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Outcomes of Carotid Endarterectomy according to the Anesthetic Method: General versus Regional Anesthesia

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Background: The surgical strategies for carotid endarterectomy (CEA) vary in terms of the anesthesia method, neurological monitoring, shunt usage, and closure technique, and no gold-standard procedure has been established yet. We aimed to analyze the feasibility and benefits of CEA under regional anesthesia (RA) and CEA under general anesthesia (GA). **Methods:** Between June 2012 and December 2017, 65 patients who had undergone CEA were enrolled, and their medical records were prospectively collected and retrospectively reviewed. A total of 35 patients underwent CEA under RA with cervical plexus block, whereas 30 patients underwent CEA under GA. In the RA group, a carotid shunt was selectively used for patients who exhibited negative results on the awake test. In contrast, such a shunt was used for all patients in the GA group. **Results:** There were no cases of postoperative stroke, cardiovascular events, or mortality. Nerve injuries were noted in 4 patients (3 in the RA group and 1 in the GA group), but they fully recovered prior to discharge. Operative time and clamp time were shorter in the RA group than in the GA group (119.29±27.71 min vs. 161.43±20.79 min, $p<0.001$; 30.57±6.80 min vs. 51.77±13.38 min, $p<0.001$, respectively). The hospital stay was shorter in the RA group than in the GA group (14.6±5.05 days vs. 18.97±8.92 days, $p=0.022$). None of the patients experienced a stroke or restenosis during the 27.23±20.3-month follow-up period. **Conclusion:** RA with a reliable awake test reduces shunt use and decreases the clamp and operative times of CEA, eventually resulting in a reduced length of hospital stay.

Key words: 1. Carotid arteries
2. Endarterectomy
3. Anesthesia
4. Shunts

Introduction

Carotid endarterectomy (CEA) is the standard procedure for stroke prevention in patients with atherosclerotic carotid stenosis [1]. The goals of CEA are to prevent cerebral infarction due to carotid artery stenosis and to relieve neurological symptoms, thereby improving the quality of life of patients. The superiority of CEA over other medical treatments for the prevention of major strokes has been demonstrated in cases of asymptomatic stenosis of >70% and ipsilateral symptomatic stenosis of >50% [2]. However,

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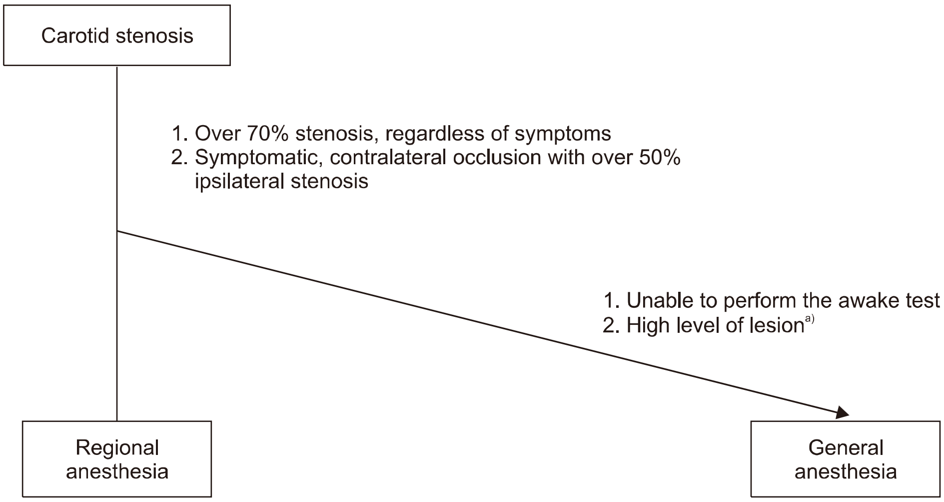

Fig. 1. Operative indication of carotid endarterectomy and strategy for selection of anesthetic method. [a]A high level of the lesion indicates that the distal end of the stenotic lesion was located in the second cervical vertebra (a C2 lesion).

Table 1. Characteristics of patients

Characteristic	Total (n=65)	Regional anesthesia (n=35)	General anesthesia (n=30)	p-value
Age (yr)	72.3±9.07	70.4±8.95	74±8.84	0.068
Male	58 (89)	30 (86)	28 (93)	0.437
Hypertension	50 (77)	28 (80)	22 (73)	0.567
Atrial fibrillation	9 (14)	6 (17)	3 (10)	0.488
Myocardial infarction	8 (12)	6 (17)	2 (7)	0.27
Angina	21 (32)	13 (37)	8 (27)	0.432
Peripheral arterial disease	4 (6)	2 (6)	2 (7)	1.000
Chronic obstructive pulmonary disease	6 (9)	4 (11)	2 (7)	0.678
Diabetes	28 (43)	13 (37)	15 (50)	0.326
Dyslipidemia	22 (34)	11 (31)	11 (37)	0.794
Chronic kidney disease	4 (6)	2 (6)	2 (7)	1.00
Current or ex-smoker	35 (54)	22 (63)	13 (43)	0.293
American Society of Anesthesiologists classification	2.54±0.56	2.57±0.56	2.5±0.57	0.806
Neurological symptoms				
Asymptomatic	23 (35)	16 (46)	7 (23%)	0.022
Symptomatic				
Hemispheric infarct	28 (43)	9 (26)	19 (63)	
Hemispheric TIA	8 (12)	5 (14)	3 (11)	
Retinal infarct	3 (5)	2 (5)	1 (3)	
Retinal TIA	3 (5)	3 (9)	0	
Level of stenotic lesion				0.312
C2	1 (2)	0	1 (3)	
C3	26 (40)	12 (34)	14 (47)	
C4	38 (58)	23 (66)	15 (50)	
Degree of stenosis				0.047
50%–69%	7 (11)	6 (18)	1 (3)	
70%–98%	42 (65)	24 (67)	18 (60)	
Near total stenosis	16 (24)	5 (15)	11 (37)	
Bilateral stenosis or occlusion	49 (75)	25 (71)	24 (80)	0.566

Values are presented as mean±standard deviation or number (%). The level of the stenotic lesion was defined as the level at which the distal end of the stenosis was located.
TIA, transient ischemic attack; C2, the second cervical vertebra; C3, the third cervical vertebra; C4, the fourth cervical vertebra.

CEA itself carries a risk of stroke and death [3]. Developments in the CEA procedure have enabled the prevention of both embolic and ischemic perioperative strokes. Several articles have suggested that there is no definitively superior approach in terms of anesthetic method and shunt usage [4-6].

This study aimed to compare the feasibility and benefits of CEA performed under general anesthesia (GA) with those of CEA under regional anesthesia (RA) using our center's strategy.

Methods

The study protocol adhered to the guidelines stipulated in the Declaration of Helsinki and was approved as an electronic medical record-based retrospective study by the Institutional Review Board of Pusan National University Hospital (IRB approval no., H-1901-015-075); as such, the requirement for obtaining informed consent from the patients prior to study participation was waived.

1) Patient characteristics

Clinical data from 65 patients who had undergone CEA between June 2012 and December 2017 in the Pusan National University Hospital were prospectively collected and retrospectively reviewed. The strategy behind CEA is described in Fig. 1. Based on the type of anesthesia induced, patients were classified into either those who underwent CEA under RA (the RA group) with selective shunt insertion (n=35) or those who underwent CEA under GA (the GA group) with routine shunt insertion (n=30). Patients' baseline data and indications of surgery are presented in Table 1. Symptomatic patients were defined as those with a history of a transient ischemic attack or stroke within a 3-month period prior to surgery. All patients were evaluated by brain magnetic resonance imaging, computed tomography perfusion imaging, and computed tomographic or interventional cerebral angiography. The degree of stenosis was measured according to the method used in the North America Symptomatic Carotid Endarterectomy Trial. The indication for CEA was at least 70% stenosis of the internal carotid artery regardless of symptoms and more than 50% stenosis with severe contralateral stenosis or occlusion in symptomatic patients.

CEA was preferred over carotid artery stenting if the patient did not have contraindications for CEA, such as previous neck surgery, radiation therapy of the neck, or an extremely high level of the lesion (above the second cervical vertebra). The level of the stenotic lesion was defined as the level where the distal end of the stenosis was located (Fig. 2).

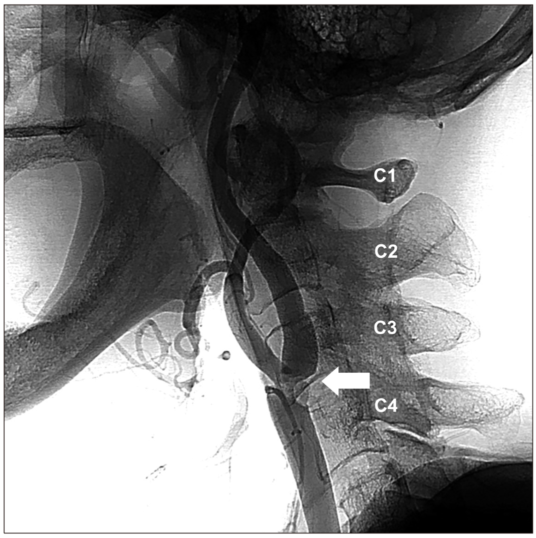

Fig. 2. Level of a stenotic lesion (C3). The level of the stenotic lesion was defined as the level where the distal end of the stenosis was located (arrow).

2) Anesthesia

(1) Regional anesthesia: RA was introduced by an ultrasound-guided deep cervical block consisting of 0.75% ropivacaine (20 mL) and 1% lidocaine (20 mL), which was injected by an anesthesiologist into the level of the third to fifth transverse processes of the cervical vertebrae [7]. Then, the patient was lightly sedated while continuously being infused with dexmedetomidine targeted at sedation status level 2 of the Richmond Agitation-Sedation Scale. Prior to CEA clamping for 5 minutes, we performed the awake test, which included speech, grasping a rubber ball, and toe flexion and extension. After CEA clamping, we performed the awake test immediately and every 5 minutes thereafter. If abnormal findings on the awake test were noted during the operation, we inserted a carotid artery shunt (Pruitt-Inahara carotid shunt with T-port; Le maître Vascular Inc., Burlington, MA, USA) to allow patients to recover from the cerebral ischemic state.

(2) General anesthesia: The induction of anesthesia

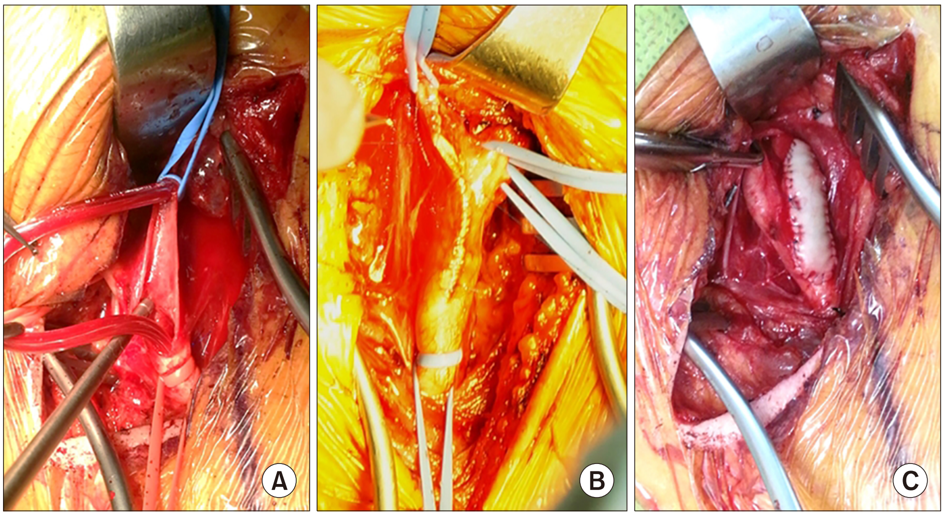

Fig. 3. Operative field view of carotid endarterectomy. (A) Usage of shunt. (B) Direct closure. (C) Patch closure.

was performed with propofol (2 mg/kg) and rocuronium (0.6 mg/kg) followed by tracheal intubation. Anesthesia was maintained using a 2% sevoflurane concentration with remifentanil (0.05–2.00 μg/kg/min) titrated as required [8]. In patients with a stenotic lesion at the third cervical vertebral level, nasotracheal intubation was performed for appropriate neck extension of the target lesion.

3) Operative technique

Each patient underwent a cervical incision along the anterior border of the sternocleidomastoid muscle. The common carotid artery, internal carotid artery, external carotid artery, and superior thyroid artery (as necessary) were dissected and double-looped using a tourniquet. Heparin (50–100 IU/kg) was administered intravenously 5 minutes prior to clamping. An arteriotomy was constructed from the common carotid artery to the internal carotid artery to expose the entire atheromatous plaque. In the RA group, no shunt was used except in cases that displayed abnormal findings in the awake test. In those patients, as well as in all patients in the GA group, the shunt was inserted into the internal carotid artery first, then into the common carotid artery (Fig. 3A). Endothelium that was thickened with plaque was dissected using a Freer elevator, and the plaque was removed to ensure that the endothelium was plaque-free. Heparin-mixed saline irrigation was topically applied at the arterial lumen to prevent thromboembolism. In the RA group, the arteriotomy was closed directly, except in patients with a shunt (Fig. 3B). The 2 main reasons for direct closure were better exposure without interference of the shunt and reduction of clamp time. In the GA group, the arteriotomy was closed using path angioplasty of the bovine pericardium (Vascu-Guard; Biovascular, St. Paul, MN, USA) (Fig. 3C). The shunt was removed before completely closing the suture with de-airing.

4) Postoperative care

After surgery, the patients under GA were extubated in the operative room and transferred to the neurological intensive care unit (ICU) to stay for at least one day for strict monitoring of their blood pressure (systolic blood pressure $<$140 mm Hg), any neurological deficits, and any operative wound complications. All patients immediately underwent postoperative computed tomographic angiography of the brain to evaluate the possible presence of anastomotic site stenosis, acute thrombosis, vascular spasm, embolism, cerebral edema, and hemorrhage. All patients were asked to revisit at 3 months from the discharge date for a neurological examination and carotid duplex ultrasound scanning.

5) Statistical analysis

The categorical variables were assessed using the Fisher exact test, whereas the continuous variables were assessed using the Wilcoxon rank-sum test. All analyses were performed using R software ver. 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria), and a p-value of less than 0.05 was considered to indicate statistical significance.

Table 2. Operative details and outcomes of carotid endarterectomy

Variable	Total (n=65)	Regional anesthesia (n=35)	General anesthesia (n=30)	p-value
Operative time (min)	131.62±31.01	119.29±27.71	161.43±20.79	<0.001
Clamp time (min)	40.35±14.80	30.57±6.80	51.77±13.38	<0.001
Usage of shunt	33 (50.8)	3 (8.6)	30 (100.0)	<0.001
In-hospital mortality	0	0	0	
Complications				
Stroke	0	0	0	
Nerve injury	4 (6.2)	3 (8.6)	1 (3.3)	0.618
Use of intravenous painkiller[a)]	51 (78.5)	27 (77.1)	24 (80.0)	0.780
Use of intravenous blood pressure control drug	37 (56.9)	17 (48.6)	20 (66.7)	0.142
Intensive care unit stay (day)	1.57±0.83	1.54±0.78	1.6±0.89	0.786
Hospital stay (day)	16.62±7.38	14.6±5.05	18.97±8.92	0.022

Values are presented as mean±standard deviation or number (%). Systolic blood pressure was strictly controlled below 140 mm Hg.
[a)]Number of patients who needed painkiller intravenously during the first 24 hours postoperatively because they presented a score above 6 on the numeric pain rating scale.

Results

There were no cases of postoperative stroke, cardiovascular events, or mortality. Nerve injuries were noted in 4 patients (3 patients [8.6%] in the RA group and 1 patient [3.3%] in the GA group [p=0.618]). Among the 3 patients in the RA group, 1 patient experienced a recurrent laryngeal nerve injury, and 2 had a hypoglossal nerve injury. In the GA group, 1 patient displayed a hypoglossal nerve injury. These patients fully recovered before discharge. There was no difference in the use of analgesics and intravenous anti-hypertensive drugs between the 2 groups.

Selective shunt placement during CEA under RA was needed in 3 cases owing to abnormal awake test findings, as those patients displayed infarction symptoms during surgery. Shunt use was significantly lower in the RA group (n=3, 8.6%) than in the GA group (n=30, 100%) ($p<0.001$). The operative time and clamp time were significantly shorter in the RA group than in the GA group (119.29±27.71 minutes versus 161.43±20.79 minutes, $p<0.001$; 30.57±6.80 minutes versus 51.77±13.38 minutes; $p<0.001$, respectively). The ICU stay was similar in both groups, but the hospital stay was shorter in the RA group than in the GA group (14.6±5.05 days versus 18.97±8.92 days, p=0.022). No patient experienced stroke or restenosis during the 27.23±20.3-month follow-up period. Other operation-related results are detailed in Table 2.

Discussion

There were 3 important findings in our study. First, the awake test under RA allowed us to detect cerebral ischemia effectively and to reduce unnecessary shunt use. Only 3 patients (8.6%) in whom the awake test was used also required shunt use; these included 2 patients with contralateral occlusion and 1 patient without any specific findings in the contralateral artery. Moreover, none of the patients without shunts had a stroke. Second, by minimizing the use of shunts in the RA group, operative time and clamp time were statistically significantly reduced. Moreover, surgery could be performed with a better field of vision. Direct closure was performed, and no carotid artery stenosis occurred after surgery. Third, the hospital stay was significantly shorter in the RA group. However, there was no statistically significant difference in the length of the ICU stay because all patients were required to stay for at least 24 hours in the ICU after surgery for strict and immediate blood pressure control. Considering that the patients were older and had comorbidities, recovery in the RA group was significantly faster without postoperative complications.

CEA under GA is beneficial for the immobilization of patients, potential neuroprotection, and securing of the airway [9,10]. However, the weaknesses of CEA under GA include hemodynamic changes during the perioperative or postoperative periods and the lack of direct neurological monitoring, thereby requiring shunt insertion [11,12]. Theoretically, routine shunt insertion may maintain cerebral blood flow; however, it has been found that shunt use in 85% of cases was unnecessary [13] and was associated with complications such as atheromatous emboli, arterial dissection, and arterial occlusion [14]. In the GA group with selective shunt usage, the incidences of perioperative stroke and perioperative stroke and death were confirmed using the following monitoring tools of cerebral perfusion: transcranial Doppler (4.8% and 4.8%, respectively), stump pressure (1.6% and 1.7%, respectively), electroencephalography (4.8% and 4.8%, respectively), and somatosensory evoked potentials (1.8% and 1.9%, respectively) [6]. Thus, selective shunt use with cerebral monitoring may be an ideal and cost-effective method for accurately assessing cerebral flow and the state of ischemic changes [3,11,15-18].

In the RA group, the rates of perioperative stroke and perioperative stroke and death were 1.1% and 1.7%, respectively [6]. CEA under RA enables real-time monitoring of neurological changes, thereby avoiding airway interventions, reducing hospital stay length, and lowering the shunt usage rate [5,19,20]. In our institution, RA with the awake test is preferred for patients requiring CEA, as CEA under RA is known to have the advantage of reducing reperfusion injuries through simple control of blood pressure and pain, in contrast to CEA under GA [21]. In this study, however, no statistically significant difference was found in blood pressure or pain control between both groups. This is most likely due to the relatively short duration of the cervical block.

However, RA with the awake test is not possible in all patients. We performed CEA under GA with routine shunt insertion in some patients who were unable to cooperate, who had stenotic lesions located at high vertebral levels, who demonstrated anxiety, or who refused RA. The disadvantages of RA include the need for full cooperation of the patient, restriction of access to the airway, and patient discomfort [22]. We overcame these limitations of RA via the continuous infusion of dexmedetomidine, which does not depress respiratory function, and patients can be easily awakened following its use [23]. Owing to its central sympatholytic effects, dexmedetomidine is safe and is associated with favorable hemodynamics.

There were significant differences in the indications for surgery. Asymptomatic carotid stenosis was a more common indication in the RA group than in the GA group ($p < 0.022$), implying that the awake test was difficult to perform in patients with symptomatic conditions.

CEA under RA could reduce shunt use, which could reduce clamp time and operative time, eventually reducing the length of the hospital stay. Schechter et al. [5] reported the influence of anesthesia modality on outcomes after CEA through the American College of Surgeons National Surgical Quality Improvement Program. In their study, there was no difference in the 30-day postoperative composite stroke/myocardial infarction/death rate or complication rate between both groups; however, the RA group had a shorter operative time (99±36 minutes versus 119±53 minutes, $p < 0.0001$) and anesthesia time (52±29 minutes versus 64±37 minutes, $p < 0.0001$), and patients in this group were more likely to be discharged the next day (77.0% versus 64.4%, $p < 0.0001$) [5]. Although previous studies reported better postoperative outcomes in general, we found distinct results regarding the length of the ICU stay versus the length of hospitalization. This could have been due to the fact that we were especially careful to avoid postoperative hyperperfusion of the brain to prevent brain edema; accordingly, our protocol recommends that patients should stay in the ICU for at least 1 day for management of their blood pressure, as well as for evaluation of neurological and rehabilitative characteristics in symptomatic patients. Given that we have not experienced a sufficient number of CEA cases, it is likely that our protocols will be modified in the future—particularly as we gain more experience with the procedure—to reduce the length of hospitalization.

Nevertheless, CEA under RA is a good option for carotid stenosis treatment in patients who can perform the awake test. However, our results suggest that surgeons should decide the surgical plan according to their patients' medical condition and compliance, their own surgical proficiency, and the anesthetic conditions in the hospital. Using a single surgical and anesthetic method for all patients is not recommended, and choosing these methods according to individual patients' characteristics will ultimately improve patient outcomes.

Our study has several limitations. First, this study had a non-randomized and retrospective design. In addition, selection bias was present, as patients were not assigned to a certain treatment strategy; instead, their medication status, anesthetic compliance, and concomitant lesions were considered. Moreover, the sample size was not sufficiently large to differentiate the outcomes between anesthetic methods and surgical techniques.

In conclusion, CEA under RA with the awake test is advantageous compared to the CEA under GA with routine shunt use. However, for CEA under RA, it is important to select patients who are capable of performing the awake test. CEA can result in favorable outcomes through individualized anesthetic and surgical approaches according to the patient's condition.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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