Neurologic Derangement and Regional Cerebral Oxygen Desaturation Associated With Patency of the Circle of Willis During Carotid Endarterectomy

Byung-moon Choi, MD, PhD,* Soo-kyung Park, MD,† Sung Shin, MD,‡ Yong-pil Cho, MD, PhD,‡ Tae-won Kwon, MD, PhD,‡ Young-jun Choi, MD,§ Eun-Kyung Lee, PhD,¶ and Gyu-Jeong Noh, MD, PhD‖

Objectives: **To explore the relationship between the maximal fractional decrease of regional cerebral oxygen saturation (rSO_2) in neurologic derangement and the patency of the circle of Willis and contralateral carotid artery stenosis.**

Design: **A prospective observational study.**

Settings: **A tertiary-care university hospital**

Participants: **This study enrolled 307 patients undergoing carotid endarterectomy under regional anesthesia.**

Interventions: **No interventions.**

Measurements and Main Results: **Magnetic resonance angiography and carotid color-duplex ultrasound were performed, and the rSO_2 was recorded. The relationship between the maximal fractional decrease of rSO_2 from preclamp baseline against shunt insertion and patency of the circle of Willis was analyzed by a 2-way analysis of variance. Receiver operating characteristic analysis of the maximal fractional decrease of rSO_2 also was performed to calculate the cut-off value for detecting neurologic derangement. In addition, probability of shunt insertion was estimated by logistic regression. Patency of the circle of Willis did not influence the maximal fractional decrease of rSO_2. When both anterior and posterior circulations were nonpatent, the degree of contralateral carotid artery stenosis (Contra) was 54.7% ± 29.0% versus 40.7% ± 26.0% in patients with versus without shunting, respectively ($p < 0.05$). The cut-off value of rSO_2 for predicting shunt insertion was 25.8%, regardless of the patency of the circle of Willis. Probability of shunt insertion for nonpatent anterior circulation = $\exp(-2.02 + 0.02 \times \text{Contra})/[1 + \exp(-2.02 + 0.02 \times \text{Contra})]$.**

Conclusions: **The rSO_2 can be used to predict shunt insertion, regardless of the patency of the circle of Willis. The probability of shunt insertion increased with increasing degree of contralateral carotid artery stenosis in the absence of anterior circulation in the circle of Willis.**

KEY WORDS: ***carotid endarterectomy, circle of Willis, regional anesthesia, regional cerebral oxygen saturation***

CAROTID ENDARTERECTOMY (CEA) is an established treatment to reduce the incidence of strokes in patients with moderate-to-severe symptomatic or severe asymptomatic carotid stenosis.[1,2] Neurologic derangement induced by cerebral hypoperfusion or embolization during cross-clamping of the carotid artery can be a cause of perioperative strokes in patients undergoing CEA.[3,4] When the ipsilateral carotid artery is cross-clamped, collateral pathways contributing to cerebral perfusion are anterior (left and right A1, anterior communicating arteries) and posterior (left and right P1 and posterior communicating arteries) circulations in the circle of Willis, contralateral carotid arteries, and vertebral arteries. Compromised patency in these collateral pathways may result in intraoperative cerebral ischemia, which makes cerebral monitoring essential during CEA. In an earlier study, a 20% decrease in the near-infrared spectroscopy-based regional cerebral oxygen saturation (rSO_2) from the preclamp baseline was a predictor of neurologic compromise during CEA under regional anesthesia.[3] However, this cut-off value of rSO_2 was calculated without taking patency of collateral pathways to cerebral hemispheres into account.

Collateral pathways explored for the prediction of shunt insertion during CEA were the ipsi- and contralateral internal carotid arteries,[5,6] anterior and posterior communicating arteries in the circle of Willis,[7] and anterior and posterior parts in the circle of Willis.[8] In the first 3 earlier studies, all collateral pathways were not evaluated for predicting cerebral ischemia or shunt insertion during CEA. The fourth earlier study found that total occlusion of the contralateral carotid artery and incomplete occlusion of the posterior part of the circle of Willis were significant risk factors for development of ischemia, which was inconsistent with other studies concluding that the anterior communicating artery was a key collateral pathway to protect against cerebral ischemia.[9–11] Although the standard method to determine the patency of the circle of Willis is digital subtraction angiography using carotid artery compression,[12] magnetic resonance angiography (MRA) is also a useful method to evaluate the patency of the circle of Willis.[13,14]

The aims of this study were to investigate maximal fractional decrease of rSO_2 and its cut-off value for predicting shunt insertion, and to estimate the probability of shunt insertion, according to the patency of the circle of Willis evaluated by MRA, in the contralateral carotid artery and vertebral arteries, during cross-clamping of the carotid artery under superficial cervical plexus block.

METHODS

This study was approved by the institutional review board of Asan Medical Center (Seoul, Korea). A total of 307 patients undergoing 310 CEAs under cervical plexus block from February 2003 to February 2012 were enrolled. Indications

*From the Departments of *Anesthesiology and Pain Medicine; †Department of Anesthesiology and Pain Medicine, Seoul National University Hospital, Seoul, Republic of Korea; ‡Surgery, Division of Vascular Surgery; §Radiology and Research Institute of Radiology; ‖Clinical Pharmacology and Therapeutics/Anesthesiology and Pain Medicine, University of Ulsan College of Medicine and Asan Medical Center, Seoul, Republic of Korea; and ¶Department of Statistics, Ewha Womans University, Seoul, Republic of Korea.*

Address reprint requests to Gyu-Jeong Noh, MD, PhD, Department of Clinical Pharmacology and Therapeutics/Anesthesiology and Pain Medicine, Asan Medical Center, University of Ulsan College of Medicine, 388-1, Pungnap 2-dong, Songpa-gu, Seoul 138-736, Republic of Korea. E-mail: nohgj@amc.seoul.kr

1053-0770/2601-0001$36.00/0

http://dx.doi.org/10.1053/j.jvca.2015.05.059

for surgery were >60% and >80% stenosis of the internal carotid artery for symptomatic and asymptomatic patients, respectively. Patient characteristics are presented in Table 1. Patients with and without shunt insertion during cross-clamping of the carotid artery did not show any significant differences in demographic characteristics except sex.

All patients fasted from midnight, and no patient received any premedication on the day of surgery. The radial artery was cannulated with a 20-gauge catheter for continuous monitoring of blood pressure. Electrocardiography, pulse oximetry, end-tidal carbon dioxide partial pressure, and invasive blood pressure (Datex-Ohmeda S/5, Planar Systems, Inc., Beaverton, OR) were monitored continuously during the surgery. After August 1, 2009, the rSO_2 (INVOS 5100B, Somanetics Corp., Troy, MI) was monitored continuously and downloaded to a personal computer until recovery from anesthesia.

All patients underwent superficial cervical plexus block. Briefly, a 23-gauge needle was introduced into the skin at the midpoint of the posterior border of the sternocleidomastoid muscle. Then, 30 mL of 0.525% ropivacaine were injected subcutaneously (both superficially and deeply) into the muscle fascia along the posterior border in both the cranial and caudal directions.[15] A mandibular nerve block was achieved by injecting 5 mL of 0.75% ropivacaine at the mastoid apex.[16] Oxygen was administered intranasally at 2 L/min during the surgery. The baseline value of rSO_2 was obtained with administration of supplemental oxygen. To maintain the responsiveness of the patients to verbal stimuli and to prevent respiratory depression, no intravenous sedatives or analgesics were administered. The systolic blood pressure was maintained to the upper limit of resting values in the general ward, specific to each patient, until the declamping of the carotid artery. After declamping, the systolic blood pressure was lowered to the lower limit of preoperative values. Vasopressors and antihypertensive drugs were used to titrate the systolic blood pressure during surgery. During clamping of the carotid artery, patients were closely monitored for neurologic deterioration at 5-minute intervals by assessing orientation to time, person, and place, contralateral hand strength, and cognitive function (subtraction in units of 7, eg, 100 − 7, 93 − 7, 87 − 7). Disorientation, motor weakness, compromised cognitive function, slurred speech, and unconsciousness were used as criteria for shunt insertion. Change in neurologic function and the times of shunt insertion and removal were recorded.

Table 1. Patient Characteristics

	Group S (n = 37)	Group NS (n = 273)
Age (yr)	66.6 ± 8.6	67.3 ± 8
Sex, M/F	27/10*	241/32
Weight (kg)	64.2 ± 10.4	65.5 ± 12.9
Height (cm)	161.0 ± 8.2	163.4 ± 11.9
ASA PS, 1/2/3	0/29/8	22/203/47
Hemoglobin (mg/dL)	13.7 ± 1.1	13.3 ± 1.5
Total bilirubin (mg/dL)	0.6 (0.5-0.9)	0.7 (0.5-0.9)
SpO_2	97.5 ± 2.8	97.9 ± 1.6
SaO_2	97.7 ± 1.6	98.2 ± 1.2
Coexisting diseases		
Diabetes mellitus	14	99
Hypertension	31	202
Coronary artery disease	13	63
Peripheral vascular disease	4	24
COPD	1	13
Heart failure	2	6

NOTE. Data are expressed as the mean ± SD, median (range), or count and compared by the 2-sample *t* test, Mann-Whitney rank-sum test, or χ^2 test, as appropriate.

Abbreviations: S, shunt; NS, no shunt; M, male; F, female; ASA PS, American Society of Anesthesiologists Physical Status; SpO_2, pulse oximeter oxygen saturation measured before cervical plexus block; SaO_2, arterial oxygen saturation at administration of oxygen of 2 L/min using nasal prong; COPD; chronic obstructive pulmonary disease.

*$p < 0.001$ versus group NS.

Preoperative MRA was performed with a 1.5- or 3-T MR imaging system (Magnetom Vision; Siemens, Erlangen, Germany). The patency of the anterior circulation (bilateral A1 and anterior communicating arteries) and posterior circulation (bilateral P1 and posterior communicating arteries) in the circle of Willis were evaluated by a radiologist independent of the study and was scored as 0 (nonpatent) or 1 (patent). A carotid color-duplex ultrasound was used to determine stenosis of the contralateral carotid artery, which was measured as a percentage of decrease in luminal diameter. Stenosis of the vertebral arteries was subdivided by 5 grades (1: <20%, 2: 20%-59%, 3: 60%-79%, 4: 80%-99%, 5: compete occlusion).

Statistical analysis was conducted with Sigmaplot for Windows version 12.0 (Systat Software, Inc., San Jose, CA) or SAS (version 9.1.3, SAS Institute, Cary, NC). Data are expressed as the mean ± standard deviation (SD) for normally distributed continuous variables, median (range) for non-normally distributed continuous variables, and count for categorical variables. To assess the accuracy of rSO_2 in discriminating ischemic from nonischemic patients, receiver operating characteristic (ROC) analysis was performed. For the ROC curve, the true-positive rate (sensitivity) of a test was plotted against the false-positive rate (1 − specificity). The curve was constructed by calculating the sensitivity and specificity for each possible test result. The maximal fractional decrease of rSO_2 was calculated as follows: maximal fractional decrease of rSO_2 (%) = [(baseline value − minimum rSO_2 during cross-clamping)/baseline value] × 100. Baseline rSO_2 was defined as the average value of rSO_2 from skin incision to carotid cross-clamping. Logistic regression was used to calculate the probability of shunt insertion during clamping of the carotid artery. The highest percent decrease in luminal diameter of the contralateral carotid arteries (Contra), patency of the anterior (A) and posterior (P) circulations in the circle of Willis, and the vertebral (V) arteries (1: < 20%, 2: 20%-59%, 3: 60%-79%, 4: 80%-99%, 5: compete occlusion) were considered as explanatory variables. Because interactions among explanatory variables also may influence the probability of shunt insertion, backward elimination from a full model (A, P, Contra, V, A × P, A × Contra, A × V, P × Contra, P × V, Contra × V, A × P × Contra, A × P × V, P × Contra × V, A × P × Contra × V, where "×" means interaction) was used to identify significant explanatory variables. The criterion for the elimination of a variable from a model was $p > 0.05$ for the coefficient of the variable. In addition, forward and