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Clinical outcomes of carotid artery stenting in an experienced center

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Abstract

Carotid artery stenting (CAS) is increasingly used as an alternative revascularization strategy for carotid artery stenosis, particularly in selected patients treated at experienced centers. The aim of this study was to evaluate procedural safety, technical performance, and clinical outcomes of CAS performed using a uniform endovascular strategy at a single institution. In this retrospective analysis, 120 consecutive patients with angiographically documented carotid artery stenosis ranging from 50% to 99% underwent carotid artery stenting. Both symptomatic and asymptomatic cases were included. All interventions were performed by senior operators using a standardized stent system, with cerebral protection devices used whenever anatomical conditions permitted. Clinical and imaging-based outcomes were reviewed over a follow-up period of 5 to 84 months. Successful stent deployment was achieved in all cases, yielding a technical success rate of 100%, with no procedure-related deaths. Periprocedural myocardial infarction occurred in two patients (1.6%). One patient (0.8%) experienced an ischemic event within the treated vascular territory, while another patient (0.8%) developed thromboembolic occlusion of the ipsilateral middle cerebral artery requiring thrombectomy, without persistent neurological impairment. Transient neurological symptoms were observed in two patients (1.6%) after bilateral stenting procedures. During follow-up, in-stent restenosis was identified in three patients (2.5%), with reintervention required in only one case. No stent occlusions were detected. When performed by experienced teams using a consistent endovascular technique and routine cerebral protection, carotid artery stenting is associated with high procedural success and low rates of adverse events. These results support the role of CAS as a safe and effective revascularization option in appropriately selected patients.

Keywords: Carotid artery stenosis, carotid artery stenting, endovascular revascularization, cerebral protection devices, carotid revascularization

Introduction

Carotid artery stenosis represents one of the leading etiologies of ischemic stroke and transient ischemic attack (TIA) and remains a major contributor to global cerebrovascular morbidity and mortality. Progressive atherosclerotic disease of the extracranial internal carotid artery may result in cerebral hypoperfusion or artery-to-artery embolization, thereby necessitating timely revascularization in appropriately selected patients. Carotid endarterectomy (CEA) has been widely accepted as the standard surgical treatment for patients with high-grade symptomatic carotid stenosis. Multiple randomized controlled trials have established its superiority over best medical therapy alone, demonstrating a significant reduction in recurrent stroke risk. Seminal investigations led by Barnett and colleagues showed that CEA markedly lowered the incidence of stroke in patients with symptomatic severe carotid stenosis when compared with conservative, non-operative management [1,2].

Over the past two decades, carotid artery stenting (CAS) has become an established minimally invasive alternative to carotid endarterectomy, particularly for patients considered to be at increased surgical risk due to significant comorbid conditions or unfavorable cervical anatomy. Advances in endovascular technology, along with the widespread adoption of cerebral protection devices (CPDs), have contributed to improvements in the procedural safety of CAS. Numerous randomized controlled trials and meta-analyses have compared the outcomes of CAS and CEA. Data from large studies, including the Carotid Revascularization Endarterectomy versus Stenting Trial (CREST), indicate that long-term stroke prevention is largely comparable between the two treatment strategies; however, CAS

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has been associated with a higher rate of periprocedural stroke, especially in older patients, whereas CEA may be associated with lower overall complication rates in both symptomatic and asymptomatic populations [3,4].

Despite these comparative data, outcomes after CAS are strongly influenced by operator expertise, institutional volume, use of cerebral protection strategies, and patient selection. Meta-analytic evidence supports the use of CPDs during carotid stenting to reduce embolic complications, with studies showing lower rates of periprocedural neurological events when CPDs are used [5,6]. Current vascular and stroke guidelines emphasize that CAS may be considered a reasonable alternative to CEA when performed by experienced endovascular practitioners and in centers with documented low perioperative stroke and death rates, especially in patients with high surgical risk [7].

In the present analysis, we evaluated the results of carotid artery revascularization using endovascular stent placement in a consecutive cohort of patients treated at a single institution by experienced operators. A uniform procedural approach was adopted, including the use of a consistent stent system and cerebral protection devices, in order to assess procedural safety, technical performance, and clinical outcomes of carotid artery stenting in both symptomatic and asymptomatic patients over mid- to long-term follow-up.

Material and Methods

Study Design and Patient Population

This retrospective analysis was conducted at a single institution to assess clinical outcomes following endovascular treatment of carotid artery disease. Patients with angiographically verified carotid artery stenosis who underwent carotid artery stenting (CAS) between January 2018 and December 2025 were consecutively included. All interventions were performed by the same group of senior operators to maintain procedural uniformity and reduce operator-related variability. The study protocol received approval from the İstanbul University, İstanbul Faculty of Medicine Clinical Research Ethics Committee (approval date: 13 March 2024; decision number: 2024/2475191), and the requirement for informed consent was waived because of the retrospective study design.

During the study period, 120 patients with carotid artery stenosis ranging from 50% to 99% underwent treatment. Both symptomatic and asymptomatic cases were included. Symptomatic status was defined by the presence of ipsilateral ischemic stroke or transient ischemic attack (TIA) prior to the procedure, whereas patients without a history of focal neurological symptoms attributable to the treated carotid artery were classified as asymptomatic.

Patient Selection Criteria

Patients were selected for carotid artery stenting based on multidisciplinary evaluation, including vascular surgery, neurology, and interventional radiology teams. Symptomatic carotid stenosis was defined as an ipsilateral ischemic stroke or transient ischemic attack (TIA) within the preceding 6 months attributable to the target carotid artery. Asymptomatic stenosis was defined as the absence of focal neurological symptoms referable to the treated carotid territory. Anatomical suitability for CAS included accessible vascular anatomy, absence of prohibitive aortic arch complexity, and lesion characteristics amenable to endovascular treatment. Patients with heavily calcified, extremely tortuous, or long-segment lesions were evaluated individually for feasibility.

High surgical risk was defined according to contemporary clinical practice standards and included one or more of the following: severe cardiopulmonary disease, prior neck surgery or radiation therapy, contralateral carotid artery occlusion, restenosis after prior endarterectomy, or anatomically high carotid bifurcation. In patients without high-surgical-risk features, CAS was performed when deemed appropriate by the multidisciplinary team based on patient preference and institutional expertise.

Preprocedural Assessment

Before intervention, all patients underwent thorough clinical evaluation, including comprehensive neurological examination and assessment of relevant vascular risk factors. The severity of carotid artery stenosis was established using digital subtraction angiography and categorized as moderate (50–70%) or severe (70–99%). Patients with unilateral or bilateral carotid artery disease were included, as were those with contralateral carotid artery occlusion.

Dual antiplatelet therapy was initiated prior to the procedure in accordance with institutional protocol unless contraindicated. Periprocedural anticoagulation was administered during the intervention following standard endovascular practice.

Endovascular Procedure

All procedures were performed under local anesthesia with continuous neurological monitoring. Carotid artery stenting was carried out using a standardized endovascular technique. A self-expandable nitinol open-cell stent (Precise stent, Cordis, USA) was used in all cases to maintain uniformity of device selection. Cerebral protection devices (Angioguard, Cordis, USA) were routinely employed whenever anatomically feasible (Figure 1, Figure 2 and Figure 3).

After deployment of the cerebral protection device distal to the stenotic lesion, the lesion was crossed and predilated if necessary. The stent was subsequently deployed across the diseased segment, followed by post-dilatation at the operator's discretion. Technical success was defined as successful stent deployment with restoration of adequate luminal diameter and no residual stenosis requiring additional intervention.

In patients with bilateral carotid artery stenosis, both lesions were treated during the same session when clinically appropriate.

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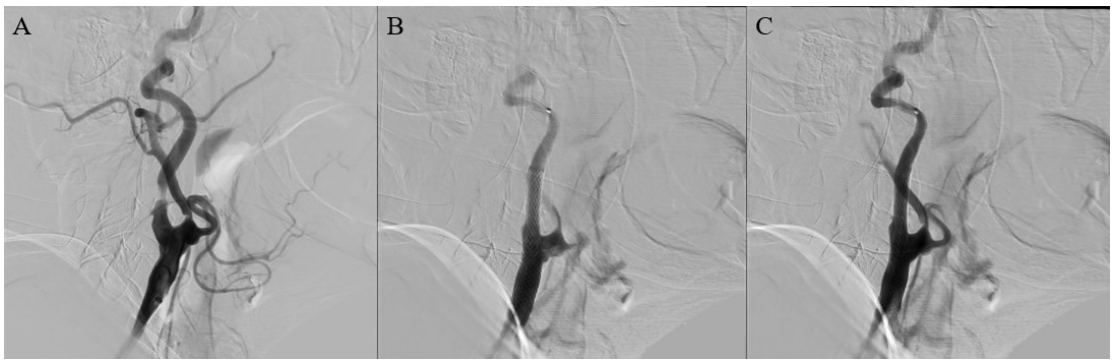

Figure 1. Digital subtraction angiography of a representative patient undergoing carotid artery stenting; (**A**) Preprocedural angiography demonstrating severe internal carotid artery stenosis; (**B**) Angiographic image following deployment of a self-expandable carotid stent, showing restoration of luminal diameter; (**C**) Final control angiography demonstrates satisfactory vessel patency with no residual stenosis and preserved distal cerebral perfusion

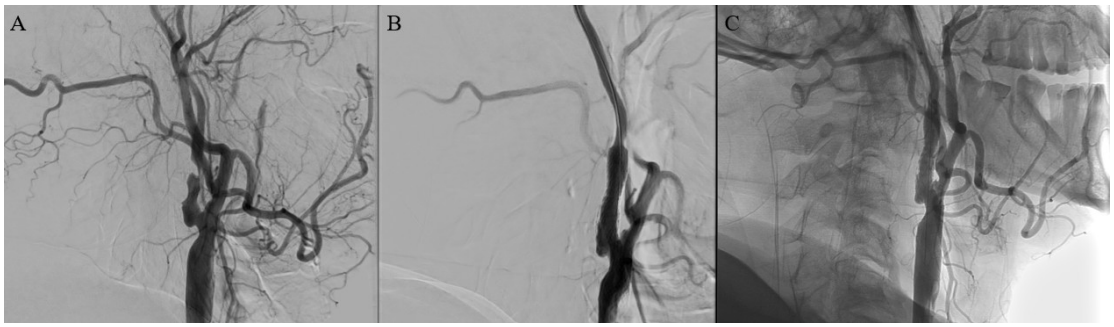

Figure 2. Digital subtraction angiography of a representative patient undergoing carotid artery stenting; (**A**) Preprocedural angiography demonstrates high-grade internal carotid artery stenosis with irregular plaque morphology; (**B**) Angiographic image following deployment of a self-expandable carotid stent, showing improvement in luminal diameter; (**C**) Final angiographic control confirmed adequate stent expansion, satisfactory vessel patency, and preserved intracranial flow

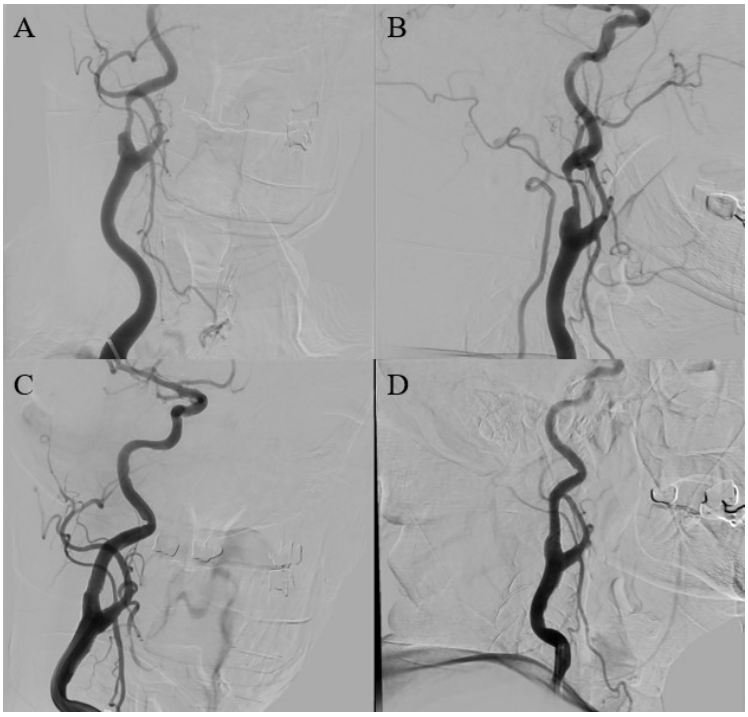

Figure 3. Digital subtraction angiography of a representative patient with complex internal carotid artery anatomy undergoing carotid artery stenting; (**A, B**) Preprocedural angiographic views demonstrating high-grade internal carotid artery stenosis with marked vessel tortuosity; (**C**) Angiographic image following deployment of a self-expandable carotid stent, showing restoration of luminal diameter despite tortuous anatomy; (**D**) Final control angiography confirmed adequate stent expansion, satisfactory vessel patency, and preserved distal cerebral circulation

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Postprocedural Care and Follow-Up

Following the procedure, patients were monitored in a dedicated neurological or intensive care unit to detect neurological or cardiac complications early. Dual antiplatelet therapy was continued postprocedurally according to institutional protocol.

Clinical follow-up consisted of outpatient visits with neurological examinations. Imaging follow-up included carotid duplex ultrasonography and, when indicated, cross-sectional imaging or angiography. In-stent restenosis was defined as a significant luminal narrowing detected on follow-up imaging.

Outcome Measures

Primary outcome measures included procedural technical success, periprocedural stroke, myocardial infarction, and mortality occurring within 30 days of the procedure. Periprocedural myocardial infarction was defined as the occurrence of chest pain or ischemic symptoms associated with new electrocardiographic changes and/or elevation of cardiac biomarkers exceeding the institutional upper reference limit. Periprocedural ischemic stroke was defined as a new focal neurological deficit lasting more than 24 hours with corresponding radiological evidence of cerebral ischemia within the treated vascular territory.

Transient neurological symptoms were defined as reversible focal neurological deficits resolving within 24 hours without imaging-confirmed infarction. In-stent restenosis was defined as ≥50% luminal narrowing detected by duplex ultrasonography or confirmed by cross-sectional imaging during follow-up. Secondary outcome measures included access-site complications, need for reintervention, and late stent occlusion.

Statistical Analysis

This study was designed as a descriptive single-center retrospective analysis. No formal comparative statistical testing was performed due to the sample size and the observational design. Continuous variables were expressed as mean values and ranges, while categorical variables were presented as absolute numbers and percentages.

Results

Patient Characteristics

A total of 120 patients underwent carotid artery stenting during the study period. There were 77 male (64.2%) and 43 female (35.8%) patients, with a mean age of 67.3 years (range: 45–86 years). Ninety-five patients (79.2%) were symptomatic at presentation, having experienced an ipsilateral ischemic stroke or transient ischemic attack, while 25 patients (20.8%) were asymptomatic.

Regarding stenosis severity, 53 patients (44.2%) had moderate stenosis (50–70%), and 67 patients (55.8%) had severe stenosis (70–99%). Forty-two patients (35.0%) had contralateral carotid artery occlusion. Unilateral carotid stenosis was present in 94 patients (78.3%), whereas 26 patients (21.7%) had bilateral carotid artery stenosis and underwent treatment of both lesions during the same session (Table 1).

Table 1. Baseline demographic and clinical characteristics of the study population

Characteristic	Value
Number of patients	120
Age, mean (range), years	67.3 (45–86)
Male sex, n (%)	77 (64.2)
Female sex, n (%)	43 (35.8)
Symptomatic patients, n (%)	95 (79.2)
Asymptomatic patients, n (%)	25 (20.8)
Degree of stenosis 50–70%, n (%)	53 (44.2)
Degree of stenosis 70–99%, n (%)	67 (55.8)
Contralateral carotid occlusion, n (%)	42 (35.0)
Unilateral carotid stenosis, n (%)	94 (78.3)
Bilateral carotid stenosis treated in the same session, n (%)	26 (21.7)

Procedural Characteristics

All interventions were completed without technical complications, yielding a procedural success rate of 100%. Cerebral protection devices were utilized in 112 procedures (93.3%). In eight cases (6.7%), CPDs were not used due to unfavorable distal landing zones, severe vessel tortuosity preventing safe device advancement, or extremely tight stenosis that precluded secure filter deployment. Deployment of a self-expandable nitinol open-cell stent was achieved successfully in every case. No procedures were discontinued as a result of anatomical challenges or technical limitations (Table 2).

Table 2. Procedural details and periprocedural outcomes

Variable	Value
Technical success rate	100%
Procedures using cerebral protection device, n (%)	112 (93.3)
Procedure-related mortality	0
Periprocedural stroke, n (%)	1 (0.8)
Myocardial infarction, n (%)	2 (1.6)
Thromboembolic MCA occlusion, n (%)	1 (0.8)
Transient neurological symptoms, n (%)	2 (1.6)

Periprocedural and Early Outcomes

There were no procedure-related deaths. Periprocedural myocardial infarction occurred in two patients (1.6%). One patient (0.8%) experienced an ischemic stroke in the treated vascular territory three days after the procedure. One additional patient (0.8%) developed thromboembolic occlusion of the ipsilateral middle cerebral artery requiring mechanical thrombectomy; this patient recovered without a permanent neurological deficit (Table 2).

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Transient neurological symptoms were observed in two patients (1.6%) who had undergone bilateral carotid stenting; these patients developed reversible confusion and disorientation that resolved without residual deficits.

Follow-Up Outcomes

The duration of clinical and radiological follow-up ranged from 5 to 84 months. During follow-up, three patients (2.5%) developed in-stent restenosis. Of these, one patient (0.8%) required balloon angioplasty, while the remaining cases were managed conservatively. No cases of stent occlusion were observed during follow-up (Table 3).

Table 3. Long-term follow-up outcomes after carotid artery stenting

Outcome	Value
Follow-up duration, months	5–84
In-stent restenosis, n (%)	3 (2.5)
Reintervention for restenosis, n (%)	1 (0.8)
Stent occlusion	0

Discussion

This single-center experience demonstrates that carotid artery stenting (CAS) can be performed with excellent technical success and low complication rates when undertaken by experienced operators using a standardized endovascular approach. In our cohort of 120 patients treated between 2018 and 2025, there were no procedure-related deaths, and the incidences of periprocedural stroke and myocardial infarction were low, supporting the safety and effectiveness of CAS in appropriately selected patients.

Large randomized trials have shaped contemporary practice in carotid revascularization. The Carotid Revascularization Endarterectomy versus Stenting Trial (CREST) showed no significant difference between CAS and carotid endarterectomy (CEA) in the composite endpoint of stroke, myocardial infarction, or death, although CAS was associated with a higher periprocedural stroke rate and CEA with a higher myocardial infarction rate. Long-term follow-up from CREST and other trials confirmed comparable durability between the two modalities [8,9]. The periprocedural stroke rate of 0.8% observed in our series compares favorably with these randomized data and with large registry reports, underscoring the importance of institutional experience and procedural consistency.

Age has been identified as a critical modifier of outcomes after CAS, with increasing stroke risk observed in elderly patients undergoing stenting [8,10]. Despite a mean age exceeding 67 years in our population, complication rates remained low, suggesting that careful patient selection and technical expertise can mitigate age-related risks. This observation aligns with meta-analyses demonstrating improved CAS outcomes in high-volume centers with experienced operators [2,6].

The routine use of cerebral protection devices (CPDs) is a key factor in achieving favorable neurological outcomes in CAS. In our study, CPDs were used in more than 90% of procedures, likely contributing to a significant reduction in embolic complications. Previous studies have demonstrated that embolic protection reduces the incidence of periprocedural neurological events, particularly in symptomatic patients and those with complex plaque morphology [3,4]. Current guideline statements and expert reviews consistently recommend the use of CPDs whenever anatomically feasible during CAS [11].

Another notable aspect of this study is the standardized use of a single self-expandable nitinol open-cell stent system. Variability in stent design and endovascular equipment has been associated with differences in embolic risk and procedural outcomes. By maintaining consistency in device selection and technique, our center achieved a 100% technical success rate, with no device-related failures. Similar observations have been reported in single-center series, emphasizing that procedural standardization contributes significantly to improved outcomes in CAS [12–15].

Long-term durability is an important consideration following carotid revascularization. In-stent restenosis occurred in 2.5% of patients during follow-up in our cohort, with only one patient requiring repeat intervention. These findings compare favorably with published restenosis rates after CAS, which typically range from 3% to 10%, and are similar to or lower than restenosis rates reported after CEA [2,8]. Importantly, no stent occlusions were observed, supporting the long-term patency of carotid stents when deployed under optimal conditions.

An important consideration in carotid artery stenting is the requirement for prolonged antithrombotic therapy to prevent acute and late stent thrombosis. Unlike carotid endarterectomy, CAS necessitates dual antiplatelet therapy in the early postprocedural period and long-term single antiplatelet therapy thereafter. In selected patients, particularly those with atrial fibrillation or other indications for oral anticoagulation, complex antithrombotic regimens may be required. Contemporary neurointerventional guidelines emphasize the importance of adequate antiplatelet management to reduce thromboembolic complications while balancing bleeding risk. Cases of acute, early, and late carotid stent thrombosis have been described in the literature, underscoring the need for careful pharmacological management and long-term surveillance. Therefore, although CAS offers a minimally invasive alternative to surgery, the requirement for sustained antithrombotic therapy may represent a relative disadvantage compared with carotid endarterectomy, particularly in patients at high bleeding risk [16–20].

Taken together, these results highlight that the clinical success of carotid artery stenting is closely linked to operator expertise, institutional experience, appropriate patient selection, and strict adherence to standardized procedural protocols. When these factors are present, carotid artery stenting constitutes a dependable alternative to carotid endarterectomy, particularly for patients with elevated surgical risk, contralateral carotid occlusion, or challenging cervical anatomy.

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Limitations

Several limitations should be acknowledged. First, the retrospective design introduces potential selection and reporting bias. Second, the single-center nature of the study and performance by experienced operators may limit generalizability to lower-volume centers. Third, the absence of a contemporaneous control group, such as patients undergoing carotid endarterectomy, precludes direct comparative evaluation of treatment strategies. Additionally, no formal subgroup statistical comparisons were performed between symptomatic and asymptomatic patients. Finally, a detailed assessment of long-term adherence to antithrombotic therapy and bleeding complications was beyond the scope of this analysis.

Conclusion

Carotid artery stenting achieved high procedural success with a low incidence of both periprocedural and long-term adverse events when performed by experienced teams using a standardized endovascular strategy. The absence of procedure-related mortality, together with the low rates of stroke and myocardial infarction and the sustained vessel patency observed during follow-up, supports the safety, effectiveness, and durability of this treatment in both symptomatic and asymptomatic patients. These findings further emphasize that optimal outcomes depend on appropriate patient selection, consistent use of cerebral protection devices, and adherence to standardized techniques, and they confirm carotid artery stenting as a valid and effective alternative to carotid endarterectomy in contemporary carotid revascularization practice.

Ethical Approval
This study was approved by the İstanbul University İstanbul Faculty of Medicine Clinical Research Ethics Committee (Approval date: 13 March 2024; Decision number: 2024/2475191).

Patient Consent
Due to the retrospective nature of the study, the requirement for written informed consent was waived by the ethics committee.

Conflict of Interest
The authors confirm the absence of any conflicts associated with this work.

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