Comparing near-infrared spectroscopy monitoring and stump pressure measurement to estimate the need for shunting during carotid artery endarterectomy

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ABSTRACT

Objectives: In this study, we aimed to evaluate and compare the cerebral oximetry monitoring with near-infrared spectroscopy and the mean stump pressure measurement for the decision of shunting after carotid artery cross-clamping during carotid endarterectomy.

Patients and methods: Between January 2015 and October 2017, a total of 42 patients (33 males, 9 females; mean age 71.3±8.5 years; range, 56 to 92 years) who underwent carotid endarterectomy were retrospectively analyzed. The patients were divided into shunting/non-shunting groups and patients with postoperative major neurological complications/without complications groups.

Results: Carotid artery cross-clamping caused a significant decrease in regional cerebral oxygen saturation (rSO_2) in the shunting group (p=0.01), while the contralateral remained stable (p=0.121). The mean ipsilateral rSO_2 reduction was 35% in the shunting group and only 6.6% in the non-shunting group (p=0.019). Postoperative hemiplegia developed in three (7.1%) patients in the shunting group whose ipsilateral rSO_2 was not reduced during cross-clamping, despite the mean stump pressure was reduced (p=0.03).

Conclusion: Our study results show that near-infrared spectroscopy can demonstrate much more precise results than stump pressure measurement in predicting the need for shunting to prevent perioperative major neurological complications after carotid cross-clamping during carotid endarterectomy.

Keywords: Carotid endarterectomy, near-infrared spectroscopy, stump pressure.

Carotid artery stenosis is one of the most important causes of stroke. Carotid artery endarterectomy (CEA) is the standard treatment method which reduces the risk of stroke. It is recommended for symptomatic and asymptomatic patients under the age of 75 years with ≥70% stenosis in line with the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria.[1,2] Major stroke and mortality after CEA were reported in the NASCET and European Carotid Surgery Trial (ESCT) study as 5.8%, 2.1%, and 7.5%, 3.2%, respectively.[1,3] Cerebral ischemia caused by either embolism or inadequate cerebral perfusion during carotid cross-clamping is the main intraoperative complications of CEA. During general anesthesia,

detection of cerebral ischemia and the decision for shunting are the major issues. Placement of an intraluminal shunt during cross-clamping may prevent cerebral ischemia in patients with poor collateral circulation; however, 85% of patients have sufficient collateral cerebral perfusion and, thus, routine shunting is redundant during cross-clamping.[4]

Several cerebral monitoring modalities such as transcranial Doppler (TCD), near-infrared spectroscopy (NIRS), jugular venous oxygen saturation, carotid artery stump pressure (SP), and also bispectral index (BIS) are used to identify the need for shunting in patients during CEA.[5] However, BIS cannot distinguish ischemia and deep anesthesia, but can only

measure the single hemisphere.[3] Valid assumptions can be only made, if both hemispheres are assessed.

The NIRS provides continuous monitoring of the regional cerebral oxygen saturation (rSO$_2$) changes, which is based on measuring the deoxygenated hemoglobin reflections from the skin, subcutaneous tissue, bone tissue and, also, in a deep watershed area at the junction of the anterior cerebral artery and the middle cerebral artery (MCA) within the near-infrared spectrum (700 to 1,000 nm) which consists of 30% arterial and 70% venous blood.[6] However, NIRS has a 2.6% false-negative rate and has a 66.7% false-positive rate and no certain cut-off value has been established for identification of cerebral ischemia.[7] The NIRS can be also used during open heart surgery, neurosurgical procedures, and head traumas.[8] On the other hand, it has certain limitations such as the need for an ambient light, avoiding the sweating of the patient, and the need for a good contact with the skin.[5]

In the present study, we aimed to evaluate the use of the cerebral oximetry monitoring and the SP measurement in the decision of redundant shunt usage, during CEA.

PATIENTS AND METHODS

Between January 2015 and October 2017, a total of 73 patients who underwent CEA for carotid artery stenosis were screened for eligibility. All data including the demographic and clinical features of the patients were retrieved from the hospital database. Patients who underwent simultaneous coronary artery bypass grafting (CABG), valve surgery, history of neck surgery, and redo CEA were excluded. Five patients were excluded due to simultaneous CABG, one due to redo CEA surgery, and two due to bilateral staged CEA operation. The remaining 25 patients were excluded due to missing data. Finally, a total of 42 patients (33 males, 9 females; mean age 71.3±8.5 years; range, 56 to 92 years) who underwent either unilateral or bilateral staged CEA were retrospectively analyzed. A written informed consent was obtained from each patient. The study protocol was approved by the Ondokuz Mayıs University, Faculty of Medicine, Institutional Review Board (OMU KAEK 2018/126). The study was conducted in accordance with the principles of the Declaration of Helsinki.

The patients were divided into two groups according to the need of shunting during surgery

and the presence of postoperative major neurological complications. Postoperative hemiplegia, hemiparesis, and cerebral hyperperfusion syndrome (CHS) were accepted as postoperative major neurological complications.

Patient-related data including symptoms on admission, length of intensive care unit (ICU) and hospital stay, death, stroke, bleeding, hematoma, cranial nerve injury, and myocardial infarction were analyzed. Physical and laboratory examination findings, medical history, risk factors, and medication use of the patients were also noted.

Treatment indication was ≥50% stenosis of the internal carotid artery (ICA) for symptomatic patients and ≥70% stenosis of the ICA for asymptomatic patients according to the NASCET[1] and European Society for Vascular Surgery (ESVS) guidelines.[9] The severity of the ICA stenosis was preliminary examined by carotid color Doppler ultrasonography and confirmed by computed tomography angiography (CTA). Transthoracic echocardiographic imaging was routinely performed to all patients and the decision of preoperative coronary angiography was made according to ejection fraction, motion disorder of left ventricle wall, and a treadmill test.

Operative technique

All CEA operations were performed under general anesthesia using remifentanil, midazolam, and propofol. Standard monitoring was used including five-lead electrocardiography (leads II and V5), invasive arterial blood pressure, and oxygen saturation via pulse oximetry (SpO$_2$), arterial blood gases, end-tidal carbon dioxide (CO$_2$) in each patient during surgery. All patients underwent a conventional longitudinal endarterectomy with Dacron® or saphenous patch closure of the arteriotomy.

Continuous bilateral rSO$_2$ (cerebral oximetry) was continuously monitored from the time of anesthesia induction, until the patient was recovered from the anesthesia using NIRS (INVOS® 5100C Cerebral/Somatic Oximeter, Somanetics Corp., Troy, MI, USA) to determine the presence of inadequate cerebral flow and, ICA SP was measured during cross-clamping in need of shunting. The ICA SP was measured routinely via a 21-gauge needle distal to the stenosis in ICA, after common carotid artery (CCA) and external carotid artery (ECA) were occluded. A clamping test for 1 min was performed to determine the relative changes in the rSO$_2$ in the frontal lobe. A decline in the rSO$_2$ greater than 20% of pre-clamping and a mean SP of <50 mmHg during cross-clamping were

accepted as the cut-off values of cerebral ischemia to predict the need for shunting. An intraluminal shunt (Javid shunt [Bard carotid shunt, 17F tapered to 10F; Bard® Javid™ Carotid Shunts, Bard Ltd., West Sussex, UK], or Pruitt-Inahara shunt [Horizon Medical, CA, USA) was used selectively, only if cerebral oximetry or/and SP were reduced. All shunts were checked in terms of patency during surgery.

The mean target of blood pressure during cross-clamping and after de-clamping was 110 mmHg. All patients were administered heparin 5,000 IU (based on the body weight) intravenously before cross-clamping of the ICA. Activated clotting time monitoring was used in all patients to measure appropriate heparin dosage (≥250 sec). All patients underwent surgery under single anticoagulant (acetylsalicylic acid 100 mg/day or clopidogrel 75 mg/day) and continued with single or dual antiplatelet therapy throughout life, and low-molecular-weight heparin was administered for three days after surgery.

All patients were evaluated after extubation for the development of a new major neurological deficit. Postoperative neurological examination and reporting of neurological complications until discharge and in the first week, and at one, six, and 12 months were recorded. The patients were also examined by Doppler ultrasonography for residual stenosis, restenosis, occlusion, and pseudoaneurysm at six and 12 months.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 21.0 software (IBM Corp., Armonk, NY, USA). Continuous variables were expressed in mean ± standard deviation (SD) or median (min-max), while categorical variables were expressed in number and frequency. The Kolmogorov-Smirnov test was used to analyze normally distributed continuous variables. The independent sample t-test was used to compare the means of dependent groups including cross-clamp time, mean stenosis, ipsilateral-contralateral rSO_2, and mean SP. The categorical data were analyzed using the chi-square test or Fisher's exact test for postoperative stroke, death, cranial nerve injury, bleeding and hematoma. The Pearson correlation analysis was used to evaluate possible correlations between variables. A p value of <0.05 was considered statistically significant.

RESULTS

Of all patients included in the study, three (7.1%) were symptomatic and 39 (92.8%) were asymptomatic.

Bilateral staged CEA was performed in two (4.7%) patients. There was no statistically significant difference in the baseline demographic and clinical characteristics of the patients who needed shunting and who did not (p>0.05) (Table 1). The mean follow-up was 429.3±157.6 (range, 187 to 1,051) days. The mean arterial pressure (MAP) between the shunting group/non-shunting group and those with and without postoperative major neurological complications did not differ significantly (p>0.05). The median time from the last neurological symptoms to subsequent CEA was 16.6±6.5 (range, 12 to 21) days. The mean operation time was 85.2±24.7 (range, 65 to 140) min, and the mean cross-clamp time was 19.3±4.5 (range, 12 to 28) min. Of the shunting group, no significant difference was observed in cross-clamp time between the patients with and without postoperative neurological complications (p>0.05).

The mean degree of stenosis of the operated and non-operated side was 82.6±8.7% and 27.9±38.9%. The mean right ICA stenosis was 57.1±35.4% (range, 0 to 99%) and the mean left ICA stenosis was 48.4±28.9% (range, 0 to 99%). None of the patients had contralateral occlusion, while contralateral severe stenosis (≥70%) was detected in 39 (92.8%) patients.

The mean rSO_2 reduction in the ipsilateral ICA from baseline during the carotid cross-clamping was 35% in patients requiring shunting, while this rate was 6.6% among those who did not require shunting (p=0.019). In other words, carotid cross-clamping caused a significant decrease during clamping in the ipsilateral rSO_2 in the shunting group (46.4±11.2 vs. 67.3±4.7%, respectively; p=0.01), while the contralateral cerebral oxygen saturation remained stable (68.7±7.1 vs. 71.6±4.7%, respectively; p=0.121) and no significant difference was detected after shunting in terms of ipsilateral rSO_2 (69.5±6.3 vs. 72.8±6.4%, respectively; p=0.121). The results of NIRS and SP are summarized in Table 2.

After the shunt insertion, the rSO_2 in the ipsilateral side returned close to the baseline level. In addition, after de-clamping, rSO_2 returned to baseline level or 10% above the baseline level on the ipsilateral side (except for three patients with neurological defects) among the shunting group. No neurological complications occurred after carotid clamping in patients with a decrease in rSO_2 of ≤20% with a mean SP of >50 mmHg.

Shunting was used in 14 of the patients (33.3%), whereas 28 (66.7%) patients underwent surgery without shunting. Of the shunting group, both SP and

Table 1. Baseline demographic and clinical features of shunting and non-shunting groups									
	Shunting group (n=14)			Non-shunting group (n=28)			Total (n=42)		
	n	%	Mean±SD	n	%	Mean±SD	n	%	p
Age (year)			70.6±9.4			72.8±6.8			0.276
Sex									
Male	12	85.7		21	75		33	78.5	0.692
Surgical side									
Right	7	50		10	35.7		17	40	0.550
Symptomatic	-	-		3	10.7		3	7.1	0.539
Asymptomatic	14	100		25	89.3		39	92.8	0.539
Right ICA stenosis (%)			64.2±36.7			53.7±4			0.429
Left ICA stenosis (%)			39.2±41.5			53.1±41.5			0.312
Mean operation side stenosis (%)			84.6±9.6			81.6±13.1			0.457
Contralateral stenosis (%)									
<70%	1	7.1		2	7.1		3	7.1	1
>70%	13	92.9		26	92.9		39	92.8	1
Diabetes mellitus	10	71.4		16	57.1		26	61.9	0.368
Hypertension	8	57.1		13	46.4		21	50	0.512
Coronary artery disease	4	28.5		7	25		11	26.1	1
History of CABG	2	14.2		2	7.1		4	9.5	0.590
Peripheral artery disease	4	28.5		1	3.5		5	11.9	0.03
Chronic obstructive pulmonary disease	2	14.2		3	10.7		5	11.9	1
Hemoglobin (g/dL)			11.4±1.2			12.9±1.8			0.009
Hematocrit (%)			34.6±4.1			38.9±5.0			0.007
Platelet (1,000/µL)			248±113.8			269±100.9			0.545
Creatinin (mg/dL)			1.2±0.6			1.0±0.4			0.247
Total cholesterol (mg/dL)			172.7±31.7			178±46.4			0.384
Triglycerides (mg/dL)			154.7±182			180±103.8			0.568
High-density lipoprotein (mg/dL)			41.6±9.5			37.3±12			0.249
Low-density lipoprotein (mg/dL)			111.8±41.3			109±39.8			0.833
fT3 (pg/mL)			2.7±1.1			2.7±0.6			0.877
fT4 (ng/dL)			1.4±0.4			1.3±0.3			0.60
Thyroid-stimulating hormone (µIU/mL)			1.3±1.2			1.5±1.1			0.553

SD: Standard deviation; ICA: Internal carotid artery; CABG: Coronary artery bypass grafting.

ipsilateral rSO_2 were reduced in 11 (78.5%) patients during cross-clamping, while ipsilateral rSO_2 was not reduced in three (21.5%) patients during cross-clamping, despite SP was reduced. Therefore, we decided to use an intra-arterial shunt. Ipsilateral rSO_2 decreased by 20% for a short while after shunting. This rate declined to 10%, when the systemic blood pressure was increased; however, it did not reach the baseline value before cross-clamping during surgery. This decline was not considered a late reaction.

Postoperative major neurological complications developed in three (7.1%) patients. Of these patients, none of them had preoperative symptoms. This damage

was permanent in two (4.7%) patients and temporary in one (2.3%) patient. No postoperative mortality was noted. The mean SP on the ipsilateral carotid artery was also lower in the shunting group than the non-shunting group (43.2±10.8 vs. 56.1±6.9 mmHg, respectively; p=0.01).

In terms of postoperative major neurological complications, no changes were detected in the mean ipsilateral rSO_2 (65.2±5.6 vs. 67.1±3.7%, respectively; p=0.195) during clamping, whereas the mean SP were significantly lower in the patients who had postoperative major neurological complications (45.5±6.3 vs. 57.2±7.7 mmHg; p=0.01).

Table 2. Intraoperative measurements of NIRS monitoring and SP measurement of shunting and non-shunting groups

	Shunting group (n=14)		Non-shunting group (n=28)		
	%	Mean±SD	%	Mean±SD	p
Ipsilateral rSO$_2$%					
Pre-clamping		71.4±4.9		72.1±6.3	0.472
During clamping		46.4±11.2		67.3±4.7	0.01
During shunting		65.1±5.6		-	-
Post clamping/post shunting		69.5±6.3		72.8±6.4	0.121
Relative change in rSO$_2$% during cross-clamping compared with pre-clamp	35		6.6		0.019
Contralateral rSO$_2$%					
Pre-clamping		72.6±3.9		73.2±5.9	0.732
During clamping		68.7±7.1		71.6±4.7	0.121
Post clamping		71.8±5.2		73.1±5.4	0.461
Mean arterial pressure (mmHg)		92.8±3.53		95.6±7.71	0.205
Stump pressure (mmHg)		43.2±10.8		56.1±6.9	0.01

SD: Standard deviation; NIRS: Near-infrared spectroscopy; SP: Stump pressure; rSO$_2$%: regional cerebral oxygenation.

Table 3. Postoperative outcomes of shunting and non-shunting groups

	Shunting group			Non-shunting group			Total		
	n	%	Mean±SD	n	%	Mean±SD	n	%	p
Postoperative complications									
Stroke	3	21.4		-	-		3	7.1	0.03
Cranial nerve injury	2	14.2		2	7.1		4	9.5	0.590
Hematoma	2	14.2		2	7.1		4	9.5	0.590
Bleeding	-	-		2	7.1		2	4.7	0.544
Death (in 30 days)	1	7.1		-	-		1	2.3	0.333
ICU stay (day)			7.4±13.8			3.2±0.42			0.02
Overall in-hospital stay			18.6±26.9			4.6±0.69			0.008

SD: Standard deviation; ICU: Intensive care unit.

Three (7.1%) patients developed hemiplegia, two (4.7%) patients developed cranial nerve injury, and two (4.7%) patients developed hematoma in the shunting group in the postoperative period. Two patients (4.7%) underwent reoperation due to bleeding in the non-shunting group (p=0.544). Overall neurological event rate was 16.6% (n=7) (Table 3). All four (9.5%) patients with cranial nerve injury (particularly facial paralysis) completely recovered at the end of six months. The 30-day stroke and death rates were 7.1% and 2.3%, respectively. Of these three patients, permanent neurological sequelae were developed in one (2.3%), while the other two (4.6%) patients fully recovered at six months. None of the patients had myocardial infarction or heart failure perioperatively.

During follow-up, no residual stenosis, restenosis, occlusion, or pseudoaneurysm was detected. When we excluded three patients with postoperative neurological complications from the shunting group, no significant difference was found in either group in terms of ICU and hospital stay (p>0.05). No case of heparin-induced thrombocytopenia was observed.

DISCUSSION

In the present study, we compared the cerebral oximetry monitoring with NIRS and the mean SP measurement for the decision of shunting after carotid artery cross-clamping during CEA. In our study, postoperative major neurological complications developed in three patients. Of these patients, none of them had preoperative symptoms. This damage was permanent in two patients and temporary in one patient. Based on these results, we concluded that it was a false-positive result of SP measurement, as the ipsilateral rSO$_2$ was not reduced and redundant shunting was used. Although NIRS has a low rate of false positivity, we believe that it is more reliable than the SP measurement, which has a high false-negativity rate, in deciding to apply shunt. We also believe that its effectiveness would increase even more in the awake

patient under local anesthesia. To the best of our knowledge, NIRS should be chosen for the decision of shunting during CEA.

The NIRS is an easy, inexpensive, and non-invasive technique which can be applied to all patients and allows continuous monitoring of the cerebral blood flow to detect cerebral ischemia which may lead to perioperative stroke.[10-15] On the other hand, SP gives valuable information about the patient's cerebral collateral circulation. Many CEA operations are performed under general anesthesia and, during cross-clamping of the ICA, the watershed of the MCA zone and the cerebral collateral circulation should be evaluated to prevent ischemic complications.[4] Using intra-arterial shunt to provide cerebral circulation is still controversial. Some surgeons prefer routine shunting, while the others advocate selective shunting. Shunting is required in 10 to 15% of patients undergoing CEA, while 85 to 90% of those have been shunted unnecessarily.[16] Inadequate shunt flow, shunt thrombosis, carotid artery dissection, and plaque/air embolization are the potential complications of shunting. Additionally, it may also reduce the exposure of the distal portion of the plaque, leading to perioperative stroke.[5,17] The reported risk of embolism or dissection during CEA is about 1 to 3%.[16,18]

The SP is an inexpensive method to measure the ICA pressure and reflects the status of the Willis circulation; however, it does not obtain any information about adequate cerebral perfusion during cross-clamping.[4] Contralateral carotid artery occlusion is also a risk factor for low SP.[19] The NIRS allows continuous monitoring of the cerebral blood flow non-invasively and provide simultaneous information about the oxygenation of the cerebral tissue and shunt function with 95% sensitivity and 81% specificity.[10,16] Several factors can influence the rSO_2 values including arterial oxygen saturation, systemic blood pressure, arterial CO_2 tension, cerebral blood volume, hematocrit level, skin color, and sex and shows large individual variations.[20,21]

A significant correlation was detected between the SP, electroencephalography (EEG), TCD ultrasonography, and rSO_2 values.[22] However, Johnson et al.[15] found no correlation between the MAP and SP with a 50-mmHg cut-off value with 85% (95% CI: 64-95) sensitivity and 54% (95% CI: 46-61) specificity. In addition, they reported that the positive predictive value (PPV) of SP was 19% (95% CI: 12-28) and negative predictive value (NPV) of SP was 96% (95% CI: 90-99), and a decrease in the rSO_2 was

more accurate than SP in predicting cerebral ischemia during cross-clamping of the ICA. Consistent with these findings, in the present study, no false-negative test result was detected for rSO_2, while false-positive results were obtained in three patients during SP measurement.

The threshold values for critical rSO_2 of cerebral oximetry during CEA are still controversial. Pennekamp et al.[13] Ritter et al.,[14] and Samra et al.[23] reported 16%, 19% and 20% reduction, respectively in the rSO_2 as a clinical threshold value to predict the need for shunt placement. Moreover, Rigamonti et al.,[24] reported that, in a 50-patient cohort comparing NIRS versus EEG/clinical symptoms, more than 15% decrease from baseline was associated with a 20-fold increase in the risk of cerebral ischemia. In another study, Mille et al.[25] showed that the sensitivity of cut-off value for 11.7% was 75% (95% CI: 71-78) and the specificity was 77% (95% CI: 74-80). More than 25 to 27% reduction in the rSO_2 can reduce the false-positive rate and shunting; however, the rate of neurological complications may increase.[26] A total of 5% decline in the rSO_2 increases the sensitivity to 100%, while it decreases the specificity to 51%.[15] Various devices may probably show diverse optimal cut-off values. In our study, we considered a cut-off value of 20% and the mean reduction from baseline during the carotid clamping test was 35%, while the mean SP was 43.2±10.8 (range, 15 to 49) mmHg in patients who required shunting. No postoperative major neurological complications were observed in the non-shunting group having no more than 20% decline in the ipsilateral rSO_2 values.

The TCD monitors the mean blood flow velocity (V_{mean}) of the MCA, also related to EEG changes, but it does not reflect the cerebral oxygenation. The TCD monitoring may fail in 15% of patients due to the insufficient temporal bone window.[27] Fassiadis et al.[28] compared NIRS monitoring with TCD in patients who underwent CEA in a 47-patient prospective study and demonstrated that NIRS was a satisfactory and superior monitoring device for sufficient cerebral perfusion and oxygenation during CEA. Additionally, Pugliese et al.[5] reported that rSO_2 was more reliable than TCD. Of note, monitoring of TCD needs a specialized technician. Pennecamp et al.[13] reported that NIRS and TCD had moderate PPV and high NPV to detect cerebral ischemia compared to EEG.

The amplitude of somatosensory evoked potential (SEP) and EEG is reduced by drugs which are

commonly used during general anesthesia. Such drugs inhibit the brain metabolism; however, NIRS is not affected by drugs. The SEP should be combined with NIRS to increase the ability to predict cerebral ischemia.[4]

Some authors have advocated that EEG should be the first choice to detect the decrease of cerebral perfusion during cross-clamping of the ICA under local anesthesia; however, it requires a dedicated neurology technician. In addition, it is time-consuming and sometimes difficult to interpret. Moreover, EEG has a high procedural cost and needs an experienced neurological technician, and preoperative EEG and anesthetic-induced changes make it difficult to interpret the EEG results.[28]

Postoperative CHS occurs in 1 to 3% of patients after CEA, which is related to intracerebral hemorrhage with a 40%-mortality rate. There is a limited number of data regarding its causes and prevention methods. None of our patients developed CHS in our study. Postoperative major neurological complications were seen in only three (7.1%) patients in the shunting group. No permanent neurological deficit occurred in the first patient with hemiplegia and this patient fully recovered after six months. The second patient was discharged with hemiplegia, while the third patient with hemiplegia was tracheostomized and died due to respiratory tract infection on postoperative Day 25.

Cossman et al.[30] reported that, to accurately measure the SP as indicated, the needle should be inserted into the ICA, instead of the CCA. Measuring the SP from the ICA distal to the stenosis is of utmost importance. High false-negative results for SP measurement were reported in some previous studies.[15,31,32] We believe that measuring the SP from the CCA proximal to the stenosis should increase the false-positive results, instead of false-negative results. In this regard, NIRS has the lowest ratio of wrong measurements than SP measurement. Consistent with these findings, in the present study, no false-negative test result was detected for rSO_2 which is the most important advantage over SP measurement.

Moderate perioperative results were obtained in our study with a 30-day stroke and death rate of 7.1% and 2.3%, respectively which is also higher than the previous studies.[29] Almost no decrease in the cerebral oxygen saturation during shunting was seen, except for three patients. The cerebral oximetry values of the patients with unilateral or bilateral carotid stenosis were close to the normal values and provided more accurate data to decide. We considered that all three

postoperative neurological complications were caused by redundant shunting. Although the hematocrit and hemoglobin levels were statistically significantly lower in the shunting group, it was not of clinical relevance.

Nonetheless, there are some limitations to the present study. First, the number of patients in our study is relatively small than previous studies. Second, the number of strokes in the shunting group was relatively high compared to the non-shunting group. Third, we were unable to compare NIRS and/or SP with awake testing and, therefore, we cannot make any comment on the sensitivity and specificity of these tests, as all patients underwent surgery under general anesthesia in our study. Further large-scale studies are needed to determine the optimal threshold value and to confirm our findings.

In conclusion, our study results demonstrate that NIRS allows continuous non-invasive monitoring of the cerebral oxygenation of the superficial brain cortex which gives accurate information about shunting during cross-clamping compared to SP measurement, and it may prevent redundant shunting, probably leading to perioperative shunt-related disastrous results. In addition, NIRS may yield much more precise results than SP measurement in predicting shunting and perioperative major neurological complications during cross-clamping in CEA surgery.

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