

Near-Infrared Spectroscopy versus Transcranial Doppler-Based Monitoring in Carotid Endarterectomy

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Background: Proper monitoring of cerebral perfusion during carotid artery surgery is crucial for determining if a shunt is needed. We compared the safety and reliability of near-infrared spectroscopy (NIRS) with transcranial Doppler (TCD) for cerebral monitoring. **Methods:** This single-center, retrospective review was conducted on patients who underwent carotid endarterectomy (CEA) using selective shunt-based TCD or NIRS at Daegu Catholic University Medical Center from November 2009 to June 2016. Postoperative complications were the primary outcome, and the distribution of risk factors between the 2 groups was compared. **Results:** The medical records of 74 patients (45 TCD, 29 NIRS) were reviewed. The demographic characteristics were similar between the 2 groups. One TCD patient died within the 30-day postoperative period. Postoperative stroke (n=4, p=0.15) and neurologic complications (n=10, p=0.005) were only reported in the TCD group. Shunt usage was 44.4% and 10.3% in the TCD and NIRS groups, respectively (p=0.002). **Conclusion:** NIRS-based selective shunting during CEA seems to be safe and reliable for monitoring cerebral perfusion in terms of postoperative stroke and neurologic symptoms. It also reduces unnecessary shunt usage.

Key words: 1. Carotid endarterectomy
2. Near-infrared spectroscopy
3. Stroke

Introduction

Cerebral infarction caused by carotid artery disease can be prevented by revascularization procedures, among which carotid endarterectomy (CEA) is a well-established procedure. Although post-CEA stroke rates are as low as 0.7% to 1.5%, more than 1,000 patients suffer from post-CEA stroke or death in the United States annually, where CEA is used in as many as 100,000 cases each year [1]. CEA has an inherent weakness, as post-CEA cerebral infarction results from the carotid artery clamp inducing hypoperfusion or embolic infarction perioperatively. Postoperative infarction can be reduced by preventing

hypoperfusion during the application of the carotid artery clamp and by minimizing the embolic events caused by atherosclerotic debris. In this respect, proper monitoring during the application of the carotid artery clamp is crucial for determining the exact state of cerebral perfusion, which in turn indicates whether a shunt is needed. Notably, the shunt itself increases the risk of embolism, because it involves the manipulation of the carotid artery. As selective shunting during CEA is not a standardized method, but it is in common use, and several cerebral monitoring devices have therefore been introduced [2]. Electroencephalogram, somatosensory evoked potential, and transcranial Doppler (TCD) are the tradition-

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ally used monitoring methods, but they require varying degrees of expertise for proper use. Furthermore, the limited temporal view of TCD renders it unusable in about 15%–20% of patients with carotid artery diseases [3,4]. Recently, near-infrared spectroscopy (NIRS) has been utilized as a substitute for traditional methods of cerebral monitoring.

In the present study, we evaluated the effectiveness of NIRS compared with TCD in CEA. Our cardiovascular surgical team has performed TCD-based selective shunts during CEA since 2009 and has used a cerebral oximeter for cerebral monitoring since 2015. All carotid operations were performed by a single surgeon.

Methods

1) Study design

This single-center, retrospective review was conducted on patients who underwent CEA using selective shunt-based TCD or NIRS at Daegu Catholic University Medical Center from November 2009 to June 2016. The data was obtained retrospectively through a review of their medical records and the protocol was approved by the Institutional Review Board of Daegu Catholic University Medical Center (IRB No. CR-16-170-L), with individual informed consent waived. We excluded patients who underwent CEA with concomitant cardiac surgery or local anesthesia. Postoperative stroke was defined as cerebral infarction or a hemorrhagic lesion that occurred ipsilaterally within 30 days after surgery. Minor stroke was defined as a stroke with no symptoms that was radiologically confirmed. In the TCD group, selective shunts were inserted when middle cerebral artery blood flow decreased to less than 30% of the baseline value or in patients with a poor temporal view. In the NIRS group, shunts were inserted when regional cerebral oxygen saturation (rSO₂) decreased to less than 80% of the baseline value. All procedures were performed by an experienced cardiovascular surgeon. The details of the surgical procedure have been described in our previous study [5]. A Doppler box (DWL, Singen, Germany) was used in the TCD group, with surveillance by a neurologist and sonographer, whereas a cerebral oximeter (INVOS 5100CTM; Covidien, Minneapolis, MN, USA) was used in the NIRS group, with surveillance by only the sur-

geons or anesthesiologists rather than a neurologist. Antiplatelet agents were administered 12 hours after surgery, and postoperative brain magnetic resonance imaging was performed within 1 week of surgery. The patients with atrial fibrillation were managed according to the European Society of Cardiology guidelines.

The primary aim of the study was to compare the outcomes between the 2 groups in terms of 30-day mortality, 30-day stroke, and postoperative neurologic complications. Additionally, a risk analysis of postoperative neurologic complications was performed.

2) Statistical analysis

We divided the patients into 2 groups and compared them by the Mann-Whitney test or the Student t-test for continuous variables and by the Pearson chi-square test or Fisher exact test for categorical variables. The 2 groups were compared in terms of the prevalence of risk factors, including hypertension, diabetes mellitus, hyperlipidemia, severe stenotic lesion (more than 80% stenosis), appearance of symptoms, coronary artery disease, current smoking, previous smoking, current alcohol use, ulcerative lesions on the carotid artery, contralateral lesion, high-level lesion (stenosis above the second cervical spine), atrial fibrillation, operative time, shunt use, and operative side. All p-values <0.05 were considered to indicate statistical significance. The data were analyzed using IBM SPSS ver. 21.0 (IBM Corp., Armonk, NY, USA).

Results

Seventy-nine patients underwent CEA from November 2009 to June 2016. Five patients with concomitant cardiac surgery (3 patients) or local anesthesia (2 patients) were excluded from the TCD group, thereby resulting in a final number of 74 patients. Among them, 45 patients were in the TCD group and 29 patients were in the NIRS group. The demographic characteristics of the 2 patient groups are presented in Table 1, and no significant differences were found between the 2 groups. One TCD patient who suffered from pneumonia died within the 30-day postoperative period. Minor postoperative stroke was reported in 4 cases in the TCD group and 0 cases in the NIRS group. There were no statistically sig-

Table 1. Comparison of the baseline characteristics of the 2 groups

Characteristic	Transcranial Doppler group (n=45)	Near-infrared spectroscopy group (n=29)	p-value
Age (yr)	70.02±1.091	72.21±0.981	0.174
Height (cm)	161.42±1.265	160.03±1.446	0.412
Weight (kg)	61.53±1.431	59.24±1.555	0.400
Sex (male)	77.8	65.5	0.290
Severe stenosis (more than 80%)	86.7	82.8	0.742
Symptomatic	93.3	86.2	0.422
Hypertension	64.4	69.0	0.803
Diabetes	33.3	44.8	0.338
Hyperlipidemia	44.4	58.6	0.341
Coronary disease	44.4	48.3	0.814
Atrial fibrillation	6.7	3.4	0.651
Current smoker	15.6	13.8	1.000
Ex-smoker	20.0	27.6	0.573
Current alcohol user	17.8	13.8	0.754
Ulcerative lesion	22.2	6.9	0.110
Contralateral lesion (no severe stenosis)	40.0	24.1	0.210
High-level lesion (stenosis above the second cervical spine)	35.6	13.8	0.060
Operative time (min)	166.89±55.51	155.59±47.26	0.086

Values are presented as mean±standard deviation or %.

Table 2. Comparison of postoperative complications between the 2 groups

Variable	Overall (N=74)	Transcranial Doppler group (n=45)	Near-infrared spectroscopy group (n=29)	p-value
30-day mortality	1 (1.4)	1 (2.2)	0	1.000
30-day stroke (major and minor)	4 (5.4)	4 (8.9)	0	0.150
Hypoglossal nerve injury	1 (1.4)	1 (2.2)	0	1.000
Other neurologic symptoms	10 (13.5)	10 (22.2)	0	0.005
Myocardial infarction	0	0	0	-
Hyperperfusion syndrome	0	0	0	-

Values are presented as number (%).

nificant differences in postoperative stroke incidence and 30-day mortality between the 2 groups. Hypoglossal nerve injury was reported in 1 TCD patient. Other neurologic symptoms, including headache, exacerbation of preexisting symptoms, peripheral neuropathy, and dizziness not related to postoperative stroke or hypoglossal injury, were reported in 10 cases in the TCD group, while no such complications occurred in the NIRS group ($p=0.005$). The data regarding postoperative complications are presented in Table 2.

This study also compared postoperative complications by shunt use. Notably, a shunt was used in 44.4% of the patients in the TCD group, compared to 10.3% in the NIRS group ($p=0.002$). There were no

significant differences in 30-day mortality, postoperative stroke incidence, operative time, and other neurologic symptoms based on shunt use. However, shunt use did have an effect on the incidence of other neurologic symptoms ($p=0.079$). The results are presented in Table 3.

Hyperperfusion syndrome is one of the most serious complications after CEA; however, there were no reports of postoperative hyperperfusion syndrome in the current study population. Five patients in the NIRS group did show more than a 5% increase in cerebral oxygenation after declamping as measured by an oximeter, but they did not show any postoperative complications.

Table 3. Comparison of postoperative complications by shunt use

Variable	Shunt used (n=23)	No shunt used (n=51)	p-value
30-day mortality	1 (4.3)	0	0.681
30-day stroke (major and minor)	3 (5.9)	1 (4.3)	1.000
Other neurologic symptoms	6 (26.1)	4 (7.8)	0.079
Operative time (min)	166.7±63.0	160.6±47.4	0.647

Values are presented as number (%) or mean±standard deviation.

Discussion

Cerebral oximetry is based on the theory of the transmission and absorption of near-infrared light by brain tissue and measures the ratio of oxygenated hemoglobin to total hemoglobin. Interindividual variability of cerebral oxygenation results from different distributions of venous blood, which contributes 70%–75% of blood volume in the frontal lobe [6]. Cerebral oximetry results can be influenced by factors such as head position, mean arterial pressure, systemic arterial blood oxygen saturation, partial pressure of carbon dioxide in the arterial blood, hemoglobin concentration, cardiac output, cerebral tissue oxygen consumption, and intracranial pressure [7]; nevertheless, cerebral oximetry has been used as a substitute for other, traditional monitoring methods such as TCD. In addition to its ease of application and the fact that it allows a relatively short operative time, NIRS has been proven to result in improved postoperative results by many studies.

The cut-off value of NIRS varies among different clinical settings. Mille et al. [8] reported that a 12% decrease in rSO₂ had higher sensitivity, specificity, and predictive values than did a 20% decrease in rSO₂. However, a consensus has recently emerged that more than a 20% decrease in rSO₂ compared with the baseline value indicates a need for intervention to enhance neurocognitive functions [9,10]. Zogogiannis et al. [11] reported that a 20% decrease in rSO₂ from the baseline value could be considered as a cut-off value indicating cerebral ischemia.

Some research groups have asserted that as many as 85% of shunts are unnecessary in patients who receive them during CEA [12,13]. Although the actual figure might vary in different clinical settings, the unnecessary shunt use rate is expected to be high for selective shunts applied under TCD monitoring. In our present study, the TCD group had a higher shunt

use rate than the NIRS group (44.4% versus 10.3%). In line with our findings, Ali et al. [14] showed that the positive predictive value of TCD was lower than that of NIRS (37.5% versus 85.7%). A possible reason for the high incidence of shunt use in the TCD group was discussed in our previous study, in which a poor temporal view of TCD resulted in monitoring failure in 31.1% of the study patients [5]. Moreover, especially with shunts, manipulation of the carotid artery during CEA can provoke carotid artery dissection or embolism; approximately a 1%–3% increase in the risk of dissection or embolism has been reported [15]. It is therefore reasonable to assume that the higher rate of shunt use in the TCD group was related to the higher incidence of postoperative stroke.

Along with postoperative stroke, cerebral hyperperfusion syndrome is another serious complication after CEA. Komoribayashi et al. [16] reported that reduced cerebrovascular reactivity and a reduced SO₂ ratio (SO₂ 5 minutes before clamping divided by the lowest SO₂ value during clamping) are risk factors of cerebral hyperperfusion syndrome after CEA. Ogawara et al. [17] found that patients suffering from cerebral hyperperfusion syndrome showed increasing rSO₂ values, exceeding 105% of the baseline value after declamping (sensitivity 100%, specificity 86.4%) and exceeding 110% of the baseline value at the end of the procedure (sensitivity 100%, specificity 100%). In our study population, none displayed cerebral hyperperfusion syndrome, although 2 patients showed more than a 5% increase in the rSO₂ value and 3 patients showed more than a 10% increase in the rSO₂ value. Further studies are needed to establish more effective cut-off values for preventing cerebral hyperperfusion syndrome.

Since the surgical procedures were performed by a single surgeon, it is possible that the outcomes of surgery were biased because the surgeon's profi-

ciency and experience increased over time. Although the operative time is not a perfect indicator of proficiency of surgery, no statistically significant difference was found between the 2 groups in terms of operative time (Table 1).

Our study is limited in that it was retrospective by design, with a relatively small number of patients and a short study period. Our conclusions on the benefits of NIRS compared to other traditional monitoring methods would be further bolstered by prospective studies with randomized cohorts conducted in multicenter settings.

In conclusion, based on the present retrospective study, we suggest that selective cerebral perfusion under NIRS monitoring during CEA seems to be safe and reliable. When compared with TCD monitoring, NIRS monitoring during carotid surgery reduced unnecessary manipulation of the carotid artery and resulted in fewer postoperative neurologic complications.

Conflict of interest

No potential conflicts of interest relevant to this article are reported.

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