ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

DOI:10.5336/cardiosci.2017-57122

Evaluation of Shunt Use with Near Infrared Spectroscopy During Carotid Endarterectomy: An Observational Clinical Study

Karotid Endarterektomi Sırasında Near İnfrared Spektroskopi ile Şant Kullanımının Değerlendirilmesi: Gözlemsel Klinik Çalışma

Kürşad ÖZ,[a]
Salih GÜLER,[a]
Zeynep KAHRAMAN,[b]
Melek ÖZARSLAN,[c]
Mehmet ERTÜRK[d]

Clinics of
[a]Cardiovascular Surgery,
[b]Anaesthesiology and Reanimation,
[c]Neurology,
İstanbul Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital,
[d]Department of Cardiology,
İstanbul University
İstanbul Faculty of Medicine,
İstanbul

Geliş Tarihi/*Received:* 27.06.2017
Kabul Tarihi/*Accepted:* 11.09.2017

Yazışma Adresi/*Correspondence:*
Kürşad ÖZ
Istanbul Mehmet Akif Ersoy
Thoracic and Cardiovascular Surgery
Training and Research Hospital,
Clinic of Cardiovascular Surgery,
İstanbul,
TURKEY/TÜRKİYE
drkursadoz@gmail.com

ABSTRACT Objective: Measurement of cerebral saturation (NIRS) with is that noninvasive method can early and easily demonstrate disorders in cerebral blood flow without the need for specialized personnel. In this study, we evaluated not only the relationship between cerebral monitoring values and shunt use but also postoperative short term effect of cerebral monitoring in patients undergoing carotid endarterectomy. **Material and Methods:** Between 2010 and 2015, 427 patients underwent 481 carotid endarterectomy operations. Sixty-five of these patients (13.5%) had bilateral critical carotid stenosis. Carotid endarterectomy was performed under shunt requirement in 54 cases (11.2%). The NIRS probe was placed in the frontal region of the patient to monitor the cerebral oxygen level of the patients. At this time, NIRS values of patients were recorded before cross-clamp (rSO 0), cross-clamp (rSO1) and post-clamp (rSO2). Following operation, the patients were transfered to intensive care unit and then to the ward after staying 2-4 hours. Operational time, cross-clamp time, complications within 30 days associated with operation were recorded. Subsequent checks were made by the neurologist on the 30th day and every 6 months on follow-up. **Results:** The mean age was 69.95±12.84 in group 1 and 66.18±7.11 years in group 2. There was a significant difference in the carotid clamping time (min), percentage of carotid angioplasty, bilateral carotid procedures between group 1 and group 2 (23.85±12.4 vs 15.18±7.11, 100% vs 79.2%, 74.07 vs 5.85, p<0.01, respectively). The length of intensive care unit and hospital stays were similar among groups. regional cerebral oxygen saturation in first 3 min after carotid artery clamping (rSO1) in shunt group was lower compared to the patients in no-shunt group (48.7±11.5 vs 59.7±6.77, p=0.03) **Conclusions:** As a result, NIRS is a safely and a reliable cerebral monitoring technique and also it may help to reduce unnecessary shunt use in patients undergoing carotid endarterectomy.

Keywords: Endarterectomy, carotid; spectroscopy, near-infrared

ÖZET Amaç: Near infrared spectroscopy (NIRS) ile serebral oksijen saturasyonu ölçümü, serebral kan akımının noninvaziv bir ölçümüdür. Bu çalışmada sadece karotis endarterektomi uygulanan hastalarda serebral monitörizasyon değerleri ile şant kullanımı arasındaki ilişkiyi değil, aynı zamanda postoperatif serebral monitörizasyon etkisini de değerlendirdik. **Gereç ve Yöntemler:** 2010 ile 2015 yılları arasında 427 hasta 481 karotis endarterektomi ameliyatı geçirdi. Bu hastalardan 65'inde (%13,5) bilateral kritik karotis stenozu vardı. 54 hastada (%11,2), karotis endarterektomi şant gereksinimi altında uygulandı. Near infrared spectroscopy ile, hastanın serebral oksijen seviyesini izlemek için frontal bölgeye elektrodlar yerleştirildi. Bu sırada, hastaların kross klemp öncesi (rSO 0), kross klemp sırasında (rSO1) ve kross klemp sonrasında (rSO2) bölgesel serebral oksijen değerleri kayıt edildi. Ameliyat sonrasında hastalar yoğun bakıma alındı ve 2-4 saat takip edildikten sonra servis odasına nakil edildi. Operasyon süresi, kross klemp süresi, ameliyat ile ilişkili 30 gün içindeki komplikasyonlar kaydedildi. Daha sonraki kontroller 30 günlük ve takip eden 6 ayda nöroloji uzmanı tarafından yapıldı. **Bulgular:** Ortalama yaş şant grubunda 69,95±12,84 yıl iken, şant kullanılmayan grupta ise 66,18±7,11 yıl idi. Karotis klemp süresi, karotid patch anjiyoplasti, iki taraflı karotis prosedürleri açısından şant grubu ile şant kullanılmayan grup arasında anlamlı fark vardı (23,85±12,4 vs 15,18±7,11, %100' vs %79,2, 74,07 vs 5,85, sırasıyla, p=0,01). Yoğun bakım ünitesi ve hastanede kalış süreleri gruplar arasında benzerdi. Şant grubundaki karotis arter klemplendikten sonraki bölgesel serebral oksijen satürasyonu (rSO1), şant kullanılmayan gruba kıyasla daha düşüktü (48,7±11,5 vs 59,7±6,77, p=0,03). **Sonuç:** Sonuç olarak near infrared spektrsokopi,karotid endarterektomi uygualanan hastalarda güvenli ve güvenilir bir serebral izleme tekniğidir ve ayrıca gereksiz şant kullanmayı azaltmaya da yardımcı olabilir.

Anahtar Kelimeler: Endarterektomi, karotis; spektroskopi, near-infrared

Carotid endarterectomy is a treatment option for the prevention of future cerebrovascular events in symptomatic patients with severe internal carotid artery stenosis.The benefits of surgical treatment of carotid stenosis have been demonstrated in international and multicenter studies such as NASCET and ECST.[1,2]

However the procedure itself carries a risk of stroke. The main causes of the stroke during carotid endarterectomy may be intraoperative ischemia associated with hypoperfusion during thrombosis, embolism, or cross clamping of the carotid artery.[3]

In order to reduce the perioperative stroke rate, it is recommended to use one of the multiple methods that can be used to monitor cerebral perfusion. Internal carotid artery stump pressure monitoring, EEG analysis, evaluation of somatosensory evoked potentials (SSEP) and continuous neurological status monitoring are the methods used to monitor cerebral perfusion in patients undergoing regional anesthesia. But it is difficult to measure cerebral blood flow in the operation room.[4,5]

Shunt may be needed to maintain cerebral perfusion at a certain level. Routine shunt use leads to unnecessary shunting in approximately 85% of patients. Because most patients have collaterals for adequate cerebral perfusion during cross clamping.[6] However, the use of unnecessary shunting has some disadvantages, including carotid artery dissection, plaque embolization, insufficient shunt flow, and shunt thrombosis.[7] The shunt may cause restriction of the distal part of the plaque. Most surgeons thus prefer to use selective shunting. This requires the use of cerebral follow-up techniques during the cross-clamp test.[8] Measurement of cerebral saturation with NIRS is that noninvasive method can early and easily demonstrate disorders in cerebral blood flow without the need for specialized personnel. In this study, we evaluated the relationship between cerebral monitoring values and shunt use during carotid endarterectomy in awake patients and its effect on postoperative short term.

MATERIAL AND METHODS

In this study, Between 2010 and 2015 years, 427 patients underwent 481 carotid endarterectomy operations. We investigated the relationship between shunt requirements and near infrared spectroscopy (NIRS) values in patients undergoing vigilant carotid endarterectomy. Patients were divided into two groups according to shunt requirement (shunt group= Group 1, n = 54 and no-shunt group=Group 2, n=427). In all patients, demographic data, preoperative risk factors, peroperative, early (first 30 days) and late neurological findings were examined. According to the Helsinki declaration, the local ethics committee was approved before the study, and informed consent form was obtained from all the patients and their records were examined.

Doppler ultrasonography was performed in all patients and the diagnosis was confirmed by digital subtraction angiography (DSA), computed tomography (CT) or magnetic resonance (MR) angiography. Each patient presented for an elective carotid endarterectomy (CEA) within the indications established by the European Carotid Surgery Trial (ECST)/North American Symptomatic Carotid Endarterectomy Trial (NASCET) studies, or as a part of the Asymptomatic Carotid Surgery Trial (ACST). Symptomatic and asymptomatic patients with carotid stenosis >70% underwent carotid revascularization. The decision making process for carotid intervention (surgery or stent) was determined by a multidisciplinary team of cardiologists, neurologists, cardiovascular surgeons.

All patients underwent awake carotid endarterectomy under regional anesthesia. In addition, the NIRS probe was placed in the frontal region of the patient to monitor the cerebral oxygen level of the patients. At this time, NIRS values of patients before cross-clamp (rSO_0), cross-clamp (rSO_1) and post-clamp (rSO_2). The NIRS method was measured in the ipsilateral frontoparietal region using the INVOS 4100 cerebral oxymeter (Somanetics, Troy, Mich., USA). The main criterion in determining the shunt requirement was the patient's consciousness and loss of motor function on the opposite extremity of the operating area.

OPERATIVE MANAGEMENT

Five-lead ECG, pulse oximetry for oxygen saturation and invasive measurement of mean arterial blood pressure were performed for all patients. During the procedure each patient received oxygen at 4–8 min/l via a facemask or nasal cannula. Deep and superficial cervical block anesthesia was applied to all of the patients. Deep cervical plexus block C 2-3-4 cervical nerve dermatomes were combined with 5-10 ml of 0.25% bupivacain and 1% prilocain injection followed by superficial cervical plexus block. Superficial cervical plexus block 15-20 ml of 1% lidocain was applied as subcutaneous tissue infiltration in the posterior head region of the sternocleidomastoid muscle. All patient were heparinized IV 5000 IU before clamping. Controlled hypertension was maintained by the anesthetist during carotid clamping. The state of consciousness was tested with verbal stimuli. To test the motor functions, periodic motor functions and talking state of consciousness were assessed by the anesthetist. Operation was performed if no neurological changes were observed within 5 seconds after carotid clamping. If consciousness change occurred during the clamping, decided to place the vascular shunt during the operation. Standard surgical technique is atherosclerotic plaque removal and carotid artery reconstruction. After the operation, the patient is transfered to the service room after staying 2-4 hours in the intensive care unit. Operational time, cross-clamp time, complications within 30 days associated with operation were recorded. Subsequent checks were made by the neurologist on the 30th day and every 6 months on follow-up.

EARLY AND MID-TERM FOLLOW UP

In intensive care unit postoperative patients were monitored until hemodynamically stable. Any neurological deficit was checked by a neurologist and, if necessary, a cranial CT scan was performed. Patients were assessed with NIHSS (National Institutes of Health Stroke Scale) and Rankin Scale. Short-term neurological deficits were evaluated as transient neurological deficits. Rankin score 2 or lower lacunary changes were accepted as good prognostic neurological sequelae of sensorimotor stroke. Motor hemiparesis, hemiplegia, and Rankin score of 3 or more were evaluated as poor prognosis. Patients were evaluated for perioperative myocardial infarction.

All patients were evaluated on the postoperative 7th, 30th day and every 6 months by a neurologist, cardiologist and surgeon. The average follow- up period is 52 months (Between 12 and 65 months). Carotid doppler USG was administered every 6 months.

STATISTICAL ANALYSIS

Statistical analysis was performed using SPSS version 20 statistical software (SPSS Inc. Chicago, IL, USA). Data are presented as means, standard deviation (SD) for continuous data and numbers (percentage) for categorical data were analyzed using a paired or unpaired Student t tests when appropriate, subsequently rSO and MAP were calculated and are presented as mean ± standard error of the mean.

RESULTS

PATIENT CHARACTERISTICS

The demographic characteristics of all patients are presented in Table 1. The mean age was 69.95±12.84 in group 1 and 66.18±7.11 years in group 2. Both groups were similar with respect to age, sex, presence of hypertension (HT), diabetes mellitus (DM), renal dysfunction, chronic obstructive pulmonary disease (COPD), peripheric arterial disease (PAD). Also there was no difference with respect to previous neurologic event and asymptomatic carotid artery stenosis.

There was a significant difference in the peroperative data including carotid clamping time, percentage of carotid angioplasty, bilateral carotid procedures between group 1 and group 2 (23.85±12.4 vs 15.18±7.11, 100% vs 79.2%, 74.07 vs 5.85, $p < 0.01$, respectively). On the other hand, the length of intensive care unit and hospital stays were similar among groups (Table 2).

HEMODYNAMIC AND CEREBRAL MEASUREMENTS

Peroperative mean arterial pressure, arterial oxygen saturation, regional cerebral oxygen satura-

TABLE 1: Patient characteristics.

		all n (%)	Group 1 n (%)	Group 2 n (%)	p
Age (year)		62.7±8.43	58.95±12.84	64.18±7.11	0.74
Sex	F	141 (29.31)	15 (27.8)	130 (30.44)	0.913
	M	340 (70.69)	39 (72.2)	296 (69.33)	0.758
Hypertension		424 (88.14)	46 (85.18)	371 (86.88)	0.92
DM		113 (23.49)	13 (24.07)	27 (24.82)	0.826
Renal dysfunction		89 (18.5)	9 (16.66)	59 (13.81)	0.652
COPD		165 (34.3)	19 (35.18)	166 (38.88)	0.771
PAD		103 (21.41)	12 (22.22)	14 (19.44)	0.865
CAD		19 (13.92)	23 (16.9)	102 (23.88)	0.852
Symptomatic stenosis	TIA	150 (31.18)	17 (31.48)	130 (30.45)	0.713
Stroke		28 (5.82)	3 (5.56)	24 (5.62)	0.934
Asymptomatic stenosis		303 (70)	34 (62.96)	273 (63.93)	0.512

DM, Diabetes mellitus; COPD, Chronic obstructive pulmonary disease; PAD, Periferic arterial disease; TIA, Transientischemic attack; Continous data are presented as mean±standard deviation, categorical data as number (%).

TABLE 2: Patient characteristics.

	all n (%)	Group 1 n (%)	Group 2 n (%)	p
Carotid clamping (time/min)	18.12±6.72	23.85±12.4	15.18±7.11	<**0.01**
Carotid patch angioplasty	394 (81.91)	54 (100)	340 (79.62)	**<0.01**
Operation' site left	160 (33.26)	8 (14,81)	152 (35.59)	0.06
bilateral	65 (13.51)	40 (74.07)	25 (5.85)	<**0.01**
Postoperative morbidity				
Hematoma	13 (2.7)	2 (3.7)	11 (2.57)	0.321
Hoarseness	6 (1.24)	1 (1.85)	5 (1.17)	0.07
Cranial nerve damage	3 (0.62)	0	3 (0.65)	0.132
Length of intensive care (h)	2.69±2.29	2.86±3.91	2.65±1.36	0.723
Length of hospital stay (d)	3.9±1.41	4.25±1.92	3.71±185	0.861

DM, Diabetes mellitus; COPD, Chronic obstructive pulmonary disease; PAD, Periferic arterial disease; TIA, Transientischemic attack; Continous data are presented as mean±standard deviation, categorical data as number (%).

tion before carotid artery clamping (rSO_0) and regional cerebral oxygen saturation after removing carotid artery clamping (rSO_2) did not differ between shunt group and no-shunt group patients. However, regional cerebral oxygen saturation in first 3 min after carotid artery clamping (rSO_1) in group 1 was lower compared to the patients in group 2 (48.7±11.5 vs 59.7±6.77, p=0.03) (Table 3).

There was no significant difference in the all stroke (major or minor stroke) and mortality (related to stroke or cardiac) between the groups (Table 4). The changes in values of rSO2 and MAP elicited by cross clamping in both groups are presented in figures (Figure 1 and Figure 2).

TABLE 3: Cerebral oxygenation values of ipsilateral hemispher according to shunt use.

	Group 1 n (%)	Group2 n (%)	p
MAP	96 ± 18	101± 15	0.239
Sat O_2(%)	97±2	96±2	0.165
rSO0	62.2±9.8	64.4±8.7	0.381
rSO_1	48.7±11.5	59.7±6.77	**0.03**
rSO_2	64.5±6.1	67.3±8.9	0.75

MAP, mean arterial pressure; Sat O*2*, arterial oxygen saturation; rSO_0, regional cerebral oxygen saturation before carotid artery clamping; rSO_1, regional cerebral oxygen saturation in first 3 min after carotid artery clamping; rSO_2, regional cerebral oxygen saturation after removing carotid artery clamping.

DISCUSSION

Intraoperative stroke during cross clamp or thromboembolism constitutes 15-20% of perioperative

TABLE 4 Neurologic and mortality outcomes in 30 days.

	all n (%)	Group 1 n (%)	Group 2 n (%)	p
all stroke	7 (1.14)	4 (7.4)	3 (0.7)	0.412
Type				
major stroke	2 (0.41)	2 (3.7)	1 (0.23)	0.821
minor stroke	5 (1.03)	3 (5.55)	2 (0.46)	0.167
mortality related to stroke	4 (0.83)	2 (3.7)	2 (0.46)	0.32
related to cardiac	5 (1.03)	2 (3.7)	3 (0.7)	0.656

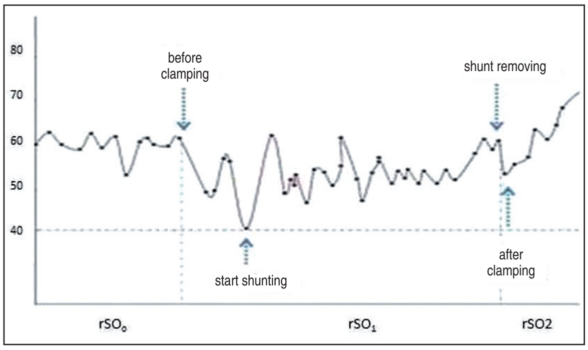

FIGURE 1: Follow up regional cerebral oxygen saturation (rSO) with NIRS during carotid endarterectomy using shunt.

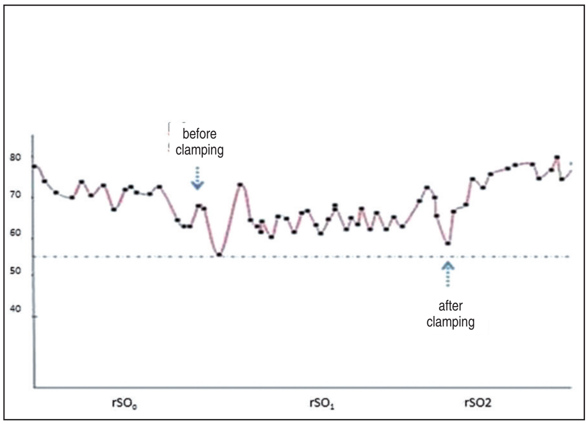

FIGURE 2: Follow up regional cerebral oxygen saturation (rSO) with NIRS during carotid endarterectomy without using shunt.

stroke.[3] The cerebral ischemia resulting from occlusion of internal carotid artery depends on cerebral collateral flow. Several methods have been described to monitor and evaluate this risk during and before surgery. This is important not only for assessing the effect of the cross-clamp, but also for evaluating the quality of the surgeon. This technical defect may lead to blood flow disturbances and thromboembolism.[9,10]

Some authors have argued that it is critical understanding of the pathophysiology of post-operative stroke in carotid artery surgery. Some of these stroke cases can be avoided and are associated with the shunt.[11] Hingorani et al. 444 patients reported a postoperative 1% early stroke rate (five patients). Only two of these five patients had embolic stroke; Only one of these five stroke was thought to be due to intraluminal shunt trauma.[12] The optimal method for assessing cerebral perfusion or determining the need for selective shunting is still a controversial issue, despite the large number of medical literature studies involving CEA.[13] The application of intraoperative cerebral monitoring varies between surgeons and institutions, depending on local tradition, the preferences of the surgeon, the technical resources, the lack of a superior method of economics and surgeon's every aspect. Cerebral monitoring techniques differ in terms of probability of finding cerebral ischaemia, expert opinion and availability. Transcranial Doppler (TCD), somatosensory evoked potentials (SEP) and electroencephalography (EEG) are well-defined follow-up patterns, but some disadvantages in terms of accessibility and/or interpretation. The measurement of the stump pressure of the carotid artery is used for a long time. It is technically simple but the threshold values that determine the risk of cerebral hypoperfusion are poorly defined and the specificity is low.[14] Intraoperative flow measurements using transit time flowmeter are shown for lower extremity vascular surgery. Experimental data on its accuracy have also been reported. However, its application during CEA has not been fully researched.[15] Gordon et al. reported a series characterizing flow differences before and after endarterectomy. The method gives quantitative volume flow measurements and morphological differences in the current waveform of common carotid artery (CCA), external carotid artery (ECA) and internal carotid artery (ICA).[16]

With near infrared spectroscopy, the cerebral oximeter allows continuous monitoring of changes in cerebral oxygenation (rSO_2) through the adhesive sensors on the patient's side. Extracranial interferences can affect readings, but the dual detector system focuses on oxygenation changes and this risk can be reduced by using sequential compression. However, a reliable comparison between these studies is limited due to lack of standardization of applied devices, changes in study protocols and indications of shunt use. Some studies indicate that dual follow-up parameters is more reliable than single follow-up during carotid endarterectomy under general anesthesia or regional anesthesia. They also have been emphasized to indicate that NIRS can be used to determine the need for shunt placement.[17]

Carotid endarterectomy under local or regional anesthesia is routinely used in many centers. Many surgeons regard cerebral monitoring as the best method and gold standard. Although awake carotid endarterectomy with loco-regional anaesthesia provides direct cerebral monitoring, additional follow-up of cerebral oxygen flow in high-risk and critically ill patients will positively contribute to early outcome improvement.[18]

In patients with contralateral carotid artery occlusion, the need for routine intravascular shunt use in the light of the fact that shunt requirements, mortality and morbidity are not different from patients with contralateral stenosis.[19] When the patient's intraoperative neurological status is assessed continuously, the choice of shunt usage is safe. This situation requires strong co-operation and expertise between the anesthesiologist and the surgical team. Silva et al. studied 700 patients undergoing CEA [108 patients had contralateral carotid occlusion (CCO), 15.4%] and found an insignificantly higher risk in those with CCO (stroke 3.7% vs. 1.9% and death 0.9% vs. 1.2%). However, they used internal shunts in a significantly higher proportion of patients with contralateral occlusion (83.3% vs. 64.6%).[20]

In our study, the shunt was used in only 54 (11.2%) of 481 carotid endarterectomy procedures. rSO_1 mean value of these patients were 48.7±11.5. NIRS exchange by baseline value $DrSO_1 = rSO_0 - rSO_1$ is range 22.71%. Although it has been mentioned that the motor function is followed by a treadmill or toy duck that sounds consciously by being awakened to the patient in awake hospital, especially in critically patients who require shunt due to the occlusion of the contralateral carotis artery, which has bilateral carotid artery stenosis. We believe that safer cerebral monitoring may be achieved with ipsilateral or bilateral NIRS follow-up alone, which is not sufficient for cerebral monitoring.

CONCLUSION

As a result, we conclude that NIRS is a safely and a reliable monitoring technique in patients at risk of developing peroperative stroke and also it will be help to reduce unnecessary shunt use.

Conflict of Interest

Authors declared no conflict of interest or financial support.

Authorship Contributions

Concept: *Kürşad Öz, Zeynep Kahraman;* ***Design:*** *Kürşad Öz;* ***Control / Control:*** *Melek Özarslan; D****ata Collection and Processing:*** *Salih Güler;* ***Analysis And / Or:*** *Kürşad Öz; Literature* ***Review:*** *Kürşad Öz, Salih Güler,* ***Article writer to take responsibility when writing the whole or a substantial part of the work****: Kürşad Öz;* ***Significant Joint Writing in a scientific way, except for spelling and grammar:*** *Mehmet Ertürk.*

REFERENCES

1. Ferguson GG, Eliasziw M, Barr HW, Clagett GP, Barnes RW, Wallace MC, et al. The North American Symptomatic Carotid Endarterectomy Trial: surgical results in 1415 patients. Stroke 1999;30(9):1751-8.
2. MRC European Carotid Surgery Trial: interim results for symptomatic patients with severe (70-99%) or with mild (0-29%) carotid stenosis. European Carotid Surgery Trialists' Collaborative Group. Lancet 1991;337(8752): 1235-43.
3. de Borst GJ, Moll FL, van de Pavoordt HD, Mauser HW, Kelder JC, Ackerstaf RG. Stroke from carotid endarterectomy: when and how to reduce perioperative stroke rate? Eur J Vasc Endovasc Surg 2001;21(6):484-9.
4. Jansen C, Vriens EM, Eikelboom BC, Vermeulen FE, van Gijn J, Ackerstaff RG. Carotid endarterectomy with transcranial Doppler and electroencephalographic monitoring. A prospective study in 130 operations. Stroke 1993;24(5):665-9.
5. Blume WT, Ferguson GG, McNeill DK. Significance of EEG changes at carotid endarterectomy. Stroke 1986;17(5):891-7.
6. Chongruksut W, Vaniyapong T, Rerkasem K. Routine or selective carotid artery shunting for carotid endarterectomy (and different methods of monitoring in selective shunting). Cochrane Database Syst Rev 2014;(6):CD000190.
7. Benjamin ME, Silva MB Jr, Watt C, McCaffrey MT, Burford- Foggs A, Flinn WR. Awake patient monitoring to determine the need for shunting during carotid endarterectomy. Surgery 1993;114(4):673-9.
8. Hans SS, Catanescu I. Selective shunting for carotid endarterectomy in patients with recent stroke. J Vasc Surg 2015;61(4):915-9.
9. Visser GH, van der Grond J, van Huffelen AC, Wieneke GH, Eikelboom BC. Decreased transcranial Doppler carbon dioxide reactivity is associated with disordered cerebral metabolism in patients with internal carotid artery stenosis. J Vasc Surg 1999;30(2):252-60.
10. Nielsen MY, Sillesen HH, Jørgensen LG, Schroeder TV. The haemodynamic effect of carotid endarterectomy. Eur J Vasc Endovasc Surg 2002;24(1):53-8.
11. Uchino H, Nakamura T, Kuroda S, Houkin K, Murata J, Saito H. Intraoperative dual monitoring during carotid endarterectomy using motor evoked potentials and near-infrared spectroscopy. World Neurosurg 2012;78(6): 651-7.
12. Hingorani A, Ascher E, Tsemekhim B, Markevich N, Kallakuri S, Schutzer R, et al. Causes of early post carotid endartectomy stroke in a recent series: the increasing importance of hyperperfusion syndrome. Acta Chir Belg 2002;102(6):435-8.
13. Zogogiannis ID, Iatrou CA, Lazarides MK, Vogiatzaki TD, Wachtel MS, Chatzigakis PK, et al. Evaluation of an intraoperative algorithm based on near-infrared refracted spectroscopy monitoring, in the intraoperative decision for shunt placement, in patients undergoing carotid endarterectomy. Middle East J Anesthesiol 2011;21(3):367-73.
14. Tambakis CL, Papadopoulos G, Sergentanis TN, Lagos N, Arnaoutoglou E, Labropoulos N, et al. Cerebral oximetry and stump pressure as indicators for shunting during carotid endarterectomy: comparative evaluation. Vascular 2011;19(4):187-94.
15. Albäck A, Roth WD, Ihlberg L, Biancari F, Lepäntalo M. Preoperative angiographic score and intraoperative flow as predictors of the mid-term patency of infrapopliteal bypass grafts. Eur J Vasc Endovasc Surg 2000;20(5): 447-53.
16. Gordon IL, Stemmer EA, Wilson SE. Redistribution of blood flow after carotid endarterectomy. J Vasc Surg 1995;22(4):349-60.
17. Pennekamp CW, Immink RV, den Ruijter HM, Kappelle LJ, Bots ML, Buhre WF, et al. Near-infrared spectroscopy to indicate selective shunt use during carotid endarterectomy. Eur J Vasc Endovasc Surg 2013;46(4):397-403.
18. Mendonça CT, Fortunato JA Jr, Carvalho CA, Weingartner J, Filho OR, Rezende FF, et al. Carotid endarterectomy in awake patients: safety, tolerability and results. Rev Bras Cir Cardiovasc 2014;29(4):574-80.
19. Marques de Marino P, Martinez Lopez I, Hernandez Mateo MM, Cernuda Artero I, Cabrero Fernandez M, Reina Gutierrez MT, et al. Open versus endovascular treatment for patients with post-carotid endarterectomy restenosis: early and long-term results. Ann Vasc Surg 2016;36:159-65.
20. da Silva AF, McCollum P, Szymanska T, de Cossart L. Prospective study of carotid endarterectomy and contralateral carotid occlusion. Br J Surg 1996;83(10):1370-2.