Features of Carotid Endarterectomy in Russia. How do we Resolution Issues?

Yuri V. Belov[a], Anton N. Kazantsev[b*], Vyacheslav N. Kravchuk[c,d], Roman A. Vinogradov[e,f], Alexander V. Korotkikh[g], Dmitriy V. Shmatov[h], Konstantin P. Chernykh[b], Aslan B. Zakeryaev[e], Pavel V. Sukhoruchkin[e], Vyacheslav V. Matusevich[e], Roman Yu Lider[i], Elizaveta G. Kazantseva[i], Christina L. Zakharova[b], Goderzi Sh Bagdavadze[d], Alina S. Zharova[d], Sergey V. Artyukhov[b], Victor A. Lutsenko[i], and Roman V. Sultanov[i]

From the [a] Federal State Budgetary Scientific Institution "Russian Scientific Center of Surgery named B.V. Petrovsky", Moscow, Russian Federation, [b] City Alexandrovskaya Hospital, Saint Petersburg, Russian Federation, [c] Federal State Budgetary Educational Institution of Higher Education, Military Medical Academy named after SM. Kirov, Saint Petersburg, Russian Federation, [d] North-Western State Medical University named after I.I. Mechnikov, Saint Petersburg, Russian Federation, [e] Research Institute Regional Clinical Hospital No. 1 named. prof. S.V. Ochapovsky , Krasnodar, Russian Federation, [f] Department of Surgery No. 1 FPK and teaching staff of the Kuban State Medical University, Krasnodar, Russian Federation, [g] Clinic of cardiac surgery of the Amur State Medical Academy of the Ministry of Health of Russia, Blagoveshchensk, Russian Federation, [h] Clinic of high medical technologies named after N.I. Pirogov St. Petersburg State University, Saint Petersburg, Russian Federation, [i] Kemerovo State Medical University of the Ministry of Health of the Russian Federation, Kemerovo, Russian Federation and [j] Kemerovo Regional Clinical Hospital named after S.V. Belyaeva, Kemerovo, Russian Federation.

Abstract: This review of the literature discusses the solution of unresolved issues related to carotid endarterectomy in Russia: (1) A program has been created for choosing the tactics of revascularization of patients with simultaneous atherosclerotic lesions of the coronary and carotid arteries; (2) Using the methods of computer modeling, studying the genetics and morphology of

The work has no funding.
The authors declare no conflict of interest.
Curr Probl Cardiol 2022;47:101272
0146-2806/$ – see front matter
https://doi.org/10.1016/j.cpcardiol.2022.101272

restenosis, it was found that the classic carotid endarterectomy with plasty of the reconstruction zone with a patch is an unsafe type of revascularization; (3) An eversion carotid endarterectomy with transposition of the internal carotid artery over the hypoglossal nerve has been developed, which makes it possible to prevent damage to the latter during repeated carotid endarterectomy for restenosis; (4) It has been established that carotid endarterectomy is associated with a high risk of complications in patients over 75 years of age; (5) It has been proven that emergency carotid endarterectomy in the first hours after the development of a stroke is not safe because. combined with the maximum number of all non-favorable cardiovascular events; (6) 3 new types of carotid endarterectomy with carotid glomus preservation have been developed. (Curr Probl Cardiol 2022;47:101272.)

Introduction

Carotid endarterectomy is an operation to prevent ischemic stroke, aimed at removing an atherosclerotic plaque from the internal carotid artery that stenoses its lumen.[1-5] The degree of stenosis of more than 60%-70% can cause neurological events with subsequent disability and/or death.[6–10] Therefore, the issues of carotid endarterectomy are of extremely high relevance on an all-Russian and global scale.[11-15]

The purpose of this literature review was to analyze the latest Russian publications on unresolved issues of carotid endarterectomy.

Combined Lesion of the Internal Carotid Arteries and Coronary Arteries

The first and most important direction is the choice of revascularization strategy in patients with simultaneous atherosclerotic lesions of the internal carotid arteries and coronary bed. In a large domestic study, which included more than 300 patients, 4 treatment tactics were analyzed, including staged operations (coronary bypass grafting and carotid endarterectomy in various sequences), simultaneous (carotid endarterectomy + coronary bypass grafting) and hybrid interventions (percutaneous coronary intervention + carotid endarterectomy).[16-20] The authors came

to the conclusion that there can be no single universal optimal strategy for revascularization, since patients with multifocal atherosclerosis are completely disparate among themselves. The choice of the method of treatment should be only personalized.[21-25] And then, under the guidance of the cardiovascular surgeon A. N. Kazantsev, a unique program was developed based on a complex mathematical analysis of the predictors of the development of certain cardiovascular complications after each of the 4 revascularization strategies.[26-30] This development made it possible to determine the likelihood of postoperative adverse events, creating opportunities for personalized determination of treatment tactics associated with the lowest risk of developing the latter.[31-35]

A separate sub-direction of this study was associated with the development of a hybrid form of revascularization, which had not been performed anywhere else in the world before - percutaneous coronary intervention + carotid endarterectomy.[36-40] The patient received a loading dose of clopidogrel, after which the first stage, percutaneous coronary intervention, was performed by an endovascular surgeon.[41-45] Then the patient was transported to the vascular operating room for carotid endarterectomy.[41-45] The authors described in detail the entire scheme of surgical treatment, developed a method for hemostasis and drainage of the wound after intervention on the internal carotid artery.[41-45] During hybrid revascularization, the patient was subjected to aggressive anticoagulant and deaggregant therapy, which was accompanied by high wound bleeding, as well as the risk of developing an acute hematoma of the intervention area.[43,46,47] The use of local hemostasis, as well as the key factor - double drainage, made it possible to significantly reduce the incidence of all hemorrhagic complications in this cohort of patients, which made percutaneous coronary intervention + carotid endarterectomy a safe form of treatment.[43,46,47] Its introduction into practice made it possible to abandon traumatic coronary bypass grafting, which not only reduced postoperative mortality, but also significantly reduced the period of rehabilitation of patients.[43,46,47] The study of hospital and long-term results of percutaneous coronary intervention + carotid endarterectomy proved its high efficiency.

Restenosis of the Internal Carotid Artery: Computer Modeling, Genetics

Analyzing hospital and long-term results of carotid endarterectomy, as well as predictors of adverse cardiovascular events, a group of Russian authors came to a number of interesting conclusions.[48-52] In particular,

one of the important provisions demonstrated a high incidence of restenosis of the internal carotid artery after the classical technique of surgery with plasty of the reconstruction area with a patch.[53] Studying histological preparations of a removed substrate that narrows the lumen of the artery, it was found that neointimal hyperplasia, which does not depend on dyslipidemia, diabetes mellitus, smoking, etc., plays a fundamental role in this process.[54] Later, on the basis of computer modeling of the properties of hemodynamics in the carotid bifurcation, the team of authors led by the cardiovascular surgeon Kazantsev A.N. proved for the first time in Russia that patch implantation leads to expansion of the carotid bulb.[55-59] This, in turn, causes a turbulent nature of the blood flow, with parietal thrombosis and congestion zones, which is a trigger for future changes and restenosis of the internal carotid artery.[55-59] Therefore, classical carotid endarterectomy is an unsafe type of surgery on the internal carotid artery.[55-59] Subsequently, long-term outcomes of ipsilateral classical carotid endarterectomy and contralateral eversion carotid endarterectomy in the same patient were demonstrated.[60,61] Thus, there was an equal amount of all biochemical, physical, and genetic factors that could cause restenosis of the internal carotid artery. The study showed that after the classical technique of surgery with plastic reconstruction of the reconstruction zone with a patch, a greater number of verified cases of loss of the lumen of the vessel is observed, which confirmed the unsafety of this method of revascularization.[60,61]

However, cases of restenosis have also been observed after the eversion intervention technique.[62,63] But they, as a rule, were diagnosed in a later period of observation (more than 2 years).[62-64] Genetic studies have shown that the DNA contained in an atherosclerotic plaque removed from the internal carotid artery has strict sequences that occur only when restenosis develops.[65-69] Thus, the direct hereditary nature of this phenomenon was proved in Russia.[70-74]

But with the development of medical technologies, carotid angioplasty with stenting has become an alternative to carotid endarterectomy, and in some cases a significant competitor.[75] To date, the results of carotid angioplasty with stenting in Russia have been studied, demonstrating a high rate of complications in the long-term follow-up period associated with stent fracture and restenosis.[75-77] In general, the number of adverse cardiovascular events reached the equivalent values of the classical carotid endarterectomy, but was much inferior to the eversion technique.[75] Thus, eversion carotid endarterectomy may be the only safe operation of choice for patients with hemodynamically significant stenoses of the internal carotid artery in Russia.

Methods of Surgical Treatment of Restenosis of the Internal Carotid Artery in Russia

The development of hemodynamically significant restenosis of the internal carotid artery after carotid endarterectomy and carotid angioplasty with stenting is always accompanied by a risk of ischemic stroke.[78–80] Therefore, the choice of treatment tactics for these patients plays a key role in the prevention of this complication. It is known that restenosis after carotid angioplasty with stenting is successfully eliminated by carotid endarterectomy with stent removal.[76,77] The most common cause of restenosis in these conditions was stent fracture or progressive growth of atherosclerotic plaque through its cells.[76,77] Therefore, a radical operation made it possible to remove both the foreign body (stent) and the substrate (plaque) with an optimal result of the operation. If it was about restenosis of the internal carotid artery after carotid endarterectomy, then the most preferred option for reconstruction was carotid angioplasty with stenting.[78] After all, repeated carotid endarterectomy under these conditions is performed with the release of arteries from scar tissue, which is associated with a risk of bleeding and trauma to the cranial nerves.[78,81,82] However, in some cases, when contraindications to carotid angioplasty with stenting are absolute (renal failure with high creatinine levels, allergy to a contrast agent, etc.), the operation of choice is repeated carotid endarterectomy.[81,82] One of the studies demonstrated a high incidence of hypoglossal nerve neuropathy after repeated carotid endarterectomy, which was accompanied by a decrease in the quality of life of the patient and was not always characterized by regression of symptoms.[81] Under these conditions, in Russia, to eliminate this complication, a new eversion carotid endarterectomy with transposition of the internal carotid artery over the hypoglossal nerve was developed.[83,84] Thus, if a patient developed restenosis and there was a need to perform repeated carotid endarterectomy, then the nerve was located under the internal carotid artery, which excluded its traumatization during arterial isolation.[83,84] Ultimately, the issue of hypoglossal neuropathy was completely eliminated.[83,84]

Optimal Age for Carotid Endarterectomy

Characterizing patients with multifocal atherosclerosis, numerous works have repeatedly mentioned that these patients most often have a aggravated comorbid background and an age exceeding 60 years.[85-87] Conducting small single-centre studies, the authors' teams demonstrated

that age over 75 years does not affect the incidence of postoperative complications.[88-90] Although it is logical that it is in this cohort of patients that the maximum number of cases of multivessel coronary lesions, atrial fibrillation, diabetes mellitus, chronic renal failure, etc. should be concentrated. In August 2021, a multicenter Russian (8 medical institutions in St. Petersburg, Krasnodar, Kemerovo) study on this issue was published.[91] For 12 years, the results of 7248 operations on the internal carotid arteries were analyzed. Of these, in 712 cases, carotid endarterectomy was performed in patients older than 75 years.[91] Among them, mortality reached 1%, myocardial infarction - 2%, stroke - 1.7%. Thus, the combined endpoint was 4.6% ($P < 0.0001$).[91] For the first time in Russia, it was proved that carotid endarterectomy in old age is an unsafe method of brain revascularization.[91] In this regard, the authors came to the conclusion that a more justified type of reconstruction in patients over 75 years of age may be carotid angioplasty with stenting, which is not combined with high trauma and the need to clamp the internal carotid artery.[91]

Carotid Endarterectomy in the First Hours After the Development of Stroke and in the Acute Period of Stroke

A separate interest was associated with the timing of cerebral revascularization after the development of ischemic stroke. Dr. Tarasov R.S. proved that carotid endarterectomy in the acute period of stroke is a safe method of treating patients, leading to a significant regression of neurological symptoms and associated with a low risk of adverse cardiovascular events.[92,93] In publications devoted to emergency carotid endarterectomy in the first hours after the development of a stroke, the entire amount of preoperative preparation of the patient was demonstrated, which made it possible to achieve a satisfactory outcome of urgent revascularization.[94] In particular, the routine use of a temporary shunt has been proposed to reduce the hemodynamic shock after occlusion of the internal carotid artery, which is associated with the likelihood of hemorrhagic transformation.[95] It is this complication that has become the most frequent adverse cardiovascular event in this cohort of patients.[94-97] And in 2021, the first worldwide Russian multicenter study was completed (13 medical institutions, 615 patients), studying the comparative results of carotid endarterectomy and carotid angioplasty in the first hours after the development of a stroke.[96] The authors demonstrated that the greatest number of “symptomatic” (3.6%) hemorrhagic transformations develop after carotid endarterectomy.[96] This results in a maximum combined

endpoint of 20.4%.[96] Thus, carotid endarterectomy is an unsafe method of revascularization in the first hours after the development of a stroke.[96]

Glomus-Sparing Carotid Endarterectomy in Russia

One of the achievements of carotid surgery in Russia was the development of 3 new types of surgery aimed at removing atherosclerotic plaque and preserving the carotid glomus (Fig 1).[98-100]

The first 2 options are used for local and extended atherosclerotic plaque in the internal carotid artery.[101,102] In turn, with the help of "Chikchirik" carotid endarterectomy, a similar operation is performed with transposition of the internal carotid artery over the hypoglossal nerve.[103,104] However, the purpose of these types of reconstruction is to perform carotid endarterectomy with preservation of the carotid glomus.[98-100] Such manipulation is necessary to reduce the risk of developing uncontrolled arterial hypertension in the postoperative period, which can cause the development of hemorrhagic transformation and myocardial infarction.[98-100] Cardiovascular surgeon Kazantsev A.N. proved that the implementation of the operations proposed by him allows not only to eliminate these complications, but also to reduce the frequency of all adverse cardiovascular events.[98-100] Alone and even in combination with coronary artery bypass grafting, these carotid endarterectomies are safer and more effective than conventional reconstruction options.[105] In the first hours after the development of a stroke, emergency glomus-sparing CEE demonstrates more optimal outcomes compared to eversion and classical techniques, which can recommend it as the revascularization of choice in emergency carotid surgery.[100] In 2021, the results of a multicenter study (13 institutions, 1827 patients) on the treatment of resistant arterial hypertension with carotid endarterectomy were published.[106] The authors concluded that carotid endarterectomy with preservation of the carotid glomus effectively contributes to the achievement of target levels of arterial hypertension, which makes it possible to recommend it as the operation of choice.[106]

Conclusion

Over the past 5 years, Russian scientists have made a significant contribution to the development of carotid endarterectomy. For the first time in the world: (1) A program was created to select tactics for revascularization of patients with simultaneous atherosclerotic lesions of the coronary and carotid arteries; (2) Using the methods of computer modeling,

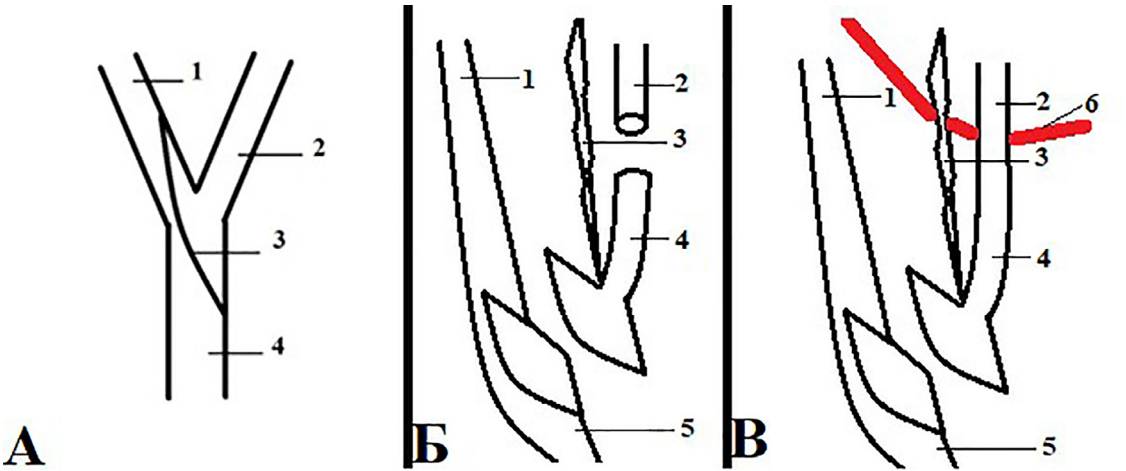

FIG 1. Glomus-sparing carotid endarterectomy developed in Russia. *А* - Glomus-sparing carotid endarterectomy: 1 - external carotid artery, 2 - internal carotid artery, 3 - arteriotomy, 4 - common carotid artery; Б - Glomus-sparing autotransplantation of the internal carotid artery: 1 - external carotid artery, 2 - section of the internal carotid artery remaining in the wound, 3 - carotid glomus, 4 - resected section of the internal carotid artery with preserved carotid glomus, 5 - common carotid artery; В – «Chik-chirik» carotid endarterectomy: 1 - external carotid artery, 2 - section of the internal carotid artery remaining in the wound, 3 - carotid glomus, 4 - resected section of the internal carotid artery with preserved carotid glomus, 5 - common carotid artery, 6 - hypoglossal nerve under the internal carotid artery and carotid glomus after transposition. (Color version of figure is available online.)

studying the genetics and morphology of restenosis, it was found that the classic carotid endarterectomy with plasty of the reconstruction zone with a patch is an unsafe type of revascularization; (3) An eversion carotid endarterectomy with transposition of the internal carotid artery above the hypoglossal nerve has been developed, which makes it possible to prevent damage to the latter during repeated carotid endarterectomy; (4) It has been established that carotid endarterectomy is associated with a high risk of complications in patients over 75 years of age; (5) It has been proven that carotid endarterectomy in the first hours after the development of a stroke is not safe because it is combined with the maximum number of all adverse cardiovascular events; (6) 3 new types of carotid endarterectomy with preservation of the carotid glomus have been developed.

REFERENCES

1. Bockeria LA, Abdulgasanov RAO, Shogenov MA, Abdulgasanova MR. Infection of synthetic patches and prostheses of brachiocephalic arteries: diagnostic and treatment methods. *Breast Cardiovasc Surg* 2020;62:494–505. https://doi.org/10.24022/0236-2791-2020-626-494-505.
2. Pokrovsky AV, Kuntsevich GI, Beloyartsev DF, Timina IE, Kolosov RV. Comparative analysis of long-term results of carotid endarterectomy, depending on the operation technique. *Angiol Vasc Surg* 2005;11:93–103.
3. Gavrilenko AV, Kuklin AV, Al-Yousef NN, Xiaochen Wang, Bulatova LR, Rui Li. Meta-analysis of the results of eversion carotid endarterectomy and endarterectomy with plastic patch. *Angiol Vasc Surg* 2020;26:176–83. https://doi.org/10.33529/ANGIO202012.
4. Altman DA, Fokin AA, Vladimirsky VV, et al. Immediate results of reconstructive interventions on the carotid arteries in patients in the acute stage of ischemic stroke. *Bull Chelyabinsk Reg Clin Hosp* 2018;2:40–4.
5. Shlomin VV, Khrustalev MI, Puzdryak PD, et al. Surgical treatment of a large paraganglioma of the bifurcation of the right common carotid artery. *Angiol Vasc Surg* 2020;26:155–9. https://doi.org/10.33529/ANGIO2020417.
6. Krylov VV, Lukyanchikov VA, Polunina NA, Tokarev AS, Dalibaldyan VA, Grigoriev IV. Surgical revascularization of the brain in patients with acute ischemic stroke. *Angiol Vasc Surg* 2020;26:124–32. https://doi.org/10.33529/ANGIO2020207.
7. Alekyan BG, Pokrovsky AV, Zotikov AE, et al. Results of various treatment strategies for patients with combined lesions of the internal carotid and coronary arteries. *Endovasc Surg* 2021;8:144–53. https://doi.org/10.24183/2409-4080-2021-8-2-144-153.
8. Akchurin RS, Shiryaev AA, Galyautdinov DM, et al. Immediate results of simultaneous coronary artery bypass grafting and carotid endarterectomy. *Cardiol Cardiovasc Surg* 2017;10:4–8. https://doi.org/10.17116/kardio20171064-8.

9. Sigaev IYu, Kudashev IF, Keren MA, Kazaryan AV, Starostin MV, Morchadze BD. The choice of optimal tactics of surgical treatment when performing combined operations of carotid endarterectomy and coronary artery bypass grafting in terms of reducing the incidence of neurological complications. *Clin Physiol Blood Circ* 2017;14:31–8.
10. Darvish NAMA, Shogenov MA, Abdulgasanov RAO, Yesseneev MF. Surgical treatment methods for atherosclerotic lesions of the carotid arteries. *Breast Cardiovasc Surg* 2020;62:405–16. https://doi.org/10.24022/0236-2791-2020-62-5-405-416.
11. Rosseikin EV, Voevodin AB, Radzhabov DA, Bazylev VV. Internal carotid artery autotransplantation in patients with a high spread of atherosclerotic plaque. *Angiol Vasc Surg* 2017;23:104–10.
12. Ignatenko PV, Gostev AA, Saaya ShB, et al. Autoarterial remodeling of the bifurcation of the common carotid artery in the treatment of stenotic lesions. *Angiol Vasc Surg* 2020;26:82–8. https://doi.org/10.33529/ANGIO2020117.
13. Bazylev VV, Shmatkov MG, Morozov ZA, Pyanzin AI, Allenov AA, Smagin DV. Predictors of complications in the early postoperative period after carotid artery stenting and carotid endarterectomy. *Angiol Vasc Surg* 2019;25(S2):46–7.
14. Dudanov IP, Abuazab BS, Akhmetov VV. Comparative characteristics of classical and eversion endarterectomy of the carotid arteries. *Res Pract Med* 2017;4:8–15. https://doi.org/10.17709/2409-2231-2017-4-3-1.
15. Vachev AN, Prozhoga MG, Dmitriev OV. Protection of the brain from ischemia during carotid endarterectomy surgery. *Angiol Vasc Surg* 2020;26:96–101. https://doi.org/10.33529/ANGI02020109.
16. Kazantsev AN, Vinogradov RA, Yerofeyev AA, et al. The problem of the choice of revascularization in combined lesion of the coronary and carotid arteries. Review of current recommendations and article series. *Emerg Med Care. J them. N.V. Sklifosovsky.* 2022;11:147–57. https://doi.org/10.23934/2223-9022-2022-11-1-147-157.
17. Tarasov RS, Ivanov SV, Kazantsev AN, et al. Hospital outcomes of various strategies for surgical treatment of patients with concomitant coronary and internal carotid artery disease. *Complex Probl Cardiovasc Dis* 2016;5:15–24.
18. Barbarash LS, Tarasov RS, Kazantsev AN, et al. Factors of an unfavorable prognosis of various surgical strategies for the treatment of patients with combined lesions of the coronary and brachycephalic arteries in the long-term postoperative period. *Cardiol Cardiovasc Surg* 2017;10:22–39. https://doi.org/10.17116/kardio201710222-39.
19. Kazantsev AN. Personalized choice of the optimal strategy for surgical treatment of patients with combined lesions of the coronary bed and brachiocephalic arteries. *Sib Med J (Tomsk)* 2017;32:74–8.
20. Tarasov RS, Kazantsev AN, Ivanov SV, Burkov NN, Anufriev AI, Barbarash LS. Surgical treatment of multifocal atherosclerosis: pathology of the coronary and brachiocephalic areas and predictors of early adverse events. *Cardiovasc Ther Prev* 2017;16:37–44. https://doi.org/10.15829/1728-8800-2017-4-37-44.
21. Tarasov RS, Kazantsev AN, Kagan ES, Glinchikov KE, Barbarash LS. Model of personalized choice of revascularization strategy in patients with simultaneous lesions of carotid and coronary arteries: predicting hospital outcomes. *Complex Probl Cardiovasc Dis* 2017;6:60–70.

22. Kazantsev AN. Decision support program for choosing a revascularization strategy in patients with simultaneous coronary and brachiocephalic artery disease. *Complex Probl Cardiovasc Dis* 2017;6(S4):25.
23. Tarasov RS, Kazantsev AN, Zinets MG, Burkov NN, Anufriev AI, Barbarash LS. Five-year results of surgical treatment of patients with simultaneous atherosclerotic lesions of the coronary and brachiocephalic arteries. *Breast Cardiovasc Surg* 2017;59:386–93. https://doi.org/10.24022/0236-2791-2017-59-6-386-393.
24. Tarasov RS, Kazantsev AN, Ivanov SV, Kagan ES, Glinchikov KE, Barbarash LS. Personalized choice of optimal revascularization tactics in patients with combined coronary and brachiocephalic artery disease: results of testing an automated decision support system in clinical practice. *Cardioll Bull* 2018;13:30–9. https://doi.org/10.17116/Cardiobulletin201813130-39.
25. Kazantsev AN, Vinogradov RA, Artyukhov SV, et al. Hybrid revascularization of the heart and brain: which carotid endarterectomy is preferable? *Ann Clin Exp Neurol* 2021;15:15–26. https://doi.org/10.54101/ACEN.2021.4.2.
26. Tarasov RS, Kazantsev AN, Kagan ES, Glinchikov KE, Barbarash LS. Model of personalized choice of revascularization strategy in patients with simultaneous lesions of carotid and coronary arteries: predicting long-term outcomes. *Breast Cardiovasc Surg* 2018;60:133–42. https://doi.org/10.24022/0236-2791-2018-60-2-133142.
27. Tarasov RS, Kazantsev AN, Ivanov SV, et al. Risk factors for an unfavorable outcome of various surgical strategies for treating patients with combined coronary and carotid artery disease in the 30-day postoperative period. *Circ Pathol Card Surg* 2018;22:36–48. https://doi.org/10.21688/1681-3472-2018-1-36-48.
28. Tarasov RS, Kazantsev AN, Ivanov SV, Ganyukov VI, Barbarash LS. A look at the problem of choosing a strategy for revascularization of the brain and myocardium in patients with atherosclerosis of the internal carotid arteries and coronary arteries: the place of personalized medicine. *Endovasc Surg* 2018;5:241–9.
29. Tarasov RS, Kagan ES, Kazantsev AN, Barbarash LS, Gutova SG. A method for determining the optimal revascularization strategy in patients with simultaneous atherosclerotic lesions of the brachiocephalic and coronary arteries. Patent for invention RU 2681581 C1, 11.03.2019. Application No. 2017134655 dated 03.10.
30. Grachev KI, Kazantsev AN, Glebov KA, Yakhnis EYa, Leader RYu. The structure of unfavorable cardiovascular events at different time intervals in atherosclerotic lesions of the coronary and carotid arteries. *Complex Probl Cardiovasc Dis* 2018;7(S2):22.
31. Glinchikov KE, Kagan ES, Tarasov RS, Kazantsev AN. Software support of the decision-making process for choosing a surgical strategy for revascularization in multifocal atherosclerosis. Certificate of registration of a computer program. RU 2017619457, 24.08.Application No. 2017616433 dated 03.07.2017.
32. Tarasov RS, Kazantsev AN, Zinets MG, Burkov NN, Anufriev AI, Ganyukov VI. Prospective testing of the program for the choice of surgical tactics in multifocal atherosclerosis. *Cardiol Cardiovasc Surg* 2019;12:402–9.
33. Tarasov RS, Kazantsev AN, Burkov NN, Leader RYu, Yakhnis EYa. The structure of hospital and long-term complications of surgical treatment of stenotic lesions of

the coronary and carotid arteries. *Angiol Vasc Surg* 2020;26:89–95. https://doi.org/10.33529/ANGIO2020113.
34. Kazantsev AN, Sumtsova EM, Shabaev AR, Burkov NN. Percutaneous coronary intervention, coronary artery bypass grafting, carotid endarterectomy. Simultaneous versus phased tactics - which is better? *Emerg Med* 2020;22:39–48.
35. Kazantsev AN, Tarasov RS, Chernykh KP, et al. A clinical case of the treatment of combined pathology: rupture of an aneurysm of the middle cerebral artery against the background of stenosis of the internal carotid and coronary arteries. *Circ Pathol Card Surg* 2020;24:109–18. https://doi.org/10.21688/1681-3472-2020-2-109-118.
36. Kazantsev AN, Chernykh KP, Zarkua NE, et al. Combined open and hybrid interventions on the coronary and internal carotid arteries - the search for the ideal approach. *Cardiol Bull* 2020;15:46–53. https://doi.org/10.36396/MS.2020.16.3.006.
37. Kazantsev AN, Tarasov RS, Ganyukov VI, et al. Long-term results of revascularization of the brain and myocardium: carotid endarterectomy and percutaneous coronary intervention in hybrid and staged modes. *Breast Cardiovasc Surg* 2020;62:325–33. https://doi.org/10.24022/0236-2791-2020-62-4-325-333.
38. Kazantsev AN, Khubulava GG, Kravchuk VN, Erofeev AA, Chernykh KP. Evolution of carotid endarterectomy. Literature review. *Circ Pathol Card Surg* 2020;24:22–32. https://doi.org/10.21688/1681-3472-2020-4-22-32.
39. Kazantsev AN, Leader RYu, Chernykh KP, et al. Revascularization of the brain and myocardium in concomitant atherosclerotic lesions: coronary artery bypass grafting, percutaneous coronary intervention, carotid endarterectomy. *Breast Cardiovasc Surg* 2020;62:439–46. https://doi.org/10.24022/0236-2791-2020-62-5-439-446.
40. Kazantsev AN, Kravchuk VN, Vinogradov RA, et al. Solobuev A.I. Percutaneous coronary intervention and carotid endarterectomy: hospital and long-term outcomes of hybrid interventions and predictors of complications. *Surgeon* 2021:33–44. https://doi.org/10.33920/med-15-2101-04.
41. Kazantsev AN, Chernykh KP, Chernyavsky MA, et al. Risk stratification of postoperative complications in cardiovascular surgery. *Russ Med J* 2020;26:341–50. https://doi.org/10.17816/0869-2106-2020-26-6-341-350.
42. Kazantsev AN, Tarasov RS, Burkov NN, Ganyukov VI. Hybrid revascularization of the brain and myocardium: stratification of the risk of hospital complications. *Angiol Vasc Surg* 2020;26:118–23. https://doi.org/10.33529/ANGIO2020212.
43. Kazantsev AN, Chernykh KP, Leader RYu, et al. Carotid endarterectomy while taking clopidogrel and acetylsalicylic acid: combating hemorrhagic complications. *Breast Cardiovasc Surg* 2020;62:115–21. https://doi.org/10.24022/0236-2791-2020-62-2-115-121.
44. Belov YUV, Kazantsev AN, Vinogradov RA, et al. Ten-year long-term outcomes of conventional and eversion carotid endarterectomy. Multicenter study. *Russ J Cardiol* 2021;26:103–12. https://doi.org/10.15829/1560-4071-2021-4742.
45. Kazantsev AN, Tarasov RS, Burkov NN, et al. Hospital results of percutaneous coronary intervention and carotid endarterectomy in hybrid and staged modes. *Angiol Vasc Surg* 2019;25:101–7. https://doi.org/10.33529/angio2019114.
46. Kazantsev AN, Chernykh KP, Bagdavadze GSh. Prevention of hemorrhagic complications in hybrid interventions on the carotid and coronary arteries under conditions

of hypoaggregation and hypocoagulation. *Bull Russ Mil Med Acad* 2021;2:67–74. https://doi.org/10.17816/brmma26306.
47. Bayandin MS, Kazantsev AN, Burkov NN, Leader RYu. The results of reconstructive interventions on the carotid pool under conditions of double antiplatelet therapy. *Complex Probl Cardiovasc Dis* 2020;9(S1):9.
48. Kazantsev AN, Tarasov RS, Burkov NN, et al. Predictors of long-term complications after carotid endarterectomy. *Surg. J them. N.I. Pirogov*. 2019;6:20–5. https://doi.org/10.17116/hirurgia201906120.
49. Belov YuV, Ustinova AS, Yu GK, et al. Long-term outcomes of combined coronary bypass surgery and carotid endarterectomy in patients with type 2 diabetes. *Russ J Cardiol* 2022;27:4924. https://doi.org/10.15829/29/1560-4071-2022-4924.
50. Tarasov RS, Kazantsev AN, Shabaev AR, et al. Predictors of adverse events in the mid-term postoperative period in patients undergoing carotid endarterectomy. *Circ Pathol Card Surg* 2017;21:50–8.
51. Shabaev AR, Kazantsev AN, Tarasov RS. Annual outcomes of carotid endarterectomy and predictors of adverse events in patients with multifocal atherosclerosis. *Complex Probl Cardiovasc Dis* 2017;6(S4):45–6.
52. Tarasov RS, Kazantsev AN, Burkov NN, et al. Predictors of adverse events during hospitalization in patients undergoing carotid endarterectomy. *Cardiol Cardiovasc Surg* 2017;10:68–75. https://doi.org/10.17116/kardio201710368-75.
53. Kazantsev AN, Chernykh KP, Leader RYu, et al. Comparative results of classical and eversional carotid endarterectomy. *Cardiol Cardiovasc Surg* 2020;13:550–5. https://doi.org/10.17116/kardio202013061550.
54. Kazantsev AN, Bogomolova AV, Burkov NN, et al. Morphology of restenosis after classical carotid endarterectomy with diepoxy-treated xenopericardium patch. *Cardiol Cardiovasc Surg* 2020;13:68–71. https://doi.org/10.17116/kardio202013011168.
55. Kazantsev AN, Vinogradov RA, Zakharov YuN, et al. Prediction of restenosis after carotid endarterectomy by computer simulation. *Emerg Med Care. J them. N.V. Sklifosovsky.* 2021;10:401–7. https://doi.org/10.23934/2223-9022-2021-10-2-401-407.
56. Tarasov RS, Kazantsev AN, Anufriev AI, et al. Surgical factors of restenosis of the internal carotid artery after carotid endarterectomy. *Cardiol Cardiovasc Surg* 2018;11:47–53. https://doi.org/10.17116/kardio201811447.
57. Kazantsev AN, Burkov NN, Zakharov YuN, Borisov VG, Lider RYu, Bayandin MS, Anufriev AI. Personalized brain revascularization: a method of computer modeling of the reconstruction area for carotid endarterectomy. *Surgery* 2020:71–5. https://doi.org/10.17116/hirurgia202006171.
58. Kazantsev AN, Chernykh KP, Bagdavadze GS, et al. Rapid popliteal artery release sensu A.N. Kazantsev in acute thrombosis in patients with COVID-19. *Russ J Cardiol* 2021;26:4413. https://doi.org/10.15829/1560-4071-2021-4413.
59. Kazantsev AN, Burkov NN, Borisov VG. Computer modeling of hemodynamic parameters in the bifurcation of the carotid arteries after carotid endarterectomy. *Angiol Vasc Surg* 2019;25:107–12. https://doi.org/10.33529/ANGIO2019311.

60. Kazantsev AN, Leader RYu, Chernykh KP, et al. Ipsilateral classical carotid endarterectomy and contralateral eversional carotid endarterectomy in the same patient. *Breast Cardiovasc Surg* 2020;62:534–40. https://doi.org/10.24022/0236-2791-2020-62-6-534-540.
61. Kazantsev AN, Chernykh KP, Zarkua NE, et al. Simultaneous or staged carotid endarterectomy on both sides? *RussMed J* 2020;26:145–51. https://doi.org/10.17816/0869-2106-2020-26-3-145-151.
62. Kazantsev AN, Tarasov RS, Burkov NN, Shabaev AR, Leader RYu, Mironov AV. Carotid endarterectomy: three-year follow-up in a single-center registry. *Angiol Vasc Surg* 2018;24:101–8.
63. Kazantsev AN, Sultanov RV, Burkov NN, et al. Long-term results of surgical and conservative treatment of patients with occlusive-stenotic lesions of the carotid arteries. *Surgery* 2020;1:67–73. https://doi.org/10.17116/hirurgia202001167.
64. Kazantsev AN, Chernykh KP, Shabaev AR, et al. Thirty-day results of carotid endarterectomy with xenopericardial patch versus conservative treatment. *Breast Cardiovasc Surg* 2020;62:51–6. https://doi.org/10.24022/0236-2791-2020-62-1-51-56.
65. Golubenko MV, Tarasenko NV, Kazantsev AN, et al. Polymorphism of the mitochondrial genome in patients with carotid atherosclerosis. *Complex Probl Cardiovasc Dis* 2017;6(S4):18.
66. Nazarenko MS, Markov AV, Koroleva YuA, et al. Identification of differentially methylated genes potentially associated with atherosclerosis in humans. *Russ J Cardiol* 2017;22:42–8. https://doi.org/10.15829/1560-4071-2017-10-42-48.
67. Sleptsov AA, Nazarenko MS, Skryabin NA, Kazantsev AN, Barbarash OL, Puzyrev VP. Spectrum of structural genome variations in patients with coronary heart disease. *Med Genet* 2018;17:30–3. https://doi.org/10.25557/2073-7998.2018.03.30-33.
68. Koroleva YuA, Zarubin AA, Markov AV, Kazantsev AN, Barbarash OL, Nazarenko MS. Analysis of the relationship between the level of methylation of genes mir10b and mir21 in blood leukocytes with clinically pronounced atherosclerosis of the carotid arteries. *Sib Med J (Tomsk)* 2018;33:77–82. https://doi.org/10.29001/2073-8552-2018-33-2-77-82.
69. Golubenko MV, Markov AV, Zarubin AA, et al. DNA methylation level in regulatory regions of mtDNA and three mitochondria-related nuclear genes in atherosclerosis. In: *Systems Biology and Biomedicine (SBioMed-2018). Symposium. Abstracts. The Eleventh International Conference*; 2018. p. 45.
70. Markov A, Zarubin A, Nazarenko M, et al. DNA methylation and expression of microRNA genes in unstable carotid atherosclerotic plaques. In: *Systems Biology and Biomedicine (SBioMed-2018). Symposium. Abstracts. The Eleventh International Conference*; 2018. p. 88.
71. Nazarenko MS, Sleptsov AA, Markov AV, Kazantsev AN, Barbarash OL, Puzyrev VP. Omics-based approach to profiling of human atherosclerotic plaques. In: *Systems Biology and Biomedicine (SBioMed-2018). Symposium. Abstracts. The Eleventh International Conference*; 2018. p. 101.
72. Sleptsov AA, Nazarenko MS, Markov AV, et al. Copy number calling from infinium methylationepic array in human carotid atherosclerotic plaques. Systems Biology

and Biomedicine (SBioMed-2018). Symposium. Abstracts. *Eleventh Int Conf* 2018:137.
73. Markov AV, Zarubin AA, Sharysh DV, et al. The problem of cellular heterogeneity in the analysis of DNA methylation in samples of arteries affected by atherosclerosis: a bioinformatic approach. *Complex Probl Cardiovasc Dis* 2019;8(S3-2):37.
74. Sleptsov AA, Nazarenko MS, Skryabin NA, et al. Structural variability of the genome in cardiovascular pathology. *Complex Probl Cardiovasc Dis* 2019;8(S3-2):60.
75. Kazantsev AN, Burkov NN, Bayandin MS, et al. Hospital results of carotid artery stenting in patients with multifocal atherosclerosis. *Cardiol Cardiovasc Surg* 2020;13:224–9. https://doi.org/10.17116/kardio202013031224.
76. Kazantsev AN, Burkov NN, Chernyavsky MA, Chernykh KP. Carotid endarterectomy in a patient with bilateral stent restenosis in the internal carotid arteries. *Angiol Vasc Surg* 2020;26:86–9. https://doi.org/10.33529/ANGIO2020424.
77. Kazantsev AN, Burkov NN, Shabaev AR, Volkov AN, Ruban EV, Leader RYu, Anufriev AI. Surgical treatment of a patient with stent restenosis in the orifice of the common carotid artery and the proximal part of the internal carotid artery. *Circ Pathol Card Surg* 2019;23:104–10. https://doi.org/10.21688/1681-3472-2019-3-104-110.
78. Burkov NN, Kazantsev AN, Tarasov RS, et al. Xenopericardial plastics of the internal carotid artery in case of its restenosis. *Complex Probl Cardiovasc Dis* 2019;8(S3):26.
79. Yakhnis EYa, Leader RYu, Kazantsev AN, Shabaev AR, Burkov NN. Application of a xenopericardium patch in the correction of carotid artery restenosis after carotid endarterectomy. *Complex Probl Cardiovasc Dis* 2019;8(S3-2):73.
80. Guselnikova YuI, Leader RYu, Kazantsev AN, Shabaev AR, Burkov NN. Characteristics of restenosis and progression of atherosclerosis after carotid endarterectomy in the long-term follow-up. *Complex Probl Cardiovasc Dis* 2019;8(S3-2):17.
81. Kazantsev AN, Chernykh KP, Bagdavadze GSh, Bayandin MS. Redo-surgery of the carotid arteries in patients with contraindications for carotid angioplasty with stenting. *Angiol Vasc Surg* 2021;27:92–8. https://doi.org/10.33529/ANGIO2021217.
82. Tarasov RS, Kazantsev AN, Barbarash LS, Zinets MG, Danilovich AI, Shabaev IF. THE Results of an aimed incomplete myocardial revascularization with low invasive and standard technics of coronary bypass. *Russ J Cardiol* 2018:47–52. https://doi.org/10.15829/1560-4071-2018-7-47-52.
83. Kazantsev AN, Chernykh KP, Zarkua NE, et al. Eversion carotid endarterectomy with transposition of the internal carotid artery according to A.N. Kazantsev. Hospital and long-term results. *Russ Med Biol Bull Acad I.P. Pavlova* 2021;29:73–88. https://doi.org/10.23888/PAVLOVJ202129173-88.
84. Kazantsev AN, Chernykh KP, Zarkua NE, et al. Eversion carotid endarterectomy: transposition of the internal carotid artery over the hypoglossal nerve. *Surgery* 2021;6:63–71. https://doi.org/10.17116/hirurgia202106163.
85. Kazantsev AN, Tarasov RS, Anufriev AI, Burkov NN, Shabaev AR, Ruban EV. Simultaneous operation in a patient with extracranial stenosis and intracranial aneurysm of the internal carotid artery. *Angiol Vasc Surg* 2017;23:107–11.

86. Burkov NN, Kazantsev AN, Tarasov RS. Predictors of adverse outcomes of reconstructive interventions on the aorto-femoral segment in the long-term follow-up. *Complex Probl Cardiovasc Dis* 2017;6(S4):15.
87. Kazantsev AN, Tarasov RS, Zinets MG, Anufriev AI, Burkov NN, Grigoriev EV. Thromboembolectomy in combination with coronary artery bypass grafting in the acute period of pulmonary embolism. *Cardiol Cardiovasc Surg* 2017;10:93–5. https://doi.org/10.17116/kardio201710693-95.
88. Tarasov RS, Kazantsev AN, Glebov KK, Leader RYu, Burkov NN. Results of coronary artery bypass grafting in patients of different age groups. *Angiol Vasc Surg* 2019;25:148–56. https://doi.org/10.33529/ANGIO2019213.
89. Tarasov RS, Ivanov SV, Kazantsev AN, et al. Long-term outcomes of coronary artery bypass grafting in young patients. *Surgery* 2019;11:57–63. https://doi.org/10.17116/hirurgia201911157.
90. Kazantsev AN, Chernykh KP, Zarkua NE, et al. Results of carotid endarterectomy in different age groups. *Transl Med* 2020;7:21–31. https://doi.org/10.18705/2311-4495-2020-7-4-21-31.
91. Kazantsev AN, Vinogradov RA, Erofeev AA, et al. Multicenter study to study the results of carotid endarterectomy in different age groups with the analysis of predictors of complications. *Cardiol Cardiovasc Surg* 2021;14:280–91. https://doi.org/10.17116/kardio202114041280.
92. Kazantsev AN, Vinogradov RA, Chernykh KP, et al. Methods of carotid endarterectomy. *Russ J Cardiol.* 2021;26:4445. https://doi.org/10.15829/1560-4071-2021-4445.
93. Tarasov RS, Kazantsev AN, Moldavskaya IV, et al. Hospital results of carotid endarterectomy in the acute period of ischemic stroke: data from a single-center register. *Cardiol Cardiovasc Surg* 2018;11:60–5. https://doi.org/10.17116/kardio20181105160.
94. Kazantsev AN, Chernykh KP, Zarkua NE, et al. Immediate and long-term results of carotid endarterectomy in different periods of ischemic stroke. *Russ Med Biol Bull Acad I.P. Pavlova* 2020;28:312–22. https://doi.org/10.23888/PAVLOVJ2020283312-322.
95. Kazantsev AN, Burkov NN, Tarasov RS, et al. Carotid endarterectomy in the acute period of ischemic stroke. *Circ Pathol Card Surg* 2018;22:66–72. https://doi.org/10.21688/1681-3472-2018-1-66-72.
96. Kazantsev AN, Porkhanov VA, Khubulava GG, et al. Comparative results of emergency carotid endarterectomy and emergency carotid angioplasty with stenting in the acute period of ischemic stroke. results of a multicenter study. *Emerg Med Care. J them. N.V. Sklifosovsky.* 2021;10:33–47. https://doi.org/10.23934/2223-9022-2021-10-1-33-47.
97. Kazantsev AN, Vinogradov RA, Chernyavsky MA, et al. Urgent intervention of hemodynamically significant stenosis of the internal carotid artery in the acute period of ischemic stroke. *Circ Pathol Card Surg* 2020;24(3S):89–97. https://doi.org/10.21688/1681-3472-2020-3S-89-97.
98. Kazantsev AN, Chernykh KP, Leader RYu, et al. Glomus-sparing carotid endarterectomy according to A.N. Kazantsev. Hospital and mid-term results. *Circ Pathol Card Surg* 2020;24:70–9. https://doi.org/10.21688/1681-3472-2020-3-70-79.

99. Kazantsev AN, Chernykh KP, Zarkua NE, et al. A new method of glomus-sparing carotid endarterectomy according to A. N. Kazantsev: cutting off the internal carotid artery at the site from the external and common carotid artery. *Russ J Cardiol* 2020;25:10–7. https://doi.org/10.15829/1560-4071-2020-3851.
100. Kazantsev AN, Chernykh KP, Leader RYu, et al. Emergency glomus-sparing carotid endarterectomy according to A.N. Kazantsev. Emergency medical care. *J them. N.V. Sklifosovsky.* 2020;9:494–503. https://doi.org/10.23934/2223-9022-2020-9-4-494-503.
101. Kazantsev A.N., Zarkua N.E., Chernykh K.P., et al. A method of reconstruction of the bifurcation of the carotid arteries with extended atherosclerotic lesions of the internal carotid artery. Patent for invention 2749785 C1, 16.06.2021. Application No. 2020134151 dated 16.10.2020.
102. Kazantsev A.N., Zarkua N.E., Chernykh K.P., et al. The method of glomus-sparing carotid endarterectomy. Patent for invention 2746208 C1, 08.04.2021. Application No. 2020131426 dated 09/23/2020.
103. Kazantsev AN, Chernykh KP, Zarkua NE, et al. "Chik-chirik" carotid endarterectomy. Bulletin of the N.N. A.N. Bakuleva RAMS. *Cardiovasc Dis.* 2020;21:414–28. https://doi.org/10.24022/1810-0694-2020-21-4-414-428.
104. Kazantsev A.N., Kravchuk V.N., Chernyavsky M.A., et al. Method of eversional carotid endarterectomy. Patent for invention 2750910 C1, 06.07.2021. Application No. 2020140744 dated 09.12.2020.
105. Kazantsev AN, Vinogradov RA, Kravchuk VN, et al. Which carotid endarterectomy is more effective in combination with coronary artery bypass grafting? Bulletin of the N.N. A.N. Bakuleva RAMS. *Cardiovasc Dis.* 2020;21:649–62. https://doi.org/10.24022/1810-0694-2020-21-6-649-662.
106. Kazantsev AN, Vinogradov RA, Chernyavsky MA. The dynamics of resistant arterial hypertension in the postoperative period of carotid endaterectomy with the preservation of the carotid glomus and with its cutting off. *Russ J Cardiol* 2021;26:46–53. https://doi.org/10.15829/1560-4071-2021-4253.