mRS score [a]	
0	2 (11.8%)
1	7 (41.2%)
2	8 (47.0%)

Notes: CHD – chronic heart disease; TIA – transient ischemic attack; mRS – Modified Rankin Scale. a – Percentage (%). b – Mean value ± SD.

Cerebral digital selective angiography (DSA) was performed using an Allura Xper FD20 Philips angiograph (Netherlands). Staging of MMD according to the Suzuki and Takaku angiographic scale was performed based on the results of DSA [26]. Diagnostic criteria were: 1 – Uni-/bilateral stenosis or occlusion of the distal segment of the internal carotid artery (ICA) and/or the initial segment of the anterior cerebral artery and/or MCA; 2 – Abnormal network of moyamoya vessels in the basal parts of the skull, visualized in the arterial phase of DSA.

Multislice computed tomographic angiography (MSCTA) of cerebral vessels was performed using multislice spiral computed tomography, the Toshiba Aquilion Prime 160 (Japan).

Multislice computed tomographic perfusion imaging (MSCTPI) of the brain. Cerebral hemodynamics were studied using MSCTPI, following the standard method, with a multislice spiral computed tomography, the Toshiba Aquilion Prime 160 (Japan). MSCTPI was performed before and after surgical treatment at 3 and 6 months. The Vitrea workstation software was used to process the information received. Perfusion hemodynamic parameters (cerebral blood volume (CBV, ml/100 g); cerebral blood flow (CBF, ml/100 g/min); mean transit time (MTT, s)) was recorded and evaluated in symmetrical sections of perfusion maps. The resulting perfusion maps are axial plane CT images corresponding to 4 slices of 1cm brain tissue. Regions of interest (ROIs) in each cerebral hemisphere (the medial prearterial cortex (M1), the extrainsular cortical area of the MCA (M2), the posterior middle cortex (M3), and the basal ganglia) were defined based on the Alberta Stroke Program Early CT Score. After registration, the mean values of CBF, and MTT in each flow territory were analyzed. The location and grade of vasculopathy (occlusion or severe stenosis) of each patient were identified.

Surgical treatment. Indications for surgical treatment were determined based on medical history, neurological status, diagnostic criteria, and neuroimaging findings. Preoperative planning included ultrasound Doppler, DSA, and identification of a potential donor artery for extra-intracranial microanastomosis (EICMA).

In the complex treatment of MMD, all patients underwent surgical revascularization with the formation of EICMA by STA-MCA bypass (Figure 1). Patients were prepared for surgery according to generally accepted rules. The surgical intervention was performed under intravenous anesthesia with artificial lung ventilation without any deviation from the general principles of general anesthesia in patients with cerebrovascular disease. Blood pressure was maintained at baseline. The EICMA procedure was performed under a microscope using microsurgical instruments, a Söring bipolar microcoagulator, and microsutures with Ethicon 10/0 barbed atraumatic needles. The operation of EICMA overlay between the external carotid artery and the cortical branches of the MCA included the following sequential steps: 1 - Y-shaped or arcuate incision of the skin and soft tissues in the frontotemporal region; 2 - Isolation of the donor's vessel from the soft tissues of the head; 3 - Osteoplastic craniotomy in the temporal-frontal region measuring about 6.0×6.0 cm to visualization and access to cortical vessels; 4 - Isolation of the cortical artery (segment M4 or M5 of the MCA); 5 - Preparation of vessels for anastomosis and temporary occlusion of the recipient artery; 6 - Vascular suturing (STA - MCA bypass of the "end to side"); 7 – Hemostasis; 8 - Layered suturing of the surgical wound.

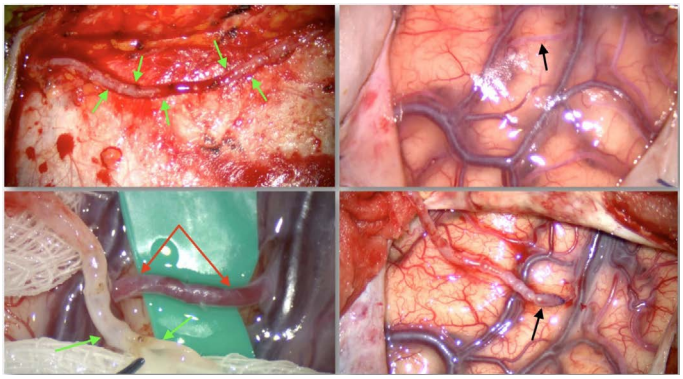

Figure 1. *STA–MCA bypass surgery stages: a – isolated donor artery (superficial temporal artery) (green arrows); b – determination of the recipient artery (cortical branch of the MCA) (black arrow); c – the donor artery (green arrows) is moved to the recipient artery (red arrows); d – view of the operating area after creation of the EICMA, STA–MCA bypass (black arrow).*

After performing a bone-plastic craniotomy and opening the dura mater, the initial intraoperative infrared intravenous indocyanine green (ICG) angiography (ICG-FLOW 800) was performed, the results of which were recorded in the formed craniotomy window (Figure 2). Following the creation of the EICMA, the patency of the anastomosis was verified visually and by contact Doppler ultrasound, after which the control intraoperative infrared ICG angiography was performed again (Figure 2).

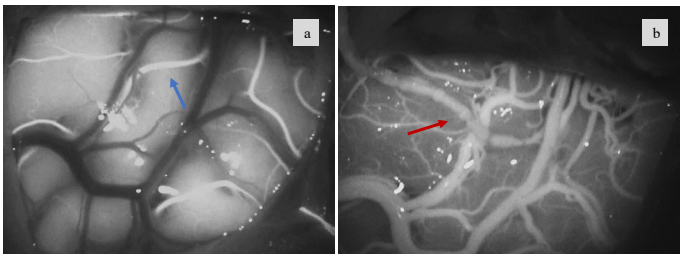

Figure 2. *Intraoperative infrared ICG angiography: a – preoperative ICG; b – postoperative ICG, where the blue arrow indicates the alternative recipient artery (the temporal superficial artery) and the red arrow indicates the patency of the anastomosis site.*

The patency of the EICMA in the postoperative period was confirmed by control MSCTA (3-5 days after surgery). Control examinations (DSA, MSCTA, MSCTPI) and clinical results were recorded 6 months after revascularization surgery.

Clinical evaluation. Prior to undergoing surgical treatment, patients were followed in the clinic and for 6 months after surgery. Recurrent symptoms were recorded, including intracerebral hemorrhage, stroke, and TIA. The modified Rankin scale (mRS) was used to assess the changes in patients'

neurologic functional status before and after surgery.

Statistical analysis. In our study, Statistica 10.0 (StatSoft, USA) was used for statistical analyses. Categorical variables are presented as counts (with percentages) [n (%)] and continuous variables are presented as the means ± standard deviations. In terms of baseline patient characteristics (e.g., disease onset and vascular risk factors) were considered for each patient, and the remaining items were described by hemisphere. The normality of the data was checked using Kolmogorov-Smirnov tests. For continuous variables including MSCTPI parameters, independent sample t analysis and one-way analysis of variance (ANOVA) were used as univariate analysis was to seek for the differences between groups. Differences were considered to be significant when the statistical $P<0.05$.

Results.

Clinical characteristics of patients. According to the inclusion criteria, 17 patients were studied. The diagnosis of moyamoya disease was confirmed in all patients by DSA and MSCTA. Tables 1 and 2 show the characteristics of patients and initial data of MMD. Among the comorbidities, 1 case had Down syndrome. The development of MMD in patients with Down syndrome can be explained by vascular dysplasia associated with the peculiarities of the coding proteins in chromosome 21, which are involved in the increased risk of developing vascular diseases [13]. The study results showed that the mean age in MMD was 35.06±10.42 years. MMD prevalence was higher in females (n=10, 58.8%) than in males (n=7, 41.2%). Hemiparesis was a characteristic feature of the disease. Headache was recorded in all cases. Progressive amaurosis was observed in 2 patients. TIA from the onset of the disease was recorded in all cases. The clinical MMD manifestation was mainly represented by ischemic stroke as a result of progressive cerebral artery occlusion (n=15, 88.2%) (Fig. 1). The ischemic variant of the disease on the one hand in the middle cerebral artery basin was presented in 11 cases (64.7%), in both MCA basins in 5 cases (29.4%), a hemorrhagic variant of the disease was observed in 1 case (n=1, 5.9%). The consequences of acute stroke were diagnosed on the MSCT of the brain as gliosis. At the time of planning the operation, no signs of acute stroke were detected during MSCT of the brain.

Table 2. *Distributions of moyamoya disease stage by Suzuki and Takaku in patients [12].*

MMD stage	Before surgery	
	n	%
2	-	-
3	8	47.1
4	5	29.4
6	4	23.5
Total	17	100

Cerebral vascular and collateral circulation status analysis. At the time of hospitalization, there were no signs of acute cerebrovascular accident. All patients underwent DSA, the gold standard for diagnosing cerebral vascular disease, and in some cases, MSCTA was performed. According to the results of both methods of examination, the characteristic signs of MMD were found in the form of steno-occlusive lesions of ICA terminal parts, proximal parts of the anterior cerebral arteries and MCA, and abnormal moyamoya vessels in the basal regions of the brain. Analyzing the results of preoperative angiography, the following stages of MMD according to Suzuki and Takaku were determined, namely: stage 3 (n=8, 47.1%), stage 4 (n=5, 29.4%), and stage 6 (n=4, 23.5%); in the last stage, the collateral vessels disappeared, and the collateral circulation was exclusively from the external carotid arteries (Figure 3, Table 2). The distribution of moyamoya disease stages according to the Suzuki and Takaku classification in patients is shown in Table 2. In all cases, there was an asymmetry of blood circulation in the cerebral hemispheres.

After surgical correction of vascular blood flow was performed, intraoperative infrared ICG angiography before the creation of EICMA in the created craniotomy window of the frontotemporal region showed signs of severe impoverishment of the arterial vascular pattern of the temporal and frontal cortex, indicating a significant deficit of blood supply to the MCA basin (Figure 2). Control intraoperative infrared ICG angiography showed satisfactory function of the created EICMA and a pronounced vascular network in the surgical field (Figure 2).

Postoperative control MSCTA demonstrated a patent anastomosis in all patients (Figure 4). In all cases, the anastomosis was well contrasted with a pronounced network of distal MCA branches on the surgical side. At the same time, postoperative improvement of blood supply in the MCA basin and reduction of the moyamoya vessels were detected at 6 months (Figure 3).

Brain perfusion analysis. In the preoperative period, in patients with MMD, CBF reduction in the corresponding cortical areas was detected by MSCTPI (Figure 4). Thus, with an increase in compensatory blood flow in the basal regions of the brain, CBF (ml/100g/min) in each selected regions of the cerebral cortex were: M1 - 34.1±9.3, M2 - 38.8±7.6, M3 - 35.2±8.7, basal ganglia - 44.9±6.1 ($p<0.05$). The described changes are associated with long-term chronic cerebrovascular disease. CBF in the presence of moyamoya vessels differed significantly from the opposite side, decreasing in the cortex of the temporal and parietal lobes by almost 2 times. With an increase in the number of collaterals, the differences in CBF and MTT were less expressed in the basal ganglia. At the scan level, CBV was within normal limits in both cerebral hemispheres.

In the late postoperative period, CBF (ml/100g/min) on the side of surgery was: M1 - 59.4±2.8, M2 - 58.5±8.3, M3 - 38.8±1.8, basal ganglia - 53.5±3.7 ($p<0.05$) (Figure 5). The MTT (s) on the surgical side was accelerated at follow-up after surgery, with a baseline (preoperative data): M1 – 6.4±1.7, M2 – 6.4±2.1, M3 – 6.1±2.2, basal ganglia – 4.1±1.3 and vs. at follow-up: M1 – 3.2±1.2, M2 – 3.6±1.5, M3 – 4.3±1.4, basal ganglia - 3.5±1.3 ($p<0.05$) (Figure 5). In the postoperative periods, CBV remained within normal limits in both cerebral hemispheres at the scan level.

Postoperative clinical follow-up. The preoperative mRS scores are presented in Table 1. Following surgery at 6 months, all cases demonstrated improvement in neurologic status, with none of the patients exhibiting a worsening of the mRS scale

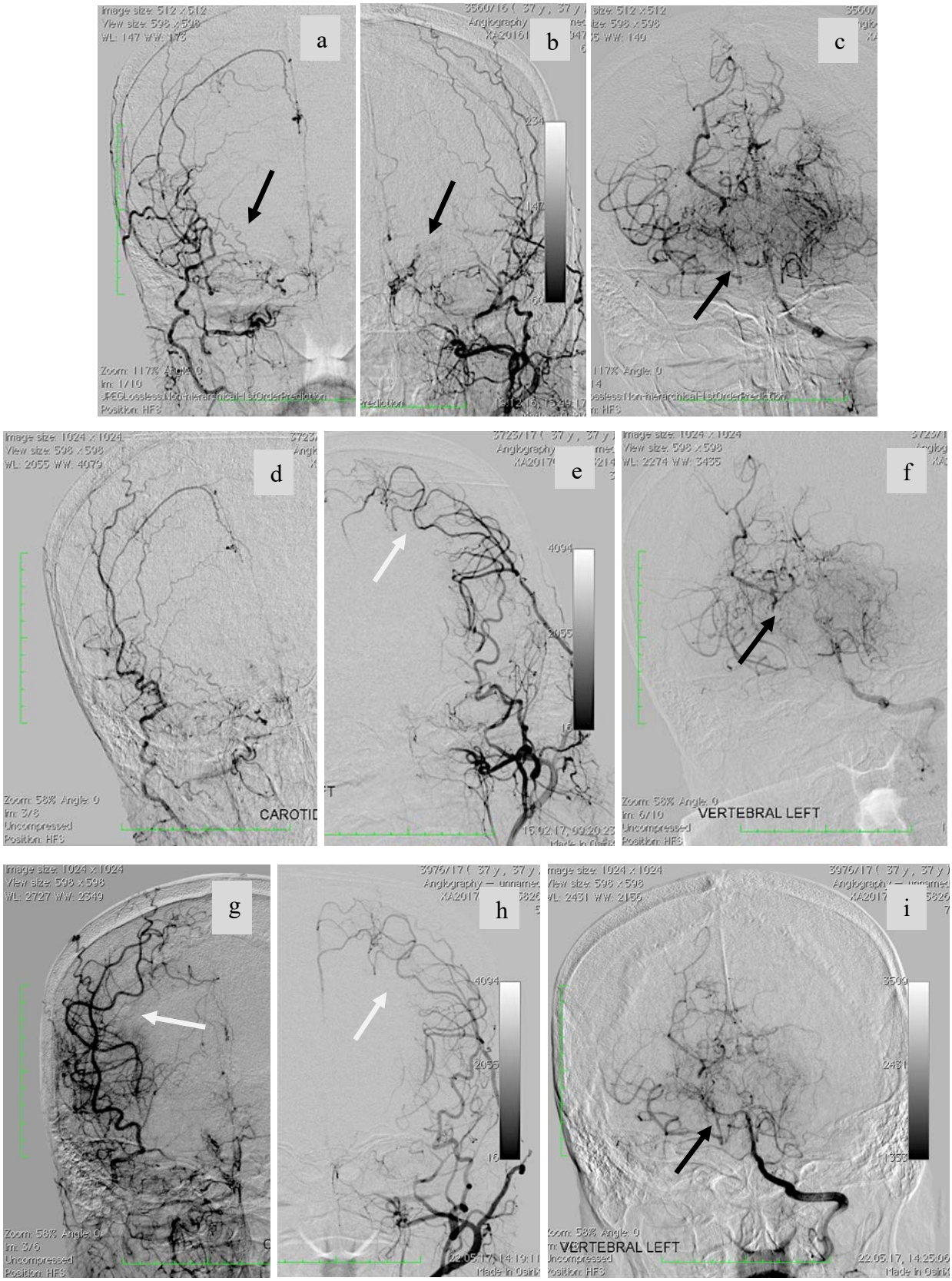

Figure 3. *DSA in the preoperative period before the creation of the EICMA (a-c); 3 months (d-f) and 6 months after the creation of the anastomosis (g-i): contrasting of the right external carotid artery (a, d, g) - occlusion of the right internal carotid artery (a); contrasting of the left external carotid artery (b, e, h) - occlusion of the left internal carotid artery (b); vertebro-basilar basin (c, f, i); moyamoya vessels in the basal regions of the brain (black arrow), sectoral contrasting of the MCA basin (white arrow).*

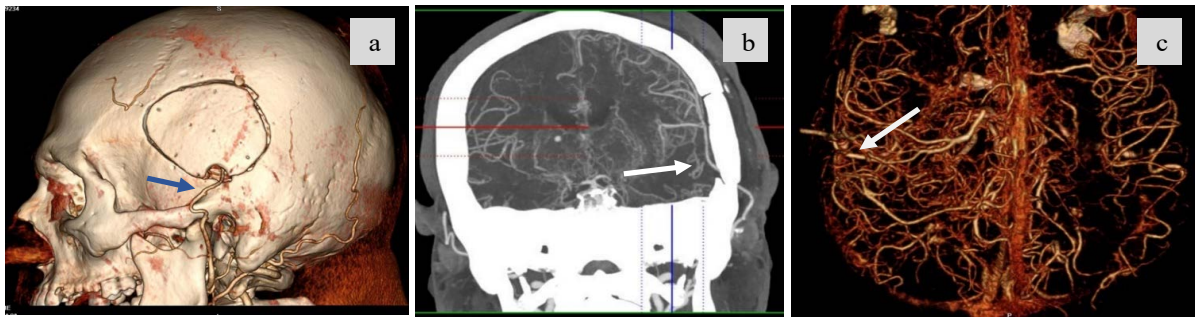

Figure 4. *MSCT angiography after EICMA creation in the early postoperative period: 3D reconstruction in bone mode (a); MIP, frontal projection (b); 3D reconstruction of the arterial phase (c); the functioning anastomosis (arrow).*

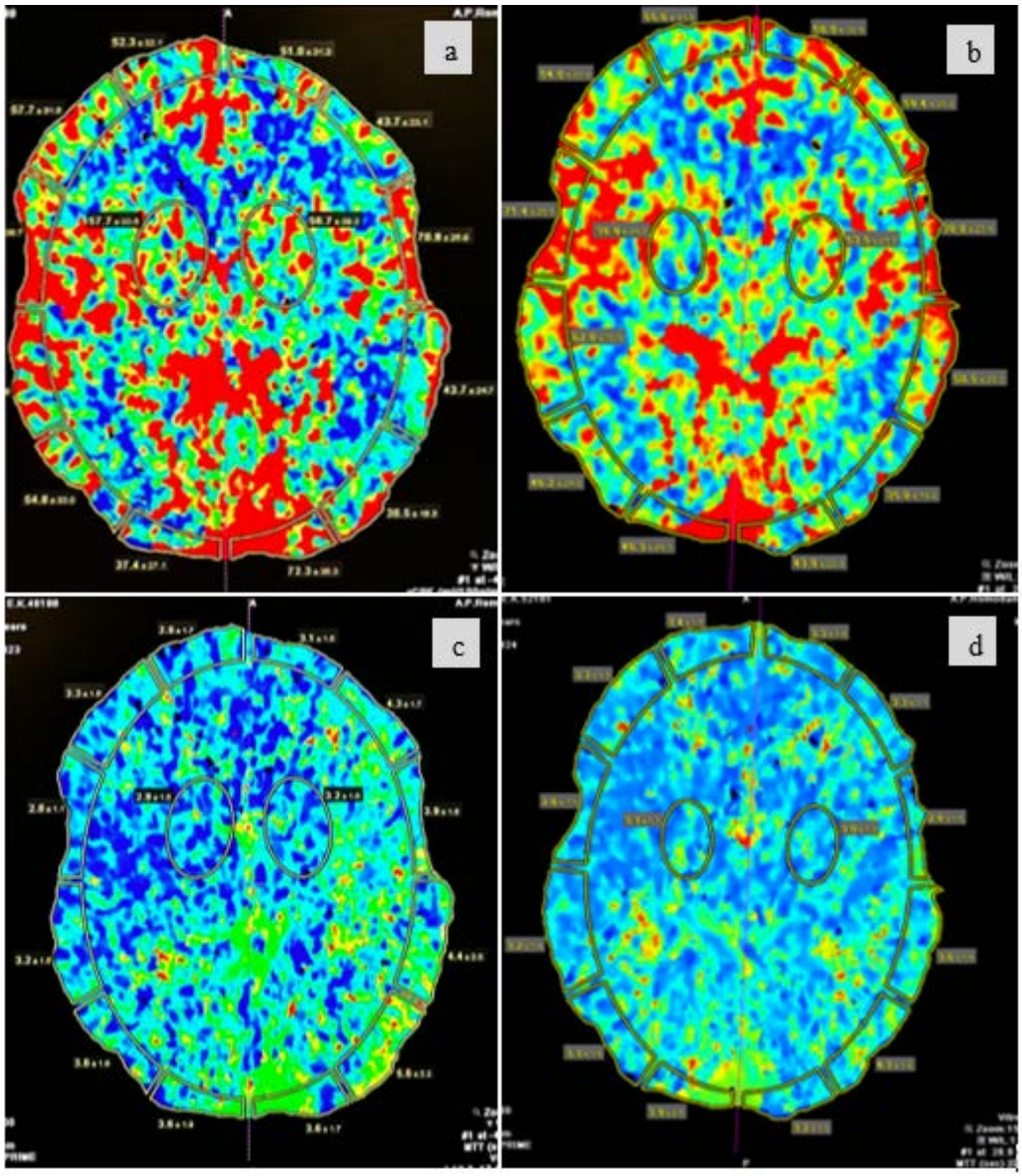

Figure 5. *Changes in cerebral hemodynamics according to MSCT perfusion (CBF (a, b), MTT (c, d)) in the period before the creation of EICMA (a, c); 6 months after the creation of EICMA (b, d).*

and the scores being higher than baseline. There were no cases of stroke. A TIA case was reported in 1 patient (Table 1).

Positive changes in neurological status were associated with improved blood supply to the brain. The study of hemodynamics in the late postoperative period showed satisfactory vascular development and satisfactory blood flow in the anatomical area where the STA-MCA bypass was formed (Figures 3-5). CBF values in the postoperative period increased almost to the values required for this area, as evidenced by the observed improvement in the neurological status in all patients, including a reduction in TIA recurrences and the absence of recurrent ischemic or hemorrhagic strokes.

Discussion.

In patients with MMD, the clinical manifestations of the disease are mainly the result of decreased blood circulation in deep brain regions as a consequence of chronic occlusive-stenotic lesions of the brachiocephalic arteries, which then leads to disruption of vascular autoregulation, hemodynamic changes, and strokes [14]. It is known that the development of moyamoya vessels, well detected and classified by the angiographic stage according to the Suzuki and Takaku classification, does not reflect the severity of the disease, but helps to establish a compensatory physiological reorganization of the cerebral circulation. The appearance of moyamoya vessels is a signal of hemodynamic cerebral ischemia. Advanced development of moyamoya vessels in the basal regions of the brain is a sign of severe hemodynamic disturbance accelerated by prolonged cortical ischemia [15]. In our study, we recorded the consequences of acute strokes in the MCA basins, which supports this hypothesis.

Considering all of the above, the metabolism of the brain in MMD will depend on its blood circulation. It is believed that collateral circulation in MMD allows for maintaining perfusion pressure at a sufficient level for a long time, and therefore CBF changes last, but intracerebral collaterals, even when fully developed, cannot provide adequate blood circulation to the cerebral cortex [16]. Currently, the single most effective treatment for MMD is considered to be the surgical restoration of cerebral blood flow in the damaged areas of the brain, which aims to prevent secondary stroke by stabilizing cerebral hemodynamics, regressing fragile moyamoya vessels, and preventing hemorrhage. For surgical treatment of MMD, endovascular treatment and revascularization are used [17]. One of the methods of surgical revascularization is the creation of a bypass path between the external carotid artery and the internal carotid artery, that is, the formation of an EICMA of the STA-MCA type to improve or restore the necessary blood flow and improve brain perfusion [18]. Therefore, addressing the presence of cerebral hypoperfusion in the preoperative period and changes in perfusion parameters in the early and long-term postoperative periods is a rather important issue, the solution of which can affect the results of surgical treatment and further prognosis of the disease. Perfusion computed tomography of the brain fulfills this task at a sufficiently high level, detecting areas of cerebral blood flow disorders in the form of hypo- and hyperperfusion.

As indicated above, the main method of treatment for MMD is the formation of EICMA. The creation of such an anastomosis is difficult due to the very small diameter of the recipient and donor vessels, which can cause acute thrombosis or occlusion of the anastomosis in case of intraoperative damage to the intima of the vessel [19]. The lack of timely detection and prevention of this complication can cause iatrogenic cerebral infarction and the emergence of new neurological symptoms [20]. Therefore, a rapid intraoperative assessment of the patency of the created EICMA is very important for the outcome of the operation.

One of the most common methods of intraoperative assessment of the functioning of the created anastomosis is microvascular Doppler ultrasound, which allows for a contact assessment of its patency [21]. Using this method in our study, we confirmed the patency of the created anastomosis with sufficient blood flow through it. After that, we used infrared ICG angiography, a standard and widely utilized method in recent years due to its ease of use and high information content. The intraoperative use of ICG during its introduction in our study was quite informative in terms of blood flow direction and provided an extremely rapid objective visualization of the patency of the created anastomosis with an intense vascular network in the surgical field in the projection of the frontal and temporal cortex (compared with preoperative data), which confirmed the effectiveness of the surgical intervention.

Direct revascularization with EICMA of the STA-MCA type provides blood flow support in the MCA basin through leptomeningeal anastomoses that develop over time [22]. It has been shown that the first changes in CBF in the hypoperfused zone occur within 2 weeks after surgery to restore cerebral blood flow. Therefore, changes in CBF within 2 weeks after surgery are known as the early postoperative period of MMD, the period of more than 2 weeks is referred to as the late postoperative period [23]. The patency of the created anastomosis in the postoperative period is an important factor in the recovery of the patients. Control angiography (MSCTA or DSA) to monitor the anastomosis condition was performed in our study within a few days after surgery and showed its functioning in all patients with MMD. No complications were recorded during the follow-up.

After the creation of EICMA, we repeated the DSA and MSCTPI in 6 months, which corresponds to the late postoperative period. During this time, certain changes in the cerebral vessels occurred in the form of the moyamoya vessel reduction and the good postoperative contrast of the distal branches of the MCA [4,16,24]. The literature shows that the abnormal network of blood vessels in the skull base gradually begins to weaken in response to CBF recovery after cerebral revascularization and collateral vessels tend to be stable and play an important role in the blood supply to the brain. Collateral revascularization can develop within 54 months [25]. In our study, the postoperative hemodynamics changes in the ICA basin were accompanied by an improvement in the perfusion of the ischemic brain tissue, which has also been shown in studies by other authors [26,27]. The creation of EICMA prevented stroke development in patients with MMD, indicating an improvement in blood flow in the study area [28,29]. Increased CBF and decreased MTT on the side of revascularization in the temporal cortex compared to preoperative values, indicating improved cerebral perfusion in the MCA basin [30]. In this study, we also found that in the postoperative period, an increase in CBF was associated

with a reduction in moyamoya vessels, which may indicate a reduction in the load on the branches of the ICA, as well as an increase of the collaterals, which helps to reduce the risk of recurrent stroke. At 6 months after surgery, we found that CBF in all cortical areas of the MCA reached a sufficient level and remained statistically significant, while the basal ganglia changed more slowly. These changes may be associated with the slow disappearance of the abnormal network of moyamoya vessels at the base of the skull, as a result of which CBF and MTT in the basal ganglia were still slightly changed by 6 months after surgery. Other authors have also shown that 6 months after STA-MCA surgery in patients with MMD, there was no significant improvement in blood flow in the basal ganglia [30]. In addition, we found that the improvement of cerebral perfusion with normalization of CBF was accompanied by a decrease in the severity of angiopathy and an improvement in the postoperative neurological status, which is also reported in the studies of other authors [31,32]. Thus, CBF and MTT are important quantitative indicators of hemodynamic changes in MMD, provide an objective assessment of the effectiveness of surgical treatment, and thus can be used to monitor the state of cerebral hemodynamics.

There were some limitations to our study that deserve attention. First, we analyzed data from a single center. Second, the study population was small. Third, the intraoperative use of ICG is not widespread enough; additional studies are needed to determine hemodynamic changes during surgery. Fourth, cerebral hemodynamics in MMD are very complex. Therefore, the assessment of cerebral hemodynamics in a single lobe (temporal) of the brain at the technically constrained scanning level may diverge from the outcomes obtained across the entire cerebral hemisphere and the whole brain. All of the above suggests that further research in this direction may be of great interest.

Conclusion.

Improving the efficiency of diagnosis of ischemic brain damage and surgical methods of its correction, especially in patients of working age, is an important problem in cerebrovascular pathology. In Ukraine, moyamoya disease is a very rare disease, but due to the development of new diagnostic technologies, the detection rate of moyamoya disease has increased significantly. Surgical revascularization is the most successful method of improving cerebral blood flow and thus reducing the risk of stroke in patients with moyamoya disease. To address the issue of surgical treatment of patients with moyamoya disease, a diverse neuroimaging approach to assess its stage is very important, including the study of angioarchitectonics using DSA, MSCTA, and MSCPI with the determination of regional hemodynamic parameters. The above-mentioned research methods allow us to accurately identify areas with an increased risk of ischemia, provide a decisive quantitative assessment of changes in cerebral hemodynamics in the cortex, the correspondence of cerebral angioarchitecture changes to a decrease in cerebral perfusion, and select an appropriate recipient artery, which is important for predicting the risk of clinical deterioration, establishing indications for surgical treatment, and deciding on the method of surgical correction.

Our study showed that surgical treatment of MMD by forming an EICMA of the STA-MCA type can significantly improve clinical outcomes and reduce the incidence of complications due to improved cerebral perfusion. Increased blood flow with STA-MCA bypass is accompanied by regression of moyamoya vessels, decreased risk of stroke, and improved neurologic status of patients.

Intraoperative control is important for the prognosis of surgical treatment of MMD. The use of infrared ICG-angiography is a promising and highly informative method of intraoperative assessment of cerebral vessels, both at the outset of surgical intervention and to assess the patency of the created anastomosis at the conclusion of the operation.

Further research in this area is considered promising due to the increased detection of moyamoya disease in Ukraine. To do this, it is necessary to conduct longer observations in this cerebrovascular pathology to increase the diagnostic value of MSCTPI of the brain, intraoperative infrared ICG angiography, and study the effectiveness of surgical revascularization.

Author's contribution.

HOYu performed MSCTPI examination of patients, data collection, interpretation of the results, and analysis of the effectiveness of the diagnostic method used. MVV performed the selection of patients, surgical treatment of patients, correction of the performed work, and analysis of the efficiency of the used surgical treatment method. All of the authors proposed the concept and the design of the study, analysis of the obtained results, writing of the manuscript.

Conflict of Interests.

The authors state no conflict of interests.

Funding information.

Financed by the state budget of Ukraine.

Abbreviation.

CBF: Cerebral Blood Flow; CBV: Cerebral Blood Volume; DSA: Digital Subtraction Angiography; EC-IC: Extracranial-Intracranial; EICMA: Extra-Intracranial Microanastomosis; ICA: Internal Carotid Artery; ICG: Indocyanine Green; MCA: Middle Cerebral Artery; MMD: Moyamoya Disease; mRS: Modified Rankin Scale; MSCT: Multislice Computed Tomography; MSCTA: Multislice Computed Tomography Angiography; MSCTPI: Multislice Computed Tomography Perfusion Imagine; MTT: Mean Transit Time; STA-MCA: Superficial Temporal Artery - Middle Cerebral Artery; TIA: Transient Ischemic Attack.

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Влияние прямой хирургической реваскуляризации на церебральную гемодинамику и развитие инсульта у пациентов с болезнью моямоя

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Резюме.

Снижение мозгового кровотока (CBF) приводит к ухудшению гемодинамики головного мозга, что является причиной повышенного риска инсульта. Было показано, что реваскуляризация улучшает CBF у пациентов с болезнью моямойя. Исследование посвящено ретроспективному изучению клинических особенностей и характеристик церебральной гемодинамики 17 пациентов с болезнью моямойя до, во время и после хирургического лечения с использованием экстракраниально-интракраниального микроанастомоза по типу STA-MCA. Пациентам были выполнены операции анастомозирования поверхностной височной артерии в среднюю мозговую артерию. Всем пациентам выполнялись ДСА, МСКТ-ангиография, МСКТ-перфузия до и через 6 месяцев после операции. С помощью МСКТ-перфузии измеряли мозговой кровоток и среднее время прохождения крови (MTT) для выявления зон гипоперфузии. Оценивались гемодинамические параметры во время МСКТ-перфузии, изменения сети церебральных сосудов и клинические исходы заболевания. Для оценки локальной церебральной гемодинамики до и после создания STA-MCA анастомоза проводился интраоперационный ICG-анализ. Результаты показали, что после реваскуляризации церебральная гемодинамика на стороне операции значительно улучшилась. После анастомозирования CBF увеличился, а MTT снизился почти в 2 раза по сравнению с уровнем до операции. Показатели модифицированной шкалы Рэнкина указали на улучшение неврологического статуса пациентов после хирургической реваскуляризации. Таким образом, хирургическая реваскуляризация по типу STA-MCA значительно улучшила показатели перфузии головного мозга и снижала развитие инсульта у пациентов с болезнью моямойя. МСКТ-перфузия может служить эффективным и неинвазивным методом мониторинга церебральной гемодинамики у этих пациентов. Интраоперационная ICG-ангиография - безопасный метод, позволяющий отобразить гемодинамические характеристики в зоне хирургического вмешательства.

Ключевые слова. Болезнь моямойя, нейровизуализация, интраоперационная внутривенная IGF ангиография, экстракраниальный микроанастомоз.