The Cardiothoracic Surgeon

RESEARCH **Open Access**

An alternative anatomical classification for carotid bifurcation and impact on outcome of carotid endarterectomy: a multicenter study

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Abstract

Background The present multicenter retrospective study included 7148 patients who underwent carotid endarterectomy (CEA) between 2010 and 2021. Based on the results of angiography (AG)/multislice computed tomography (MSCT) angiography, 3 types of carotid bifurcation were identified depending on the projection of the carotid sinus to the cervical vertebrae: type I (high)—from the upper edge of the body of the II cervical vertebra to the lower edge of intervertebral disc located between III and IV cervical vertebrae; type II (medium)—from the upper edge of the body of the IV cervical vertebra to the lower edge of the body of the V cervical vertebra; and type III (low)—from the upper edge of the intervertebral disc located between the V and VI cervical vertebrae to the lower edge of the body of the VII cervical vertebra.

Purpose of the study To develop a new classification of the types (high, medium, low) of carotid bifurcations (based on the level of cervical vertebrae) with analysis of the results of CEA depending on the type.

Results The largest number of ischemic strokes ($n = 15$; 1.1%; $p = 0.0001$) was found in type I (high) bifurcation of the carotid artery. The majority of bleedings of type 3b and higher according to the BARC scale with the formation of acute hematomas in the intervention area ($n = 14$; 1.2%; $p = 0.0029$) were recorded in type III carotid bifurcation (low).

Conclusions Type II (medium) carotid bifurcation may be the most preferred for CEA.

Keywords Carotid endarterectomy, Classical carotid endarterectomy, Eversion carotid endarterectomy, Patch, Classification, Neuropathy, Hypoglossal nerve, Glossopharyngeal nerve, Horner syndrome, Carotid thrombosis, High bifurcation, Dissection, Temporary shunt, Hematoma, Styloid process, Carotid angioplasty and stenting

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Background

Carotid endarterectomy (CEA) is the most elegant operation in modern angiosurgery. There are two popular techniques of this reconstruction—classic with patch implantation and eversion [1–5]. The current guidelines specified strict indications for CEA implementation and adopted certain "quality standards," including the acceptable rate of postoperative cardiovascular complications [6]. And today, after more than half a century of history, CEA has established itself as the "gold standard" for the treatment of patients with hemodynamically significant stenoses of the internal carotid arteries (ICA) [6–10].

With the development of endovascular technologies, carotid angioplasty and stenting (CAS) has become a serious competitor for open surgery [11–15]. According to a number of studies, in-hospital and long-term results of CEA and CAS have already reached comparable values [4, 16–19]. More often, we can observe that the choice in favor of one or another type of revascularization is determined not only by indications, but also by the patient's preference. The guidelines allow performing CAS in cases where CEA is associated with a high risk of surgical complications or when restenosis of the ICA is involved [6]. Redo carotid surgery is almost always combined with trauma of the surrounding nerves, closely adherent scar tissue to the vessels of this area [7, 20, 21]. Therefore, stent implantation in these conditions will be the most preferable option to avoid the negative consequences of neuropathy [6, 7, 20, 21].

However, the injury of the hypoglossal and glossopharyngeal nerves also occurs during primary CEA [6]. In the opinion of some authors, this is due to the need for surgical manipulations in the area where these structures are localized: (1) in view of "high" location of the carotid bifurcation; (2) with continuing intimal detachment in the ICA, requiring extended arteriotomy; and (3) with extended atherosclerotic plaque in the ICA, spreading above the mentioned nerves [2, 3, 22, 23]. As a rule, the second situation cannot be predicted by preoperative angiography (AG) data. In the first situation, guided by imaging techniques, it is possible to avoid open surgery and cranial nerve injury (CNI) by referring the patient for CAS [4, 6, 11, 14, 15]. Even though most cases of CN neuropathy are reversible, in some situations, they become irreparable, accompanied by laryngeal paresis, dysphagia, etc. [3, 4, 6, 7, 24]. These consequences undoubtedly reduce the patient's quality of life [3, 4, 6, 7, 24]. However, the current guidelines do not suggest acceptable limits for the incidence of cranial nerve injury at any particular facility and do not consider such a term as "high bifurcation" in order to refer a patient for CAS, thus avoiding open surgery with the risk of hypoglossal and glossopharyngeal neuropathy [6]. Also, despite the fact that there are references in the literature about high localization of the carotid bifurcation as an unfavorable predictor of the listed complications for CEA, there is no unified definition of this term today [24, 25]. Some practicing surgeons still try to focus on the topography of the carotid arteries relative to the mandible or cervical vertebrae [25, 26]. In the first situation, due to the mobility of the os mandibula, this method is minimally informative. In the case of the vertebrae, however, no classifications to determine the boundaries of high, medium, and low carotid bifurcation have been published to date.

The aim of this multicenter study was to develop a new classification of the types (high, medium, and low) of carotid bifurcations (based on the level of cervical vertebrae) with an analysis of CEA results depending on the type.

Methods

This retrospective multicenter study included 7148 patients who underwent CEA between 2010 and 2021. In 2362 (33%) cases, classical CEA with patch angioplasty was performed; in 4786 (67%), eversion CEA was performed. Based on the results of AG/multislice computed tomography (MSCT) angiography depending on the projection of the carotid sinus to the cervical vertebrae, 3 types of carotid bifurcation were identified:

Type I (high)—from the upper edge of the body of the II cervical vertebra to the lower edge of the intervertebral disc located between the III and IV cervical vertebrae

Type II (medium)—from the upper edge of the body of the IV cervical vertebra to the lower edge of the body of the V cervical vertebra

Type III (low)—from the upper edge of the intervertebral disc located between the V and VI cervical vertebrae to the lower edge of the body of the VII vertebra

Type I was detected in 1329 (18.6%) patients, type II in 4652 (65.1%), and type III in 1167 (16.3%).

Rationale for the boundaries between the types

The boundary between types I and II was established because the hypoglossal nerve and glossopharyngeal nerve in different variants are localized strictly within type I (from the upper edge of the body of II cervical vertebra to the lower edge of the intervertebral disc located between III and IV cervical vertebrae). The boundary between types II and III was established due to the fact that strictly within type III, the anterior surface of the carotid arteries is concealed by the sternocleidomastoid muscle, the superior belly of the omohyoid muscle, and the sternohyoid muscle (when the arteries are isolated, it becomes necessary to cross/partially cross one or two of the last listed muscles to visualize them).

The criteria for inclusion in the study are (1) the absence of acute periods of ischemic stroke, (2) indications for CEA according to the current international recommendations, and (3) the presence of imaging results of AG/MSCT of the brachiocephalic artery.

Non-inclusion criteria are (1) the presence of pathology limiting the patient's long-term follow-up (oncology, etc.).

The operative risk was calculated according to the EuroSCORE II interactive calculator. In the presence of clinical signs of angina, coronary angiography with calculation of coronary atherosclerosis severity according to the SYNTAX score was performed after consultation with a cardiologist. The degree of ICA stenosis was determined on the basis of MSCT AG/AG data (The North American Symptomatic Carotid Endarterectomy Trial (NASCET)). Prior to CEA, all patients underwent the marking of the intervention area with the support of color duplex scanning (CDS).

The choice of treatment tactics was made by a multidisciplinary council (cardiovascular surgeon, endovascular surgeon, cardiologist, neurologist, resuscitator, and anesthesiologist). The decision to place a temporary shunt was based on invasive measurement of retrograde ICA pressure (when it decreased by 60% or more of the systemic arterial pressure). The study involved those medical centers in which the tactics are unified, only this. According to Russian recommendations and standards, this is a strict regulation that cannot be ignored. So it is the same everywhere.

In the postoperative period, all patients underwent control CDS of the reconstructed area. Also, all patients were examined daily by a neurologist during the pre- and postoperative follow-up periods.

The end points were fatal outcome, myocardial infarction (MI), acute cerebrovascular accident (ACVA), transient ischemic attack (TIA), Bleeding Academic Research Consortium (BARC) type 3b or more, ICA thrombosis, Horner syndrome, hypoglossal neuropathy, glossopharyngeal neuropathy, and combined end point (Horner syndrome + hypoglossal neuropathy + glossopharyngeal neuropathy).

Statistical analysis

The type of distribution was determined using the Kolmogorov-Smirnov test. Groups were compared using Pearson's chi-square and Kruskal-Wallis tests and Pearson's chi-square with Yates correction for pairwise comparison of groups. If there were values in only two groups, Fisher's exact test was used to compare them. Differences were evaluated as significant at $p < 0.05$. The results were processed using the GraphPad Prism software package (www.graphpad.com).

Ethical review

All patients signed a written consent to the use of their data in scientific research. The work was carried out in accordance with the standards of good clinical practice (Good Clinical Practice) and the principles of the Declaration of Helsinki and did not contradict the Federal Law of the Russian Federation of November 21, 2011, No. April 1, 2016, N 200n "On approval of the rules of good clinical practice" Conclusion of the Local Ethics Committee (extract from protocol No. 5 dated December 6, 2021): the study was performed in compliance with the ethical principles of scientific medical research involving humans.

The cohorts of patients of each type were completely comparable in terms of age, sex, comorbid pathology, frequency of surgical interventions in history, and risk of postoperative complications according to the EuroSCORE II scale (Table 1).

Results

There were no statistically significant differences between the groups according to stenosis degree and coronary atherosclerosis severity (SYNTAX score). There were no cases of extended atherosclerotic plaque in carotid bifurcation type I (high) (at the stage of revascularization strategy selection by the multidisciplinary council, taking into account AG/MSCT AG data, such patients were referred for CAS) (Table 2).

Intraoperatively, the time of ICA clamping most often did not exceed 30 min. The need for placing a temporary shunt appeared in every sixth case. In the vast majority of cases, the eversion technique of CEA was used. In types II and III of the carotid bifurcation, there was no need for the removal of the styloid process (Table 2).

In the postoperative period, there were no significant intergroup differences in the incidence of fatal outcomes and MI. The highest number of ACVA/TIA (n = 15; 1.1%) was detected in type I (high) carotid bifurcation, which was associated with a statistically higher incidence of ICA thrombosis (n = 8; 0.6%) in this cohort against the background of intimal detachment behind the endarterectomy zone (Table 3).

In 2 cases of type I (high), after insertion of an inaccurately calibrated temporary shunt (it was impossible to accurately assess the ICA diameter due to low visualization behind the tissue above the hypoglossal nerve), ICA dissection occurred. After the clamp was removed and blood flow started, from the depth of the upper wound edge, bleeding developed. Further tissue dissection and removal of the styloid process did not allow us to identify the "uninjured area of the artery" (the dissection continued up to the entry of the ICA into the skull), which resulted in the necessity of ICA ligation. Both patients developed ischemic ACVA with an irreversible neurological deficit at the hospital stage.

Table 1 Comparative clinical and anamnestic characteristics of patient groups

Indicator	Types of bifurcations			p
	I (high)	II (medium)	III (low)	
	n **=1329**	***n*** **= 4652**	***n*** **= 1167**	
Age, M±m, years	68.3±7.4	66.8±8.2	66.9±7.7	0.26
Male gender, *n* (%)	847 (63.7)	3024 (65.0)	723 (61.9)	0.13
Angina 1–2 F. C, *n* (%)	292 (21.9)	1069 (22.9)	281 (24.1)	0.45
PICS, *n* (%)	136 (10.2)	526 (11.3)	147 (12.6)	0.17
DM, *n* (%)	74 (5.6)	254 (5.4)	69 (5.9)	0.83
COPD, *n* (%)	32 (2.4)	103 (2.2)	30 (2.6)	0.74
CRF, *n* (%)	48 (3.6)	151 (3.2)	42 (3.6)	0.72
MFA (subclinical), *n* (%)	261 (19.6)	857 (18.4)	203 (17.4)	0.34
Left ventricular aneurysm, *n* (%)	3 (0.2)	7 (0.15)	2 (0.17)	0.83
EuroSCORE II, M±m	3.1±1.2	3.3±1.0	3.4±1.2	0.48
History of PCI, *n* (%)	185 (13.9)	612 (13.1)	175 (14.9)	0.24
CABG in the anamnesis, *n* (%)	8 (0.6)	17 (0.36)	5 (0.42)	0.50
ACV/history of TIA, *n* (%)	519 (39.0)	1833 (39.4)	480 (41.1)	0.50

FC functional class, *PICS* postinfarction cardiosclerosis, *DM* diabetes mellitus, *AH* arterial hypertension, *COPD* chronic obstructive pulmonary disease, *CRF* chronic renal failure, *MFA* multifocal atherosclerosis, *PCI* percutaneous coronary intervention, *CABG* coronary artery bypass grafting, *ACVA* acute cerebrovascular accident, *TIA* transient ischemic attack

In other cases, the cause of ACVA/TIA (in all types) was distal embolization either due to manipulations during arterial isolation in the presence of an unstable atherosclerotic plaque area or after a temporary shunt.

Most bleedings of type 3b or more on the BARC scale with the formation of acute hematomas of the intervention area were recorded in type III (low) carotid bifurcation ($n = 14$; 1.2%). During revision, we found that in 9 cases the source of bleeding was an "erupted" suture between sections of the dissected omohyoid muscle; in 5 cases, there was diffuse bleeding along this suture (without signs of "eruption").

In 1 case of type III (low) carotid bifurcation (left), no antegrade blood flow was obtained after inserting a temporary shunt, completing the reconstruction, and removing the clamp from the common carotid artery (CCA). Due to the absence of pulsation in the entire accessible section of the CCA (up to the entrance to the thorax), it was decided to transport the patient to the radiology room. According to the angiography, the dissection of the CCA with its thrombotic occlusion was visualized, without damage to the aorta. Recanalization of the CCA with stenting was performed. A satisfactory angiographic result was obtained. According to the control CDS, the blood flow along the CCA/ICA was normal and the arteries had no signs of thrombosis/stenosis. The patient was discharged on the 10th day after the operation without the symptoms of ACVA/TIA.

The greatest number of cases of neuropathy of the hypoglossal nerve, glossopharyngeal nerve, Horner syndrome, and the combined endpoint was revealed in type I (high) carotid bifurcation, which was caused by the localization of the mentioned structures in this area above the anterior wall of the ICA. The need for dissection of

Table 2 Angiographic and perioperative characteristics

Indicator	Types of bifurcations			p
	I (high)	II (medium)	III (low)	
	n **=1329**	***n*** **= 4652**	***n*** **= 1167**	
% ICA stenosis	82.4±5.2	79.7±4.6	83.0±4.5	0.21
Unstable ABP, *n* (%)	262 (19.7)	853 (18.3)	212 (18.1)	0.48
Hemodynamically significant ICA stenoses on both sides, *n* (%)	230 (17.3)	814 (17.5)	216 (18.5)	0.67
SYNTAX score including revascularization history of myocardial infarction, M±m	5.6±1.1	4.2±1.7	4.8±1.3	0.69
Using a temporary shunt	214 (16.1)	706 (15.2)	189 (16.2)	0.55
ICA clamping time, min	23.4±5.7	22.1±6.8	22.3±5.0	0.37
Eversion carotid endarterectomy, *n* (%)	877 (65.9)	3128 (67.2)	781 (66.9)	0.69
Extended atherosclerotic plaque in ICA (more than 3 cm), *n* (%)	0	744 (15.9)	186 (15.9)	<0.0001
Styloidectomy, *n* (%)	10 (0.75)	0	0	<0.0001

ICA internal carotid artery, *ECA* external carotid artery, *ABP* atherosclerotic plaque, *P (o)* general statistical difference for all groups

Table 3 Hospital outcomes

Indicator	Types of bifurcations			p
	I (high)	II (medium)	III (low)	
	n = 1329	n = 4652	n = 1167	
Death, n (%)	4 (0.3)	6 (0.12)	0	0.33
Myocardial infarction (nonfatal + fatal), n (%)	5 (0.37)	8 (0.17)	5 (0.42)	0.17
Acute cerebral vascular accident/transient ischemic attack (nonfatal), n (%)	15 (1.1)	12 (0.25)	4 (0.34)	0.0001
Bleeding type 3b or more on the BARC scale, n (%)	11 (0.83)	14 (1.2)	14 (1.2)	0.0029
Thrombosis of the internal carotid artery, n (%)	8 (0.6)	1 (0.02)	0	< 0.0001
Horner syndrome, n (%)	36 (2.7)	13 (0.3)	5 (0.42)	< 0.0001
Neuropathy of the hypoglossal nerve, n (%)	159 (11.9)	42 (0.9)	3 (0.25)	< 0.0001
Neuropathy of the glossopharyngeal nerve, n (%)	84 (6.3)	5 (0.1)	0	< 0.0001
Combination endpoint, n (%)	279 (20.9)	60 (1.3)	8 (0.7)	<0.0001

P (o) general statistical difference for all groups

the latter with the removal of the styloid process in case of ICA dissection or detachment of the intima behind the endarterectomy zone was always accompanied by the development of irreversible neuropathy of the listed nerves.

Discussion

The presented multicenter study demonstrated that type II (medium) carotid bifurcation (from the upper edge of the IV cervical vertebra to the lower edge of the V cervical vertebra) is the most favorable topographic variant for CEA implementation. The hypoglossal and glossopharyngeal nerves are not localized in this area, which prevents their injury with subsequent neuropathy.

It is also possible to perform CEA with a satisfactory postoperative outcome in the presence of type III (low) carotid bifurcation (from the upper edge of the intervertebral disc located between the V and VI cervical vertebrae to the lower edge of the VII vertebra body). But it should be borne in mind that crossing of the muscles of this area even after their integrity has been restored by means of suturing may be accompanied by defective work of the latter due to disconnection of the continuous structure by the scar tissue with subsequent atrophy. Such a feature, firstly, will be characterized by the formation of a cosmetic defect expressed as asymmetry of the neck. Secondly, the weakened functionality of the ipsilateral muscles and the preserved activity of the contralateral group can lead to destabilization in the cervical spine with the subsequent development of osteochondrosis, cervicalgia, etc. Therefore, despite the convincing clinical result of revascularization, the patient should be warned about possible mid-term and long-term effects in the postoperative period. Thus, CAS in the presence of carotid bifurcation types I and III would probably help to avoid the listed adverse events.

Additionally, it should be reported that in conditions of high and low bifurcation imaging, it is difficult to insert a temporary shunt (if indicated). Its implantation in the distal direction (into the ICA) in type I virtually eliminates the visualization of the arterial segment in which the balloon is inflated. In the case of the development of ICA dissection with a temporary balloon shunt of this area, further manipulations will be possible if the length of the wound is continued towards the temporal bone with incision of nerves with styloidectomy, which will be manifested by irreversible neurological complications [27–29]. If we are talking about type III carotid bifurcation, the placement of a temporary shunt in the proximal direction (into the common carotid artery (CCA) with balloon inflation and dissection) can lead to the continuation of dissection (depending on anatomy) to the aorta, brachiocephalic trunk, and subclavian artery with subsequent unfavorable prognosis.

Another fact that we were able to establish as part of our study was that CEA in type III conditions is statistically more frequently accompanied by the development of acute hematoma with the need for wound revision ($p = 0.0017$). This is primarily due to the traumatic nature of access to the arteries with the incision of muscular structures. Muscle fibers are known to be richly vascularized, and in subsequent postoperative management, against the background of anticoagulant/antiplatelet therapy, this factor can lead to diffuse bleeding of the muscle incision site (regardless of the suture). It should also be pointed out that the muscle tissue is very soft and when the neck moves (after surgery), the suture connecting the crossed fibers can break, which will lead to bleeding and hematoma formation.

Another observation was that in type I carotid bifurcation a statistically higher number of ICA thrombosis ($p < 0.0001$) and associated ACVA/TIA were diagnosed ($p = 0.0001$). In all cases, the ICA thrombosis developed against the background of intimal detachment behind the endarterectomy zone, which could not be identified intraoperatively due to the lack of visualization of this arterial segment (the artery is located behind and above the hypoglossal nerve).

Thus, summarizing the results of our work, CEA can be recommended in the presence of type II (medium) carotid bifurcation. In other types (II and III), open intervention will be accompanied by a greater risk of neurological and hemorrhagic complications.

Conclusions

Type II (medium) carotid bifurcation may be the most preferred for CEA. Type I (high) carotid bifurcation when performing CEA is statistically more often combined with the need for styloidectomy, postoperative neuropathy of the hypoglossal nerve, glossopharyngeal nerve, Horner syndrome, ICA thrombosis, and ACVA/TIA. Type III (low) carotid bifurcation is characterized by statistically frequent development of acute hematoma after CEA. Types I (high) and III (low) of carotid bifurcation may be the least preferable for temporary shunt placement due to the risks of dissection of non-visualized arterial sections.

Abbreviations

ACVA	Acute cerebrovascular accident
AG	Angiography
BARC	Bleeding Academic Research Consortium
CAS	Carotid angioplasty and stenting
CCA	Common carotid artery
CDS	Color duplex scanning
CEA	Carotid endarterectomy
CN	Cranial nerve
CNI	Cranial nerve injury
ICA	Internal carotid arteries
MI	Myocardial infarction
MSCT	Multislice computed tomography
NASCET	The North American Symptomatic Carotid Endarterectomy Trial
TIA	Transient ischemic attack

Acknowledgements

Acknowledgments are missing.

Authors' contributions

ANK—execution of operations and article writing. AVK—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. RYL—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. OVL—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. AAS—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. PDP—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. MOS—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. DVS—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. SVA—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. EGK—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. GShB—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. WS—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. LVR—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. MAK—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. VMU—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. MPC—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. OGN—execution of operations, collection of primary information, registration of the database, entering data into the register, statistical analysis, and approval of the final version of the article. YVB—execution of operations, concept and design, and article writing. The author(s) read and approved the final manuscript.

Funding

The work has no funding.

Availability of data and materials

All study data are included in the All-Russian multicenter register of carotid endarterectomy.

Declarations

Ethics approval and consent to participate

The work was carried out in accordance with the standards of good clinical practice (Good Clinical Practice) and the principles of the Declaration of Helsinki and did not contradict the Federal Law of the Russian Federation of November 21, 2011, No. April 1, 2016, N 200n "On approval of the rules of good clinical practice" Conclusion of the Local Ethics Committee (extract from protocol No. 5 dated December 6, 2021): the study was performed in compliance with the ethical principles of scientific medical research involving humans.

Consent for publication

All patients signed a written consent to the use of their data in scientific research.

Competing interests

The authors declare that they have no competing interests.

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Received: 16 December 2022 Accepted: 27 January 2023
Published online: 09 February 2023

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