Surgical Treatment Modalities of Carotid Artery Stenosis (Review)

DOI: 10.17691/stm2015.7.4.25
Received January 14, 2015

© **A.V. Yarikov,** Neurosurgeon[1];
A.V. Balyabin, MD, PhD, Researcher[2]; Neurosurgeon[1];
K.S. Yashin, PhD Student[2];
A.S. Mukhin, MD, DSc, Professor, Head of the Surgery Department, Postgraduate Faculty[3]

[1]City Clinical Hospital No.39, 144 Moskovskoe Shosse, Nizhny Novgorod, 603028, Russian Federation;
[2]Privolzhsky Federal Research Medical Center, Ministry of Health of the Russian Federation, 18 Verkhne-Volzhskaya naberezhnaya St., Nizhny Novgorod, 603155, Russian Federation;
[3]Nizhny Novgorod State Medical Academy, 10/1 Minin and Pozharsky Square, Nizhny Novgorod, 603005, Russian Federation

The review presents the comparative analysis of current surgical techniques to treat atherosclerotic carotid lesions: carotid stenting and carotid endarterectomy (classical and everting), and describes the advantages and disadvantages of these methods introducing indications and contraindications. Particular emphasis is given to the technique and time to complete carotid endarterectomy. The paper concerns the benefits of a patch over a primary suture, as well as presents the requirements for a patch used in carotid endarterectomy. The authors studied all current materials used for patches, and gave merits and demerits of each material described. The review assesses the feasibility and safety of the more invasive surgical approach for brain revascularization in an acute period of ischemic stroke in strict compliance with surgical indications. The authors have concluded that carotid endarterectomy has a positive effect on cognitive functions in patients in the form of neurological and neuropsychological status improvement. There has been also proved that all above mentioned techniques have no advantages, moreover, they can be mutually complementary and, actually, used in chronic cerebral ischemia treatment.

Key words: carotid endarterectomy; carotid stenting; ischemic stroke; carotid artery stenosis.

Acute cerebrovascular accident (CVA) remains a major medical and social problem of our time. About 500 thousand new cases of ischemic stroke (IS) are recorded every year, and over 1 million people who have had stroke live in Russia [1–3]. The incidence of IS in the Russian Federation is 3.48 per 1,000 population a year, among the Caucasians ethnicity in the US this figure is 1.38–1.67 per 1,000 population, while in Northern and Central Europe it is 0.38–0.47 per 1,000 population, which is one of the lowest [4, 5]. CVA is an important factor for invalidization of the working population: only 8% of stroke survivors can return to previous work [2, 6, 7]. Out of the total mortality in Russia, CVA is 21.4% [8], and in the industrialized countries it is the third leading cause of death [9, 10]. At the same time, despite the often poor results, the treatment and rehabilitation costs are constantly going up and currently range from $16.5 to 22 billion per year [8]. The present situation promotes the development of preventive measures for the correction of risk factors and the development of methods of preventive medicine in CVA treatment.

The leading pathogenetic mechanism in the development of ischemic CVA is atherothrombosis, it being 57% [11, 12]. The idea of the link between atherosclerosis and CVA development appeared in the late XIX century. In 1875 Gowers described blindness in the left eye and right-sided hemiplegia in a patient with the occlusion of the left internal carotid artery (ICA). In 1914 Hunt suggested that ICA atherosclerosis may be a source of microemboli, causing transient ischemic attacks (TIA) [13]. This was followed by repeated attempts of surgical interventions on the carotid artery to prevent CVA. Only in 1951 Eascost reported the first successful experience of surgery on the carotid arteries. In 1953 DeBakey made the first classical carotid endarterectomy (CEE) to prevent CVA. However, the further analysis of the immediate and long-term outcomes of the surgical treatment demonstrated that some patients developed CVA despite performed CEE. It called into question the effectiveness of the surgery. In 1959 DeBakey suggested the idea of eversion CEE. This procedure included cutting off the common carotid artery (CCA), performing eversion of the primary departments of the external carotid artery (ECA) and ICA. Then Chevalier modified the eversion CEE technique. He suggested performing the intersection of the ICA more distally from

For contacts: Yarikov Anton Viktorovich, e-mail: anton-yarikov@mail.ru

the end of the atherosclerotic plaque and longitudinal CCA arteriotomy with the following eversion of the ICA proximal portion [14]. However, this technique was not very popular, as the control of the distance of the plaque distal end was practically impossible [15]. The eversion CEE technique familiar to a modern surgeon was described by Raithel and Kasprazak in 1989. During the surgery, the ICA was cut off at the mouth followed by eversion and reanastomosis at the same mouth after plaque removal [16]. Later the two techniques — classical and eversion CEE — were repeatedly compared with each other.

The implementation of interventional radiology into vascular surgery has opened a new era in the treatment of atherosclerotic lesions of the carotid arteries. The first stenting of ICA with atherosclerotic lesion was made in 1989 [17]. Since then endovascular treatment considerably improved (new stents, embolic protection devices and other aids have been developed) with the following improvement of treatment results and outcomes. The techniques of open and endovascular intervention have also been repeatedly compared with each other in the trials at different levels, but until now the method of choice for surgical treatment of carotid stenosis is under discussion.

The National guidelines for the management of patients with diseases of brachiocephalic arteries (2013) [14] contain the following indications for surgical treatment of carotid arteries with atherosclerotic lesions:

1) symptomatic patients with more than 60% stenosis;

2) patients with 50–60% ICA stenosis having morphological instability of an atherosclerotic plaque (ulceration, hemorrhage into the plaque, intimal flotation, mural thrombus) in view of neurological symptoms, those of TIA or stroke within the last 6 months;

3) asymptomatic patients with 70–99% stenosis.

At present, the major methods of surgical prevention of IS are carotid endarterectomy and carotid stenting. We shall consider the advantages and disadvantages of each method.

Carotid endarterectomy

A number of multicenter randomized trials such as NASCET, ECST, ACAS have been carried out to assess the effectiveness of CEE and develop clear indications to the given intervention [2, 10, 18–26]. It has been demonstrated to be an effective way to prevent IS in ICA atherosclerotic stenosis. A long-term follow-up shows it to be many times more effective than conservative treatment and reduce the risk for IS development. The number of reconstructive operations on carotid arteries increases every year [2]. Thus, 13,144 operations on the carotid arteries were performed in Russia in 2013, 10,656 of them being CEE. Eversion CEE was performed in 6,809 patients (63.9%), and classical CEE — in 3,847 patients (36.1%) [27]. In the US, the number of such surgical interventions is an order of magnitude greater and is about 100,000 per year [28].

Currently, the main problem of classical CEE is the choice of patch material for angioplasty of the arteriotomy site. Previously, there were two equivalent techniques: primary closure of the arteriotomy or patch plasty of the arteriotomy hole. For a long time primary closure of the arteriotomy was the standard operation and satisfied the surgeons [29]. This technique is easier to perform, does not extend the time of a surgery, does not require placing a foreign matter into the operational wound and, therefore, reduces the risk for postoperative complications. However, further analysis of early postoperative outcomes demonstrated rather high complication rates (3–20%): thrombosis, restenosis, ICA occlusion and, therefore, strokes that accompanied the given reconstruction technique [30]. Besides, restenosis at the site of the operated carotid artery can cause CVA in the immediate as well as late postoperative period [31].

To improve the immediate and late outcomes CEE, a patch plasty technique at the site of arteriotomy was suggested. Using a patch to close the arteriotomy defect demonstrated better results when compared with primary closure of arteriotomy, particularly in the long-term period [32]. The advantage of the technique has been proved in many clinical studies (Table 1).

Currently, the use of a patch for closure of the arteriotomy is a standard CEE operation [14]. A patch should meet the following requirements [28]:

durability;
strength;
lower risk for restenosis;
anticoagulant function;
low risk for infection;
easy sampling;
convenient use.

There is a wide choice of patch materials: autovein, autoartery (a portion the superior thyroid artery is commonly used), polytetrafluoroethylene (PTFE), dacron, canned dura, xenopericardium [14].

The advantage of autologous vein is that it is not a foreign material and its grafting is less expensive. The most common source of autovenous patch is a segment of the great saphenous vein. However, the place of patch sampling still remains disputable. A number of studies have shown that venous patch rupture occurs more often when sampling is performed by the ankle, therefore it is better to perform it on the hip [14]. The disadvantage of using autologous vein is a need for additional incision. Besides, sampling is impossible in a number of cases: saphenectomy in the past history, lower extremity venous disease, suppurative disease of the skin at the site of sampling, as well as a potential need for the great saphenous vein for lower extremity revascularization [42, 43].

Using an autologous artery patch can be of interest.

Table 1

Effectiveness of two methods for carotid endarterectomy: primary closure and patch plasty of an arteriotomy zone

Studies	Total number of patients		Number of strokes (%)		Number of restenosis (%)	
	Primary closure	Patch	Primary closure	Patch	Primary closure	Patch
Hertzer et al., 1987 [33]	483	434	3.1	0.7	31	9
Ranaboldo et al., 1993 [34]	104	109	5.8	1.8	16	6
AbuRahma et al., 1996 [35]	135	264	5.2	1.5	12	3
Katras et al., 2001 [36]	97	107	2.8	1.0	9	6
Ali et al., 2005 [37]	117	119	7.7	1.7	25	7
Rockman et al., 2005 [38]	233	1377	5.6	2.2		
Verhoeven et al., 2005 [39]	83	236	6.0	2.5	11	7
Mannheim et al., 2005 [40]	216	206	1.9	3.9	8.6	2.2
Hertzer, Mascha, 2006 [41]	783	1479	2.8	1.4	29	15

Table 2

Effectiveness of patch materials used for arteriotomy zone plasty

Studies	Total number of patients				Number of strokes (%)				Number of restenosis (%)			
	Autovein	Dacron	Polytetrafluoroethylene	Xenopericardium	Autovein	Dacron	Polytetrafluoroethylene	Xenopericardium	Autovein	Dacron	Polytetrafluoroethylene	Xenopericardium
AbuRahma et al., 1996 [35]	130		134		0.8		2.2		2.9		2.2	
Archie, 2000 [45]	903	359	27						0.6	6.4	3.7	
Jacobowitz et al., 2001 [46]	159	90			2.0	2.2			2.2	8.5		
Greco et al., 2003 [47]	80		80		1.3		6.4		9.3		13.3	
Naylor et al., 2004 [48]	134	133			4.5	7			1.6	7		
AbuRahma et al., 2008 [49]		100	100			3	2			21	11	
Fokin, Kuvatov, 2013 [42]	83		113		3.6		4.5		1.3		10.4	
Karpenko et al., 2013 [50]			61	178			0	1.5			31.2	9.8

It has the same advantages as autologous vein using, but with less traumatic sampling (no additional incision). It should also be mentioned that the superior thyroid artery atherosclerosis is quite rare, indicating its availability for being a source of material [14]. Therefore, in cases when autologous vein can not be used for a number of reasons, a superior thyroid artery patch can be used. Rerkasem and Rothwell's review, that includes 13 studies and 2,083 surgeries, demonstrated a risk for restenosis and perioperative stroke to be higher in the group using synthetic materials (PTFE), and the formation of pseudoaneurysms in the group using autologous vein [44]. Thus, each material has advantages and disadvantages (Table 2).

A Cochrane Stroke Group review [51] describes 5 studies on the analysis of the results of 2,589 operations of classical and eversion CEE. Eversion CEE is claimed to be associated with a lower risk for restenosis. The number of cases with restenosis and occlusion in the groups of eversion and classical CEE were 2.5 and 5.2%, respectively, with no statistically significant difference in the incidence of local and neurological complications.

Antonopoulos et al. [52] summarized the results of 8,530 eversion and 7,721 classical CEE in the meta-

analysis which included 21 trials (7 randomized and 14 unrandmized ones). A decreased incidence of stroke in the early postoperative period (up to 30 days after surgery) and death due to stroke was recorded in the eversion CEE group. In the late postoperative period (more than 30 days after the surgery) the eversion CEE group had a decreased number of cases with occlusion and mortality. Thus, eversion CEE seems to be more preferable than classical one due to the lower incidence of complications in the early and late postoperative periods.

In 2012 the "Stroke" journal published the results of the SPACE-1 trial [53]. It compared the eversion and classical CEE techniques in patients with symptomatic carotid artery stenosis (more than 50% stenosis). It was an unrandomized study conducted in 35 medical centers. An intraluminal shunt was more frequently used in the classical CEE group (65 vs. 17%), closure of the ateriotomy defect at classical CEE was performed with a patch. 516 patients were divided into two groups: the first group underwent eversion CEE (n=206, 39.9%), the second group underwent classical CEE (n=310, 60.1%). Complications and their incidence rates are shown in Tables 3 and 4.

The results of this trial suggest that the incidence of neurological complications in the early postoperative period is lower in the group of classical CEE with patch plasty repair. However, eversion CEE turned out to be more effective than classical one in the long-term prevention of stroke.

Table 3

Post-carotid endarterectomy complications in the early post-operative period (up to 30 days after surgery) (%)

Complications	Eversion carotid endarterectomy	Classical carotid endarterectomy
Stroke	4	0.3
Occlusion	0	0.3
Hematoma of the post-operative wound	8	5
Cerebral nerve lesion	8.2	8.1
Transient ischemic attacks	2	3
Infected wound	1	0.3
Headache	2	3

Table 4

Post-carotid endarterectomy complications in the late post-operative period (over 30 days after surgery) (%)

Complications	Eversion carotid endarterectomy	Classical carotid endarterectomy
Stroke in the ipsilateral vascular bed	0	2.9
Any stroke	1	6.1
Lethality	3.4	2.9
Any stroke + lethality	4.4	9.0
Restenosis	2.4	3.2

The analysis of the trials on classical and eversion CEE allowed formulating individual indications for each of the techniques.

Indications for eversion CEE are:

a high degree of brain tolerance to ischemia [20];

local atheroma up to 1 cm [20, 54];

combination of atherosclerosis with excessive ICA length (C- and S-shaped deformation, ICA looping) [20].

Indications for classical CEE:

low tolerance to cerebral ischemia when shunting is necessary [20];

prolonged atheroma (more than 2 cm) [20];

high location of bifurcation of the CCA (at the level of C2–3) [20].

The issue of the time for CEE surgery in patients after a stroke has not been fully studied yet. The time period from IS onset to surgery on brain revascularisation remains disputable. A number of publications recommend to perform surgery on 4–6th week after IS due to a high risk of intracerebral hemorrhage and/or increasing the ischemic area during surgery in the early stages [20, 55]. At the same time, prolonged waiting time for surgery increases the risk for repeated IS [56]. That is why some studies and recently published national and international guidelines recommend performing CEE within a shorter period of time — the first two weeks after IS debut [18, 32, 56–65], and according to some data, the best results of surgical treatment have been given within 2–7 days from the start of the stroke symptoms [56, 62, 65–67]. CEE performed in the first days after IS is not followed by an increase in the incidence of postoperative complications, deaths, longer hospitalization, compared with later surgery [58, 63, 68] and thus allows the quickest possible elimination of the cause of the IS pathological process, that is atherosclerosis of the carotid artery [17, 56]. This, in turn, prevents the augmentation of gross neurological deficit and reduces the risk for repeated IS, reducing treatment and rehabilitation time which significantly reduces the costs [69]. The period of up to 6 months after IS is optimal for surgery as operations performed at this time, are more favorable for the regression of neurological symptoms, improvement of clinical effect, and therefore, the quality of life [20, 58, 61]. Surgery in a later period (more than 1 year after IS) is more of preventive than therapeutic value [20].

The main factors determining the urgency of carotid revascularization in patients who have had CVA are: the lesion character of the carotid arteries, the presence (or absence) and infarct size of the brain on CT, the degree of neurological deficit, concomitant pathology. Contraindications to CEE in the immediate period after IS are impairment of consciousness and severe disabling stroke.

This supports more active tactics in the treatment of patients in the acute period of IS in strict compliance with the indications for surgery [57, 64, 69, 70].

Patients who underwent CEE in the distant postoperative period (12 months), demonstrated improvement of neurological and neuropsychic status, cognitive, higher cortical, motor and sensory functions, the level of attention and performance and, as a consequence, the quality of life [20, 71–83]. The earlier the operation for chronic cerebral ischemia is performed, the more complete the neurological deficit regression will be [20]. CEE in patients with asymptomatic carotid artery stenosis slows down chronic cerebral ischemia progression by improving neurological and/or neuropsychic status [71, 74, 76, 77, 79, 82, 83].

Thus, CEE can be considered not only a method of preventing IS, but also a method of chronic cerebral ischemia treatment and rehabilitation [57, 61].

Endovascular stenting of the carotid arteries

To date, there are no definite indications and contraindications to carotid stenting (CS). It is currently regarded as an alternative method of treatment of carotid artery atherosclerosis. Stenting is a less traumatic surgical intervention than CEE. To compare the two methods of CS and CEE we analyzed the results of multicenter studies in patients with symptomatic (>50%) and asymptomatic (>70%) carotid artery stenosis, which allow evaluating the effectiveness of treatment outcomes and complications [84].

We used the data of surgical treatment given at the medical centers in the States of New York and California. Those were 6,360 patients with CS, 41,392 — with CEE, while 43,236 patients had asymptomatic carotid stenosis (91%), and 4,516 had symptomatic stenosis (9%). The CS group demonstrated a high level of comorbidity: diabetes, hyperlipidemia, hypertension, neck and kidney cancer, peripheral vascular disease. These data are presented in Table 5.

In the group of symptomatic patients lethality in combination with stroke was higher in patients having had CS than in the CEE patients (8.3 vs. 4.6%), while in the group of asymptomatic patients, it was equivalent (2.4 vs. 1.9 %) after using both surgical methods [84]. This analysis showed CEE advantages in the group of symptomatic patients.

The analysis of the CREST trial [85, 86] showed the results of surgical treatment of 2,502 patients with symptomatic (n=1,321) and asymptomatic (n=1,181) stenosis. The patients were divided into two groups: the first group underwent CEE, the second one underwent CS (protectors were used in 98% of cases). The study was carried out in 117 medical facilities in Canada and the United States. The follow-up period was 30 days after surgery. The results of the study are presented in Table 6.

This study demonstrated a higher risk for myocardial infarction in patients who underwent CEE, and stroke — in the CS group. In patients younger than 70 years, the results were better in the CS group, while in patients over 70 — in the CEE group. The risk for cranial nerve palsy was significantly higher in the CEE group [85]. The obtained findings suggest that CS and CEE are two equally effective surgical interventions for carotid revascularization.

One more trial to compare these two methods was ICSS reported in 2010 [87]. Only patients with symptomatic carotid stenosis (>50%) were involved in the study. 1,713 patients were divided into two groups: the first group underwent CEE (n=855), the second one — CS (n=858), 75% of cases using protectors (Table 7).

In this trial, the risk for cranial nerve palsy turned out to be higher in the CEE group. Based on these results, we can conclude that CEE is a more effective method for cerebral revascularization in patients with symptomatic

Table 5

Complications during hospital staying after surgical treatment for carotid artery stenosis [84] (%)

Complications	Asymptomatic stenosis		Symptomatic stenosis	
	Carotid stenting	Carotid endarterectomy	Carotid stenting	Carotid endarterectomy
Lethality	0.55	0.39	3.68	1.29
Stroke	2.04	1.75	5.71	4.05
Respiratory complications	1.38	2.44	1.84	1.29
Hypotension	3.65	1.24	2.95	1.29
Transient ischemic attacks	0.32	0.30	0.37	0
Cerebral nerve palsy	0.18	0.44	0.18	0

Table 6

CREST trial results [85, 86] (%)

Complications	Carotid stenting	Carotid endarterectomy
Myocardial infarction (asymptomatic)	1.2	2.2
Myocardial infarction (symptomatic)	1.0	2.3
Extensive stroke (asymptomatic)	0.5	0.3
Extensive stroke (symptomatic)	1.2	0.9
Minor stroke (asymptomatic)	2.0	1.0
Minor stroke (symptomatic)	4.3	2.3
Stroke (asymptomatic)	2.5	1.4
Stroke (symptomatic)	5.5	3.2
Cranial nerve leison	0.3	4.7

Table 7

ICSS trial results [87] (number /%)

Complications	Carotid stenting	Carotid endarterectomy
Stroke (within 120 days)	65/7.7	35/4.1
Complications (stroke, lethality, mayocardial infarction)	72/8.5	44/5.2
Lethality	19/2.3	7/0.8

Table 8

Results of classical and eversion carotid endarterectomy and carotid stenting in Russia in 2013 [27]

Indices	Classical carotid endarterectomy	Eversion carotid endarterectomy	Carotid stenting
Number of operations	3.847	6.809	2.302
Number of acute cerebrovascular accident (%)	1.2	0.9	0.6
Lethality (%)	0.8	0.6	0.2

carotid stenosis. However, it should be noted that in the CREST trial for the CS group, embolic protection devices were used more often — in 98% of cases, while in the ICSS trial only in 75%, and more experienced doctors performed surgery in the CREST trial [88–90] .

Currently, the CEE is an operation of choice for carotid artery stenosis, more cost-effective surgical intervention with a lower incidence of postoperative stroke and restenosis [91, 92].

In 2013 in Russia operations on the brachiocephalic arteries were the most common vascular surgery. Their number grows from year to year [27]. The results of all the three types of surgical intervention performed in 2013 for carotid artery atherosclerosis are shown in Table 8 [27].

The analysis of numerous native and foreign publications allows formulating indications for CS:

restenosis after previously performed CEE [14];

contralateral cranial nerve paresis after a previous surgery on the neck organs [14, 18];

post-radiation condition of the neck organs [14, 93];

high location of the CCA bifurcation (at C2–3) [14, 18, 94];

inflammatory and tumor-like lumps in the neck [14];

high-risk perioperative patients and patients with severe comorbidity [14, 94–98];

patients with stenosis combined with aneurysms and arteriovenous malformations of the cerebral arteries [99];

cases of multifocal atherosclerotic lesions with a necessity of single-step operations [100];

patients with high risk for cerebral ischemia during carotid clamping (presence of carotid artery occlusion on the opposite side and/or anomalies in the circle of Willis) [94].

CS must not be performed:

in patients with a calcified atherosclerotic plaque or an extended atherosclerotic plaque (over 2 cm) [14];

when stenosis is combined with abnormal ICA tortuosity [94, 99];

in patients with an unstable atherosclerotic plaque [14];

in patients with disseminated atherosclerotic lesions of the aorta and the brachycephalic trunk [18, 99];

in patients with ICA stenosis of over 90% [99].

Conclusion. Currently, none of the types of surgery for the carotid artery atherosclerosis demonstrated significant advantages one over the other. All methods of surgical treatment should be seen not as competing but mutually complementary.

The choice of the type of surgery for each patient should be decided individually and depend on a number of factors: a type and extent of an atherosclerotic plaque; a degree of stenosis of the operated and contralateral internal carotid artery, age and the presence of comorbidity, features of local and vascular anatomy, etc.

The choice of the type of surgical intervention should be decided by a multidisciplinary team of doctors (a vascular surgeon, a neurosurgeon, an X-ray endovascular surgeon, an anesthesiologist-resuscitation specialist, a neurologist, a cardiologist) who can assess the risk of intervention and appropriateness of its performance.

Brain revascularization surgery — carotid endarterectomy and carotid stenting — should be seen not only as a method of prevention of ischemic stroke, but also as a method of treatment of chronic cerebral ischemia.

Study Funding and Conflicts of Interest. This study was not supported by any financial sources and there is no topic specific conflicts of interest related to the authors of this study.

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