

Dual Monitoring with Stump Pressure and Electroencephalography During Carotid Endarterectomy

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Background: Intraoperative monitoring during carotid endarterectomy is crucial for cerebral protection. We investigated the results of carotid endarterectomy under dual monitoring with stump pressure and electroencephalography. **Methods:** We retrospectively reviewed the medical records of 50 patients who underwent carotid endarterectomy between March 2010 and February 2016. We inserted a temporary shunt if the stump pressure was lower than 35 mm Hg or if any intraoperative change was observed on electroencephalography. **Results:** Seventeen (34%) patients used a temporary shunt, and the mean stump pressure was 26.8 mm Hg in the shunt group and 46.5 mm Hg in the non-shunt group. No postoperative mortality or bleeding occurred. Postoperatively, there were 3 cases (6%) of minor stroke, all of which took place in the shunt group. A comparison of the preoperative and the intraoperative characteristics of the shunt group with those of the non-shunt group revealed no statistically significant difference between the 2 groups ($p < 0.01$). **Conclusion:** Dual monitoring with stump pressure and electroencephalography was found to be a safe and reliable monitoring method with results comparable to those obtained using single monitoring. Further study should be performed to investigate the precise role of each monitoring method.

Key words: 1. Endarterectomy, carotid
2. Intraoperative neurophysiological monitoring
3. Stroke
4. Carotid artery disease

Introduction

Carotid endarterectomy (CEA) is one of the most frequently performed peripheral vascular procedures in the United States and is effective in decreasing the risk of stroke in patients with carotid stenosis. However, one of the most serious complications of CEA is perioperative stroke (ischemic or embolic), and intraoperative cerebral protection is of prime importance in such cases. Intraoperative monitoring is

indispensable for appropriate cerebral protection, using techniques such as electroencephalography (EEG), somatosensory evoked potential (SEP), transcranial Doppler (TCD), or stump pressure (SP), and which of these intraoperative monitoring methods are superior to the others with respect to the detection of the risk of perioperative stroke has yet to be determined. The aim of this study was to analyze the results of CEA, including perioperative stroke and other complications, under dual monitoring with EEG and SP.

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Methods

We retrospectively reviewed the medical records of 50 patients who underwent CEA between March 2010 and February 2016. The medical history was taken and the neurophysical examination, laboratory studies, and carotid duplex scanning were conducted before the operation. The indication for CEA was moderate stenosis on the carotid duplex (peak systolic velocity faster than 170 cm/sec, 60%–79% stenosis) for symptomatic patients [1] or severe stenosis on the carotid duplex (peak systolic velocity faster than 240 cm/sec, 80%–99% stenosis) for asymptomatic patients [2]. Preoperative waking EEG was performed in the baseline study to detect any intraoperative changes on the EEG. The antiplatelet agents used before the operation were maintained so as to not aggravate the patient's neurologic status.

We started EEG monitoring before the induction of general anesthesia in the operative theater, and the neurologist continued the monitoring until the end of the operation. All patients underwent the operation under general anesthesia. The common, external, and internal carotid arteries were exposed after the ligation and division of the common facial vein. Arterial clamping was applied to the common and external carotid arteries, and a 23-gauge needle was inserted into the common carotid artery for measuring SP, which reflected the arterial flow through the circle of Willis during clamping for arteriotomy. While we measured SP, the systemic blood pressure remained constant and was similar to the average pressure during the admission period.

If the SP was higher than 35 mm Hg and there were no changes on the EEG after clamping, we performed CEA without a temporary shunt. If the SP was lower than 35 mm Hg or there was a change on the EEG, such as slowing (decrease in frequency) or asymmetry (any changes in amplitude or in the shape of the waves), a temporary shunt (Pruitt F3-Polyurethane Carotid Shunt with T-port [outlying]; LeMaitre Vascular Inc., Burlington, MA, USA) was inserted. After we completed the excision of the atheromatous plaque and confirmed that the intima was normal, the arteriotomy was repaired with a bovine pericardial patch (Edwards Lifesciences, Washington, DC, USA). Tacking sutures were done selectively if there were any concerns about the dissection between the

intima and the media in the internal carotid artery. A drainage catheter was not inserted in all cases.

We focused on the changes in the neurologic examination and on the control of blood pressure to detect postoperative strokes and to prevent hyperperfusion syndrome. We performed a routine neurologic examination in the intensive care unit every 2 hours on the day of the operation and controlled blood pressure with an intravenous beta blocker. If a patient showed any changes in the neurologic examination, we consulted a neurologist and checked the imaging on the basis of the patient's status. The chi-square test and the Student t-test were used for the statistical analysis (IBM Corp., Armonk, NY, USA). All p-values <0.01 were considered to indicate statistical significance. This study was approved by the institutional review board of Jeju National University Hospital (JEJUNUH2016-06-034).

Results

The mean age of the included patients was 71.3 years (range, 51 to 86 years), and 36 of the patients (72%) were men. Twenty-nine patients (58%) were symptomatic and underwent CEA within 2 weeks from the onset of stroke symptoms. Among the 21 asymptomatic patients, 15 had a previous history of stroke and underwent CEA electively because of aggravated carotid stenosis on follow-up carotid duplex scanning. They were classified as asymptomatic because the previous stroke was not anatomically related to the stenotic carotid artery. The remaining 6 asymptomatic patients were detected through ultrasonography during a routine health checkup. The common accompanying diseases were hypertension, diabetes, and dyslipidemia. Thirty patients (60%) had a history of smoking, and 8 had a history of surgery or intervention for cardiovascular diseases. The preoperative characteristics of the patients are presented in Table 1.

Thirty-three (66%) patients underwent CEA without a temporary shunt on the basis of the above-mentioned selective shunting criteria; the mean SP of the non-shunt group was 46.5 mm Hg, and that of the shunt group was 26.8 mm Hg. Among the 17 patients with temporary shunting, 2 patients changed from an operation without a shunt to an operation with a shunt because they showed asymmetry or

Table 1. Patient characteristics (n=50)

Characteristic	No. of patients (%)
Men	36 (72)
Women	14 (28)
Symptomatic	29 (58)
Asymptomatic	21 (42)
Hypertension	38 ^{a)}
Diabetes	16 ^{a)}
Dyslipidemia	13 ^{a)}
Ever-smoker	30 (60)
History of intervention or operation for cardiovascular diseases	8 ^{a)}

^{a)}The number of patients having hypertension, diabetes, dyslipidemia, and cardiovascular diseases represents the number of cases because some patients had more than 2 of these diseases.

slowing of waves on the intraoperative EEG, even though their SP was 59 and 71 mm Hg, respectively. There were 9 patients in the non-shunt group who showed SP ranging from 36 to 39 mm Hg without any changes in the intraoperative EEG after arterial clamping. The characteristics of the patients in both the shunt and non-shunt groups are presented in Table 2.

There were no cases of operative mortality, which was defined as death within 30 days after the operation or death during the same period of admission as that of the operation. Despite the maintenance of the preoperative antiplatelet agents, there were no cases of postoperative bleeding or hematoma that required reoperation. Three patients (6%) with a minor stroke showed a change in the neurologic examinations postoperatively, such as aggravated preoperative symptoms or newly developed neurologic symptoms. Two of them were confirmed as having a border zone infarct on diffusion magnetic resonance imaging and recovered completely after two days. The third patient presented aggravated preoperative symptoms and recovered to the level of the preoperative status by the time of discharge. All the postoperative stroke patients had the following common features: presence of symptoms, low SP (25–26 mm Hg), use of a temporary shunt, and contralateral carotid stenosis greater than 70% on the carotid duplex scanning.

Table 2. Differences in clinical characteristics between the shunt group and the non-shunt group

	Non-shunt group (n=33)	Shunt group (n=17)	p-value
Hypertension	25	13	
Diabetes	11	5	
Dyslipidemia	8	5	
Symptomatic	16 (48.5)	13 (76.5)	0.057
Asymptomatic	17 (51.5)	4 (23.5)	
Contralateral stenosis ^{a)}	12 (36.4)	10 (58.8)	0.13
Postoperative stroke	0	3 (17.6)	0.0036

Values are presented as number (%).

^{a)}Defined as stenosis of >70% on carotid duplex scanning.

Discussion

At the time of launching CEA in our institution, we decided to use a selective shunting strategy instead of routine shunting, and the only selection criterion was an SP lower than 40 mm Hg. For more sophisticated cerebral protection, neurologists and vascular surgeons have discussed and agreed with the use of dual monitoring since 2009. Although we had used TCD as the intraoperative monitoring method for a small number of limited cases, we recognized that the temporal window was not always available for monitoring and that it was difficult for us to fix TCD to the appropriate monitoring position because this position was adjacent to the operative field. Therefore, we did not choose TCD as a routine intraoperative monitoring method during CEA.

Considering the results that the mean SP was 46.5 mm Hg and no patient had a postoperative stroke in the non-shunt group, we can infer that a certain level of SP is significantly related to intraoperative cerebral perfusion. Jacob et al. [3] reported that an SP higher than 45 mm Hg is a reliable predictor of adequate cerebral perfusion under general anesthesia. However, there were 2 cases of unpredictable shunt insertion in this study because of intraoperative EEG changes after arterial clamping, although the patients in question were considered to have adequate cerebral perfusion on the basis of the SP. We did not consider such EEG changes to be false positives or artifacts because they disappeared immediately after the temporary shunt insertion. Unfortunately, we could not presume the potential causes of such changes on the EEG because the patients did not

have any anatomic abnormalities such as contralateral carotid stenosis, poor collaterals, or intracranial arterial stenosis. Furthermore, 9 patients from the non-shunt group who did not show any changes in the intraoperative EEG with SPs between 36 and 39 mm Hg also did not have a postoperative stroke. We cautiously presume that SP and intraoperative EEG can be mutually complementary, and further research should be performed to investigate which preoperative examination is most closely related to intraoperative hemodynamics.

All the postoperative stroke cases occurred in the shunt group. It might be reasonable to consider that low SP or changes on the EEG that led to the temporary shunt insertion are related to the risk of postoperative stroke rather than the shunt insertion itself. According to previous research, intraoperative monitoring results can predict the risk of perioperative stroke. Nwachuku et al. [4] reported that patients with intraoperative changes in SEP or EEG had 6 times greater odds for postoperative stroke [5]. As shown in Table 2, preoperative factors including comorbidities, contralateral stenosis, or presence of symptoms did not show significant differences between the 2 groups. Cho et al. [6] reported that preoperative atrial fibrillation and ex-smoker status were statistically significant risk factors for a minor stroke in the 30-day postoperative period, and further investigation should be performed at our institution to clarify the relevant preoperative, rather than intraoperative, factors capable of predicting a high risk of shunt insertion or perioperative stroke. This would be helpful for patient selection and would lead to better postoperative satisfaction among the patients.

It is difficult for us to decide to continue using the dual monitoring strategy because this study was not a prospective randomized trial comparing the results between single and dual monitoring. Although the rate of perioperative stroke found in this study is similar to the reported rate of 2%–6% [7], it is still controversial to use EEG for comparable results because it requires special devices, specialists, and a correspondingly greater cost. EEG has well-known shortcomings including low sensitivity for recent stroke patients, a time gap between cerebral ischemia and the presentation of changes in EEG under general anesthesia, and a low detection rate of sub-

cortical ischemia [8,9]. However, according to the report of Florence et al. [10], reversible changes in EEG such as decreased amplitude or frequency occur when the cerebral blood flow reaches 22 mL/100 g/min. Even the isoelectric pattern of EEG presents when the cerebral blood flow decreases to the level of 7–15 mL/100 g/min. When we consider the fact that significant cerebral ischemic damage occurs when there is a prolonged decrease in the cerebral blood flow and the flow becomes lower than 10 mL/100 g/min [10], insertion of the prepared temporary shunt immediately after detecting any changes in EEG is thought to be appropriate management for preventing possible cerebral ischemic insult irrespective of the causes. When we consider the possibility that we could have avoided unnecessary shunt insertion in 9 cases and prevented possible postoperative stroke in 2 cases, in comparison to the single monitoring method using SP alone, we may cautiously take into consideration continuing the dual monitoring strategy.

In conclusion, dual monitoring with SP and EEG can be a safe and reliable monitoring method with comparable results to those obtained using single monitoring. Further study should be performed to investigate the role of each monitoring method.

Conflict of interest

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

Acknowledgments

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