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Routine versus selective near-infrared spectroscopy-guided shunting during carotid eversion endarterectomy

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Key question

Is routine or selective shunting associated with lower stroke incidence during carotid eversion endarterectomy?

Key finding(s)

Selective shunting was associated with a lower incidence of perioperative stroke than routine shunting.

Take-home message

In the setting of eversion endarterectomy of the internal carotid artery, selective shunting should employed.

Routine versus
selective Near-Infrared-Spectroscopy-guided
shunting
during carotid eversion endarterectomy

1 Routine shunting –
340 patients

2 NIRS-guided selective-shunting –
661 patients

277 patient pairs treated with eversion endarterectomy generated via propensity score matching

Higher stroke rate in the routine-shunting group vs. NIRS-guided selective-shunting

Routine-shunting and age were identified as risk factors associated with perioperative stroke during eversion endarterectomy

Abstract

OBJECTIVES: The aim of this study was to compare outcomes of routine shunting to near-infrared spectroscopy (NIRS)-guided shunting in patients undergoing eversion endarterectomy (EEA) under general anaesthesia.

METHODS: We retrospectively evaluated data of all patients undergoing EEA of the internal carotid artery (ICA) in our department from January 2011 until January 2019. Included were patients with EEA of the ICA and the patients were divided into 2 groups: selective-shunting group and routine-shunting group. Patients (i) with patch angioplasty during the surgery, (ii) undergoing surgery for restenosis and (ii) stenosis after radiation therapy, (iii) without recorded regional cerebral oxygen saturation trends, (iv) presenting with an emergency treatment indication and (v) operated upon by residents were excluded. In all patients, EEA was performed in general anaesthesia and under NIRS monitoring. One-to-one propensity score matching was used to compare EEA outcomes after routine shunting to NIRS-guided shunting. Primary end points were defined as perioperative stroke and in-hospital mortality after EEA.

RESULTS: Routine and NIRS-guided selective shunting were applied in 340 (34.0%) and 661 (66.0%) patients, respectively. A total of 277 pairs were generated via propensity score matching. Fifty-eight (20.1%) from the selective-shunting group were intraoperatively shunted. Concomitant procedures were more frequently performed in the routine-shunting group [170 (61.4%) vs 47 (17.0%), 180 (65%) vs 101 (36.5%), and 60 (21.7%) vs 6 (2.2%), $P < 0.001$]. The perioperative stroke rate in the routine-shunting group was higher as well [11 (4.0%) vs 3 (1.1%), $P = 0.022$]. In-hospital death was overall 0.2% ($n = 1$). Multivariable logistic regression in the matched patient indicated age (odds ratio 1.050, 95% confidence interval 1.002–1.104, $P = 0.046$) and routine shunting (odds ratio 2.788, confidence interval 1.119–7.428, $P = 0.032$) as risk factors for perioperative stroke during EEA of the ICA.

CONCLUSIONS: We found that, during EEA of the ICA, under general anaesthesia, NIRS-guided selective shunting was associated with a lower incidence of perioperative stroke than routine shunting.

Keywords: Internal carotid artery • Shunting • Eversion endarterectomy • NIRS

ABBREVIATIONS

CCA	Common carotid artery
ECA	External carotid artery
EEA	Eversion endarterectomy
ICA	Internal carotid artery
MRI	Magnetic resonance imaging
NIRS	Near-infrared spectroscopy
rSO2	Regional cerebral oxygen saturation

INTRODUCTION

Eversion endarterectomy (EEA) is a widely adopted technique to reconstruct the internal carotid artery (ICA) in case of atherosclerotic stenosis. There is recent evidence that EEA is associated with significantly lower perioperative stroke and death rates, less restenosis and late carotid occlusion rates, when compared to standard endarterectomy [1].

During standard carotid endarterectomy, carotid shunting, if necessary, can be applied immediately after arteriotomy. Shunting in the EEA setting, however, remains a controversial technique. First, it can only be done following plaque removal. Second, introducing a shunt into the ICA immediately after EEA can trigger a local dissection because of the fragility and a frequently hard to discern the distal endarterectomy end point. Third, any additional manipulation of the ICA raises the risk of embolization. Also, there is very little evidence regarding the risks and benefits of routine shunting when surgically treating the occlusive carotid disease, especially in the setting of EEA [2, 3].

In patients undergoing EEA under general anaesthesia, carotid shunting can be performed routinely in all or just in selected patients who are developing critical cerebral perfusion. Common neuromonitoring methods for detecting the patients at risk for cerebral perfusion are somatosensory-evoked potentials, stump pressure, electroencephalography, and transcranial Doppler [4–6]. Near-infrared spectroscopy (NIRS) could be a promising alternative for intraoperative neuromonitoring during carotid endarterectomy and is increasingly used as such [7–12]. However, none of the above mentioned methods provides 100% specificity and sensitivity for the detection of critical cerebral perfusion during clamping of the ICA under general anaesthesia and the gold standard remains the awake test defined by changes in NIRS monitoring after ICA clamping. NIRS has proven to be a durable tool for detecting patients requiring shunt after cross-clamping [7–10]. It was this study's aim to compare the incidence of perioperative stroke and death in patients undergoing routine compared to selective NIRS-guided shunting while performing EEA of the ICA under general anaesthesia.

PATIENTS AND METHODS

Ethics statement

The local ethics commission at Albert-Ludwigs University of Freiburg granted trial approval (application number 21-1030). The requirement for an informal agreement was waived due to this study's retrospective nature.

Study population

All patients who underwent ICA endarterectomy between January 2011 and January 2019 were retrospectively evaluated. All patients with EEA of the ICA were included. Patients (i) with patch angioplasty during the surgery, (ii) undergoing surgery for restenosis after carotid endarterectomy, (iii) after radiotherapy of the neck, (iv) without recorded regional cerebral oxygen saturation (rSO2) trends, (v) presenting with an emergency treatment indication (such as crescendo TIA and stroke in evolution, which were operated on within 24 h) [3, 13, 14] and (vii) operated upon by residents were excluded. All patients were under general anaesthesia when treated, using rSO2 as sole neuromonitoring of cerebral perfusion. The patients were divided into 2 groups We evaluated 2 groups of patients according to the shunt placement strategy: a routine-shunting group with the shunt inserted in all patients and a selective-shunting group with the shunt inserted after presenting at least a reduction of 15% in rSO2 on the ipsilateral side after ICA clamping.

Neuromonitoring

NIRS electrodes (Somanetics Corp., Troy, MI, USA) were attached to both sides of the patient's forehead, and the rSO2 values were recorded continuously during the entire operation. A cerebral oximeter INVOS^{TM} 5100 C (Medtronic Inc., Minneapolis, MN, USA) was used to ensure continuous visualization of the absolute values. In patients undergoing selective shunting, the shunt was applied in case of an rSO2 drop of at least 15% after cross-clamping compared to baseline values [7, 8]. The rSO2 baseline was chosen according to the existing literature and our personal experience using it during carotid surgery. The baseline rSO2 values were defined at the beginning of the surgery for every patient in course of the interdisciplinary team time out. Our technique of selective shunt placement guided by NIRS as the sole neuromonitoring method has been already described in detail [10].

Internal carotid artery stenosis evaluation and treatment indication

The degree of ICA stenosis was determined using colour-coded 2D duplex sonography following the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria [15]. Clinical neurological and ultrasound examinations were carried out before and after surgery by neurologists and technicians of the Department of Neurology and Neurophysiology of our institution. Indications for carotid surgery followed the recommendations of the main scientific societies [3, 14]. Patients with acute retinal or cerebral ischaemia ipsilateral to the ICA stenosis (symptomatic ICA stenosis) were treated within 14 days after symptoms onset; patients with asymptomatic stenosis were scheduled for elective surgery in a reasonable timeframe.

Definitions

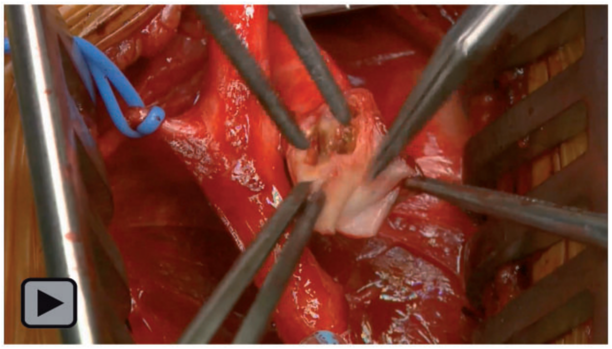
Perioperative stroke. In case of a novel perioperative stroke, the neurological deficit was quantified using the National Institutes of Health-Stroke Scale. Stroke was classified as minor (1–4 points on the National Institutes of Health-Stroke Scale), moderate (5–15 points), moderate to severe (15–20 points) or severe (21–42 points) [16]. Patients with assumed brain ischaemia underwent immediate brain imaging [computed tomography angiography or magnetic resonance imaging (MRI)] to determine the occurrence of brain infarction and pathophysiology of stroke (embolic pattern, haemodynamic stroke pattern, bleeding, etc.).

Hypertension following carotid endarterectomy. Hypertension following endarterectomy was defined as a systolic blood pressure of >170 mmHg without symptoms and a persistent blood pressure of >160 mmHg with symptoms.

Surgical procedure and anaesthesiology protocol

All patients underwent surgery while under general anaesthesia, the blood pressure was measured invasively. All surgeries were performed from 1 surgeon (Joachim Schöllhorn).

Heparin was administrated intravenously 3 min before cross-clamping the ICA (100 IU/kg). In the selective-shunting group, the target systolic blood pressure from 150 mmHg was achieved using catecholamine administration. The carotid sinus nerve fibres in the proximal ICA's adventitia were divided during surgical exposition. EEA was performed in standard fashion after transecting the ICA at the carotid bifurcation from the common carotid artery (CCA) [17–20]. Afterwards, the plaque was removed in eversion technique in a plane between the media and adventitia rolling the adventitia cranially and gently retracting the plaque in the opposite direction. Finally, the ICA was reimplanted using 6–0 polypropylene running suture. After endarterectomy, a shunt was placed in all patients of the routine-shunting group and, in case of a rSO2 drop-off at least 15% after ICA cross-clamping, in the group with NIRS-guided shunting. Two ICA-shunt sizes (LeMaitre Vascular, Burlington, MA, USA) were used: 8 and 10 F, according to the ICA's diameter. Video 1 shows the EEA and routine-shunt placement after plaque extraction. If the rSO2 drop-off was >15% after clamping the ICA during the eversion we increased the systolic blood pressure of >150 mmHg to provide more blood flow from the contralateral side. All surgeries were performed by 4 vascular surgeons, all with substantial experience. Sufficient cerebral perfusion during shunting was ensured via continuous bilateral rSO2 monitoring. If we detected significant obliterating arteriopathy in the external carotid artery (ECA), an ECA endarterectomy via eversion technique was employed, too. In case of CCA involvement, an additional local endarterectomy was performed. Finally, the ICA was reimplanted using 6 × 0 polypropylene sutures. All patients underwent intraoperative completion angiography, enabling us to visualize the EEA result. After angiography, the initial heparin dose was either fully or half antagonized, and wound drainage was put in place. All patients were extubated in the operating room and immediately examined for any novel neurologic symptoms. Postoperative systolic blood pressure was monitored invasively for 24 h. Hypertension following endarterectomy was defined as a systolic blood pressure >170 mmHg without symptoms and a persistent blood pressure >160 mmHg with symptoms. All patients were given 100 mg aspirin per day, beginning from the first postoperative day. Postoperatively, the ICA was evaluated in all patients using colour-coded 2D duplex sonography.



Video 1: Intraoperative video presenting routine shunting during eversion endarterectomy.

Study end points

Primary end points were the incidence of perioperative stroke and in-hospital death after EEA. Secondary end points were myocardial infarction, bleeding, surgical revision after angiography, postcarotid endarterectomy hypertension and any cranial nerve injury.

Statistics

To test the normality of data, we applied the Shapiro–Wilk test. Not normally distributed continuous data are presented as the median, and interquartile range was compared using the Wilcoxon–Mann–Whitney test. Normally distributed continuous data are presented as mean with standard deviation and are compared using the Student's *t*-test. Categorical and binary variables are presented as frequencies (*n*) and percentages (%) and were compared using the Pearson's χ^2 test, applying Fisher's exact test when $n < 5$. Analysis of variance was used to compare multiple groups with continuous variables. Since this is an observational, retrospective, non-randomized study and the baseline characteristics differed significantly between groups, we applied a propensity score-matching technique. We included following baseline variables in the propensity score analysis: age, sex, coronary artery disease, symptomatics, stenosis grade of the treated ICA, stenosis grade of the contralateral side, diabetes mellitus, atrial fibrillation, arterial hypertension, tobacco use and dyslipidaemia. The 2 groups were matched in a one-to-one ratio with the calliper set at 0.1 of standard deviation of the logit of the propensity score. A total of 277 patients in the group undergoing routine shunt-placement were matched to 277 patients in the selective NIRS-guided shunt placement group. Fig. 1 shows histograms illustrating the groups' propensity score distribution. After matching, we employed the appropriate statistical methods to assess treatment effects designed for paired data [21, 22]. Multivariable logistic regression was performed to identify risk factors for perioperative stroke including clinically relevant parameters (sex, age, symptomatic stenosis, stenosis grade, contralateral occlusion, diabetes, routine shunting, EEA of the CCA, EEA of the ECA and shortening of the ICA). Not normally distributed continuous variables were compared using the Wilcoxon signed-rank test. Paired Student's *t*-test was used for normally distributed continuous variables. McNemar's test served to compare frequencies. Statistical analysis was done using R version 4.1.1 for macOS (The R Foundation for Statistical Computing, Austria) and SPSS version 26 for macOS (Chicago, IL, USA) with the significance level set at $P < 0.05$.

RESULTS

Our patients' baseline characteristics and their surgical techniques are presented in Table 1. Contralateral occlusion appeared more frequently in the routine-shunting than in the selective-shunting group [19 (5.6%) vs 15 (2.3%), $P = 0.010$]. The NIRS-guided selective-shunting group suffered more often from arterial hypertension and dyslipidaemia (Table 1). After propensity score matching, we detected no differences in baseline characteristics between groups (Table 2). In both groups, the symptomatic patients dominated, respectively, $n = 229$ (82.7%) in the routine-shunting group and $n = 223$ (80.5%) in the selective-shunting group and the asymptomatic patients were accordingly 17.3% and 19.5%. The balance plot in Fig. 2 shows that balance was met within the threshold of 0.1 mean differences and improved after matching with no significant imbalance.

Surgical details

The matched patient groups' surgical details are presented in Table 3. Operative times differed significantly between the 2 groups routine shunting and selective shunting [62 (55; 75) vs 60 (54; 71), $P = 0.029$]. The median cross-clamping lasted longer in the selective-shunting group [5 (4; 6) vs 16 (11; 21) min, $P < 0.001$]. The mean time for shunt placement was in the selective-shunting group 3 (standard deviation: 1) min. Concomitant procedures such as CCA and ECA endarterectomy, as well as ICA shortening, were more frequently done in the routine-shunting group, respectively [170 (61.4%) vs 47 (17.0%), 180 (65%) vs 101 (36.5%), and 60 (21.7%) vs 6 (2.2%), $P < 0.001$]. A shunt was put in place in 58 (20.1%) of selective-shunting group patients. All patients underwent intraoperative angiography. Immediate surgical revision due to an unsatisfactory angiographic result was necessary in 8 (2.8%) routine-shunting group patients and 5 (1.8%) selective shunt patients ($P = 0.579$). Indications for revision are listed in Table 3 with no inter-group difference.

Stroke rate, in-hospital death and outcome

The routine-shunting group's perioperative stroke rate was higher compared to the selective NIRS-guided shunting group [11 (4.0%) vs 3 (1.1%), $P = 0.022$]: We noted 3 moderate to severe, 6 moderate and 2 minor strokes in the routine-shunting group. The routine-shunting group suffered 1 in-hospital death after a severe stroke. Overall, in-hospital mortality was 0.2% ($n = 1$) and the patient was in the routine-shunting group, respectively, with no inter-group difference ($P = 0.5$).

We counted 2 moderate and 1 minor strokes in the selective-shunting group. One of the moderate-stroke patients experienced a >15% rSO2 decrease after carotid clamping followed by shunt placement. The other patients with stroke did not have a >15% rSO2 decrease after clamping the ICA. Six (2.2%) routine-shunting group and 6 (2.2%) selective-shunting group patients suffered a myocardial infarction after EEA requiring a coronary intervention. Cranial nerve injury rates were lower in the routine-shunting group than in the selective-shunting group [4 (1.4%) vs 8 (2.9%) ($n = 8$), $P = 0.388$], respectively. Four (1.4%) and 8 (2.9%) routine and selective patients had to return to the operational room for bleeding ($P = 0.388$). We observed no difference in the presence of postcarotid endarterectomy hypertension between the routine-shunting group and the selective-shunting group [27 (9.7%) vs 31 (11.2%), $P = 0.694$]. Routine-shunting patients stayed longer in the hospital after surgery [5 (3; 6) vs 4 (3; 6) days, $P = 0.048$]; Table 4).

Risk factors for stroke after eversion endarterectomy

Multivariable logistic regression analysis in the matched patients indicated that the use of routine shunting (odds ratio 2.788, confidence interval 1.119–7.428, $P = 0.032$) and age (odds ratio 1.050, confidence interval 1.002–1.104, $P = 0.046$) were independent risk factors for perioperative stroke after EEA of the ACI (Table 5).

Results of postoperative duplex sonography

No patient in either group revealed any stenosis or local ICA dissection in the postoperative colour-coded 2D duplex sonography. Slight-to-moderate ECA stenoses observed in 11 patients (4.0%) in the routine shunting and in 6 patients (2.2%) of the selective shunting. These patients were all managed conservatively.

DISCUSSION

We can summarize our study finding as follows: perioperative stroke was significantly higher in the routine-shunt placement (4.0%) than the NIRS-guided selective-shunting group (1.1%) in an EEA setting ($P = 0.022$).

EEA is a safe surgical technique that enables autologous reconstruction using the native ICA, thus avoiding the need for autologous or xenogenic patch material. A meta-analysis by

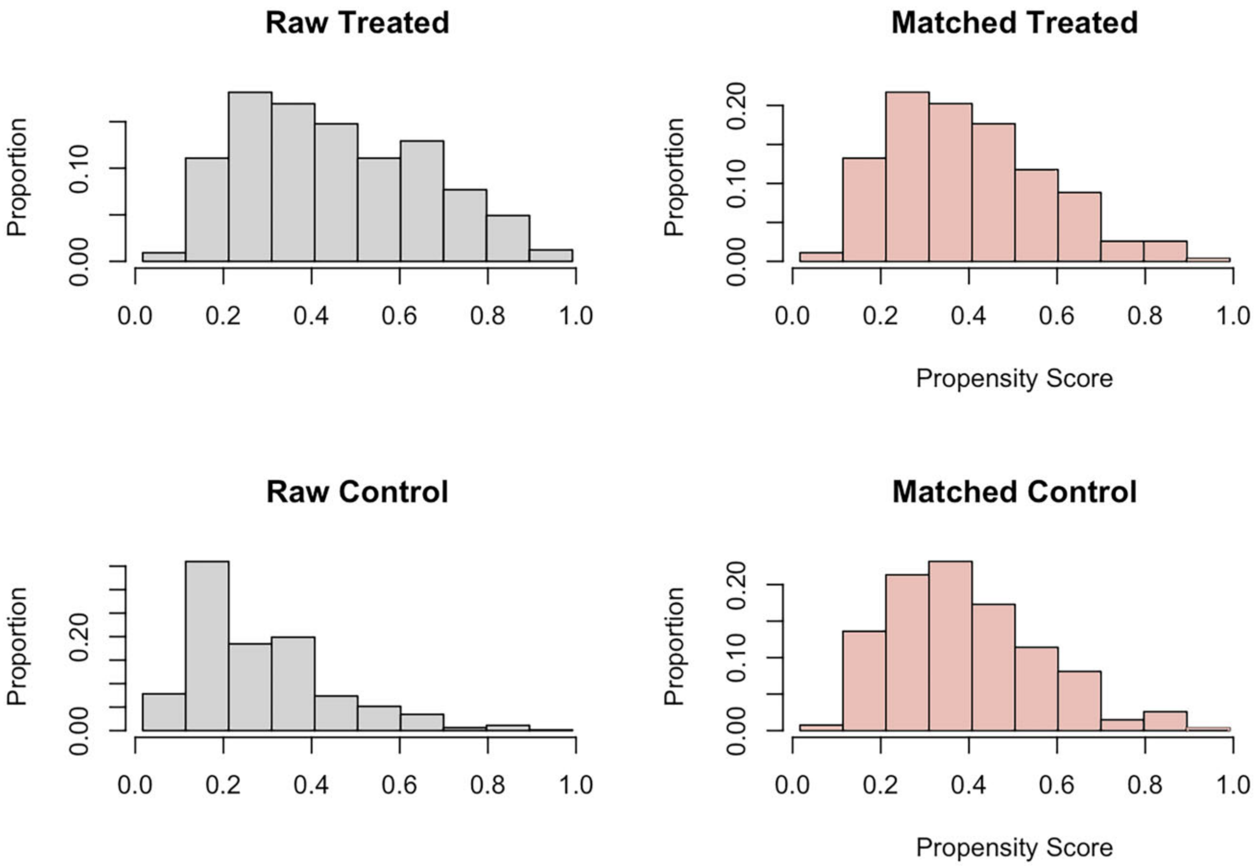


Figure 1: Groups' propensity score distribution. On the left side are the histograms of the patients variables before the propensity score matching and on the right side after employing the propensity score matching.

Table 1: Preoperative baseline characteristics—before matching

Variable	Overall, *n* = 1001	Routine shunting, *n* = 340	Selective shunting, *n* = 661	*P*-Value
Age, median (IQR)	72 (62; 77)	73 (64; 78)	72 (64; 77)	0.375
Male, *n* (%)	746 (74.5)	243 (71.5)	503 (76.1)	0.112
Stenosis grade, median (IQR)	80 (70; 90)	80 (70; 90)	80 (50; 90)	<0.001
Contralateral occlusion, *n* (%)	34 (3.4)	19 (5.6)	15 (2.3)	0.010
Symptomatic, *n* (%)	797 (79.6)	279 (82.1)	518 (78.4)	0.197
Stroke past, *n* (%)	320 (32.0)	102 (30.0)	218 (33.0)	0.376
TIA or amaurosis, *n* (%)	477 (47.7)	177 (52.1)	300 (45.4)	0.053
Atrial fibrillation, *n* (%)	115 (11.4)	46 (13.5)	69 (10.4)	0.178
Arterial hypertension, *n* (%)	932 (93.1)	297 (87.4)	635 (96.1)	<0.001
Diabetes, *n* (%)	274 (27.4)	98 (28.8)	176 (26.6)	0.507
Chronic kidney disease, *n* (%)	109 (10.9)	30 (8.8)	79 (11.9)	0.322
Dyslipidaemia, *n* (%)	704 (70.3)	177 (52.0)	520 (78.7)	<0.001
Coronary heart disease, *n* (%)	296 (29.6)	94 (27.6)	202 (30.6)	0.377
Tobacco use, *n* (%)	339 (33.9)	120 (35.2)	219 (33.1)	0.539
Eversion, *n* (%)	974 (97.3)	335 (98.5)	639 (96.7)	0.192
Patch, *n* (%)	27 (2.7)	5 (1.5)	22 (3.3)	0.192

IQR: interquartile range; TIA: transient ischaemic attack.

Antonopoulos *et al.* showed that EEA may be associated with significantly lower perioperative stroke and restenosis rates than endarterectomy with a patch [1, 23]. However, the EVEREST (Eversion versus conventional carotid Endarterectomy) trial did not demonstrate any significant differences in stroke and restenosis rates between the 2 surgical techniques [24]. Nevertheless, EEA is not inferior to endarterectomy with a patch, and in some settings, it could be the better alternative for treating complex plaque morphologies.

The use of shunts during EEA to re-establish the cerebral perfusion during clamping of the ICA remains controversial, and there is currently no evidence supporting routine-shunt placement during surgery of occlusive carotid disease [2, 3, 23, 25, 26].

Important role of the cerebral perfusion have the anatomical variations of the Circle of Willis and the collateral system. We evaluated the Circle of Willis in all patients using doppler sonography. However, that was not included in the matching criteria. There is recent evidence that the lack or incompetence of collateral segments within the Circle of Willis could be associated with a higher risk of perioperative stroke in patients with symptomatic carotid stenosis [27, 28].

Table 2: Patient baseline characteristics in propensity score-matched populations

Variable	Routine shunting, *n* = 277	Selective shunting, *n* = 277	*P*-Value
Age, median (IQR)	74 (64.5; 78)	73.0 (65; 78)	0.977
Male, *n* (%)	194 (70.0)	193 (69.7)	1.0
Stenosis grade, median (IQR)	80 (70; 95)	80 (70; 95)	0.999
Contralateral occlusion, *n* (%)	19 (7.0)	15 (5.5)	0.607
Symptomatic stenosis, *n* (%)	229 (82.7)	223 (80.5)	0.586
Asymptomatic stenosis, *n* (%)	48 (17.3)	54 (19.5)	0.621
Stroke, *n* (%)	84 (30.9)	82 (30.1)	0.938
TIA or amaurosis, *n* (%)	139 (51.1)	136 (50.0)	0.904
Arterial hypertension, *n* (%)	248 (89.5)	248 (89.5)	1.000
Atrial fibrillation, *n* (%)	35 (12.6)	37 (13.4)	0.899
Diabetes, *n* (%)	77 (27.8)	69 (24.9)	0.488
Chronic kidney disease,[a] *n* (%)	27 (9.7)	30 (10.8)	0.788
Dyslipidaemia, *n* (%)	175 (63.2)	165 (59.6)	0.337
Tobacco use, *n* (%)	99 (35.7)	95 (34.3)	0.788
Coronary heart disease, *n* (%)	79 (28.5)	81 (29.2)	0.925

[a] All patients with GFR between 89 ml/min and end stage of chronic kidney disease.

IQR: interquartile range; TIA: transient ischaemic attack.

Common neuromonitoring methods during carotid endarterectomy in general anaesthesia are somatosensory-evoked potentials, stump pressure, electroencephalography and transcranial Doppler [4–6]. Generally, the gold standard for intraoperative neuromonitoring is the awake test. However, in the GALA trial, there was no difference in the perioperative stroke rate between the patients operated in local anaesthesia versus general anaesthesia [29]. There is recent evidence that NIRS may also be a promising alternative for intraoperative neuromonitoring during carotid endarterectomy and that it may predict shunt use [7, 10–12].

On the other side, there is a wide rSO2 drop-off described in the literature varying from 9% to 25% [8, 11, 30, 31]. The baseline rSO2 depends on many factors such as electrode position, arterial oxygen saturation, blood pressure, arterial carbon dioxide tension, haematocrit level and bilirubin. Therefore, the baseline is very individual and probably the critical cut-off.

None of the established neuromonitoring methods provides 100% specificity and sensitivity for the detection of critical cerebral perfusion during clamping of the ICA under general anaesthesia. Thus, many vascular surgeons employ routine shunting in the context of an endarterectomy with patch—a solid solution enabling continuous antegrade flow in the ICA [2, 32]. However, there is still little evidence on routine shunting during EEA [33, 34].

Our 2 shunting groups (routine and NIRS guided) were balanced via propensity score matching, after which we compared their outcomes depending on the shunting strategy. We used symptomatic and asymptomatic patients as parameter in the propensity score-matching process to have more accurate compare in the pairing. We observed that the routine-shunting group underwent ECA and CCA endarterectomy more frequently. This finding may be associated with the preserved antegrade flow through the shunt in the ICA during surgical reconstruction, giving the surgeon more time to perfect his result. Nevertheless, we detected no statistically significant difference in the rate of revision after the completion angiography between these 2 groups.

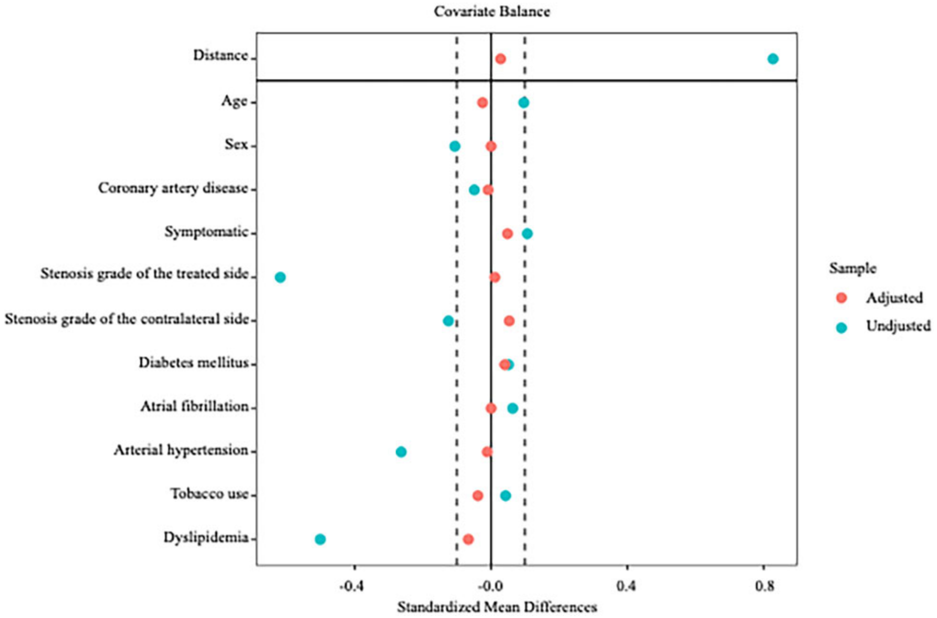


Figure 2: Balance plot for unadjusted (red) and adjusted (green) variables employed in the propensity score matching. Dotted lines represent 0.1 mean differences showing that balance was met within the threshold of 0.1 and improved after matching.

Table 3: Operative details in a propensity score-matched population

Variable	Routine shunting, *n* = 277	Selective shunting, *n* = 277	*P*-Value
Operative time (min), median (IQR)	62 (55; 75)	60 (54; 71)	0.029
Cross-clamping time (min), median (IQR)	5 (4; 6)	16 (11; 21)	<0.001
EEA of the CCA, *n* (%)	170 (61.4)	47 (17.0)	<0.001
EEA of the ECA, *n* (%)	180 (65.0)	101 (36.5)	<0.001
Shortening, *n* (%)	60 (21.7)	6 (2.2)	<0.001
Shunting, *n* (%)	277 (100)	58 (20.1)	<0.001
Revision after intraoperative angiography, *n* (%)	8 (2.8)	5 (1.8)	0.579
Causes for revision, *n* (%)			
Intima flap	5 (1.8)	4 (1.4)	1.000
ICA twisting	0 (0)	1 (0.4)	1.000
ICA stenosis	2 (0.7)	0 (0)	1.000
ECA occlusion	1 (0.4)	0 (0.0)	1.000

CCA: common carotid artery; ECA: external carotid artery; EEA: eversion endarterectomy; ICA: internal carotid artery; IQR: interquartile range.

Table 4: Outcome after eversion endarterectomy in propensity score-matched population

Variable	Routine shunting, *n* = 277	Selective shunting, *n* = 277	*P*-Value
Stroke, *n* (%)	11 (4.0)	3 (1.1)	0.022
Death, *n* (%)	1 (0.4)	0 (0.0)	0.500
Myocardial infarction, *n* (%)	6 (1.8)	6 (2.2)	1.000
Any cranial nerve injury, *n* (%)	4 (1.4)	8 (2.9)	0.388
Return to OR for bleeding, *n* (%)	8 (2.9)	5 (1.5)	0.388
Hypertension following endarterectomy, *n* (%)	27 (9.7)	31 (11.2)	0.694
Length of stay (days), median (IQR)	5 (3; 6)	4 (3; 6)	0.048

Length of stay—average (minimum; maximum) stay in days.
IQR: interquartile range; OR: operational room.

Table 5: Risk factors for in-hospital stroke after eversion endarterectomy of the internal carotid artery

	Odds ratio	CI	*P*-Value
Sex	1.346	0.573–3.544	0.122
Age	1.050	1.002–1.104	0.046
Symptomatic stenosis	0.910	0.592–7.674	0.161
Stenosis grade	0.983	0.950–1.018	0.330
Contralateral occlusion	0.228	0.189-1.001	0.829
Diabetes	1.233	0.498–2.851	0.621
Routine shunting	2.788	1.119–7.428	0.032
EEA of the CCA	0.451	0.581–4.569	0.354
EEA of the ECA	0.432	0.156–1.154	0.099
Shortening of the ICA	0.804	0.218–2.316	0.710

CCA: common carotid artery; CI: confidence interval; ECA: External carotid artery; EEA: eversion endarterectomy; ICA: internal carotid artery.

The incidence of perioperative stroke was significantly higher in patients undergoing EEA and routine shunting compared to selective NIRS-guided shunting: *n* = 11 (4.0%) vs *n* = 3 (1.1%). The higher stroke rate in the routine-shunting group could be associated with intraoperative embolization during the shunt placement or with vulnerable plaques mobilized during the vessel dissection. However, not all patients with perioperative stroke received postoperative MRI and small embolic events could not be sufficient assessed in a computed tomography scan. There is some recent evidence about using MRI for detecting potential vulnerable plaques such as lipid rich necrotic core, ruptured plaques, and haemorrhagic plaques [35]. Using additional ultrasound criteria could be as well important for detecting such high-risk atherosclerotic lesions [36, 37]. However, none of those diagnostic methods is recommended from the major scientific societies for preoperative diagnostic of vulnerable plaques [14]. Nevertheless, such information could be potentially beneficial for the intraoperative strategy. On the other hand, the issue with the intraoperative embolic events remains an important issue. Reducing the perioperative stroke is from utterly significance because every stroke is a burden for the patient and society. In our study, there was only 1 in-hospital death, and it was caused by severe stroke. Although all our patients underwent NIRS monitoring (as it is a potentially useful tool for detecting intraoperative impairment of cerebral perfusion in the anterior cerebral artery and anterior middle cerebral artery territory). However, it does not allow the detection of intraoperative brain embolization. In our study, we identified routine-shunt placement and age as risk factors for stroke after EEA of the ICA. As concomitant surgical procedures in the carotid bifurcation did not increase the stroke risk, selective shunting seems to be the safer strategy compared to routine shunting.

Limitations

Our study is monocentric, retrospective, and enrolled a high percentage of symptomatic patients, a factor that does not reflect the usual proportions between symptomatic and asymptomatic patients. Thus, a prospective study of symptomatic and asymptomatic patients at different sites and a randomization into both shunting groups are required before the superiority of one of these approaches can be determined and recommended as the method of choice. Other study limitation is the wide rSO2 drop-off range compared to the baseline for employing a shunt to prevent critical cerebral ischaemia. In addition, the Circle of Willis status was not used in the matching criteria.

CONCLUSION

NIRS-guided selective shunting during EEA under general anaesthesia was associated with lower stroke rate compared to routine shunting. Age and routine shunting were identified as risk factors for perioperative stroke in the multivariate analysis.

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DATA AVAILABILITY

The data underlying this article will be shared on reasonable request to the corresponding author.

Author contributions

Stoyan Kondov: Conceptualization; Data curation; Methodology; Supervision; Validation; Writing—original draft; Writing—review & editing. **Dominique Bothe:** Data curation; Formal analysis; Methodology; Validation; Writing—original draft. **Friedhelm Beyersdorf:** Methodology; Supervision; Validation; Writing—review & editing. **Martin Czerny:** Conceptualization; Methodology; Supervision; Validation; Writing—review & editing. **Andreas Harloff:** Methodology; Validation; Visualization; Writing—review & editing. **Jan-Steffen Pooth:** Data curation; Formal analysis; Methodology; Project administration; Validation; Writing—original draft. **Klaus Kaier:** Methodology; Supervision; Validation; Writing—original draft. **Joachim Schöllhorn:** Conceptualization; Investigation; Validation; Visualization. **Maximilian Kreibich:** Methodology; Validation; Visualization; Writing—review & editing. **Matthias Siepe:** Conceptualization; Methodology; Validation; Writing—review & editing. **Bartosz Rylski:** Conceptualization; Investigation; Methodology; Project administration; Supervision; Writing—original draft; Writing - review & editing.

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