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The Efficacy of Indocyanine Green Video Angiography During Carotid Endarterectomy: An Institutional Experience

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ABSTRACT

AIM: To present our experience of 44 consecutive carotid endarterectomy procedures in 42 patients and assess the efficacy and success of ICG-VA in the localization of the plaque sites, extent of the arteriotomy, evaluation of the flow, and presence of thrombus after closure.

MATERIAL and METHODS: This study was retrospectively designed, which included all the patients who underwent carotid stenosis operation between 2015 and 2019. ICG-VA was used in all procedures, and patients with available follow-up and full medical data were analyzed.

RESULTS: Forty-two consecutive patients who underwent a total of 44 CEAs were included. The population consisted of 5 (11.9%) female and 37 (88.1%) male patients, all of whom had at least 60% carotid stenosis, as assessed using North American Symptomatic Carotid Endarterectomy Trial stenosis ratios. The mean stenosis rate was 80.55% (range, 60%–90%), the mean patient age was 69.8 years (range, 44–88 years), and the mean follow-up duration was 40 months (range, 2–106 months). In 31 (70.5%) of 44 procedures, ICG-VA revealed the exact location of the obstructive plaque's distal end, and it successfully showed the arteriotomy length, identifying the location of the plaque. ICG-VA correctly evaluated the flow in 38 (86.4%) of 44 procedures.

CONCLUSION: Our reported study is cross-sectional, reflecting our experiment using ICG during CEA. ICG-VA can be used as a simple, practical, real-time microscope-integrated technique that can enhance the safety and effectiveness of CEA.

KEYWORDS: Aneurysm, Angiography, Arteriotomy, Carotid endarterectomy

ABBREVIATIONS: CA: Conventional angiography, **CEA:** Carotid endarterectomy, **CREST:** Carotid revascularization endarterectomy versus stenting trial, **CTA:** Computed tomography angiography, **DUS:** Doppler ultrasound, **ICG-VA:** Indocyanine green video angiography, **STA:** Superior thyroidal artery

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INTRODUCTION

Indocyanine green video angiography (ICG-VA) effortlessly and immediately allows vascular structures imagination during micro-neurosurgical operations. Kuroiwa et al. used intravenously administered indocyanine green to demonstrate the bridging veins and superior sagittal sinus through the dura mater neurosurgical practice (7). Raabe et al. first described neurosurgical microscope-integrated ICG-VA for intracranial aneurysm surgery, evaluating vascular flow with ICG-VA (14). Although many publications about the efficacy of ICG-VA use in aneurysm and by-pass surgeries have been published, a small number of reports have presented its effectiveness in carotid endarterectomy (CEA) (3-6,8,12,13,15).

In this study, we present our experience of 44 consecutive carotid endarterectomy procedures in 42 patients and assess the efficacy and success of ICG-VA in the localization of the plaque sites, extent of the arteriotomy, evaluation of the flow, and presence of thrombus after closure.

MATERIAL and METHODS

Patent Population

This retrospective study included all patients who underwent a CEA at the department of neurosurgery of Ankara University, School of Medicine between 2015 and 2019. ICG-VA was used in each procedure, and the charts of patients with available follow-up and full medical data were analyzed. Excluded were patients with previous history of neck surgery and a region-related endovascular procedure and those for whom ICG-VA was not used due to a technical issue, such as failure of microscope mode or failure in intravenous ICG administration.

Informed consent was obtained from each patient before the procedure. This study was approved by the Ankara University Institutional Ethics Board (Approval number: i5-373-21).

Reviewed patient data consisted of demographic features, clinical status, preoperative and postoperative radiological findings, operative notes, and videos from the medical records.

Preoperative Diagnosis and Planning

To aid in the diagnosis and optimal treatment planning, all patients underwent computed tomography angiography (CTA). To determine the degree of stenosis, the North American Symptomatic Carotid Endarterectomy Trial (NASCET) grading system was used (10). CEA was planned after a transient ischemic attack or mild cerebral infarction with ipsilateral carotid stenosis (>60%) or in asymptomatic patients with >60% carotid stenosis.

Surgical Techniques

All procedures are performed with the patient under general anesthesia. The patient is positioned with the head extended using folded towels and rotated to the contralateral side. The extent of head rotation is based on the position of the internal carotid artery (ICA) and external carotid artery (ECA) as seen on preoperative radiological images. The goal is to make the ICA directly accessible. An oblique incision is performed throughout the length of the medial margin of the sternocleidomastoid muscle, according to the level of the carotid bifurcation. Dissection of every anatomical level is continued until first exposure of the common carotid artery (CCA). During CCA dissection, the first dose (5000 IU) of heparin is given, and the anesthesiology team is alerted to any blood pressure or heart rate change. ECA dissection is performed distal to the superior thyroid artery (STA), and ICA dissection is performed distal to the estimated region of the intimal plaque. Four sutures are placed on the carotid sheath to stabilize the vessels during the surgical procedure (Figure 1). Before the arteriotomy, ICG is given intravenously to localize the intimal plaque (Figure 2). Doppler ultrasonography (USG) is also performed before the arteriotomy; confirming the end of the ICA plaque with visual inspection and tactile palpation with

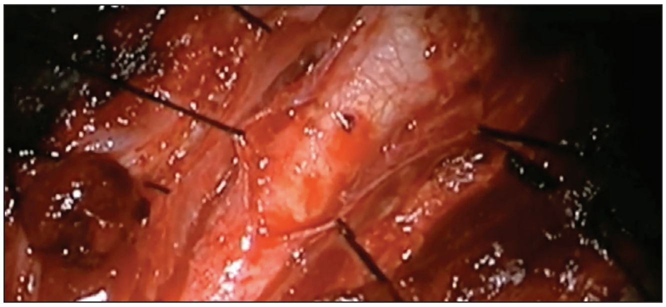

Figure 1: Stabilization sutures placed on the carotid sheath to stabilize the vessels during the surgical procedure.

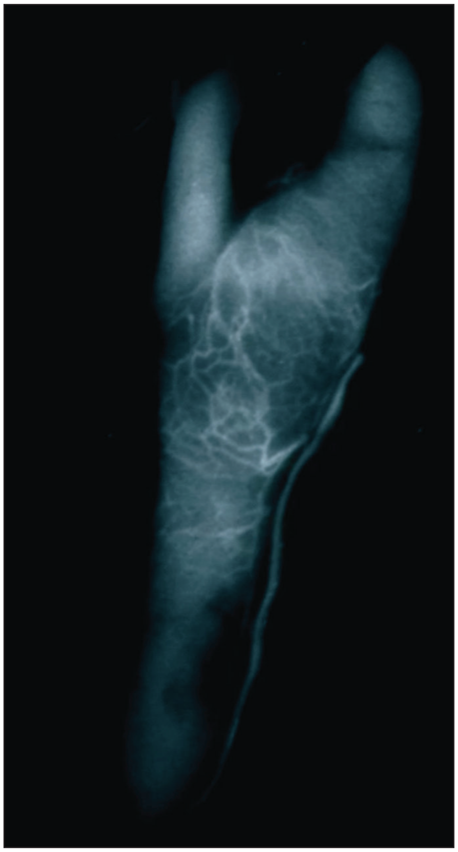

Figure 2: Using ICG before arteriotomy to know the localization of the intimal plaque.

vessel forceps is also necessary. These 3 maneuvers assist in the accurate localization of the plaque. The plaque must also be localized precisely for the cross-clamp to be placed properly to avoid undesirable thromboembolic complications. Before closing the vessels with cross-clamps, the second administration of heparin (5000 IU) is given. The closing order with the cross-clamps is as follows: the ICA first, followed by the CCA as quickly as possible, and then the ECA. A stab incision in the proximal CCA is performed using a No. 11 blade; a linear incision is performed distal to the plaque. Dissection of the plaque is performed in a lateral-to-medial and rostral-to-caudal direction with a Rhoton or No. 4 Penfield dissector. After plaque dissection, the arteriotomy site is washed with a heparin solution. Suturing is completed with a 6.0 Prolene suture (Ethicon, Raritan, NJ) under a surgical microscope. Stretching across the intimal edges is extremely important. The removal order of the cross-clamps is as follows: the ECA first, followed by the CCA, and then the ICA, after holding for approximately 10 seconds to allow any thrombus or air washing out up to the ECA. After suturing completion, ICG is given to show the patency of the surgical site and the absence of air bubbles and intraarterial thrombus (Figure 3). Doppler USG is also applied after suturing completion to confirm the blood stream of all 3 branches. If no doppler signal is noted, the vessels are reopened for examination. A Penrose drain (Graham-Field, Atlanta, GA) is placed, and the layers are closed in an anatomical manner. In our series of patients, no shunts were placed.

Intraoperative Doppler

An 8-Hz 12-mm probe (Rimed, Ra'anana, Israel) was used for all 44 CEAs. Before endarterectomy, Doppler USG was used particularly to detect blood flow in the distal ICA. It was used also to determine patency of the carotid artery complex and detect any bloodstream abnormalities just after the procedure.

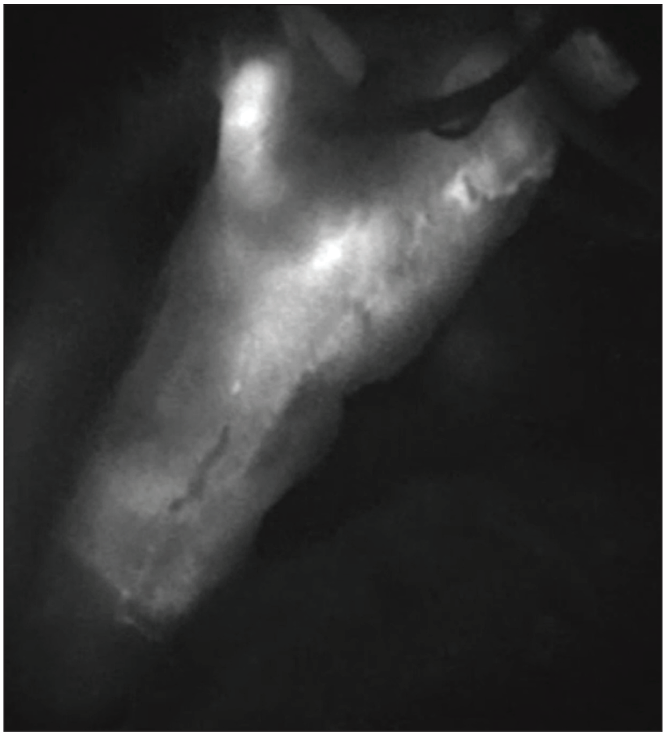

Figure 3: ICG-VA image showing the patency of the carotid passage after the suturing completion.

Intraoperative ICG-VA

ICG was administered before arteriotomy of the carotid complex and after CEA in all 44 surgeries. A 12.5 mg/5 ml bolus of ICG (5 times more than for an aneurysm procedure) was injected intravenously before arteriotomy for plaque site localization and planning of the extent of the arteriotomy. The same dose of ICG was injected after suturing of the arteriotomy to evaluate the flow of the 3 vessels and to investigate the presence of thrombus after closure. The OPMI Pentero 900 (Carl Zeiss, Oberkochen, Germany) fluorescent operating microscope was used to visualize these vessels with the use of the dye. If occlusion of the CCA, ICA, or ECA was suspected or air bubbles in the arterial complex were identified with ICG-VA, re-arteriotomy and reinspection of the surgical site were performed.

RESULTS

Patient Characteristics

In this retrospective study, we reviewed the charts of 42 consecutive patients who underwent a total of 44 CEAs between 2015 and 2019. The population consisted of 5 (11.9%) female and 37 (88.1%) male patients, all of whom had at least 60% carotid stenosis, as assessed using NASCET stenosis ratios (11). The mean stenosis rate was 80.55% (range, 60%–90%), the mean patient age was 69.8 years (median, 68 years; range, 44–88 years), and the mean follow-up duration was 40 months (median, 45 months; range, 2–106 months). Of the 44 carotid stenoses, 19 (43.2%) were on the right side and 25 (56.8%) were on the left side. Table I summarizes the general characteristics of the patients.

Intraoperative Doppler

In 7 of the 44 procedures, Doppler USG did not show blood flow in the distal ICA before arteriotomy, revealing that the ICA was considerably thinner than the ECA, possibly because of the degree of stenosis, which in each of these cases was >90%.

In 6 of the 44 procedures, Doppler USG did not detect the flow signal after arteriotomy. In 3 of these 6 procedures, ICG-VA detected the flow, but in the other 3, neither Doppler USG nor ICG-VA were able to detect flow; in these 3 cases, the arteriotomy site was reopened.

Intraoperative ICG-VA

In 31 (70.5%) of the 44 procedures, ICG-VA revealed the exact location of the obstructive plaque's distal end. Tactile palpation with vessel forceps confirmed the exact localization of the distal end of the plaque in only 8 cases.

ICG-VA successfully showed the arteriotomy length in 31 (70.5%) of the 44 procedures, identifying the location of the plaque. In the remaining cases, arteriotomy was extended up to the end of the dissection.

ICG-VA correctly evaluated the flow in 38 (86.4%) of the 44 procedures. In the remaining 3 cases, no flow was shown, which led to reopening of the arteriotomy site. The presence of thrombus was detected in only 1 of these 3 reopened procedures. In the remaining 2 procedures, thrombus was not found, and the arteriotomy site was resutured after washing with the heparin solution.

Postoperative Course

All patients underwent CTA immediately after the operation, and the patency of the carotid artery complex and possible surgical site complications (hematoma) were assessed. The Penrose drain was removed on the second postoperative day. There were no complications with the wounds or surgical sites.

DISCUSSION

Carotid artery stenosis or occlusion is a major health issue with high socioeconomic burden associated with stroke. Although carotid stenting is known to be partly effective, CEA is considered the treatment of choice in terms of the efficacy and safety of the modality (2,10,18). Most postprocedure thromboembolic events are preventable if detected and managed early (16,17). However, it has been shown that up to 7% of CEA procedures require immediate surgical correction due to technical issues (1,21).

Enhancing the efficacy and safety of the procedure is usually done with intraoperative testing (1,8). Besides ensuring the technical success of the procedure after suturing the arteriotomy, targeting the main surgery site in the prearteriotomy period is another critical stage that can influence the duration of surgery and lower the risk of associated morbidities.

Traditionally, CEA case evaluation just before the arteriotomy involves a combination of visual inspection, doppler auscultation, digital palpation of the vessel, and radiological landmarks to determine the distal extent of the plaque. These maneuvers are indispensable for verifying this specification, because distal control must be achieved well beyond the end of the plaque. Although we do not routinely use shunts in any of our cases, determining the exact location of the plaque to safely position a shunt is also crucial.

Ascertaining the extent of arteriotomy is an important rate-limiting step of the CEA procedure. Because atheroma plaque is present in the whole vascular system, the surgeon must identify the location of the obstructive plaque to decrease surgery time. Precise localization of the plaque and limiting the arteriotomy just close to both the proximal and distal plaque borders will decrease the duration of the arteriotomy, dissection of the plaque, and resuturing of the arteriotomy side, thus reducing the duration of ICA clamping. As a result, the risk of postoperative complications will be reduced.

Urgent surgical correction after a CEA is performed mostly because of the presence of a thrombus and lack of flow at the arteriotomy site. Diagnostic tools for identifying these 2 catastrophic problems must be accurate, reliable, and fast. Based on our experience, ICG-VA is a capable tool for overcoming this problem and reducing complications.

Conventional angiography (CA) is known as the gold standard of vascular imaging and can also aid in ensuring technical success. Nevertheless, this imaging method has some disadvantages; it requires the use of space-occupying fluoroscopic hardware and an arterial line, it opens the possibility of arterial dissection and air embolism, it is time-consuming, and it places a high radiation burden on the patient (9). Also, some reports have indicated up to 26% incidence of technical failure that required intraoperative correction, even in CA-guided surgeries (1).

Doppler USG was introduced as a noninvasive method that results in almost no procedure-related complications and can aid during intraoperative validation of arterial flow. However, investigator-based imaging results that lack any standard cutoff values are considered the major handicap of such imaging guidance (17). Moreover, other major technical limitations that can hinder the evaluation of sites distal to the probe include the need for a definite insonation angle and the fact that the adopted image is restricted to the periprobe region. Many reports have underlined the experience of postoperative cerebral ischemic infarction even after Doppler USG had indicated a successful surgery (8,20). Doppler USG also lacks reliability in turbulent flow and can miss fluttering atheroma during intraoperative evaluation (8). Okawa et al, in their study regarding plaque localization, reported cases in which confirmation of flow in the distal part of the ICA using Doppler USG was not possible (12).

ICG-VA is another method that recently became popular because of its advantages over other modalities, especially when used to image cerebral aneurysms and arteriovenous malformations during CEA surgery (4,8). ICG-VA provides 3-dimensional large-scale imaging of the entire arterial lumen independent of any investigator-related issues. Satisfactory results can be achieved using ICG-VA even with fluttering atheroma and turbulent flow (8). Kimura et al concluded that ICG-VA increases the safety and decreases the embolic complication rate during the declamping stage of CEA (6). Also, in contrast to CA, Haga et al reported no problem or issue regarding patient safety when repeated ICG injections are needed (4). ICG-VA can be effective in evaluating the patency of CEA-related arteries during and before ending the surgery.

Despite the major superiorities of ICG-VA over other modalities, some technical issues can still stand out. Tseng et al reported the possibility of the injection laterality acting on the intensity of the ICG, rendering neck veins to cause reflux of the agent more significantly with a left-sided injection as compared to a right-sided injection (19). They also underlined the fact that deeply ulcerated plaques can interfere with the evaluation of ulcers during a CEA. Haga et al reported the case of 1 patient with severe calcification in whom ICG-VA was unable to localize the stenosis due to spontaneous fluorescence (4).

Regarding the limitations of our study, the population size is small and it might be better to examine the results in wider populations. The software to determine the flow is not much sophisticated and may need to include more features. Also, the flow evaluation could not be achieved in all patients. Also lack of numeric values regarding flow rate caused the results prevented further statistical evaluation.

CONCLUSION

Our study was cross-sectional, reflecting our experiment using ICG-VA during CEA. It was not a large-scale study, but its findings are potent enough to guide the neurosurgeon in using ICG-VA as a real-time, simple, and practical microscope-integrated technique that can assist in our goal to perform more effective and safe CEA procedures.

AUTHORSHIP CONTRIBUTION

Study conception and design: MB, UE, EB, BCM
Data collection: MB, UE, EB, MZ, MO
Analysis and interpretation of results: MB, TEA, AACG
Draft manuscript preparation: MB, UE, EB, AACG
Critical revision of the article: MB, UE, TEA, AACG
Other (study supervision, fundings, materials, etc...): MB, AACG, BCM
All authors (MB, UE, EB, MZ, MO, TEA, AACG, BCM) reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Blaisdell FW, Lim R Jr, Hall AD: Technical result of carotid endarterectomy. Arteriographic assessment. Am J Surg 114:239-246, 1967
2. Brott TG, Hobson RW 2nd, Howard G, Roubin GS, Clark WM, Brooks W, Mackey A, Hill MD, Leimgruber PP, Sheffet AJ, Howard VJ, Moore WS, Voeks JH, Hopkins LN, Cutlip DE, Cohen DJ, Popma JJ, Ferguson RD, Cohen SN, Blackshear JL, Silver FL, Mohr JP, Lal BK, Meschia JF; CREST Investigators: Stenting versus endarterectomy for treatment of carotid-artery stenosis. N Engl J Med 363(1):11-23, 2010
3. Della Puppa A, Rossetto M, Volpin F, Rustemi O, Grego A, Gerardi A, Ortolan R, Causin F, Munari M, Scienza R: Microsurgical clipping of intracranial aneurysms assisted by neurophysiological monitoring, microvascular flow probe, and ICG-VA: Outcomes and intraoperative data on a multimodal strategy. World Neurosurg 113:e336-e344, 2018
4. Haga S, Nagata S, Uka A, Akagi Y, Hamada Y, Shono T: Near-infrared indocyanine green videoangiography for assessment of carotid endarterectomy. Acta Neurochir (Wien) 153:1641–1644, 2011
5. Kawabori M, Niiya Y, Iwasaki M, Mabuchi S, Houkin K: Identification of plaque location using intraoperative indocyanine green during carotid endarterectomy for patient with near occlusion. J Neurosurg Sci 65(4):397-401, 2021
6. Kimura T, Kidani N, Ibayashi K, Kawai K: Visualization of declamping procedure during carotid endarterectomy by ICG videoangiography. Br J Neurosurg 29:726,727, 2015
7. Kuroiwa T, Kajimoto Y, Ohta T: Development and clinical application of near-infrared surgical microscope: Preliminary report. Minim Invasive Neurosurg 44:240-242, 2001
8. Lee CH, Jung YS, Yang HJ, Son YJ, Lee SH: An innovative method for detecting surgical errors using indocyanine green angiography during carotid endarterectomy: A preliminary investigation. Acta Neurochir (Wien) 154:67-73, 2012
9. Mays BW, Towne JB, Seabrook GR, Cambria RA, Jean-Claude J: Intraoperative carotid evaluation. Arch Surg 135:525-528, 2000
10. Moore WS, Barnett HJ, Beebe HG, Bernstein EF, Brener BJ, Brott T, Caplan LR, Day A, Goldstone J, Hobson RW 2nd: Guidelines for carotid endarterectomy. A multidisciplinary consensus statement from the ad hoc Committee, American Heart Association. Stroke 26(1):188-201, 1995
11. North American Symptomatic Carotid Endarterectomy Trial Collaborators, Barnett HJM, Taylor DW, Haynes RB, Sackett DL, Peerless SJ, Ferguson GG, Fox AJ, Rankin RN, Hachinski VC, Wiebers DO, Eliasziw M: Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. N Engl J Med 325:445-453, 1991
12. Okawa M, Abe H, Ueba T, Higashi T, Inoue T: Identification of plaque location using indocyanine green videoangiography during carotid endarterectomy. Acta Neurochir Suppl 119:97–101, 2014
13. Ozgiray E, Akture E, Patel N, Baggott C, Bozkurt M, Niemann D, Baskaya MK: How reliable and accurate is indocyanine green video angiography in the evaluation of aneurysm obliteration? Clin Neurol Neurosurg 115(7):870-878, 2013
14. Raabe A, Beck J, Gerlach R, Zimmermann M, Seifert V: Near-infrared indocyanine green video angiography: A new method for intraoperative assessment of vascular flow. Neurosurgery 52:132-139, 2003
15. Rennert RC, Strickland BA, Ravina K, Bakhsheshian J, Russin JJ: Assessment of hemodynamic changes and hyperperfusion risk after extracranial-to-intracranial bypass surgery using intraoperative indocyanine green–based flow analysis. World Neurosurg 114:352–360, 2018
16. Riles TS, Imparato AM, Jacobowitz GR, Lamparello PJ, Giangola G, Adelman MA, Landis R: The cause of perioperative stroke after carotid endarterectomy. J Vasc Surg 19(2):206-214; discussion 215-216, 1994
17. Rockman CB, Halm EA: Intraoperative imaging: Does it really improve perioperative outcomes of carotid endarterectomy? Semin Vasc Surg 20:236–243, 2007
18. Silver FL, Mackey A, Clark WM, Brooks W, Timaran CH, Chiu D, Goldstein LB, Meschia JF, Ferguson RD, Moore WS, Howard G, Brott TG; CREST Investigators: Safety of stenting and endarterectomy by symptomatic status in the Carotid Revascularization Endarterectomy Versus Stenting Trial (CREST). Stroke 42(3):675-680, 2011
19. Tseng YC, Hsu HL, Lee TH, Chen CJ: Venous reflux on carotid computed tomography angiography: Relationship with left arm injection. J Comput Assist Tomogr 31:360–364, 2007
20. Winkler GA, Calligaro KD, Kolakowski S, Doerr KJ, McAffee-Bennett S, Muller K, Dougherty MJ: Comparison of intraoperative completion flowmeter versus duplex ultrasonography and contrast arteriography for carotid endarterectomy. Vasc Endovascular Surg 40(6):482-486, 2006
21. Zierler RE, Bandyk DF, Thiele BL: Intraoperative assessment of carotid endarterectomy. J Vasc Surg 1:73-83, 1984