

Original Article

Evaluation of selective shunting in carotid endarterectomy with cerebral oximetry monitoring: A comparative study with traditional methods

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Abstract

Aim: Carotid endarterectomy (CEA) is a widely used surgical procedure for treating carotid artery stenosis, yet perioperative stroke remains a significant complication. The optimal cerebral monitoring technique for guiding selective shunting during CEA is still under debate. This study examines the effectiveness of cerebral oximetry, utilizing the INVOS 5100 system, in monitoring cerebral perfusion and guiding the placement of selective shunts.

Material and Methods: This cross-sectional analytical study retrospectively analyzed data from 184 patients who underwent CEA with cerebral oximetry monitoring between 2014 and 2024. Variables collected included age, degree, and laterality of carotid occlusion, presence and type of preoperative symptoms, use of shunting, repair method, postoperative complications, and final surgical outcomes.

Results: The mean age of patients was 65.68±8.44 years. Postoperative recovery was observed in 179 patients (97.3%), while 5 patients (2.7%) died. No postoperative complications were reported. Statistical analysis showed no significant association between surgical outcomes and variables such as age, symptomatic status, side or severity of stenosis, shunt use, or repair method. A significant association was found between lower preoperative hemoglobin levels and adverse outcomes ($p=0.021$).

Conclusion: Our findings support the safety and effectiveness of CEA under cerebral oximetry monitoring using the INVOS 5100. The absence of complications and high rate of recovery suggest that cerebral oximetry may serve as a valuable tool for guiding selective shunting and improving surgical outcomes in carotid endarterectomy.

Keywords: Endarterectomy, elective shunting, cerebral oximetry, outcome, stroke

INTRODUCTION

Carotid artery plaques can lead to atherosclerosis and arterial narrowing, which may or may not result in clinical symptoms. This condition increases the risk of stroke, with about 20% of strokes being caused by the narrowing of the carotid artery [1]. Carotid endarterectomy is performed to reduce this risk and improve blood flow, but it can cause complications such as stroke,

myocardial infarction, or even death [2]. Carotid endarterectomy involves removing plaque from the common and/or internal carotid arteries to improve blood flow to the brain[1,3]. This procedure is associated with risks, including intraoperative stroke due to cerebral ischemia or embolism [4]. One way to reduce these risks is to use a shunt, which helps maintain blood flow and cerebral perfusion. Shunts can be particularly useful in patients with symptomatic carotid artery stenosis, but their

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use carries additional risks, such as embolization or dissection at the site of unstable plaques [5,6]. To monitor cerebral perfusion during surgery, various techniques such as transcranial Doppler (TCD), cerebral oximetry (CO), electroencephalography (EEG), and sensory evoked potentials (SSEP) are used [2,7]. Currently, cerebral oximetry and TCD are the most widely used techniques, although neither can definitively predict postoperative cerebral ischemia [4,8-10].

This study aimed to investigate the outcome of carotid endarterectomy with elective shunting and cerebral oximetry monitoring in patients referred from 2014 to 2024. It seeks to identify a suitable tool for monitoring cerebral oxygenation and cerebral perfusion in these surgeries. Another aim of the study is to investigate the relationship between preoperative cerebral oxygenation levels and complications after CEA surgery, and to clarify its impact on predicting postoperative complications, so that necessary preventive measures can be taken.

MATERIAL AND METHODS

This retrospective cross-sectional analytical study was approved by the Ethics Committee of Guilan University of Medical Sciences (IR.GUMS.REC.1402.595) and conducted in accordance with the Declaration of Helsinki. A total of 184 patients who underwent carotid endarterectomy (CEA) with selective shunting and cerebral oximetry monitoring between 2014 and 2024 were included. Data collected included the degree and laterality of carotid stenosis (based on Doppler ultrasound and CT angiography), symptomatic status, neurological presentation (stroke or transient ischemic attack [TIA]), NIHSS scores where available, shunt usage, type of arterial repair, and postoperative complications.

Surgical Technique and Anesthesia

All patients were placed under general anesthesia with standard monitoring. Preoperatively, antiplatelet agents were discontinued according to standard vascular surgery protocols and individualized patient assessment. Systemic heparinization was administered in all patients before clamping of the carotid arteries to prevent thromboembolic complications. The carotid endarterectomy surgery began with an incision at the medial margin of the sternocleidomastoid (SCM) muscle. After exposing the common, internal, and external carotid arteries, the vessels were clamped. The plaque was removed from the internal carotid artery, and if necessary, a great saphenous vein patch was used for arterial repair. The decision to use patch closure versus primary closure was based on intraoperative findings, including vessel diameter and arterial wall condition. Patch angioplasty was preferred in cases with significant arterial wall irregularity or narrowing. The degree of stenosis was determined according to the NASCET (North American Symptomatic Carotid

Endarterectomy Trial) criteria.

Monitoring and data collection

Cerebral oxygen saturation (rSO₂) was continuously monitored intraoperatively using the INVOS 5100 device. A selective shunting strategy was employed, with shunt placement indicated when rSO₂ levels declined by more than 25% from baseline values within the first five minutes following carotid clamping. This threshold was established based on prior studies, including those by Russo et al., which have demonstrated a significant correlation between early reductions in rSO₂ and increased risk of neurological complications. In cases where the decline occurred later or progressively, intraoperative perfusion dynamics were reassessed to determine the necessity for shunting.

Data analysis method

The data were coded and entered into SPSS version 26 software. Mean and standard deviation were used for quantitative variables, while numbers and percentages were used for qualitative variables. Mann-Whitney, Chi-square, and Fisher tests were used to examine the relationship between variables, with a significance level of 5% considered.

RESULTS

Data collected from 184 patients who underwent carotid endarterectomy with selective shunting and cerebral oximetry monitoring using the INVOS 5100 device were analyzed. Surgical indications included symptomatic carotid stenosis of $\geq 50\%$ and asymptomatic stenosis of $\geq 70\%$, consistent with established guidelines.

This study analyzed key clinical and demographic factors including patient age, preoperative hemoglobin levels, symptomatic status (TIA or CVA), side and severity of carotid artery involvement, shunt use, and repair method. Of the 184 patients included, 179 (97.3%) recovered and were discharged, while 5 (2.7%) died, indicating favorable surgical outcomes for the majority. The mean age of the cohort was 68.65 \pm 8.44 years; although the deceased group had a slightly higher mean age (72.58 \pm 8.40 years), the difference was not statistically significant (P=0.204). The mean preoperative hemoglobin level was 10.95 \pm 1.38 g/dL, and significantly lower levels were observed among patients who died (9.58 \pm 1.95 g/dL), compared to those who recovered (10.99 \pm 1.37 g/dL), with a statistically significant difference (P=0.021). Intraoperative monitoring using the INVOS 5100 system demonstrated notable changes in regional cerebral oxygen saturation (rSO₂), where a $\geq 25\%$ drop from baseline following carotid clamping was used as the threshold for shunt placement (Table 1). Illustrates this trend, emphasizing the efficacy of selective shunting in restoring cerebral perfusion (Figure 1).

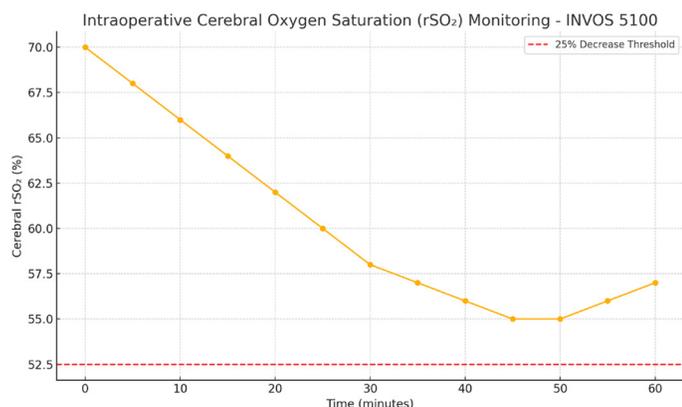


Figure 1. Intraoperative trend of regional cerebral oxygen saturation (rSO₂) measured by the INVOS 5100 device. A notable drop following carotid clamping was observed, with recovery after intervention. The red dashed line represents a 25% reduction threshold used as a shunt criterion

Of the entire cohort of 184 patients, 46.2% had symptomatic transient ischemic attacks (TIA), 37% had symptomatic cerebrovascular accidents (CVA), and 16.8% were asymptomatic. Only one patient in the TIA group (1.2%) and four patients in the CVA group (5.9%) died. In contrast, none of the asymptomatic patients died. Fisher's exact test revealed no significant difference

between symptomatic carotid occlusion and surgical outcome (P=0.197) (Table 2).

Carotid artery involvement was observed in 15.8% of patients on the right side, 16.8% on the left side, and 67.4% on both sides. No deaths occurred in patients with unilateral involvement, while a 4% mortality rate was seen in those with bilateral stenosis. Additionally, although a higher rate of improvement was observed in patients with less than 50% stenosis and more deaths occurred in those with over 70% occlusion, Fisher's exact test showed no statistically significant relationship between either the side or degree of carotid artery involvement and surgical outcome (P=0.494) (Table 3).

Thirteen patients (7.1%) received a shunt, and none of these patients died, compared with a 2.9% mortality rate among those who did not receive a shunt. However, Fisher's exact test showed no statistically significant association between shunt use and surgical outcome, possibly due to the limited size of the shunted group. Similarly, 97.3% of patients underwent repair using a great saphenous vein patch, and 2.7% underwent primary closure. While the mortality rate was 2.2% in the patch group and 20% in the primary closure group, the difference did not reach statistical significance (P=0.130) (Table 4).

Table 1. Association between patient characteristics and surgical outcomes

Surgical Outcome	Age (Mean±SD)	Age Median (IQR)	Age Min	Age Max	Hemoglobin (Mean±SD)	Hemoglobin Median (IQR)	Hgb Min	Hgb Max	P-value (Age)	P-value (Hgb)
Improved	68.54±8.51	68.0 (63.0–74.75)	47	91	10.99±1.37	11.0 (10.0–12.0)	7.30	14.00		
Deceased	72.58±8.40	70.0 (69.0–76.75)	69	77	9.58±1.95	6.9 (7.8–10.5)	4.80	9.10	0.204	0.021
Total	68.65±8.44	68.0 (63.0–75.0)	47	91	10.94±1.38	11.0 (10.0–12.0)	4.80	14.00		

Table 2. Relationship between carotid stenosis characteristics and surgical outcomes

Category	Improved (n, %)	Deceased (n, %)	P-value
TIA	84 (98.8%)	1 (1.2%)	
CVA	64 (94.1%)	4 (5.9%)	
Asymptomatic	31 (100%)	0 (0%)	
Right (R)	29 (100%)	0 (0%)	0.197 (symptoms), 0.494 (side involvement)
Left (L)	31 (100%)	0 (0%)	
Both R & L	119 (96%)	5 (4%)	
Total	179 (97.3%)	5 (2.7%)	

Table 3. Relationship between degree of carotid artery stenosis (left and right sides) and surgical outcomes

Degree of Carotid Artery Stenosis	Improvement (Left)	Death (Left)	Improvement (Right)	Death (Right)	P-value (Right)
Below 50%	34	1	44	4	
50% to 70%	10	0	16	0	
70% to 90%	101	4	85	1	0.176
Above 90%	5	0	3	0	
Total	150	5	150	5	

Table 4. Relationship between shunt usage, repair method, and surgical outcomes

Category	Improvement (Shunt)	Death (Shunt)	Improvement (Repair)	Death (Repair)	P-value (Repair)
Present	13	0			
Absent	166	5			
Total	179	5	179	5	
Patch			175	4	0.130
Primary closure			4	1	
Total			179	5	

In this study, no major postoperative complications such as hematoma, cranial nerve injury, stroke, or myocardial infarction were documented based on clinical records and postoperative assessments. However, we acknowledge that due to the retrospective nature of the study, there is a potential for underreporting of minor or transient complications. Five patients (2.7%) died postoperatively. While detailed autopsy data was not available, these deaths were likely related to underlying cardiovascular or cerebrovascular comorbidities, as suggested by the clinical course and available documentation. This highlights the importance of comprehensive preoperative risk evaluation in this patient population.

DISCUSSION

In our study, 97.3% of patients successfully underwent surgery, accompanied by a low postoperative mortality rate of 2.7%. Although there were age differences between patients who recovered and those who passed away, age did not significantly affect surgical outcomes ($P=0.204$). No significant differences in mortality were noted based on carotid stenosis symptoms ($P=0.197$) or the affected side of the carotid artery ($P=0.494$). The degree of stenosis also did not significantly influence outcomes ($P=0.999$ for the left side, $P=0.176$ for the right). Shunting did not demonstrate a significant effect on surgical outcomes ($P=0.999$), and both patch and primary closure methods yielded similar

results ($P=0.130$). Notably, no postoperative complications were documented in our patient cohort, which may reflect the potential benefits of cerebral oximetry monitoring and selective shunting during CEA. Russo et al. (2023) similarly evaluated the effectiveness of the INVOS-4100 system in detecting cerebral ischemia during carotid endarterectomy and reported a sensitivity of 98% for cerebral oximetry in identifying ischemic events [4]. This study suggests that INVOS-4100 is only effective for superficial cerebral perfusion, and further research is needed to evaluate neurological outcomes. In our study, the positive surgical outcomes and the absence of postoperative complications emphasize the efficacy of cerebral monitoring using the INVOS device. Our findings align with those of Russo, as both studies confirm the device's effectiveness in predicting cerebral ischemia. Kondov et al. (2019) utilized NIRS for monitoring and found that a drop of more than 15% in NIRS parameters signaled the need for shunting [8]. Patients with shunts required more re-operations; however, the overall outcomes remained positive. Our study found no significant difference between patients with and without a shunt, which may be attributed to variations in study design and surgical methods. Nonetheless, both studies suggest favorable outcomes with selective shunting. Similarly, Racho-Neves et al. (2020) focused on shunting in CEA surgery and reported no significant difference in neurological complications between patients with and without

shunts 30 days after surgery [11]. Surgical duration was found to be longer in patients with shunts. These results demonstrate that selective shunting, when used in conjunction with proper monitoring, is both safe and effective. The meta-analysis by Jovanovic et al. (2023) compared various cerebral monitoring methods. It concluded that the combination of EEG and TCD yielded the best results in reducing the need for shunting. No significant differences in adverse outcomes between cerebral monitoring methods were observed [12].

Our study found no stroke, whereas a similar study reported a rate of 1.6%–2.0% in symptomatic patients, suggesting that monitoring techniques or patient selection may influence outcomes. While shunting did not show a statistically significant effect, none of the shunted patients died, suggesting a potential protective benefit. However, the relatively small sample size, particularly in subgroups such as shunt recipients, may have limited the statistical power to detect meaningful differences. In addition, due to the retrospective nature of the study, we did not adjust for potential confounding variables such as comorbidities, pre-existing anemia, or intraoperative blood loss, which may influence outcomes.

Furthermore, unlike Xavier Hommery-Boucher et al., we observed no postoperative complications. This study also reported stroke and death but found no difference between shunt strategies. This suggests that cerebral oximetry monitoring with the INVOS 5100 may help improve outcomes by optimizing cerebral perfusion [13].

Our study reported no cases of stroke, whereas similar studies have documented rates ranging from 1.6% to 2.0%, potentially due to differences in cerebral monitoring techniques or patient selection criteria. Although the use of shunting did not reach statistical significance in our analysis, none of the patients who received a shunt experienced mortality, suggesting a possible protective benefit. These findings, along with the absence of documented postoperative complications in our cohort, support the potential efficacy of cerebral oximetry using the INVOS 5100 system in optimizing cerebral perfusion and enhancing surgical outcomes.

Limitations

This study is inherently limited by its retrospective design and the absence of a comparator group monitored with alternative techniques such as electroencephalography (EEG) or transcranial Doppler (TCD). Furthermore, the study did not adjust for confounding variables such as comorbidities or intraoperative factors. Future prospective, randomized trials are essential to directly compare the clinical utility and accuracy of various cerebral monitoring modalities during carotid endarterectomy.

CONCLUSION

Our study suggests that carotid endarterectomy (CEA) performed

under cerebral oximetry monitoring by using the INVOS 5100 device is a safe and effective procedure, with a low postoperative mortality rate. While demographic and clinical factors such as age, side of carotid involvement, and degree of stenosis did not significantly affect outcomes, lower preoperative hemoglobin levels were associated with increased mortality. Although no postoperative complications were documented, this finding should be interpreted cautiously, given the retrospective design and potential underreporting. The use of selective shunting guided by cerebral oximetry may offer protective benefits, as supported by comparable studies. Nonetheless, further prospective, controlled studies are necessary to validate these findings and to compare the efficacy of various cerebral monitoring strategies in CEA.

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Patient Consent for Publication: Written informed consent was obtained from the patient to publish clinical data.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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