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Timing of carotid revascularization after acute ischemic stroke: A retrospective comparison of endarterectomy and stenting

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Abstract

To evaluate the impact of timing on perioperative and clinical outcomes in patients undergoing carotid endarterectomy (CEA) or carotid artery stenting (CAS) for symptomatic carotid stenosis. This retrospective cohort study included 400 patients treated with carotid revascularization at a single center from October 2020 to October 2024. Patients were stratified into four timing groups: very early (0–7 days), early (8–14 days), moderately delayed (15–21 days), and delayed (>21 days) after symptom onset. Periprocedural and long-term outcomes, including stroke, mortality, restenosis, and recurrent ischemic events, were assessed and compared between CEA and CAS groups. Periprocedural stroke rates were highest in the very early group (5.0% for CEA vs. 6.6% for CAS, p=0.192) and lowest in the early group (1.7% for CEA vs. 4.0% for CAS, p=0.041). Periprocedural mortality decreased progressively across timing groups, with the delayed group showing the lowest rates (1.4% for CEA vs. 0.0% for CAS, p=0.353). At six months, restenosis rates and recurrent stroke rates were comparable between CEA and CAS across all timing groups. Complications, including bleeding and cardiac events, were more frequent in the very early group and declined with delayed interventions. Timely carotid revascularization within 14 days of symptom onset can reduce the risk of recurrent strokes while maintaining acceptable perioperative safety. However, individualized patient selection based on clinical factors and procedural risks remains critical. Further prospective studies are needed to establish optimal timing thresholds and refine strategies for both early and delayed revascularization.

Keywords: Carotid endarterectomy; carotid artery stenting, timing, symptomatic carotid stenosis, perioperative outcomes

Introduction

Carotid revascularization has been proposed as the most beneficial treatment for stroke prevention in patients with symptomatic carotid stenosis and timely intervention is crucial. Early intervention has been associated with improved clinical outcomes, particularly in patients with severe extracranial carotid stenosis. Among the available treatment options, carotid endarterectomy (CEA) is considered the gold standard, while carotid artery stenting (CAS) serves as an alternative for patients at elevated surgical risk due to comorbidities or unfavorable anatomical features [1-4]. While both CEA and CAS demonstrate comparable long-term outcomes in reducing the risk of stroke, myocardial infarction (MI), or death, the two procedures have distinct perioperative risk profiles. CAS is associated with a higher incidence of periprocedural stroke, whereas CEA is linked to an increased risk of perioperative myocardial infarction. These differences highlight the importance of patient selection and individualized treatment planning based on clinical and anatomical consideration [5]. The timing of carotid revascularization remains a critical determinant of clinical outcomes following acute ischemic stroke. The 2021 guidelines from the American Heart Association (AHA) emphasize the potential benefits of early revascularization, particularly within the first two weeks following the ischemic event. This window is thought to optimize the balance between reducing recurrent ischemic risk and minimizing perioperative complications. The decision to proceed with CEA or CAS should be tailored to the patient's clinical status, comorbidities, and vascular anatomy,

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with timely intervention being crucial to achieving favorable outcomes [6]. Although guidelines emphasize the importance of timely revascularization in reducing stroke recurrence, there remains a scarcity of robust comparative data on the outcomes of early versus delayed interventions for CAS and CEA. This study seeks to address this gap by assessing how the timing of revascularization influences procedural safety and clinical efficacy. By analyzing outcomes in patients undergoing CEA and CAS at different time points following acute ischemic stroke, this investigation aims to refine the understanding of optimal treatment strategies for managing carotid stenosis in this high-risk population.

Material and Methods

Study Design and Population

This retrospective cohort study analyzed patients who underwent carotid revascularization—CEA or CAS following an acute ischemic stroke. The study included consecutive patients treated at a tertiary care center between October 2020 and October 2024. Patients were stratified into groups based on the timing of the revascularization procedure: very early (0–7 days), early (8–14 days), moderately delayed (15–21 days), and delayed (>21 days). Ethical approval (2024/27) for the study was obtained from the institutional review board in accordance with the Declaration of Helsinki. A total of 400 patients were included in the study, with 70 patients (17.5%) in the very early group (0–7 days), 110 (27.5%) in the early group (8–14 days), 90 (22.5%) in the moderately delayed group (15–21 days), and 130 (32.5%) in the delayed group (>21 days). The decision to perform CEA or CAS was based on a multidisciplinary evaluation, including vascular surgeons, neurologists, and interventional neurosurgeons. CEA was preferred for patients with favorable surgical anatomy, lower procedural risk, and no contraindications to surgery. CAS was considered for patients at higher surgical risk due to comorbidities such as severe coronary artery disease, pulmonary disease, or unfavorable neck anatomy, as well as for those with prior neck irradiation or contraindications to general anesthesia. The final decision was individualized based on patient-specific risk factors and imaging findings. The decision regarding when to proceed with revascularization was influenced by factors such as stroke severity, infarct size, hemorrhagic transformation risk, patient stability, and clinician discretion. Patients with minor strokes and no large infarcts on imaging were considered for earlier intervention, while those with extensive infarcts or high hemorrhagic risk underwent delayed revascularization

Inclusion and Exclusion Criteria

Patients aged 18 years or older who experienced an acute ischemic stroke attributed to ≥50% symptomatic or ≥70% asymptomatic carotid artery stenosis and subsequently underwent CEA or CAS were included in this study. Eligible patients were required to have complete clinical, imaging, and procedural data, as well as documented follow-up evaluations at 30 days and 6 months post-procedure. Exclusion criteria encompassed prior carotid revascularization, non-atherosclerotic causes of stroke such as arterial dissection or vasculitis, and evidence of large hemorrhagic transformation on initial imaging. Additionally, patients with incomplete medical records or insufficient follow-up data were excluded to ensure the reliability of the analysis.

Procedure Details

CEA

CEA was performed under general or local anesthesia, selected based on patient-specific factors and surgical requirements. A longitudinal incision in the neck provided access to the carotid artery, where careful dissection exposed the stenotic segment. Following precise removal of the atherosclerotic plaque, the artery was reconstructed using patch angioplasty to optimize vessel diameter and minimize the risk of restenosis. Shunts were not routinely used during the procedure, consistent with institutional protocol. Postoperatively, patients were closely monitored for complications, including neurological changes and local vascular events, with headache evaluations conducted during scheduled follow-up visits.

CAS

CAS was performed under local anesthesia with light sedation to facilitate intra-procedural patient communication. Vascular access was obtained via the femoral artery, and a guiding catheter was advanced to the stenotic segment under fluoroscopic guidance. A distal embolic protection device was deployed to mitigate the risk of embolization during the intervention. Pre-dilation of the stenosis was achieved with balloon angioplasty, followed by the deployment of a self-expanding stent to restore vessel patency. After stent placement, the embolic protection device was retrieved, and completion angiography confirmed the success of the revascularization. Postoperative monitoring included assessments for procedural complications and systematic evaluation of headache symptoms as per the study protocol.

Both procedures were performed by experienced vascular and interventional specialists, adhering strictly to standardized institutional protocols to ensure uniformity in procedural quality and outcomes across cases.

Outcomes and Measurements

Primary Outcomes

The primary outcomes focused on the immediate safety of carotid revascularization and included:

Periprocedural Stroke: The incidence of major or minor strokes occurring within 30 days of the intervention. Stroke events were confirmed through clinical evaluation and neuroimaging.

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Periprocedural Mortality: All-cause mortality occurring within 30 days post-procedure.

Secondary Outcomes

Secondary outcomes assessed the intermediate and long-term efficacy and safety of the procedures:

Restenosis at Follow-Up: Defined as ≥50% recurrent narrowing of the treated carotid artery segment, as detected by Doppler ultrasonography or angiography. Follow-up assessments were performed at 6 months and 1 year to capture both intermediate and late restenosis.

Recurrent Stroke: Any ischemic stroke occurring beyond the periprocedural period up to 6 months post-procedure, confirmed by clinical presentation and imaging findings.

Timing-Based Stratification

To investigate the impact of procedural timing on outcomes, patients were stratified into four groups based on the time from the index ischemic stroke to revascularization:

Very Early (0–7 days): Procedures performed within the first week post-stroke.

Early (8–14 days): Interventions conducted during the second week.

Moderately Delayed (15–21 days): Procedures performed in the third week.

Delayed (>21 days): Interventions conducted beyond 21 days after the index stroke.

Data Collection and Outcome Assessment

Primary and secondary outcomes were systematically recorded by an independent clinical team to ensure objectivity. Periprocedural stroke and mortality were documented during the first 30 days post-intervention. Restenosis assessments were performed at 6-month and 1-year follow-ups, utilizing Doppler ultrasonography or angiography to evaluate vessel patency. Recurrent strokes were monitored throughout the 6-month follow-up period with clinical assessments corroborated by imaging. Statistical analyses, including subgroup comparisons by timing groups, were conducted to evaluate the influence of procedural timing and intervention type (CEA vs. CAS) on outcomes.

Statistical Analysis

The software IBM® SPSS® (Statistical Package for the Social Sciences) version 25 (IBM Corp. Armonk, NY, USA) was used for statistical analysis. The distribution of numerical data was performed using the Kolmogorov–Smirnov test. Qualitative data were presented as frequency and percentage. The chi-square test was utilized for comparisons involving categorical variables. A significance level of 0.05 was considered for all tests.

Results

A total of 400 patients underwent carotid revascularization during the study period, comprising 220 (55%) who received CEA and 180 (45%) who underwent CAS. The distribution of procedures showed 70 patients (17.5%) in the very early group, 110 (27.5%) in the early group, 90 (22.5%) in the moderately delayed group, and 130 (32.5%) in the delayed group (Table 1) (Figure 1).

Table 1. Timing and distribution of revascularization procedures

Group	CEA (n=220)	CAS (n=180)	Total (n=400)
Very early (0–7 days)	40	30	70
Early (8–14 days)	60	50	110
Moderately delayed (15–21 days)	50	40	90
Delayed (>21 days)	70	60	130

CEA: carotis endarterectomy, CAS: carotis artery stenting

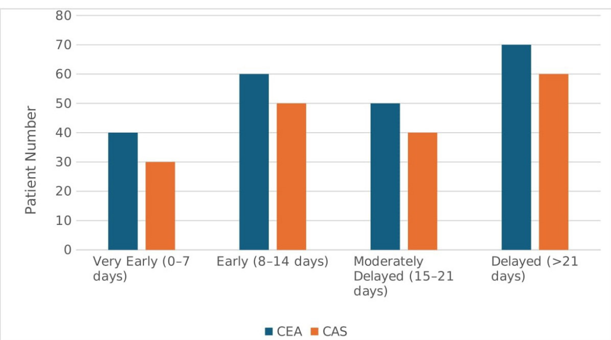

Figure 1. Timing and distribution of revascularization procedures (CEA: carotis endarterectomy, CAS: carotis artery stenting)

Periprocedural stroke rates were highest in the very early group, with 5.0% for CEA and 6.6% for CAS, though the difference was not statistically significant (p=0.192). Stroke rates decreased significantly in the early group to 1.7% for CEA and 4.0% for CAS (p=0.041). In the moderately delayed group, stroke rates were 2.0% for CEA and 2.5% for CAS (p=0.059), while the delayed group showed rates of 4.3% for CEA and 3.3% for CAS (p=0.072). Periprocedural mortality followed a similar trend, with the very early group showing the highest rates (5.0% for CEA vs. 3.3% for CAS, p=0.142), and the delayed group exhibiting the lowest mortality (1.4% for CEA vs. 0.0% for CAS, p=0.353) (Table 2).

Table 2. Primary and secondary outcomes by procedure type and timing

Outcome	Timing	CEA, n (%)	CAS, n (%)	p†
Primary outcomes				
Periprocedural stroke	VE	2/40 (5.0)	2/30 (6.6)	0.192
	E	1/60 (1.7)	2/50 (4.0)	**0.041***
	MD	1/50 (2.0)	1/40 (2.5)	0.059
	D	3/70 (4.3)	2/60 (3.3)	0.072
Periprocedural mortality	VE	2/40 (5.0)	1/30 (3.3)	0.142
	E	1/60 (1.7)	2/50 (4.0)	**0.048***
	MD	0/50 (0.0)	1/40 (2.5)	0.261
	D	1/70 (1.4)	0/60 (0.0)	0.353
Secondary outcomes				
Restenosis at follow-up	VE	3/38 (7.9)	2/29 (6.8)	0.878
	E	2/59 (3.3)	3/48 (6.2)	0.486
	MD	2/50 (4.0)	1/38 (2.6)	0.726
	D	2/69 (2.8)	2/60 (3.3)	0.887
Recurrent stroke (6-month)	VE	4/38 (10.5)	5/30 (16.6)	0.458
	E	3/59 (5.0)	3/48 (6.2)	0.794
	MD	2/50 (4.0)	2/38 (5.2)	0.778
	D	2/59 (3.3)	3/60 (5.0)	0.083

VE: very early (0–7 days), E: early (8–14 days), MD: moderately delayed (15–21 days), D: delayed (>21 days), †Chi Square Test, *p<0.05

Secondary outcomes revealed that restenosis rates at follow-up ranged from 1.8% to 4.3% for CEA and 2.6% to 6.8% for CAS across all timing groups, with no significant differences. Recurrent stroke rates at six months were highest in the very early group (10.5% for CEA vs. 16.6% for CAS, p=0.458), while the delayed group had the lowest rates (3.3% for CEA vs. 5.0% for CAS, p=0.083) (Figure 2).

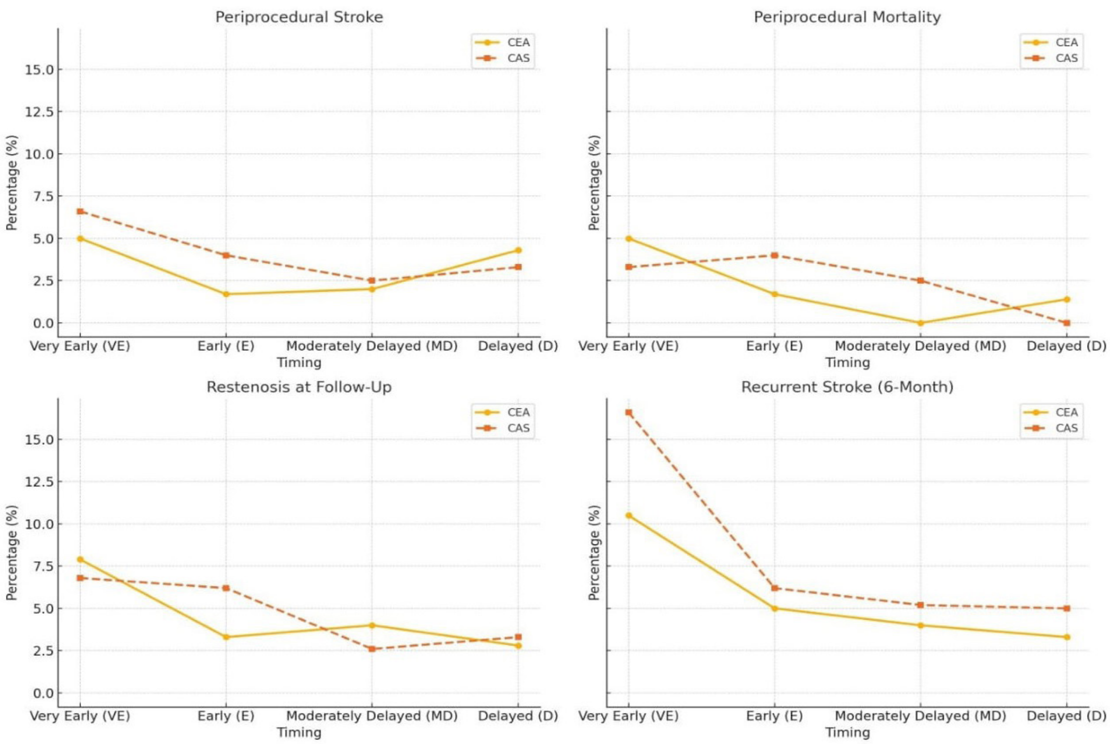

Figure 2. Primary and secondary outcomes by procedure type and timing

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Complications were more frequent in the very early group, with bleeding rates of 4.3% that declined to 0.8% in the delayed group (p=0.042) (Table 3). Similarly, cardiac events were highest in the very early group at 5.7%, stabilizing to 2.3% in the delayed group (p=0.532). Timing-related clinical outcomes demonstrated consistent rates of recurrent transient ischemic attacks (TIAs) across groups, ranging from 4.4% to 7.1% (p=0.571). Contralateral stroke rates were also stable, varying from 2.2% to 5.7% (p=0.058) (Table 4). Major bleeding events were most frequent in the very early group (2.9%) and least frequent in the delayed group (1.5%, p=0.837).

Table 3. Complications by timing

Complication	VE	E	MD	D	p†
Bleeding complications (%)	3/70 (4.3)	2/110 (1.8)	1/90 (1.1)	1/130 (0.8)	**0.042***
Hyperperfusion syndrome (%)	2/70 (2.9)	1/110 (0.9)	1/90 (1.1)	0/130 (0.0)	0.287
Cardiac events (%)	4/70 (5.7)	3/110 (2.7)	2/90 (2.2)	3/130 (2.3)	0.532

VE: very early (0–7 days), E: early (8–14 days), MD: moderately delayed (15–21 days), D: delayed (>21 days), †Chi Square Test, *p<0.05

Table 4. Timing-related clinical outcomes and complications

Outcome	VE	E	MD	D	p†
Recurrent TIA (%)	5/70 (7.1)	6/110 (5.5)	4/90 (4.4)	8/130 (6.2)	0.571
Symptomatic restenosis (%)	3/70 (4.3)	2/110 (1.8)	3/90 (3.3)	5/130 (3.8)	0.201
Contralateral stroke (%)	4/70 (5.7)	3/110 (2.7)	2/90 (2.2)	4/130 (3.1)	0.058
Major bleeding events (%)	2/70 (2.9)	3/110 (2.7)	1/90 (1.1)	2/130 (1.5)	0.837

VE: very early (0–7 days), E: early (8–14 days), MD: moderately delayed (15–21 days), D: delayed (>21 days), †Chi Square Test

Discussion

The timing of carotid revascularization remains a critical determinant of clinical outcomes in patients with symptomatic carotid stenosis. Rothwell et al. determined that the effectiveness of carotid endarterectomy is influenced by factors beyond stenosis severity, including patient age, sex, and timing of intervention, with the highest benefit achieved when performed within two weeks of the most recent ischemic event [7]. Similarly, our study showed a gradual decrease in periprocedural stroke rates between the very early (0-7 days) and early (8-14 days) and moderately delayed (15-21 days) groups, there was no significant difference in outcomes between CEA and CAS when revascularization was delayed for more than 21 days, but periprocedural stroke in the moderately delayed group was significantly higher than in the CAS group

In a meta-analysis, Rango et al. evaluated the timing-related periprocedural risks of CEA and CAS in patients with symptomatic carotid stenosis and concluded that revascularization can be safely performed within the first 7 days after symptom onset and that CEA showed a slightly lower stroke risk compared to CAS [2]. Similarly, our data indicate that in the early group, periprocedural stroke rates were significantly lower for CEA (1.7%) compared to CAS (4.0%), reinforcing the safety of CEA in early revascularization when appropriately timed and selected.

Cui et al. demonstrated that carotid endarterectomy is the safest option during the urgent period, while transcarotid artery revascularization yields comparable outcomes to endarterectomy when performed beyond 48 hours after symptom onset [8]. In our study, periprocedural mortality was highest in the very early group, particularly for CEA (5.0%), but decreased with delayed interventions, supporting the cautious use of early surgery only in select high-risk patients.

In the study reviewed 20 Randomized Controlled Trials (RCTs) by Batchelder et al., which , CAS demonstrates higher 30-day death and stroke rates compared to CEA, while long-term ipsilateral stroke rates are comparable, emphasizing the need for improved case selection, advanced stent technologies, and optimal perioperative strategies to enhance outcomes [9]. These findings align with our results, which showed comparable rates of recurrent stroke and restenosis at six months between the two procedures across all timing groups, emphasizing the need for refined patient selection and optimized procedural strategies.

Studies have associated early surgery on the stenotic but patent cervical internal carotid artery with ipsilateral cerebral hemorrhage and infarct expansion, emphasizing the need for careful timing and patient selection to reduce these risks [10,11]. Our findings support this observation, with higher incidences of bleeding complications (4.3%) and cardiac events (5.7%) in the very early group compared to later groups. Patients who developed intracerebral hematomas postoperatively shared common characteristics, including preoperative high-grade cervical carotid stenosis and hypoperfusion, as indicated by physiological measurements, while postoperative hyperperfusion of the ipsilateral hemisphere was confirmed by increased cerebral blood flow [12,13]. Conversely, delaying endarterectomy exposes patients to a 2% to 21% risk of recurrent stroke or the potential for carotid occlusion, emphasizing the need for timely intervention [14-18].

Lin et al. demonstrated that CAS can be safely performed shortly after a non-disabling stroke, with comparable 30-day rates of stroke, myocardial infarction, or death between early (≤4 weeks) and late (>4 weeks) interventions; however, advanced age (>80 years) significantly increases the risk of adverse outcomes, emphasizing the need for tailored patient selection [19]. Similarly, Topakian et al. demonstrated that CAS in patients with symptomatic carotid stenosis is associated with higher 30-day stroke and death rates in older patients and when performed within two weeks of the qualifying event, emphasizing the importance of patient selection and timing to optimize outcomes [20]. Our findings align with these observations, as the timing of intervention played a significant role in determining outcomes, reinforcing the need for individualized strategies to optimize patient selection and procedural timing. These findings suggest that while early interventions (8–14 days) provide the best balance between safety and efficacy, delayed procedures may reduce the risk of complications, particularly bleeding and cardiac events, in select patient populations.

In summary, while early revascularization offers a critical window for reducing recurrent stroke risks, it must be balanced against procedural complications, especially in high-risk groups such as older patients. Our results suggest that CEA provides safer outcomes than CAS in the early period, while both procedures are comparable in delayed settings. Future prospective studies should address these gaps by standardizing definitions of "early" intervention, evaluating long-term outcomes, and determining the role of emerging medical therapies in optimizing revascularization strategies. These insights will help refine clinical guidelines for managing carotid stenosis in the context of acute ischemic stroke.

Conclusion

This study highlights the critical role of timing in carotid revascularization for patients with symptomatic carotid stenosis. Our findings demonstrate that earlier interventions, particularly within 14 days, can reduce the risk of recurrent strokes while maintaining acceptable perioperative outcomes. However, the choice between CEA and CAS should be tailored based on patient-specific factors, including clinical presentation, comorbidities, and procedural risks. The results underscore the need for further prospective studies to refine timing thresholds and optimize patient outcomes in both early and delayed revascularization settings.

Limitations

This study has several limitations. First, the retrospective design may introduce bias in data collection and interpretation. Second, this was a single-center study, which may limit the generalizability of the findings to other settings. Third, the lack of randomization between CEA and CAS procedures may have influenced outcome comparisons. Finally, follow-up data beyond six months were unavailable, which restricts the evaluation of long-term outcomes, such as restenosis and late ischemic events. Future multicenter, prospective studies with extended follow-up are warranted to validate these findings and address these limitations.

Conflict of Interests
The authors declare that there is no conflict of interest in the study.

Financial Disclosure
The authors declare that they have received no financial support for the study.

Ethical Approval
Ethical approval (2024/22-2) for the study was obtained from the institutional review board in accordance with the Declaration of Helsinki.

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