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Cerebral oximetry in patients undergoing carotid endarterectomy : preliminary results

Ph. VETS (*), P. TEN BROECKE (*), H. ADRIAENSEN (*), P. VAN SCHIL (**) and S. DE HERT (*)

Summary : Carotid endarterectomy (CEA) is an appropriate treatment for carotid occlusive disease. The risk of stroke during CEA ranges from 1.1% to 7.5%. Shunting is usually advised when severe ischemia during cross-clamping of the internal carotid artery is suspected. Routine use of an intraluminal shunt may increase the perioperative stroke rate.
Popular and well documented methods of neurologic monitoring for ischemia during general anesthesia are electroencephalography (EEG) and transcranial Doppler ultrasonography (TCD) of the middle cerebral artery. The purpose of this prospective study was to compare cerebral oximetry using near infrared spectrophotometry (NIRS) with EEG and TCD. Preliminary data on 14 patients scheduled for elective carotid endarterectomy were included and a literature search was performed to correlate the findings. No postoperative neurologic events occurred. During carotid clamping there was a significant decrease in regional oxygen saturation (rSO2) but there was only a weak correlation with the decrease in mean Doppler flow (R = 0.74 ; P = 0.02) and no correlation with EEG changes (R = 0.49 ; P = 0.18). A useful rSO2 cut-off value predictive for cerebral ischemia could not be defined.

Key words : Carotid endarterectomy ; Cerebral oximetry ; Near infrared spectrophotometry.

INTRODUCTION

Carotid endarterectomy (CEA) is widely accepted as an appropriate treatment for carotid occlusive disease in patients with high grade (> 70%) stenosis or neurologic symptoms (6, 22, 28, 32). The reported risk of stroke during CEA ranges from 1.1% to 7.5% (15, 18, 23). The major causes of stroke during carotid endarterectomy are hypoperfusion during cross-clamping of the internal carotid artery (ICA) and distal embolisation of a portion of the atherosclerotic plaque or thrombus by surgical manipulation (5, 21, 23).

The use of an intraluminal shunt may prevent hypoperfusion during cross-clamping but bears the risk of air and plaque embolism, carotid artery dissection and shunt dysfunction. In addition it may increase the risk of local complications such as nerve injury, hematoma, infection and long-term restenosis (6, 7, 18, 21). Therefore shunting is only advised for severe persisting ischemia during cross-clamping of the ICA (18).

Popular and well documented methods of neurologic monitoring for ischemia during CEA under general anesthesia are electroencephalography (EEG), somatosensory evoked potentials (SEPP), transcranial Doppler ultrasonography (TCD) of the middle cerebral artery (MCA) and determination of the ICA stump pressure (23). However, these techniques lack sensitivity and specificity and may be difficult to interpret (10). More recently, cerebral oximetry using near infrared spectrophotometry (NIRS) has become commercially available and can be used as a non-invasive technique to monitor cerebral oxygenation. Cerebral oximetry using NIRS has proven its value during cardiac surgery, but the correct use and surplus value during CEA is still debated in literature (2, 4, 12, 27).

The purpose of this study was to evaluate the performance and the potential additional value of cerebral oximetry in vascular surgery patients undergoing CEA and to relate our findings with literature.

METHODS

Anesthesia and surgery

After approval of the ethical committee and informed written consent, a prospective study was

Ph. VETS ; P. TEN BROECKE ; H. ADRIAENSEN ; P. VAN SCHIL ; S. DE HERT.
(*) Department of Anesthesiology, University Hospital Antwerp, Wilrijkstraat 10, 2650 Edegem, Belgium.
(**) Department of Thoracic and Vascular Surgery, University Hospital Antwerp, Wilrijkstraat 10, 2650 Edegem, Belgium.
Corresponding address : S. De Hert, Department of Anesthesiology, University Hospital Antwerp, Wilrijkstraat 10, B-2650 Edegem. E-mail : Stefan.dehert@ua.ac.be.

performed in patients scheduled for elective CEA. Patients were premedicated with lorazepam 2.5 mg sublingual 30 to 60 min before arriving in the operation room. All patients had a radial artery cannula placed for continuous arterial pressure monitoring during the operation and in the early postoperative period. Pulse oximetry and 5-leads ECG were continuously monitored. After induction with remifentanil, thiopental and cisatracurium, anesthesia was maintained with a continuous infusion of remifentanil (0.15-0.4 µg.kg^{-1}.min^{-1}) and with desflurane in an oxygen-air mixture.

Considering the importance of sufficient cerebral blood flow during the carotid clamp period, the blood flow was guided by the TCD and corrected with boluses of fluid, ephedrine and/or phenylephrine. If needed, a continuous infusion of norepinephrine (0.1-0.3 µg.kg^{-1}.min^{-1}) was started.

Carotid surgery was performed by a standard technique. The decision to insert a shunt was made by the surgeon on the basis of Doppler flow (mean velocity < 30% of preclamp value) and EEG readings (> 20% left-right asymmetry). Postoperatively, patients were admitted to the post anesthesia care unit where vital and neurologic parameters were followed.

Neurologic monitoring

The basic principle of measurement of cerebral oxygen saturation is the differential photon absorbency of oxyhemoglobin and deoxyhemoglobin for near-infrared light (700-1300 nm). Cerebral oximetry using NIRS is applied in reflectance mode because pterional transmission is not possible in the adult head (3). A popular commercial available device like the INVOS 3100 or 4100 (Somanetics Corp., Troy, Wisconsin, USA) consists of a near-infrared light source and two photo detectors housed within an adhesive plastic holder for easy attachment to the skin. The photo detectors are situated at respectively 30 and 40mm distance of the light source. Emitted near-infrared light will be reflected in a parabolic pattern and will be received by the two detectors (32). The received light will be attenuated by scalp, skull and a small (30mm detector) or a larger (40mm detector) portion of the brain (Fig. 1). The oximeter subtracts the reflected signal of the superficial structures from that of the deeper tissues, thereby calculating the oxygen saturation of the blood in the brain (23). The reported regional oxygen saturation (rSO2) is biased toward venous oxygen saturation because on average, cerebral blood flow is composed of 75% venous and 25% arterial blood (23). Normal baseline rSO2 values in healthy volunteers are reported to be wide scattered (24). Routinely, two sensor pads are used, one for each hemisphere. By this way, rSO2 alterations due to non-ischemic origin are more likely differentiated from ischemic events during the carotid clamp period. In our study, an INVOS 4100 (Somanetics, Troy, Wisconsin, USA) was used for cerebral oximetry.

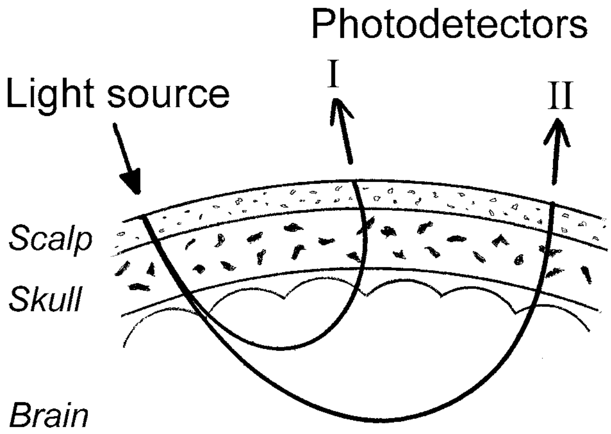

Fig. 1. — The oximeter sensor consists of a near-infrared light source and two photo detectors. The detectors are situated at 30 and 40 mm distance of the light source. Emitted near-infrared light will be reflected in a parabolic pattern. The received light will be attenuated by scalp, skull and superficial (30 mm detector) or deeper (40 mm detector) portion of the brain. The oximeter subtracts the reflected signal of the superficial structures from that of the deeper tissues, thereby calculating the oxygen saturation of the blood in the brain.

TCD and four channel EEG were used in our study as the gold standard for detecting of cerebral ischemia during carotid clamp. The transcranial Doppler probe was positioned on the ipsilateral side in order to find a flow signal of the MCA. Severe cerebral perfusion was defined as mean velocity less than 20% of preclamp value in accordance with previous reports (9, 17, 18, 19).

After induction a four channel EEG monitor was installed with needle electrodes temporo-occipital just dorsal to the ear lobe and fronto-parietal just dorsal to the eyebrow. A reference plaster electrode was placed median just above the eyebrows. In order to interpret the EEG signals, a power spectral analysis was performed. The EEG response to carotid clamp was categorized in no or minimal (< 20%) versus significant left-right asymmetry.

Baseline readings for pulse saturation, heart rate, invasive blood pressure, rSO2 and mean Doppler flow were recorded after a brief stabilization time but before induction of anesthesia. Left

Table 1

Summary of cases. A carotid shunt was inserted in patients 4, 10, 11

Patient	rSO2 (%) preclamp	△ rSO2 (%) clamp + 1 min	△ rSO2 (%) clamp + 3 min	+ TCD (%) clamp + 1 min	△ TCD (%) clamp + 3 min
1	65	- 2	0	No signal	No signal
2	52	3	- 3	No signal	No signal
3	69	3	4	- 24	- 24
4	61	No data	15	No data	- 70
5	69	- 1	0	No signal	No signal
6	48	- 8	- 3	- 42	- 64
7	59	4	1	44	42
8	62	- 9	- 10	- 42	- 48
9	81	- 11	- 17	- 21	- 16
10	65	- 17	- 15	- 100	- 100
11	51	- 5	- 5	No signal	No signal
12	62	- 9	- 8	- 60	No signal
13	77	- 4	- 4	- 57	- 36
14	70	- 12	- 12	- 34	- 40

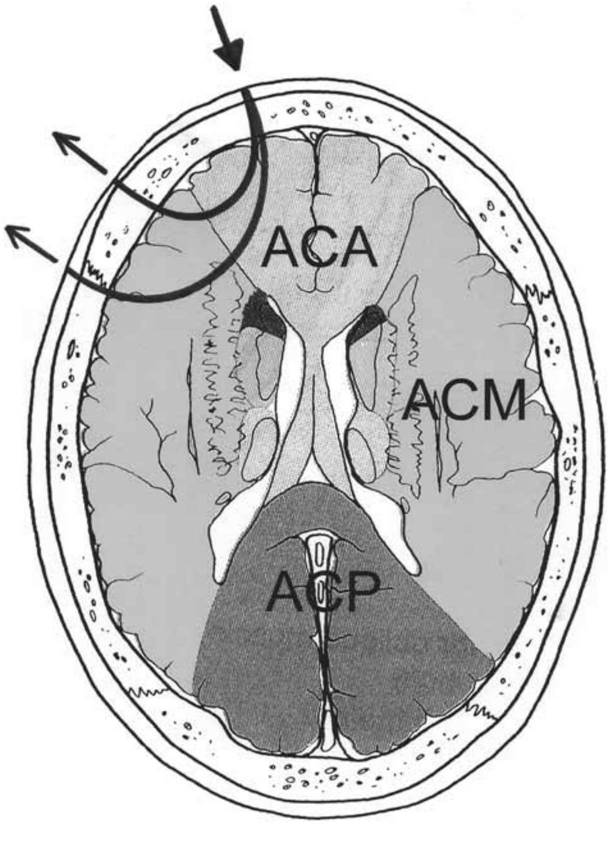

Fig. 2. — The sensor pads are placed bilaterally on the patient's forehead just under the hairline and approximately 2 cm laterally from the midline. By this manner, an attenuated signal will be received from tissue perfused by the anterior (ACA) and by the middle cerebral artery (ACM).

and right rSO2, mean Doppler flow and EEG response were recorded just before clamping the carotid artery, 1 minute after clamping and subsequently each 2 minutes until removal of the clamp and finally 5 minutes after unclamping the common carotid artery.

Analysis of data

Statistical analysis was performed using SigmaStat software (SPSS, Leuven, Belgium). Because of the wide interindividual variation in variables between patients, analysis of absolute values of rSO2 is hazardous (16, 29). Therefore percentage change in rSO2 was calculated using the formula : Change in rSO2 = (rSO2 preclamp - rSO2 cross-clamp) (5, 18, 33). As there was considerable variation in mean arterial blood velocity of the MCA between patients, the changes in mean TCD during carotid clamping were expressed as a percentage of the baseline mean blood velocity (Vm). A linear regression analysis was performed for comparing relative changes in Vm and rSO2. Values of $P < 0.05$ were considered significant.

Results

A stable rSO2 signal could be obtained in all patients. There were no perioperative cases of loss of cerebral oximetry signal due to surgical or electro-mechanical interference. A shunt was placed in 3 out of 14 (21%) patients but only one of these patients had a decrease in Vm of the MCA of > 80% (Table 1). In the other 2 patients, the surgeon decided to use a shunt because there was a 70% decrease in Vm.

During clamping of the common carotid artery no EEG asymmetry (> 20%) was seen in any patient. In 2 patients the signal of one channel of the EEG was lost during the operation due to surgical manipulation. In 4 out of 14 patients (29%)

no MCA Doppler flow signals could be detected. No Doppler signals were permanent lost during the operation and none even temporarily during the clamp period. Nevertheless, disturbance associated with surgical manipulation leading to alterations of the signal did occur in 4 patients.

Cross-clamping of the common carotid artery resulted in a decrease in Vm of the MCA (-39% ± 40%) and of rSO2 (-6% ± 7%). The relative alteration of Vm and rSO2 was correlated after 1min. carotid clamping (R = 0.74 ; P = 0.02) but not anymore after 3 min. clamping (R = 0.49 ; P = 0.18).

No complications were observed in the post anesthesia care unit other than some mild nausea and hypertension. No patient showed any sings of new neurologic deficit and no patient needed a re-exploration of the carotid artery after initial surgery.

Discussion

There are several well documented methods of central neurologic monitoring during general anesthesia. In many institutions, EEG is considered to be the gold standard for determining cerebral ischemia during carotid endarterectomy (23). EEG is reported to have a sensitivity of 83-92% and a specificity of 80-92% for detection of ischemia during clamping of the ICA and can therefore be used to determine the need for a temporary shunt (11, 23, 30). However, EEG is inadequate for the assessment of marginally perfused cerebral regions, can not detect small areas of hypoperfusion (e.g. micro emboli) and is influenced by most intravenous and volatile anesthetics (21, 23). In addition the installation of EEG is time consuming, highly sensible for electromechanical interference and rather difficult to interpret (13, 21, 23). The sensibility for electromechanical interference was also noted in our study as illustrated by the loss of one of four EEG channels in two patients during the carotid clamp period.

Transcranial Doppler provides reliable information on blood velocity in the MCA and is a good indicator for the necessity of shunting (8, 25, 26, 31). Because it gives true continuous velocity information, it can also be used to detect shunt dysfunction and emboli during the surgical procedure. On the other hand, the MCA can not be insonated in 10-20% of patients (28% in our study), is time consuming to install and is very sensitive to the slightest surgical disturbance (1, 18, 21, 32). In several patients in our population, finding a decent Doppler flow pattern of the MCA could take more than 30 minutes. Although the surgeons were very aware of the susceptibility of the Doppler probe, disturbance of the probe did occur in 4 out of 10 patients where the MCA could be insonated.

More recently, NIRS has been introduced as a promising technique to monitor cerebral oxygenation. It has particularly proven its merits during cardiac surgery (2, 4, 12, 27). Cerebral oximetry using NIRS during CEA was also the subject of several studies. Compared to EEG, Hirofumi *et al.* reported a correlation between the main frequency of the ipsilateral EEG signal and rSO2 (20). De Letter *et al.* calculated a receiver operating characteristic curve of the percentual decrease of rSO2 versus EEG asymmetry and found the 95% confidence interval of the area under the curve was 0.66-0.93 (14). The current results indicated no correlation between EEG and rSO2. However this is probably related to the absence of EEG asymmetry in our relative small study population. More data are available on the correlation between transcranial Doppler flow of the MCA and rSO2 using NIRS. Several studies reported a strong correlation between the decrease in rSO2 and the relative change in peak flow readings (23, 32). However, Grubhofer *et al.* found a weaker correlation (R = 0.63 ; P = 0.003) between the relative (%) change of Vm and rSO2 during cross-clamping (18). A weaker correlation was also observed in our study and by other authors (16, 33). A possible explanation suggested by Duncan *et al.* is that NIRS measures the saturation mainly over the cerebral cortex primarily perfused by the anterior cerebral artery (16). It should be noted that transcranial Doppler flow measurement of the MCA is not always a reliable indicator of cerebral perfusion because extensive cerebral collateralization can maintain adequate perfusion despite significant decreases in MCA flow (23).

To be of any use for carotid endarterectomy, a neurologic monitor system has to detect severe cerebral ischemia accurately. Not only is a high sensitivity required for ischemia, but also a high specificity in order to avoid too high numbers of unnecessary interventions such as shunting. The sensitivity and specificity for cerebral oximetry using NIRS for detecting cerebral ischemia depends on the used rSO2 cut-off value (5, 18). As compared to SSEP, data in literature are widely scattered regarding the performance of cerebral oximetry using NIRS (5, 11). Only one study has calculated the positive and negative predictive value of cerebral oximetry using NIRS as compared to TCD of the MCA (18). In this study, assuming a reduction to less than 20% of the initial mean flow velocity of the MCA during carotid clamp indicative for cerebral ischemia, a relative decrease of 13% rSO2 had a sensitivity of 100% and a specificity of 87%. This resulted in a negative predictive value of 100% but a positive predictive value of only 22%. However, studies comparing cerebral oximetry using NIRS with an indirect gold standard as EEG, TCD and SSEP may in reality underestimate the performance of NIRS. For example in awake patients undergoing carotid endarterectomy with cervical plexus bloc, a study of SAMRA *et al.* suggested that a 20% decrease in rSO2 readings from the preclamp baseline had a somewhat better positive predictive value of 33% and a negative predictive value of 97% for neurologic compromise during carotid clamping (29). Using the same cut-off value of -13% rSO2 as GRUBHOFER *et al.* in our population, we calculated a sensitivity of 100% and a specificity of 78%. The resulting low positive predictive value of 33% may be rather low compared to TCD, EEG or SSEP.

Cerebral oximetry using NIRS may be valid for assessing the functionality of a shunt inserted for ischemia. This was also noted in the three patients requiring a shunt in our study. The increase in cerebral oxygenation after insertion of a shunt was indicative for proper shunt function. SAMRA *et al.* suggested also a role for cerebral oximetry using NIRS in the immediate postoperative phase. A postoperative decrease in rSO2 after carotid endarterectomy might demonstrate carotid reocclusion before the sensorium is altered, thereby reducing the time needed to make a decision to reexplore the vessels (28). This was not the subject of our investigation.

CONCLUSION

Cerebral oximetry using NIRS can be used as a non-invasive technique to monitor cerebral oxygenation during cardiac surgical procedures. It is a non-invasive continuous monitor, insensitive to electrical or surgical interference, simple and little time-consuming to use and easy to interpret. Furthermore cerebral oximetry using NIRS has a valuable use for assessing the functionality of a shunt inserted for ischemia and may be of use in the immediate postoperative phase.

However, at this time no reliable cut-off value of rSO2 or rSO2 change during carotid clamp indicative for cerebral ischemia can be proposed. The reported cut-off values in literature may seem to have acceptable sensitivity and specificity to detect the need for shunting but, due to the relative low incidence of perioperative stroke, the positive predictive value remains rather low, while the negative predictive value is very good. It seems therefore that the use of cerebral oximetry using NIRS as a single monitor device during CEA can not be formally recommended to date.

References

1. Ackerstaff R. G., van de Vlasakker C. J., *Monitoring of brain function during carotid endarterectomy : an analysis of contemporary methods*, J. CARDIOTHORAC. VASC. ANESTH., **12**, 341-7, 1998.
2. Alexander J. C., Kronenfeld M. A., Dance G. R., *Reduced postoperative length of stay may result from using cerebral oximetry monitoring to guide treatment*, ANN. THORAC. SURG., **73**, 373S, 2002.
3. Al-Rawi P. G., Smielewski P., Kirkpatrick P. J., *Evaluation of a near-infrared spectrometer (NIRO 300) for the detection of intracranial oxygenation changes in the adult head*, STROKE, **32**, 2492-2500, 2001.
4. Austin E. H. 3rd., Edmonds H. L. Jr., Auden S. M., Seremet V., Niznik G., Sehic A., Sowell M. K., Cheppo C. D., Corlett K. M., *Benefit of neurophysiologic monitoring for pediatric cardiac surgery*, J. THORAC. CARDIOVASC. SURG., **114**, 707-15, 717, 1997.
5. Beese U., Langer H., Lang W., Dinkel M., *Comparison of near-infrared spectroscopy and somatosensory evoked potentials for the detection of cerebral ischemia during carotid endarterectomy*, STROKE, **29**, 2032-7, 1998.
6. Biller J., Feinberg W. M., Castaldo J. E., Whittemore A. D., Harbaugh R. E., Dempsey R. J., Caplan L. R., Kresowik T. F., Matchar D. B., Toole J., Easton J. D., Adams H. P. Jr., Brass L. M., Hobson R. W. 2nd., Brott T. G., Sternau L., *Guidelines for carotid endarterectomy : a statement for healthcare professionals from a special writing group of the Stroke Council, American Heart Association*, STROKE, **29**, 554-62, 1998.
7. Bond R., Rerkasem K., Rothwell P. M., *Routine or selective carotid artery shunting for carotid endarterectomy (and different methods of monitoring in selective shunting)*, STROKE, **34**, 824-5, 2003.
8. Bornstein N. M., Rossi G. B., Treves T. A., Shifrin E. G., *Is transcranial Doppler effective in avoiding the hazards of carotid surgery*, CARDIOVASC. SURG., **4**, 335-7, 1996.
9. Cao P., Giordano G., Zannetti S., De Rango P., Maghini M., Parente B., Simoncini F., Moggi L., *Transcranial Doppler monitoring during carotid endarterectomy : is it appropriate for selecting patients in need of a shunt*, J. VASC. SURG., **26**, 973-9, 1997.
10. Carlin R. E., McGraw D. J., Calimlim J. R., Mascia M. F., *The use of near-infrared cerebral oximetry in awake carotid endarterectomy*, J. CLIN. ANESTH., **10**, 109-13, 1998.
11. Cho H., Nemoto E. M., Yonas H., Balzer J., Sclabassi R. J., *Cerebral monitoring by means of oximetry and somatosensory evoked potentials during carotid endarterectomy*, J. NEUROSURG., **89**, 533-8, 1998.
12. Daubeney P. E., Smith D. C., Pilkington S. N., Lamb R. K., Monro J. L., Tsang V. T., Livesey S. A, Webber S. A., *Cerebral oxygenation during paediatric cardiac surgery : identification of vulnerable periods using near infrared spectroscopy*, EUR. J. CARDIOTHORAC. SURG., **13**, 370-7, 1998.

13. de Letter J. A., Sie T. H., Moll F. L., Algra A., Eikelboom B. C., Ackerstaff G. A., *Transcranial cerebral oximetry during carotid endarterectomy : agreement between frontal and lateral probe measurements as compared with an electroencephalogram*, CARDIOVASC. SURG., **6**, 373-7, 1998.
14. de Letter J. A., Sie H. T., Thomas B. M., Moll F. L., Algra A., Eikelboom B. C, Ackerstaff R. G., *Near-infrared reflected spectroscopy and electroencephalography during carotid endarterectomy – in search of a new shunt criterion*, NEUROL. RES., **20**, Suppl., 1, S23-7, 1998.
15. Duffy C. M., Manninen P. H., Chan A., Kearns C. F., *Comparison of cerebral oximeter and evoked potential monitoring in carotid endarterectomy*, CAN. J. ANAESTH., **44**, 1077-81, 1997.
16. Duncan L. A., Ruckley C. V., Wildsmith J. A., *Cerebral oximetry : a useful monitor during carotid artery surgery*, ANAESTHESIA, **50**, 1041-5, 1995.
17. Fiori L., Parenti G., Marconi F., *Combined transcranial Doppler and electrophysiologic monitoring for carotid endarterectomy*, J. NEUROSURG. ANESTHESIOL., **9**, 11-6, 1997.
18. Grubhofer G., Plochl W., Skolka M., Czerny M., Ehrlich M., Lassnigg A., *Comparing Doppler ultrasonography and cerebral oximetry as indicators for shunting in carotid endarterectomy*, ANESTH. ANALG., **91**, 1339-44, 2000.
19. Halsey J. H. Jr., *Risks and benefits of shunting in carotid endarterectomy. The International Transcranial Doppler Collaborators*, STROKE, **23**, 1583-7, 1992.
20. Hirofumi O., Otone E., Hiroshi I., Satosi I., Shigeo I., Yasuhiro N., Masato S., *The effectiveness of regional cerebral oxygen saturation monitoring using near-infrared spectroscopy in carotid endarterectomy*, J. CLIN. NEUROSCI., **10**, 79-83, 2003.
21. Lang W., Dinkel M., *Zerebrale Ischämie während des Carotis-clampings. Diagnostik und Vermeidung*, ZENTRALBL. CHIR., **125**, 243-50, 2000.
22. Lee E. S., Melnyk D. L., Kuskowski M. A., Santilli S. M., *Correlation of cerebral oximetry measurement with carotid artery stump pressure during carotid endarterectomy*, J. VASC. SURG., **34**, 403-409, 2000.
23. McKinsey J. F., Davidovitch R., Gewertz B. L., *Intraoperative monitoring for cerebral ischemia during carotid endarterectomy*, PROBL. ANESTH., 11, 193-206, 1999.
24. Misra M., Stark J., Dujovny M., Widman R., Ausman J. I., *Transcranial cerebral oximetry in random normal subjects*, NEUROL. RES., **20**, 137-41, 1998.
25. Naylor A. R., Wildsmith J. A., McClure J., Jenkins A. M., Ruckley C.V., *Transcranial Doppler monitoring during carotid endarterectomy*, BR. J. SURG., **78**, 1264-8, 1991.
26. Padayachee T. S, Bishop C. C., Gosling R. G., Browse N. L., *Monitoring cerebral perfusion during carotid endarterectomy*, J. CARDIOVASC. SURG., **31**, 112-4, 1990.
27. Prabhune A., Sehic A., Spence P. A., Church T., Edmonds H. L. Jr., *Cerebral oximetry provides early warning of oxygen delivery failure during cardiopulmonary bypass*, J. CARDIOTHORAC. VASC. ANESTH., **16**, 204-6, 2002.
28. Samra S. K., Dorje P., Zelenock G. B., Stanley J. C., *Cerebral oximetry in patients undergoing carotid endarterectomy under regional anesthesia*, STROKE, **27**, 49-55, 1996.
29. Samra S. K., Dy E.A., Welch K., Dorje P., Zelenock G. B., Stanley J. C., *Evaluation of a cerebral oximeter as a monitor of cerebral ischemia during carotid endarterectomy*, ANESTHESIOLOGY, **93**, 964-70, 2000.
30. Schneider J. R., Droste J. S., Schindler N., Golan J. F., Bernstein L. P., Rosenberg R. S., *Carotid endarterectomy with routine electroencephalography and selective shunting : Influence of contralateral internal carotid artery occlusion and utility in prevention of perioperative strokes*, J. VASC. SURG., **35**, 1114-22, 2002.
31. Spencer M. P., Thomas G. I., Moehring M. A., *Relation between middle cerebral artery blood flow velocity and stump pressure during carotid endarterectomy*, STROKE, **23**, 1439-45, 1992.
32. Williams I. M., Mead G., Picton A. J., Farrell A., Mortimer A. J., McCollum C. N., *The Influence of contralateral carotid stenosis and occlusion on cerebral oxygen saturation during carotid artery surgery*, EUR. J. VASC. ENDOVASC. SURG., **10**, 198-206, 1995.
33. Williams I. M., Vohra R., Farrell A., Picton A. J., Mortimer A. J., McCollum C. N., *Cerebral oxygen saturation, transcranial Doppler ultrasonography and stump pressure in carotid* surgery, BR. J. SURG., **81**, 960-4, 1994.