64-detector CT angiography within 24 hours after carotid endarterectomy and correlation with postoperative stroke

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OBJECT Carotid endarterectomy (CEA) carries a small but not insignificant risk of stroke/transient ischemic attack (TIA), most frequently observed within 24 hours of surgery, which can lead to the need for urgent vascular imaging in the immediate postoperative period. However, distinguishing expected versus pathological postoperative changes may not be straightforward on imaging studies of the carotid artery early after CEA. The authors aimed to describe routine versus pathological anatomical findings on CTA performed within 24 hours of CEA, and to evaluate associations between these CTA findings and postoperative stroke/TIA.

METHODS The authors reviewed 113 consecutive adult patients who underwent postoperative CTA within 24 hours of CEA at a single academic institution. Presence and location of arterial “flaps,” luminal “step-off,” intraluminal thrombus and hematoma were documented from postoperative CTA scans. Medical records were reviewed to determine the incidence of new postoperative neurological findings.

RESULTS Postoperative CTA findings included common carotid artery (CCA) step-off (63.7%), one or more intraarterial flaps (27.4%), hematoma at the surgical site (15.9%), and new intraluminal thrombus (7.1%). Flaps were seen in the external carotid artery (ECA), internal carotid artery (ICA), and CCA in 18.6%, 9.7%, and 6.2% of patients, respectively. New postoperative neurological findings were present in 7.1% of patients undergoing CTA. Flaps (especially ICA/CCA) and/or intraluminal thrombi were more frequently seen in patients undergoing CTA for new postoperative stroke/TIA (85.7%) versus patients undergoing CTA for routine postoperative imaging (14.3%, $p = 0.002$).

CONCLUSIONS CTA within 24 hours of CEA demonstrates characteristic anatomical findings. CCA step-offs and ECA flaps are relatively common and clinically insignificant, whereas ICA/CCA flaps and thrombi are less frequently seen and are associated with postoperative stroke/TIA.

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KEY WORDS stroke; carotid endarterectomy; CT angiography; vascular disorders

WHILE carotid endarterectomy (CEA) is a well-established treatment for patients with carotid stenosis,^{2,11,21} it is associated with a small but not insignificant rate (3.9%–6.5%) of perioperative stroke/transient ischemic attack (TIA).^{9,16} This can necessitate urgent postoperative neuroimaging of the brain and supplying vasculature. Imaging findings associated with ischemic/hemorrhagic stroke^{3,5,18,26} and hyperperfu-

sion syndrome¹² after CEA are well reported, as are arterial changes (days to weeks)^{8,19} and restenosis (months to years)^{6,7,10,17} after CEA. However, there are few studies examining the carotid artery within the early 24-hour period following CEA (during which more than 75% of perioperative strokes occur),⁹ and, to our knowledge, all have relied upon duplex ultrasound.⁴ Ultrasound is problematic in the immediate post-CEA period with certain

ABBREVIATIONS CCA = common carotid artery; CEA = carotid endarterectomy; CREST = Carotid Revascularization Endarterectomy versus Stenting Trial; CTA = CT angiography; ECA = external carotid artery; ICA = internal carotid artery; NASCET = North American Symptomatic Carotid Endarterectomy Trial; TIA = transient ischemic attack.

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patch grafts⁴ and has overly low sensitivity and poor correlation with abnormal defects seen on post-CEA CTA.²⁰

Published results of CTA after CEA have only reported findings several days¹³ to months²⁰ after CEA. We focused on early CTA (< 24 hours), since rapid (typically 64-detector) CT-based acquisition of parenchymal and vascular neuroimaging is now routinely part of acute stroke protocols at many institutions,²² and has been advocated for workup of perioperative stroke after CEA.¹⁶ We therefore aimed to describe characteristic anatomical findings in a consecutive cohort of patients undergoing CTA within 24 hours of CEA, and to evaluate associations between early postoperative CTA findings and outcomes in this group of patients.

Methods

Patients and Techniques

All consecutive adult patients who underwent 64-detector CTA within 24 hours after CEA at our institution between November 2008 and September 2012 were retrospectively reviewed with approval from our institutional review board. Medical records were reviewed, and demographics, history, operative details, indications for CTA, postoperative course, and complications were recorded. Stroke was defined (per CREST [Carotid Revascularization Endarterectomy vs. Stenting Trial]¹⁴) as an acute neurological event with focal symptoms and signs lasting 24 hours or longer consistent with focal cerebral ischemia; TIA was defined similarly but with complete resolution of symptoms and signs after less than 24 hours. Postoperative CTA (and preoperative CTA, if performed within 6 months of CEA) was analyzed and the following findings were recorded by a blinded board-certified neuroradiologist (Fig. 1; 80% to 100% intraobserver agreement): 1) degree of stenosis (measured according to NASCET [North American Symptomatic Carotid Endarterectomy Trial] criteria);² 2) luminal “step-off” (defined as an abrupt transition in diameter of the artery, typically best seen on coronal or sagittal projections; Fig. 1A);⁸ 3) presence and location of arterial “flaps” (defined as an intraluminal linear hypodensity, typically best seen on combined axial and orthogonal projections; Fig. 1B); 4) presence of thrombus (defined as a focal intraluminal filling defect, typically best seen on axial source images; Fig. 1C); and 5) presence of neck hematoma.

Imaging Protocol

CTA was performed using a 64-detector CT scanner (Brilliance, Philips Medical Systems) after initial noncontrast CT of the brain. Intravenous contrast (75 ml of Optiray 350) was administered at 5 ml/second, followed by a 50-ml saline bolus. Caudocranial acquisition was performed with 64 × 0.625-mm collimation, 0.609:1 pitch, 100 kV, and 300–400 mA. Image analysis involved review of all 0.8-mm raw source images, along with axial, coronal, and sagittal 5-mm overlapping maximum intensity projection reconstructions at 1-mm increments. Soft tissues were evaluated using 3-mm axial reconstructions at 3-mm increments. Further analysis was performed using Vitrea visualization and analysis software (Vital Images).

Statistical Analysis

Data are presented as the mean ± SD or percentage, unless otherwise specified. Comparisons used unpaired t-tests or odds ratios; Fisher's exact test was used to determine significant associations. A p value < 0.05 was considered significant. All analyses were performed using SAS version 9.2/JMP version 9 (SAS Institute).

Results

Patient Characteristics

We identified 113 consecutive patients who underwent CTA within 24 hours of CEA. The mean age was 66.6 ± 10.0 years and 37.2% were female. The majority of patients (92, 81.4%) underwent CEA for symptomatic stenosis; 79.3% initially presented with ischemic stroke (median NIH Stroke Scale score 3) and 20.7% initially presented with TIA. No patient had a prior ipsilateral CEA. Additional demographics are provided in Table 1. Most patients (105, 92.9%) underwent preoperative CTA (25.5 ± 62.9 days prior to CEA), which showed ≥ 70% stenosis in 84 patients (80.0%). The distribution of preoperative stenosis as measured on CTA is given in Table 2. Nearly all patients (112, 99.1%) underwent CEA under general anesthesia; 8 were treated with shunting, 7 had patch angioplasty, and 1 had eversion endarterectomy. The mean cross clamp time in patients who were not treated with shunting was 73.2 ± 18.3 minutes.

CTA Within 24 Hours of CEA: Anatomical Findings

Postoperative CTA demonstrated residual stenosis of 0%–19% (no-to-minimal stenosis) in 98 patients (86.7%) and 20%–49% stenosis in 15 patients (13.3%). The most common postoperative CTA findings (Fig. 1) were a common carotid artery (CCA) step-off (63.7%), followed by one or more intraarterial flaps (27.4%; external carotid artery [ECA], internal carotid artery [ICA], and CCA in descending order of frequency), hematoma at the surgical site (15.9%, none demonstrating contrast extravasation), and intraluminal thrombus (7.1%). The distribution of CTA findings is summarized in Table 3. There was no statistically significant difference in cross-clamp times between patients with or without a CCA step-off (p = 0.31) or flap (p = 0.19).

Thrombus was found to be present on 7.1% of post-CEA CT angiograms (Table 3); half of these angiograms had been obtained in patients who experienced a postoperative stroke or TIA (Table 4). Thrombus was frequently seen in patients with flaps (7 of 11 ICA flaps [63.6%] and 3 of 7 CCA flaps [42.9%]; Tables 3 and 4), but was not seen in any patient with an isolated CCA step-off (0 of 51 patients). The only time thrombus was seen with CCA step-off was when the patient also had a flap (5 of 21 patients [23.8%] who had both CCA step-off and flap; Table 5).

CTA Within 24 Hours of CEA: Clinical Correlation

Of all CT angiograms analyzed, 8 (7.1%) were obtained in patients who demonstrated an early or immediate postoperative neurological event: 5 had a major stroke, 2 experienced a TIA, and 1 had a seizure. Postoperative stroke/

FIG. 1. Characteristics of CTA findings within 24 hours of CEA. **A:** CCA step-off: Preoperative CT angiogram shows severe ICA stenosis and plaque (*left*). Endarterectomy plaque from CEA (*center*). Postoperative CT angiogram demonstrating no residual stenosis but a typical step-off at site of proximal endarterectomy plaque removal (*arrows, right*). **B:** Dissection Flap: Postoperative coronal (*left*) and axial (*right*) CT angiograms with the flap (*arrows*) projecting into the CCA lumen. **C:** Thrombus: Postoperative coronal (*left*) and axial (*right*) CT angiograms with intraluminal thrombi (*arrows*) within the CCA (note also the concurrent flap).

TABLE 1. Patient demographics and history in 113 patients who underwent CTA within 24 hours of CEA

Variable	Value*
Mean age in yrs	66.6 ± 10.0
Female sex	42 (37.2)
Carotid stenosis	
Symptomatic	92 (81.4)
Asymptomatic	21 (18.6)
Medical history	
Coronary artery disease	25 (22.1)
Dyslipidemia	64 (56.6)
Hypertension	85 (75.2)
Diabetes mellitus	25 (22.1)
Coagulation abnormalities	2 (1.8)
Cancer	16 (14.2)
Seizure	4 (3.5)
Valvulopathy	4 (3.5)
Peripheral vascular disease	7 (6.2)
Atrial fibrillation	12 (10.6)
Smoking past	79 (69.9)
Smoking present	38 (33.6)

* Values are presented as the number of patients (%) unless stated otherwise. The mean value is presented as the mean ± SD.

TIA was significantly associated with ICA and CCA (but not ECA) flaps on postoperative CTA (Table 5). Patients underwent post-CEA CTA either as part of routine postoperative screening (separately analyzed below), or as part of emergency post-CEA stroke/TIA. Flaps and/or intraluminal thrombi were more frequently seen in patients undergoing CTA specifically for a new post-CEA stroke/TIA ($n = 7$) than in patients undergoing CTA per the surgeon's postoperative protocol ($n = 106$) (85.7% vs 14.3%, $p = 0.002$). Thrombi in particular were highly associated with new stroke/TIA post-CEA: 57.1% of patients with new stroke/TIA had new thrombus on their postoperative CTA, whereas only 3.8% of patients without new stroke/TIA demonstrated such a finding ($p = 0.0003$). In contrast, there was no significant difference in frequency of CCA step-off between these 2 groups (42.9% vs 65.1%, respectively, $p = 0.25$).

CTA Within 24 Hours of CEA: Yield in Routine Screening

Since few data exist on early CTA findings after CEA, it may be difficult to distinguish a typical/expected finding that would be considered unremarkable after routine

TABLE 2. Distribution of preoperative stenosis (as measured per NASCET criteria) in the 105 patients who underwent preoperative CTA

Stenosis	No. of Patients (%)
Near occlusion	24 (22.9)
70–99%	60 (57.1)
50–69%	19 (18.1)
<50%	2 (1.9)

TABLE 3. Distribution of findings on CTA within 24 hours after CEA in 113 patients

CTA findings	No. of Patients (%)
CCA step-off	72 (63.7)
Any arterial flap*	31 (27.4)
Flap in ECA	21
Flap in ICA	11
Flap in CCA	7
Flap in >1 artery	8
Thrombus	8 (7.1)
Hematoma	18 (15.9)

* Some patients had more than one flap; hence, numbers within arterial subcategories overlap.

CEA, versus a pathological finding on early CTA after a CEA that has been complicated by postoperative stroke/TIA. To estimate the average yield and range of expected findings on an early postoperative CTA in the routinely screened CEA patient (irrespective of postoperative stroke/TIA), we restricted our analysis to the 106 consecutive patients in our series who underwent CTA as part of their surgeon's routine postoperative imaging protocol. In this group, 88 patients (83%) underwent CTA for symptomatic stenosis, and there were 2 (1.9%) postoperative TIAs and 1 nondisabling stroke (0.9%). Yield of early postoperative CTA in this group comprised CCA step-offs in 68 of 106 patients (64.2%), one or more intraarterial flaps in 27 of 106 (25.5%; $n = 19, 9$, and 5 in the ECA, ICA, and CCA, respectively), and thrombi in 6 of 106 patients (5.7%). In this group of routinely screened patients, only intraluminal thrombi and CCA/ICA flaps were significant predictors of postoperative stroke/TIA ($p = 0.008$ and 0.03, respectively). Due to the retrospective nature of this study, prespecified 3-month follow-up with modified Rankin Scale scoring was not available in the majority of these patients. However, 94.3% had 1-month and 74.5% had 6-month documented follow-up, with no patient experiencing a recurrent stroke.

Evolution of Postoperative CTA Findings on Subsequent Repeat CTA

A smaller number of patients ($n = 35$) underwent additional CTA (median 5.4 months) after their initial postoperative CTA, with indications including follow-up of initial findings of thrombus/flap, recurrent symptoms, restenosis found on surveillance ultrasound, and/or postoperative CTA after a contralateral CEA. The small number and het-

TABLE 4. Incidence of flaps and stroke/TIA in 8 patients with thrombus*

Variable	No. of Patients (%)
Stroke/TIA	4 (50)
ICA flap	7 (87.5)
CCA flap	3 (37.5)
ECA flap	2 (25.0)

* Patients with intraluminal thrombus on CTA frequently had a concomitant flap and experienced a high rate of postoperative stroke/TIA.

TABLE 5. Postoperative CTA findings associated with intraluminal thrombus or stroke/TIA in 113 patients*

CTA Finding	N (%)	Association w/ Thrombus		Association w/ Stroke/TIA	
		n	OR (95% CI)	n	OR (95% CI)
CCA step-offs					
Any CCA step-off	72 (63.7)	5	0.95 (0.2–4.2)	3	0.4 (0.1–1.9)
w/ a flap	21 (18.6)	5	9.3 (2.0–42.7)	3	3.7 (0.8–17.8)
w/o a flap	51 (45.1)	0	NA	0	NA
ECA flaps					
Any ECA flap	21 (18.6)	2	1.5 (0.3–8.1)	3	3.7 (0.8–17.8)
w/ other flap	4 (3.5)	1	4.9 (0.5–53)	1	5.7 (0.5–63.6)
w/o other flap	17 (15.0)	1	0.8 (0.1–6.9)	2	2.4 (0.4–13.7)
CCA flaps	7 (6.2)	3	15.2 (2.6–86.8)	2	8.1 (1.3–52.4)
ICA flaps	11 (9.7)	7	176.8 (17.4–1801.0)	4	18.9 (3.5–101.4)

N = total patients harboring a specific CTA finding (step-off or flap); n = number of patients within the category who also had thrombus or stroke/TIA.

* CCA step-offs and ECA flaps were the most common findings on CTA, and were not significantly correlated with thrombus or stroke/TIA when seen as an isolated finding. In contrast, CCA and ICA flaps (and CCA step-offs that also included a flap) were significantly associated with thrombus and stroke/TIA (denoted in boldface).

erogeneous indications did not permit formal analysis and correlation with clinical course, but they do provide insight into the evolution of some of the early findings after CEA. We found resolution of most thrombi (2 of 3) and flaps (10 of 14), whereas most CCA step-offs remained visible, but with smoother margins, on follow-up CTA (Fig. 2).

Discussion

CEA is a routinely performed surgical procedure for treatment of carotid stenosis, with more than 100,000 procedures/year in the United States alone.²³ CEA remains a safe operation in skilled hands, with a small but well-documented perioperative stroke/death rate that has only modestly improved in the two decades between the initial NASCET publication (5.8%)² and the more recent EVA-3S (Endarterectomy versus Angioplasty in Patients with Symptomatic Severe Carotid Stenosis), CREST, and ICSS (International Carotid Stenting Study) trial results (3.2%–3.9% in patients with symptomatic stenosis).²⁵ Analysis of all 1415 patients who underwent CEA in NASCET found that more than three-quarters of perioperative strokes occurred either intraoperatively or within 24 hours after surgery.⁹ Multidetector CT/CTA can be a useful investigative tool in this group of potentially unstable patients¹⁶ by providing rapid and safe access to high-resolution, noninvasive parenchymal and vascular imaging in a single session. Characterization of typical versus pathological changes on early CTA (within 24 hours of CEA) and their association with postoperative stroke/TIA may therefore be of benefit.

Our data suggest that there are distinct radiographic findings on CTA performed within 24 hours of CEA, the most frequent of which is the CCA step-off, seen in nearly two-thirds of our patients. Diaz et al. found only a 25% incidence of CCA step-offs on catheter angiography within the first 2 weeks of CEA, although their data may have been limited by angiographic projections, as this finding was “generally seen only on one angiographic projection” in their series.⁸ In agreement with Diaz et al., we believe

the CCA step-off represents the proximal surgical excision site of the plaque from the CCA (see Fig. 1A), as opposed to focal arterial injury at the site of the CCA cross-clamp during CEA, which would presumably resemble a more focal CCA “indentation” rather than a luminal step-off. Correlation with intraoperative findings revealed that the CCA step-off was always distal to the clamp site and there was no significant difference in cross-clamp times between patients with or without this step-off. While some have reported the CCA step-off to be predictive of postoperative stroke/TIA and restenosis,¹ its relatively high frequency and lack of correlation with postoperative stroke/TIA (Table 5) in our series would argue against this. In patients who undergo additional CTA, the CCA step-off generally persisted but appeared “smoothed over” and did not seem to predispose to restenosis (Fig. 2).

Intraarterial flaps were the second most common finding on early CTA, seen in more than one-quarter of our patients (Table 3). These were most frequently seen in the ECA (18.6% of all patients). This may be related to the “eversion technique” typically used to remove plaque from the ECA, which provides less direct visualization and control of the tapering end of the plaque within the distal lumen. Given the extracranial supply of the ECA, it is not surprising that dissection flaps within this artery did not correlate with postoperative stroke/TIA (Table 5); of 21 patients with ECA flaps, only 3 (14.3%) had stroke/TIA, one of whom also had a concurrent ICA flap. It is possible that the other 2 stroke patients with ECA flaps also had thrombi or a flap in the ICA or CCA that was either too small to be seen on CTA or had embolized by the time the CTA was performed. ICA and CCA flaps occurred less frequently, but appeared to carry more clinical weight than ECA flaps; approximately one-third of patients with an ICA flap or a CCA flap on CTA also had a postoperative stroke/TIA (Table 5).

Intraluminal thrombus was most frequently associated with postoperative stroke/TIA (50.0%). Thrombi were strongly associated with flaps, especially in the ICA; all

FIG. 2. Evolution of early CTA findings on repeat CTA. **A:** CCA step-off: Coronal CT angiogram obtained within 24 hours of CEA, showing typical step-off (arrows) after plaque removal (left). Repeat CTA obtained 2 years later, demonstrating CCA step-off but with smoother margins (right). **B:** Dissection flap: Sagittal CT angiogram obtained within 24 hours of CEA, showing typical ECA dissection flap (arrow; left). Additional CT angiogram obtained 3 months later, demonstrating resolution of the flap (right). **C:** Intraluminal thrombi: Sagittal CT angiogram obtained within 4 hours of CEA, showing intraluminal thrombus (arrow) in the ICA (left). Repeat CTA demonstrating resolution of thrombus 24 hours after heparinization (right).

except one thrombus were associated with an ICA flap, and more than a third had a CCA flap (Tables 4 and 5). This may suggest potential thrombogenicity of post-CEA ICA/CCA flaps, with possible therapeutic implications when seen on early postoperative CTA. ECA flaps were less frequently associated with thrombus, seen in only 2 of 21 ECA flaps; one of these patients also had an ICA flap.

We found a 15.9% incidence of postoperative hematoma on CTA within 24 hours of CEA; none required intervention. This is consistent with the low rate (3.3%) of reoperation for neck hematoma in NASCET, which reported clinically apparent hematomas in 7.1% of patients,⁹ and recent data reporting an incidence of 24% wound hematoma with a similarly low (3.6%) reoperation rate in patients undergoing CEA while receiving dual antiplatelet therapy.¹⁵

Our conclusions must be tempered by the retrospective nature of data collection, the overrepresentation of patients undergoing CEA for symptomatic stenosis (81.4% in this series vs 8.4% in general practice²⁴) and institutional and

physician preferences in choice of surgical technique and use of CTA in carotid artery imaging. Other institutions may therefore find a different range and incidence of CTA findings. However, the associations we found between ICA/CCA dissection flaps, intraluminal thrombi, and stroke/TIA may reasonably be expected to hold elsewhere. We should note that our interpretation of postoperative flaps and/or thrombi seen on CTA could not be directly verified, and may therefore differ at other institutions. We did not analyze how CTA findings changed management. Importantly, while we studied consecutive patients undergoing CTA within 24 hours after CEA, the indications for CTA were heterogeneous and included both routine postoperative imaging as well as CTA specifically performed as part of post-CEA stroke/TIA. As such, our data cannot address the clinical utility, risk-benefit ratio, or cost-effectiveness of routine screening CTA after CEA, and only aims to provide guidance for the physician reviewing findings on a CTA early after CEA.

Conclusions

We categorize findings on early CTA within 24 hours of CEA in the largest series available to date, and provide estimates of the incidence of these findings and their clinical associations. Early post-CEA CTA demonstrates several characteristic findings, some of which are commonly present after CEA (i.e., CCA step-off) and/or are of little clinical consequence (i.e., isolated ECA flaps), whereas others (i.e., ICA/CCA flaps and intraluminal thrombi) are associated with stroke/TIA in our patients. Knowledge of this range of findings may help surgeons and radiologists when reviewing early postoperative CTA after CEA.

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