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Noninvasive cerebral oximetry during carotid endarterectomy: application and results

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Background. Cerebral monitoring during carotid endarterectomy allows to detect brain hypoperfusion following carotid clamping and hyperperfusion after restoring the blood flow. Immediate corrections of these changes have the potential in reducing adverse neurologic outcomes. In this study we share our experience using cerebral oximetry in carotid endarterectomy surgery, as well as finding a connection between comorbidities and baseline cerebral oxygenation values.

Materials and methods. A non-randomised perspective study was performed at Vilnius University Hospital Santariškių Clinics. During 2012–2013 all consecutive elective patients undergoing carotid surgery were enrolled in the study.

Results. No difference was found in the baseline values on the operative and control sides (71.15% vs 76.76%, $p = 0.15$). After carotid clamping regional brain saturation decreased by 4.34% of the baseline on the operative side. During the clamping cerebral oxygenation was lower on the operative side (68.06% vs 77.32%, $p = 0.03$). Following carotid declamping the difference between operative and control side oxygenation diminished (73.57% vs 79.30%, $p = 0.16$). Neither diabetes nor peripheral atherosclerosis had influence on baseline cerebral oxygen saturation values. There was a tendency towards the lower cerebral oxygenation baseline for smokers (70.12% vs 76.54%, $p = 0.103$).

Conclusions. Cerebral oximetry is a valuable method of cerebral monitoring reflecting changes in brain perfusion during carotid endarterectomy. Certain comorbidities might have a role in affecting baseline oximetry values.

Key words: baseline, cerebral oximetry, comorbidities, endarterectomy

INTRODUCTION

Cerebral infarction is one of the most dangerous acute cardiovascular diseases often leading to long-term disability and even death. One in five patients suffer from ischemic stroke caused by internal carotid artery stenosis (1). The available level I evidence recommends surgery as currently the best option for symptomatic patients (2).

During the surgery temporary clamping of the internal and/or external carotid artery is performed to safely remove atheromatous plaque. Carotid clamping can lead to cerebral ischemia and hypoxia. In order to avoid that, an intraluminal shunt can be used – a temporal bypass to ensure perfusion above the obstruction site. However, shunting itself can predispose embolisation and cause perioperative

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cerebral infarction (1). To avoid shunt-related stroke, monitoring of the cerebral function and a selective use of an intraluminal shunt has been suggested (3). Cerebral monitoring may reduce the perioperative stroke rate as it allows detection of the main causes of perioperative stroke: embolism, intraoperative hypoperfusion and postoperative hyperperfusion syndrome (4).

The cerebral status can be assessed using various invasive and non-invasive methods: electroencephalogram (EEG), somatosensory evoked potentials (SSEP), transcranial doppler (TCD), cerebral oxygenation (CO) method. Nevertheless, there is no common agreement on what monitoring methods to prefer in carotid endarterectomy (5).

Since every method has its advantages and disadvantages, the choice of a monitoring type remains in question. In the recent meta-analysis the best results for detecting brain ischemia during carotid artery cross-clamping were found with a combination of stump pressure and either TCD or EEG (6). However, these methods are relatively difficult to apply into clinical practice and require special skills. Furthermore, some studies show that cerebrooximetry is more precise than transcranial doppler when deciding for the necessity of an intraoperative shunt (7).

Cerebral oxygenation monitoring is a non-invasive, quick, cheap and available method. Its use becomes popular in surgical setting. There are two main types of cerebral oximetry: absolute and trend monitoring. Absolute monitoring focuses on the meaning of the cerebral oxygenation value while the latter measures the change from a set baseline oxygenation value (8). Normal values for healthy individuals are described at 58–82% (5). Decrease of oxygenation by 20% of the initial value (or 15% if the initial value is less than 50%) implies disturbances in delivering oxygen to the brain tissue (9).

Measuring regional cerebral saturation has been used by many cardiothoracic and vascular anesthesiologists to provide continuous data on brain perfusion and oxygenation dynamics intraoperatively (10). Interventions based on this data have a potential of reducing neurologic complications, as well as hospital costs (11). Despite this, cerebral oximetry has several disadvantages. First of all, oxygenation is measured only in regions underlying oximetry probes, so a large amount of the brain tissue remains unmonitored (8). Moreover, oxygenation values do not provide direct information on the amount of oxygen reaching the brain cells nor brain oxygen metabolism itself (12).

Even though cerebral oximetry alone cannot reveal the cause of cerebral ischemia, it serves as an alert for practitioners. Detecting ischemia at a given moment provides an opportunity for early interventions and assessment of potential causes (13).

METHODS

This perspective non-randomized study was performed at Vilnius University Hospital Santariškių Clinics during the years 2012–2013. All consecutive patients undergoing carotid endarterectomy surgery were enrolled in this study. The patient status was evaluated by an anesthesiologist before surgery and a questionnaire conserning patients diseases (diabetes, myocardial infarction, atherosclerosis, obesity, smoking) was filled in. Severity of carotid stenosis was evaluated preoperatively by ultrasound.

The operative side was chosen individually based on the degree of stenosis. 100% stenosis was an exclusion criterion because in that case surgery is not recommended based on the increased risk of perioperative cerebral infarction (1). All patients underwent general endotracheal anesthesia. Surgery was performed using the conventional technique.

Cerebral oximetry monitoring, performed using the INVOS^{TM} system (Somanetics, Troy, Michigan), was started before induction of anesthesia. During the surgery the basic vital parameters were recorded. In addition to that, cerebral oximetry values and trends were recorded every 5 minutes on both hemispheres and the time of carotid clamping and unclamping was noted.

We compared the initial saturation between operative and control hemispheres, also analysed deviations from the baseline values after carotid clamping and unclamping. Accompanying diseases and lifestyle features were analysed as potentially having influence on baseline oximetry values. Patient's neurological status was assessed by a neurologist before discharging from the hospital.

A statistical analysis was performed using SPSS 19. Quantitative data were compared using the t-test. Correlation between variables was evaluated by the Spearman's correlation coefficient. The statistical significance level was set to $p < 0.05$.

RESULTS

Patient characteristics

10 consecutive patients (4 female and 6 male) undergoing carotid surgery were enrolled in the study during the period of 2012–2013. All patients had the surgery done under elective circumstances. The average age was 65.3 years (SD ± 8.5). 5 patients had surgery done on the right internal carotid artery and 5 patients on the left. The degree of carotid stenosis evaluated by preoperative ultrasound was 84.9% (SD ± 9.5) on the operative side. Stenosis on the control (non-operative) side was 46.5% (SD ± 15.6). The carotid clamping time was 19.3 minutes (SD ± 5.5), while the surgery took 83.0 (SD ± 21.8) minutes. Data on individual patients is presented in Table 1.

Table 1. Patient characteristics

No.	Sex	Age	Stenosis on the operative side, %		Stenosis on the control side, %		Time of carotid ischemia, min
1.	f	73	90	(R)	50	(L)	15
2.	m	65	99	(R)	50	(L)	20
3.	m	62	90	(R)	50	(L)	17
4.	m	79	70	(L)	30	(R)	15
5.	f	62	90	(R)	25	(L)	12
6.	m	70	80	(L)	50	(R)	19
7.	f	50	80	(R)	50	(L)	27
8.	m	72	70	(L)	50	(R)	30
9.	m	57	90	(L)	80	(R)	20
10.	f	63	90	(L)	30	(R)	18

Abbreviations: f – female, m – male, R – right side, L – left side.

The greatest decrease observed after carotid clamping was 16.6% of the baseline. Based on the clinical and cerebral oximetry data none of the patients required using of an intraoperative shunt. The patients spent 8.2 (SD ± 2.9) days in hospital after the surgery, then were discharged. During a neurological exam at the discharge none of the patients were documented to have neurological adverse events. There were no deaths also.

Changes in cerebral oxygenation during carotid endarterectomy

When comparing the data on cerebral oxygenation on operative and control sides before carotid clamping, it was found that oxygenation was lower on the operative side – 71.15% vs 76.76%, however, the difference was not significant ($p = 0.15$).

After carotid clamping, oxygen saturation on the operative side decreased by 4.34% from the baseline while on the control side oxygenation remained approximately at the initial value – increased by 0.73% from the baseline. During the period of ischaemia cerebral oximetry values were significantly lower on the operative side (68.06% vs 77.32%, $p = 0.03$), however, no difference was found comparing oxygenation before and after clamping neither on the operative ($p = 0.18$) nor control ($p = 0.96$) side.

Following carotid declamping, the oxygenation difference between the operative and control side diminished (73.57% vs 79.30%, $p = 0.16$). Cerebral oximetry values on both hemispheres returned to the baseline and even suggested a tendency towards above the baseline values: 71.15% to 73.57% and 76.76% to 79.30% on operative ($p = 0.52$) and control ($p = 0.53$) hemispheres, respectively. This increase in oxygen saturation was not significant though.

Impact of lifestyle and comorbidities on cerebral oximetry baseline values

No difference was found on baseline values of smokers and non-smokers (70.12% vs 76.54%, $p = 0.103$), as well as patients having diabetes or peripheral atherosclerosis (see Table 2). History of previous cerebral infarction showed a tendency towards higher cerebral oxygenation baseline (70.12% vs 69.97%), however, the difference was statistically insignificant ($p = 0.178$). Only a weak correlation was found between the age and baseline oxygenation values ($r = 0.323$). The chosen variables had no influence on initial oximetry values neither on the operative nor control hemisphere.

Table 2. Influence of comorbidities on initial oximetry values

Comorbidities	Baseline values YES and NO		p value
Smoking	70.12 ± 7.20	76.54 ± 8.73	0.103
Previous stroke	75.66 ± 8.34	69.97 ± 8.31	0.178
Peripheral atherosclerosis	71.57 ± 6.50	74.55 ± 9.06	0.548
Diabetes	75.8 ± 3.25	73.75 ± 8.87	0.757

DISCUSSION

Surgical treatment of carotid stenosis >70% in order to prevent cerebral infarction is proved to be an effective choice of treatment. However, it still carries a 5–7.5% risk of perioperative cerebral infarction (14). The main reason for cerebrovascular events is hypoperfusion during carotid clamping. In order to ensure favourable postoperative outcomes it is necessary to have a quick and reliable method to detect collateral blood flow insufficiency.

Neurologic examination in the awake patient is considered the most sensitive monitor of cerebral perfusion and function (15), however, most carotid endarterectomies are performed under general anesthesia. Alternative monitoring methods, such as electroencephalography, transcranial Doppler, carotid stump pressure and somatosensory-evoked potentials, are known and used for years. Near-infrared spectroscopy is a relatively new technique; it is non-invasive, suitable and easy to apply (4). Yet it has been criticized for the wide range of values in normal conditions and for the lack of a clear cut-off value. Furthermore, many confounding factors may influence regional brain saturation, such as modification of systemic oxygen saturation and blood pressure or bronchodilation (16).

Cerebral oximetry serves as the first indicator of an intraoperative event (i. e. a technical problem or a physiologic change) that could potentially lead to an adverse outcome (10). A cut off ≥19% drop in regional oxygen saturation has a high sensitivity and specificity when compared with awake testing (17). Another study identified a cut-off of 21 and 10.1% reduction from the baseline as optimal when deciding whether patients needed or not a shunt regarding the first and fifth minute after cross-clamping, respectively (18).

We found a 4.34% baseline decrease following carotid clamping, similar to Cuadra and colleagues who investigated 40 patients and detected a 12.3% (6.2% from baseline) decrease in oxygenation after carotid clamping on the operative side, while the control side values remained approximately at the initial level (19). Likewise in our study, regional oxygen saturation on the control hemisphere did not deviate from the baseline after carotid clamping.

A decrease in regional saturation on the control side is possible due to redistribution of blood flow from the control to operative side (1). This effect was not found in our study though.

Following restoration of cerebral blood flow, an increase in cerebral oxygen saturation values was detected by Shang and colleagues. They identified a 43.2% (SD ± 16.9%) increase compared to baseline values at the start of the surgery (1). A similar tendency was found in our study, however, the increase was insignificant.

Not only intraoperative hemodynamic shifts influence cerebral oxygenation values. Some studies reveal factors having impact on baseline oxygen saturation in the brain. Age, preoperative haematocrit and SpO_2 explain a significant portion of cerebral oxygen saturation variability in patients with hip fractures (20). In the study of Baikoussis and colleagues, diabetes and hypercholesterolaemia were also associated with lower initial brain oxygenation values (9).

However, we did not found differences in baseline cerebral oxygenation values when investigating smoking, peripheral atherosclerosis and diabetes, although there was a trend towards lower baseline values for smokers (76.54% vs 70.12%). Correlation between age and regional cerebral oxygenation was also poor.

One of the greatest limitations of cerebral oximetry monitoring is failure to confidently define which clinical outcomes have relevance to regional oxygenation measurements (21). The brain has been called an index organ for other tissue saturation (22). However, it has distinctive protective mechanisms; this suggests it is likely that other organs and tissues have long desaturated before a decrease in brain oxygen saturation occurs (23).

During the hospitalization none of our patients had an adverse neurologic complications, transient ischaemic attack or stroke included. No deaths also occurred. Therefore, it is not possible to correlate intraoperative cerebral oxygenation values to postoperative adverse outcomes.

Despite a prospective design of this study, interpretation of results in this study is limited by a small sample size since carotid endarterectomy is performed relatively rarely in our hospital. Therefore future studies are needed.

CONCLUSIONS

Cerebral monitoring during carotid endarterectomy is necessary to provide direct information concerning changes in the neurological status, which might otherwise be missed. Moreover, intraoperative monitoring allows immediate correction of unfavourable changes. Most cerebral monitoring methods are of limited application or cannot evaluate cerebral blood flow in real-time. Cerebral oxygenation monitoring is a useful, precise and simple method to detect cerebral saturation changes in real-time, although oximetry baseline values can be affected by age or comorbidities.

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NEINVAZINĖ SMEGENŲ OKSIMETRIJA MIEGO ARTERIJOS ENDARTEREKTOMIJOS METU: PRITAIKYMAS IR REZULTATAI

Santrauka

Įžanga. Smegenų funkcijos monitoravimas miego arterijų endarterektomijų metu leidžia aptikti smegenų hipoperfuziją, perspaudus miego arteriją, bei hiperperfuziją, atkūrus kraujotaką. Nedelsiant koreguojant šiuos pokyčius galima sumažinti neurologinių komplikacijų dažnį. Šiame tyrime atskleidžiame savo patirtį naudojant smegenų oksimetriją miego arterijų endarterektomijų metu ir ryšį tarp bazinių smegenų oksimetrijos įverčių bei gretutinių ligų.

Metodika. Tyrimas atliktas Vilniaus universiteto Santariškių klinikose. Į tyrimą įtraukti visi ligoniai, kuriems 2012–2013 m. buvo atliekamos miego arterijos endarterektomijos.

Rezultatai. Tiek operuojamo, tiek kontrolinio pusrutulio bazinės oksimetrijos reikšmės nesiskyrė (71,15 vs. 76,76 %, p = 0,15). Perspaudus miego arteriją, operuojamoje pusėje regioninė smegenų saturacija sumažėjo 4,34 %. Miego arterijos perspaudimo laikotarpiu operuojamos pusės oksigenacija buvo patikimai mažesnė nei neoperuojamos pusės (68,06 vs. 77,32 %, p = 0,03). Atkūrus operuojamos pusės kraujotaką, skirtumas tarp pusrutulių oksigenacijos išnyko (73,57 vs. 79,30 %, p = 0,16). Nei cukrinis diabetas, nei periferinių kraujagyslių aterosklerozė neturėjo įtakos bazinėms smegenų oksimetrijos reikšmėms, tačiau pastebėta tendencija, kad rūkančiųjų pradiniai oksimetrijos įverčiai mažesni nei nerūkančiųjų (73,57 vs. 79,30 %, p = 0,16).

Išvados. Smegenų oksimetrija yra naudingas smegenų monitoringo metodas, atspindintis smegenų perfuziją miego arterijų endarterektomijos metu. Tam tikros gretutinės ligos ir būklės gali turėti įtakos pradinėms oksimetrijos reikšmėms.

Raktažodžiai: endarterektomija, lydinčios ligos, pradinės reikšmės, oksimetrija