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Original Article

Patch angioplasty versus primary closure and restenosis after carotid endarterectomy

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Abstract

Aim: This study aimed to compare restenosis rates and perioperative outcomes following carotid endarterectomy (CEA) using Dacron patch angioplasty versus primary closure.

Material and Methods: This retrospective single-center study included patients who underwent primary CEA between January 2015 and December 2024. Of 944 screened patients, 776 met the eligibility criteria and were included in the final analysis. Patients were stratified according to arteriotomy closure technique into a patch closure group (n = 412) and a primary closure group (n = 364). Restenosis was assessed using duplex ultrasonography at 1, 6, and 12 months postoperatively. Moderate restenosis was defined as ≥ 50% luminal narrowing and severe restenosis as ≥ 70% luminal narrowing. Multivariable logistic regression analyses were performed to identify independent predictors of restenosis.

Results: The mean age of the study population was 67.2 years, and 550 patients (70.9%) were male. At 12 months, moderate restenosis was observed in 25 patients (6.1%) in the patch closure group and 53 patients (14.6%) in the primary closure group ($p < 0.001$), whereas severe restenosis occurred in 12 patients (2.9%) and 30 patients (8.2%), respectively ($p < 0.001$). In multivariable analysis, primary closure remained independently associated with both moderate restenosis (odds ratio [OR] 2.41, 95% confidence interval [CI] 1.42–4.09; $p = 0.001$) and severe restenosis (OR 2.58, 95% CI 1.28–5.18; $p = 0.008$). Rates of perioperative stroke, mortality, myocardial infarction, cranial nerve injury, and neck hematoma were comparable between the groups.

Conclusion: Patch angioplasty was associated with significantly lower rates of both moderate and severe restenosis following CEA without an increase in perioperative morbidity. Primary closure remained independently associated with restenosis after multivariable adjustment. These findings suggest that patch angioplasty may be associated with improved mid-term vessel patency after CEA.

Keywords: Carotid endarterectomy, carotid restenosis, patch angioplasty, primary closure, carotid stenosis

INTRODUCTION

Carotid endarterectomy (CEA) remains a cornerstone in the prevention of ischemic stroke in patients with significant carotid artery stenosis. Despite substantial advances in endovascular techniques over recent decades, evidence from randomized controlled trials, systematic reviews, and contemporary clinical guidelines continues to support CEA as a durable and effective treatment, particularly for symptomatic patients and selected asymptomatic individuals at increased cerebrovascular risk [1-3].

In addition to patient selection and perioperative management, technical aspects of the procedure may influence long-term outcomes after CEA. Among these, the method of arteriotomy closure remains an important and potentially modifiable surgical factor. Primary closure, patch angioplasty, and eversion techniques are widely used; however, the choice of closure strategy often varies according to surgeon preference, institutional practice, and anatomical considerations [4,5].

Restenosis following CEA is clinically relevant because it may compromise the long-term protective effect of the procedure and,

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in selected patients, lead to recurrent neurological symptoms or the need for reintervention. Previous studies have demonstrated lower restenosis rates and improved vessel patency with patch angioplasty compared with primary closure [6-8]. Importantly, restenosis is not a uniform entity. Moderate (≥ 50%) and severe (≥ 70%) restenosis carry different clinical implications, with higher-grade restenosis being more strongly associated with adverse cerebrovascular outcomes [9].

Meta-analyses and registry-based investigations have further supported the benefit of patch angioplasty in reducing restenosis after CEA [10-12]. Although both biological and synthetic patch materials have been evaluated, favorable long-term patency rates have been reported with synthetic patches while maintaining acceptable safety profiles [11,12]. Nevertheless, variations in surgical practice, patient characteristics, and follow-up protocols continue to contribute to heterogeneity in reported outcomes.

Despite the existing literature, several important gaps remain. Many studies have evaluated restenosis as a single outcome without distinguishing between moderate and severe restenosis, despite their differing clinical significance. Furthermore, contemporary data derived from large cohorts undergoing standardized duplex ultrasonography surveillance remain limited. Real-world observational studies may therefore provide additional insight into restenosis patterns following CEA in routine vascular surgical practice.

Therefore, the present study aimed to evaluate the association between arteriotomy closure technique and restenosis following carotid endarterectomy in a large single-center cohort. We separately analyzed moderate (≥ 50%) and severe (≥ 70%) restenosis using a standardized duplex ultrasonography follow-up protocol. In addition, all patch angioplasties were performed using a single synthetic patch material (Dacron), allowing a more homogeneous assessment of the relationship between closure technique and restenosis while also examining perioperative clinical outcomes.

MATERIAL AND METHODS

Ethical Approval

The study protocol was approved by the Ethics Committee of Dr. Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital (Approval No: E-28001928-604.01-301902216; January 19, 2026) and was conducted in accordance with the principles of the Declaration of Helsinki.

Study Design and Patient Selection

This retrospective observational study was conducted at a high-volume tertiary cardiovascular surgery center. A total of 944 consecutive patients who underwent primary carotid endarterectomy (CEA) for significant carotid artery stenosis between January 2015 and December 2024 were screened for eligibility.

Patients were eligible if postoperative duplex ultrasonography follow-up data were available. Patients who underwent concomitant major cardiac procedures (n = 104) and those with incomplete follow-up data (n = 64) were excluded. Consequently, 776 patients met the study eligibility criteria and were included in the final analysis.

Study Groups

Patients were stratified according to the arteriotomy closure technique and assigned to either the patch closure group (n = 412) or the primary closure group (n = 364).

The study center consisted of eight independent vascular surgery teams. Each team routinely followed its preferred surgical strategy regarding arteriotomy closure during carotid endarterectomy. Therefore, the use of primary closure or patch angioplasty was largely determined by surgeon- or team-specific practice patterns rather than patient-specific clinical characteristics. Patients were subsequently categorized according to the closure technique employed.

Baseline demographic and clinical characteristics were compared between groups to evaluate potential differences associated with closure technique selection.

Surgical Technique

All procedures were performed under general anesthesia by board-certified vascular surgeons. Conventional carotid endarterectomy was performed through a longitudinal arteriotomy.

Arteriotomy closure was achieved either by primary closure or patch angioplasty. In the patch closure group, synthetic Dacron patches (Vascutek Ltd., Inchinnan, Scotland, United Kingdom) were used in all patients.

Selective carotid shunting was performed in patients with significant contralateral carotid artery disease according to institutional practice. Intraoperative neuromonitoring was used at the discretion of the operating surgical team [13].

Perioperative Medical Therapy

All patients received standardized medical therapy according to institutional protocol. Acetylsalicylic acid and statin therapy were initiated preoperatively unless contraindicated. Following surgery, dual antiplatelet therapy and statin treatment were routinely prescribed and continued for 12 months.

Postoperative Follow-up and Restenosis Assessment

All patients underwent a standardized postoperative surveillance program using duplex ultrasonography with a Consona N6 ultrasound system (Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China) at 1, 6, and 12 months after surgery.

Restenosis severity was assessed using established velocity-based duplex ultrasonography criteria. Moderate restenosis (≥

50%) was defined as a peak systolic velocity (PSV) ≥ 125 cm/s, whereas severe restenosis (≥ 70%) was defined as a PSV ≥ 230 cm/s together with an internal carotid artery-to-common carotid artery velocity ratio ≥ 4.0.[9]

Moderate and severe restenosis were analyzed separately because of their differing clinical significance.

Because restenosis was assessed at predefined surveillance intervals, the exact timing of restenosis development could not be determined. Therefore, time-to-event analyses were not performed.

Clinical Outcomes

Perioperative clinical outcomes included stroke, myocardial infarction, cranial nerve injury, neck hematoma, and 30-day mortality.

All adverse events were prospectively recorded in institutional databases and subsequently verified through detailed review of electronic medical records.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 28.0 (IBM Corp., Armonk, NY, USA).

Continuous variables were expressed as mean ± standard deviation (SD), whereas categorical variables were presented as frequencies and percentages. Comparisons between groups were performed using Student's t-test for continuous variables and the chi-square test or Fisher's exact test, as appropriate, for categorical variables.

Multivariable logistic regression analyses were performed to identify independent predictors of moderate (≥ 50%) and severe (≥ 70%) restenosis. Variables entered into the models included closure technique, diabetes mellitus, hypertension, current smoking, sex, and procedural laterality, which were selected a priori based on clinical relevance and previously reported associations with carotid restenosis. Odds ratios (ORs) and corresponding 95% confidence intervals (CIs) were calculated.

All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant.

RESULTS

Patient Characteristics

A total of 776 patients were included in the final analysis, comprising 412 patients in the patch closure group and 364 patients in the primary closure group.

The mean age of the study population was 67.2 years, and 550 patients (70.9%) were male. Baseline demographic and clinical characteristics are presented in Table 1. No significant differences were observed between the patch closure and primary closure groups regarding demographic characteristics, cardiovascular risk factors, symptomatic status, degree of carotid stenosis, procedural laterality, or shunt utilization.

Table 1. Baseline demographic and clinical characteristics of patients undergoing carotid endarterectomy

Variable	Patch closure (n = 412)	Primary closure (n = 364)	p-value
Age, years (mean ± SD)	67.4 ± 8.1	66.9 ± 8.6	0.38
Male sex, n (%)	298 (72.3)	252 (69.2)	0.34
Hypertension, n (%)	316 (76.7)	274 (75.3)	0.64
Diabetes mellitus, n (%)	164 (39.8)	141 (38.7)	0.76
Hyperlipidemia, n (%)	289 (70.1)	258 (70.9)	0.82
Current smoking, n (%)	174 (42.2)	149 (40.9)	0.72
Coronary artery disease, n (%)	206 (50.0)	179 (49.2)	0.85
Prior myocardial infarction, n (%)	71 (17.2)	66 (18.1)	0.75
Chronic kidney disease, n (%)	43 (10.4)	41 (11.3)	0.69
Symptomatic carotid stenosis, n (%)	237 (57.5)	206 (56.6)	0.79
Degree of stenosis ≥ 70%, n (%)	331 (80.3)	288 (79.1)	0.67
Left-sided procedure, n (%)	211 (51.2)	181 (49.7)	0.67
Shunt use, n (%)	98 (23.8)	90 (24.7)	0.77

Values are presented as mean ± standard deviation (SD) or number (%); Continuous variables were compared using Student's t-test and categorical variables using the chi-square test or Fisher's exact test, as appropriate

Restenosis During Follow-up

Restenosis rates at 1, 6, and 12 months are summarized in Table 2. Across all follow-up intervals, patients undergoing patch closure demonstrated significantly lower rates of both moderate (≥ 50%) and severe (≥ 70%) restenosis than those undergoing primary closure.

At 1 month, moderate restenosis was observed in 10 patients (2.4%) in the patch closure group and 23 patients (6.3%) in the primary closure group (p = 0.008). Severe restenosis occurred in 2 patients (0.5%) and 8 patients (2.2%), respectively (p = 0.048).

At 6 months, moderate restenosis was identified in 17 patients (4.1%) in the patch closure group and 37 patients (10.2%) in the primary closure group (p = 0.001). Severe restenosis was detected in 7 patients (1.7%) and 20 patients (5.5%), respectively (p = 0.003).

At 12 months, moderate restenosis was present in 25 patients (6.1%) in the patch closure group and 53 patients (14.6%) in the primary closure group (p < 0.001). Severe restenosis was observed in 12 patients (2.9%) and 30 patients (8.2%), respectively (p < 0.001).

The temporal distribution of moderate and severe restenosis during follow-up is illustrated in Figure 1 and Figure 2.

Table 2. Restenosis rates during follow-up

≥50% Restenosis			
Follow-up	**Patch closure (n = 412)**	**Primary closure (n = 364)**	***p*-value**
1 month	10 (2.4)	23 (6.3)	0.008
6 months	17 (4.1)	37 (10.2)	0.001
12 months	25 (6.1)	53 (14.6)	<0.001
≥70% Restenosis			
Follow-up	**Patch closure (n = 412)**	**Primary closure (n = 364)**	***p*-value**
1 month	2 (0.5)	8 (2.2)	0.048
6 months	7 (1.7)	20 (5.5)	0.003
12 months	12 (2.9)	30 (8.2)	<0.001

Values are presented as the number of patients with restenosis and the corresponding percentage of the total group population.

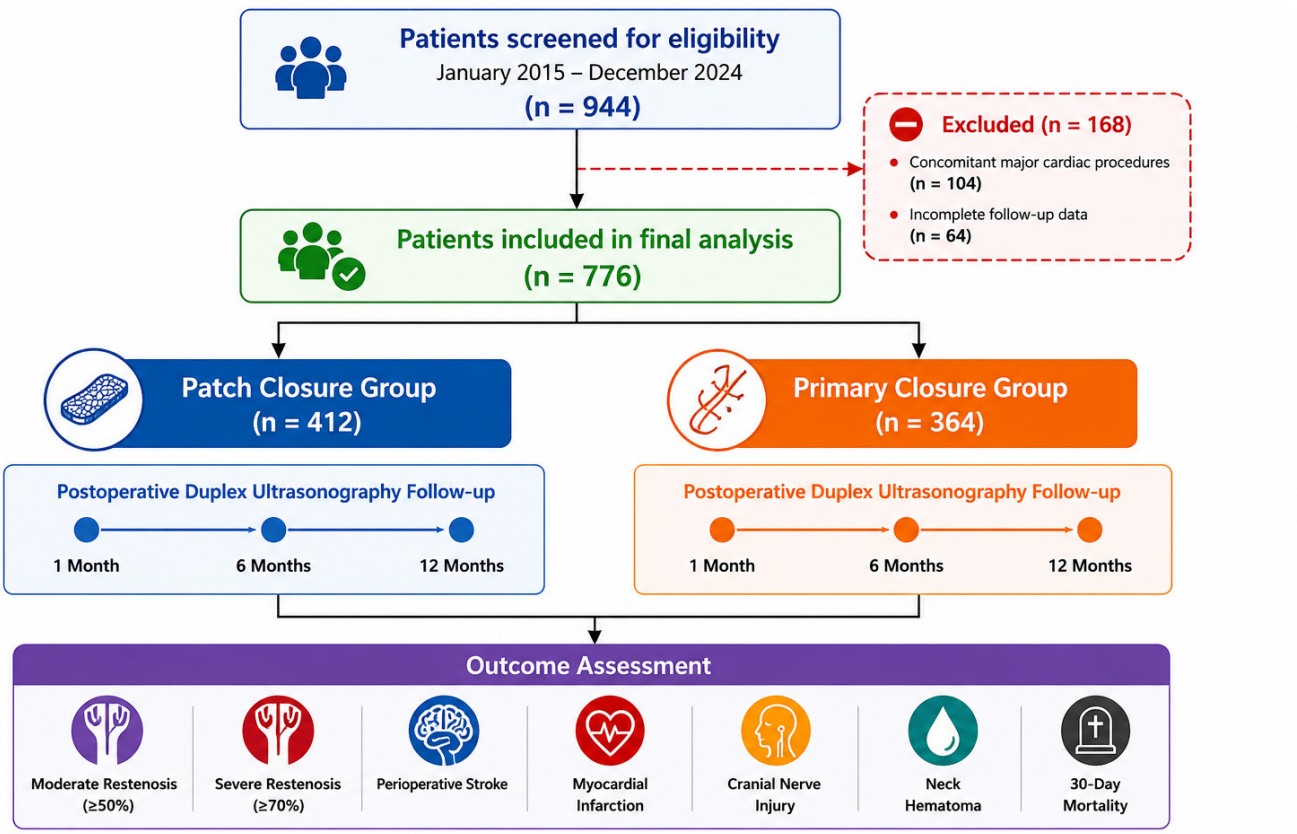

Figure 1. Study Flow Diagram; Flow diagram illustrating patient selection, exclusion criteria, allocation according to arteriotomy closure technique, postoperative duplex ultrasonography surveillance, and outcome assessment; Of 944 patients screened for eligibility, 776 met the inclusion criteria and were included in the final analysis

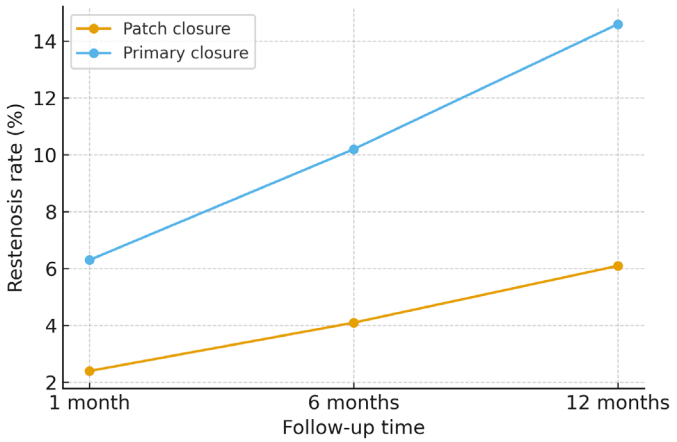

Figure 2. Temporal distribution of moderate (≥ 50%) restenosis following carotid endarterectomy according to closure technique; Rates of moderate (≥ 50%) restenosis at 1, 6, and 12 months after carotid endarterectomy in patients undergoing patch closure and primary closure

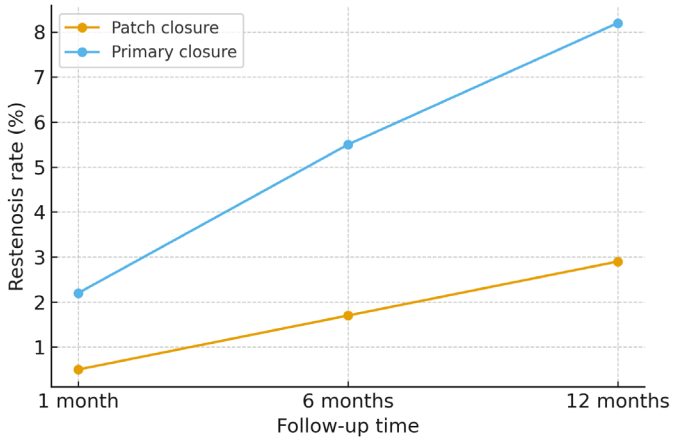

Figure 3. Temporal distribution of severe (≥ 70%) restenosis following carotid endarterectomy according to closure technique; Rates of severe (≥ 70%) restenosis at 1, 6, and 12 months after carotid endarterectomy in patients undergoing patch closure and primary closure

Predictors of Restenosis

Multivariable logistic regression analyses were performed to identify independent predictors of restenosis.

In the multivariable model evaluating moderate restenosis (≥ 50%), primary closure remained independently associated with restenosis (adjusted OR 2.41, 95% CI 1.42–4.09; p = 0.001) (Table 3, Figure 3). No significant independent associations were identified for diabetes mellitus, hypertension, current smoking, male sex, or left-sided carotid disease.

Similarly, in the multivariable model evaluating severe restenosis (≥ 70%), primary closure remained independently associated with restenosis (adjusted OR 2.58, 95% CI 1.28–5.18; p = 0.008) (Table 4, Figure 4). None of the remaining covariates included in the model demonstrated an independent association with severe restenosis.

Table 3. Multivariable logistic regression analysis for predictors of ≥ 50% restenosis

Variable	Adjusted OR	95% CI	p-value
Primary closure	2.41	1.42–4.09	0.001
Diabetes mellitus	1.09	0.62–1.91	0.76
Hypertension	1.28	0.74–2.22	0.38
Current smoking	1.05	0.58–1.90	0.87
Male sex	1.02	0.58–1.79	0.94
Left-sided procedure	1.19	0.68–2.09	0.54

OR: odds ratio, CI: confidence interval; Variables entered into the multivariable model included closure technique, diabetes mellitus, hypertension, current smoking, sex, and procedural laterality

Table 4. Multivariable logistic regression analysis for predictors of ≥ 70% restenosis

Variable	Adjusted OR	95% CI	p-value
Primary closure	2.58	1.28–5.18	0.008
Diabetes mellitus	1.12	0.59–2.13	0.73
Hypertension	1.31	0.71–2.42	0.39
Current smoking	1.08	0.56–2.07	0.82
Male sex	1.04	0.57–1.91	0.90
Left-sided procedure	1.21	0.65–2.27	0.55

OR: odds ratio, CI: confidence interval; Variables entered into the multivariable model included closure technique, diabetes mellitus, hypertension, current smoking, sex, and procedural laterality

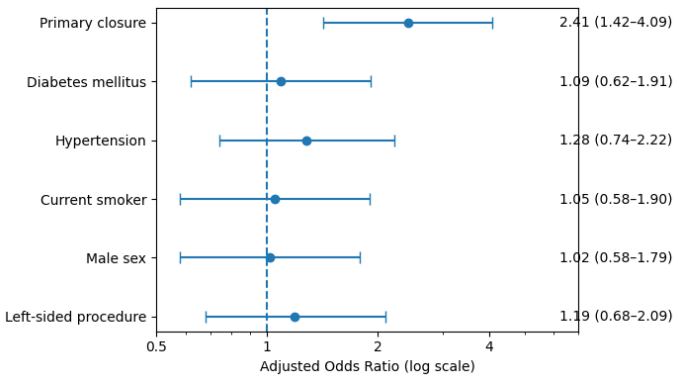

Figure 4. Multivariable logistic regression analysis for predictors of moderate (≥ 50%) restenosis; Forest plot showing adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for variables included in the multivariable logistic regression model evaluating predictors of moderate (≥50%) restenosis

Perioperative Outcomes

Perioperative clinical outcomes are summarized in Table 5.

The incidence of perioperative stroke was low in both groups and did not differ significantly between patients undergoing patch closure and those undergoing primary closure. Likewise, no statistically significant differences were observed in 30-day mortality, myocardial infarction, cranial nerve injury, or neck hematoma rates.

Overall perioperative event rates were comparable between the two groups. A graphical summary of perioperative outcomes is presented in Figure 5.

Table 5. Perioperative clinical outcomes

Outcome	Patch closure (n = 412)	Primary closure (n = 364)	p-value
Perioperative stroke, n (%)	8 (1.9)	10 (2.7)	0.61
30-day mortality, n (%)	3 (0.7)	4 (1.1)	0.87
Cranial nerve injury, n (%)	13 (3.1)	12 (3.3)	1.00
Neck hematoma, n (%)	11 (2.6)	10 (2.7)	1.00
Myocardial infarction, n (%)	4 (0.9)	4 (1.1)	1.00

Values are presented as the number of patients and the corresponding percentage of the total group population

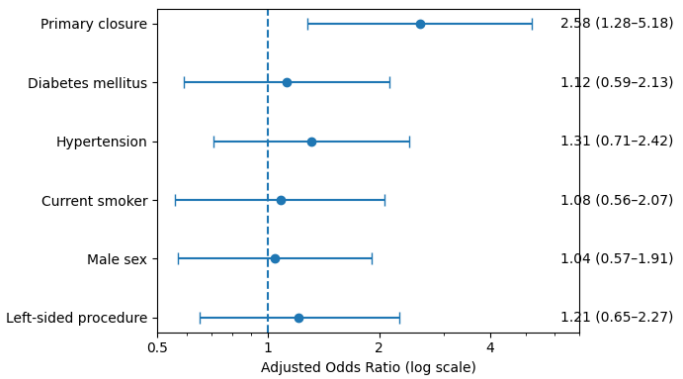

Figure 5. Multivariable logistic regression analysis for predictors of severe (≥ 70%) restenosis; Forest plot showing adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for variables included in the multivariable logistic regression model evaluating predictors of severe (≥70%) restenosis

DISCUSSION

In this retrospective single-center study, patch angioplasty was associated with significantly lower rates of both moderate (≥ 50%) and severe (≥ 70%) restenosis during the first postoperative year following carotid endarterectomy. Importantly, this association persisted after multivariable adjustment, while perioperative stroke, mortality, myocardial infarction, cranial nerve injury, and neck hematoma rates remained comparable between the two groups.

The beneficial effect of patch angioplasty on restenosis has a plausible biological basis. Experimental and hemodynamic studies have demonstrated that patch reconstruction enlarges the arterial lumen, improves flow characteristics, reduces turbulence, and decreases the development of neointimal hyperplasia at the endarterectomy site [13-15]. These mechanisms may contribute to the lower restenosis rates consistently reported after patch closure and observed in the present cohort.

Our findings are consistent with previous clinical investigations comparing closure techniques after carotid endarterectomy. Maertens et al. [16] reported comparable perioperative complication rates between patch angioplasty and primary closure, while Wu et al. [17] demonstrated favorable patency outcomes with patch reconstruction. Similarly, perioperative stroke, mortality, myocardial infarction, cranial nerve injury, and neck hematoma rates were comparable between groups in the present study, suggesting that improved patency with patch closure was not accompanied by increased perioperative morbidity.

Restenosis following carotid endarterectomy is a multifactorial process influenced by both procedural and patient-related characteristics. Vukasinovic et al. [18] identified diabetes mellitus and hyperlipidemia as predictors of adverse long-term outcomes and restenosis after carotid endarterectomy. Although closure technique remained independently associated with restenosis in the present study, these findings support the concept that both technical and patient-related factors contribute to long-term vessel patency.

Not all contemporary studies have demonstrated a clear superiority of patch angioplasty. Parsa et al. [19] reported no significant differences in recurrent stenosis or stroke between primary closure and patch angioplasty during long-term follow-up. Such findings highlight the heterogeneity of the available literature and suggest that institutional practice patterns, patient selection, and operative strategy may contribute to variations in reported outcomes.

Long-term observational studies nevertheless continue to support the durability of patch reconstruction. Okazaki et al. [20] demonstrated low restenosis and ipsilateral stroke rates at both five and ten years after carotid endarterectomy with patch graft closure. Although follow-up in the present study was limited to 12 months, the lower restenosis rates observed in the patch group may represent the early manifestation of these longer-term benefits.

An important strength of the present study is the separate evaluation of moderate (≥ 50%) and severe (≥ 70%) restenosis rather than treating restenosis as a single outcome measure. Furthermore, all patients underwent a standardized duplex ultrasonography surveillance protocol, and patch angioplasty

was performed exclusively using a single synthetic patch material (Dacron). These methodological features reduced heterogeneity and allowed a more consistent assessment of the relationship between closure technique and postoperative restenosis.

The role of alternative operative strategies should also be considered. Cheng et al. [21] compared primary closure, patch angioplasty, and eversion endarterectomy and reported higher restenosis rates after primary closure, while observing no significant differences between patch angioplasty and eversion techniques. Collectively, these findings suggest that closure technique may be an important determinant of postoperative restenosis, although the relative contribution of other procedural factors remains to be clarified.

Recent systematic reviews, including a trial sequential analysis by Marsman et al. [22] and the latest Cochrane review, [23] have suggested that patch angioplasty may reduce restenosis and adverse cerebrovascular outcomes compared with primary closure. However, both reviews emphasized the limited certainty of the available evidence and highlighted the need for additional high-quality contemporary studies. In this context, real-world observational investigations continue to provide valuable complementary evidence regarding closure techniques in routine vascular surgical practice.

Several limitations should be acknowledged. First, the retrospective observational design introduces the possibility of selection bias and residual confounding. Second, the closure technique was not randomized but reflected the established practice patterns of eight independent vascular surgery teams within our institution. Although closure strategy was largely determined by team-specific practice patterns rather than individualized patient selection, unmeasured anatomical variables may still have influenced procedural choice. Third, the restenosis assessment relied on duplex ultrasonography, and the exact timing of restenosis development between surveillance examinations could not be determined, precluding formal time-to-event analyses. Finally, the follow-up was limited to 12 months and therefore does not permit assessment of late restenosis or long-term cerebrovascular outcomes.

CONCLUSION

Patch angioplasty was associated with significantly lower rates of both moderate and severe restenosis following carotid endarterectomy without an increase in perioperative morbidity. Primary closure remained independently associated with restenosis after multivariable adjustment. These findings suggest that patch angioplasty may improve mid-term vessel patency after carotid endarterectomy. Prospective multicenter studies with longer follow-up are warranted to further clarify the long-term clinical implications of closure technique.

Ethics Committee Approval: The study protocol was approved by the Ethics Committee of Dr. Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital (Approval No: E-28001928-604.01-301902216; January 19, 2026) and was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: The requirement for individual informed consent was waived due to the retrospective nature of the study.

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

Author Contributions: All authors contributed equally to the article.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

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