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**Area of Expertise:** Neurosciences

**Title:** Revitalizing traditional carotid endarterectomy methods: A comprehensive review of primary closure techniques.

**Short title:** Revitalization of the traditional carotid endarterectomy technique.

### **Abstract**

**Purpose:** Carotid endarterectomy (CEA) remains essential for the treatment of carotid artery disease; however, primary closure techniques have recently gained interest. This study investigated the outcomes, efficacy, and safety of primary closure compared with conventional methods.

**Methods:** A retrospective analysis of 130 patients who underwent CEA with primary closure at our clinic between January 2018 and April 2024 was performed. All surgeries followed a standardized procedure under general anesthesia. Data on demographics, surgical time, cross-clamp time, mortality, morbidity, and length of hospital stay were collected. Follow-up evaluations were performed 1, 6, and 12 months post-surgery.

**Results:** The study included 130 patients, 90 males (69%) and 40 females (31%), with an average age of  $69.54 \pm 5.42$  years. Restenosis occurred in five patients (3%) at 12 months, all of whom were asymptomatic. Three patients experienced transient ischemic attacks (TIA) postoperatively, which fully resolved within one month. Importantly, no early mortality was recorded during the one-month follow-up period.

**Conclusion:** Primary closure in CEA demonstrates promising outcomes, with low rates of restenosis and postoperative complications and no early mortality. These findings highlight primary closure as a potentially advantageous approach for CEA. Further research and prospective trials are necessary to validate and optimize this technique and ultimately improve patient outcomes in carotid artery disease management.

**Keywords:** Carotid endarterectomy, primary closure, surgical techniques, restenosis,

**Makale başlığı:** Karotis endarterektomide geleneksel yöntemlerin canlandırılması: primer kapatma tekniklerinin kapsamlı bir incelemesi.

**Kısa başlık:** Geleneksel karotis endarterektomi tekniğini canlandırma.

## Öz

**Amaç:** Karotid endarterektomi (KEA), karotid arter hastalığının tedavisinde önemini korurken, son zamanlarda birincil kapatma tekniklerine olan ilgi artmıştır. Bu çalışma, geleneksel yöntemlerle karşılaştırıldığında birincil kapatmanın sonuçlarını, etkinliğini ve güvenliğini araştırmaktadır.

**Gereç ve yöntemler:** Ocak 2018 ile Nisan 2024 tarihleri arasında kliniğimizde primer kapatma ile KEA uygulanan 130 hastanın retrospektif analizi yapıldı. Tüm ameliyatlarda genel anestezi altında standart bir prosedür izlendi. Hastaların demografik özellikleri, ameliyat süresi, kros klemp süresi, mortalite, morbidite ve hastanede kalış süresiyle ilgili veriler toplandı. Takip değerlendirmeleri ameliyattan 1, 6 ve 12 ay sonra gerçekleştirildi.

**Bulgular:** Çalışmaya 90 erkek (%69) ve 40 kadın (%31) olmak üzere toplam 130 hasta dahil edildi. Hastaların ortalama yaşı  $69,54 \pm 5,42$  yıldır. Takiplerin 12. ayında, asemptomatik olarak 5 hastada (%3) restenoz gelişti. Postoperatif dönemde 3 hastada geçici iskemik atak (TIA) görüldü ve bu ataklar bir ay içinde tamamen düzeldi. Önemli olarak, bir aylık takip süresi boyunca hiçbir erken ölüm vakası bildirilmedi.

**Sonuç:** KEA'da primer kapatma tekniği, düşük restenoz ve postoperatif komplikasyon oranları ile erken mortalite olmaması bakımından umut verici sonuçlar ortaya koymaktadır. Bu bulgular, primer kapatma tekniğinin KEA'da avantajlı bir yaklaşım olabileceğini göstermektedir. Yöntemin doğrulanması ve optimize edilmesi amacıyla daha fazla araştırma ve prospektif çalışmalar gereklidir, böylece karotis arter hastalığının yönetiminde hasta sonuçları iyileştirilebilir.

**Anahtar kelimeler:** Karotis endarterektomi, primer kapatma, cerrahi teknikler, restenoz.

## **Introduction**

Carotid artery disease (CAD) is an important cause of ischemic stroke worldwide. Carotid endarterectomy is one of the most effective treatment modalities for both symptomatic and asymptomatic patients [1]. Intervention in carotid stenosis (endarterectomy or stenting depending on the clinical situation) is generally recommended in symptomatic patients with stenosis greater than 70% and in selected asymptomatic low-risk patients and symptomatic patients with stenosis between 50-69% [2]. Carotid endarterectomy (CEA) is the surgical removal of atherosclerotic plaques deposited in the carotid artery and has long been recognized as the gold standard treatment [3]. Over the years, various innovations have been made in CEA techniques to improve the safety and outcomes of surgery. Among these innovations, the method of arterial closure remains an important research topic. A correct closure technique plays an important role in maintaining hemodynamic stability of the vessel; however, the optimal surgical closure method during CEA is still the focus of controversy. Patch closure is widely preferred because of its potential to reduce the risk of restenosis, but its favorable effect on the hemodynamic profile has been questioned [4]. The primary closure technique involves direct suturing of the arterial wall without the use of a patch, and offers advantages such as shortening the operation time, reducing the complexity of the procedure, and avoiding the use of foreign material [5]. However, questions regarding the risk of restenosis and long-term efficacy of this method are among the factors limiting its widespread use. This study aimed to evaluate the safety and efficacy of CEA with primary closure and to demonstrate its potential advantages over conventional closure techniques. By analyzing surgical and postoperative data from 130 patients treated in our clinic, we aimed to strengthen the evidence for primary closure and to examine the potential role of this technique in the management of carotid artery disease.

## **Materials and methods**

This study retrospectively analyzed data from 130 patients who underwent CEA using the primary closure method at our clinic between January 2018 and April 2024. The study protocol was in accordance with the ethical rules of the Declaration of Helsinki, and approval was obtained from the Ethics Committee of the Zonguldak Bülent Ecevit University Faculty of Medicine Application and Research Hospital (date: 02/10/2024 and decision number: 2024/17).

In this retrospective study, specific exclusion criteria were applied to enhance the reliability and accuracy of results. First, patients who had previously undergone surgical interventions, such as CABG or carotid artery stenting, were not included in the study.

Additionally, patients who had patches used for artery closure during surgery were excluded, as this study only examined cases performed using the primary closure method. Patients who did not complete the 12-month follow-up period after surgery or were lost to follow-up during the monitoring period were also excluded from the evaluation.

Patients with serious comorbidities that could negatively affect surgical outcomes (such as advanced heart failure, kidney failure, or cancer) were excluded from the study because they could potentially affect the surgical results of this group. Additionally, patients diagnosed with active infection or inflammatory disease during or after surgery were excluded from the study.

### **Patient selection**

The patients included in the study were symptomatic or asymptomatic patients with > 70% stenosis detected in the carotid artery using Doppler ultrasonography or other imaging methods. Additionally, patients who were symptomatic and had stenosis between 50-69% have also been included. Demographic data (age, sex, and comorbidities) and clinical information were obtained retrospectively from hospital records.

### **Surgical protocol**

All surgical procedures were performed under general anesthesia by an experienced vascular surgeon using standard techniques. Patients underwent a standard preoperative evaluation, and the risk assessment for surgical suitability was completed by the anesthesia team. Patients were positioned in the supine position on the operating table, and the head was slightly extended to best expose the surgical field.

During the operation, the neck area of the patient was cleaned with antiseptic solutions and isolated with sterile drapes. A surgical incision was made along the sternocleidomastoid muscle, typically parallel to the medial border. The carotid artery triangle was carefully exposed, and the carotid bifurcation, internal and external carotid arteries, and adjacent structures were carefully dissected and isolated. While dissecting along the carotid artery, care was taken to protect critical structures, such as the nervus vagus and hypoglossal nerve.

To remove atherosclerotic plaque, the artery was cross-clamped to stop blood flow and expose the plaque area. During the endarterectomy procedure, the arterial wall was carefully opened and the atheromatous material was removed. After the plaque was completely removed, the inner surface of the artery was cleaned using a soft spatula. At this stage, careful technique was used to avoid damage to the carotid artery and distal embolization.

After plaque removal, artery closure was performed using a primary closure. Primary closure was performed via direct suturing of the arterial wall without the use of any patch material. A thin monofilament suture material (usually 5-0 or 6-0 polypropylene (Ethicon, Sommerville, NJ, )) was used during closure. During the suturing process, care was taken to obtain a smooth anastomosis without damaging the hemodynamics of the artery or causing stenosis. During all closure procedures, the distal and proximal arterial structures were carefully protected to ensure adequate blood flow.

After removal of the cross-clamp, blood flow was restored and hemodynamic stability was assessed. Blood flow in the carotid artery was assessed using Doppler ultrasonography for any obstruction or flow disturbance. After hemostasis was achieved, the surgical field was washed with sterile serum and the operation was completed by closing the layers. In the postoperative period, patients were closely monitored for neurological status, and intervention was performed in case of any complications. Postoperatively, the patients were admitted to the intensive care unit or surgical ward in accordance with standard follow-up protocols, and postoperative follow-up was performed.

### **Postoperative follow-up and evaluation**

All patients were followed-up regularly at 1, 6, and 12 months postoperatively. During follow-up, neurological evaluations were performed, and restenosis was confirmed using Doppler ultrasonography. Postoperative complications include restenosis, transient ischemic attack (TIA), stroke, and mortality. Restenosis was defined as more than 50% stenosis of the carotid artery. In addition, the length of the hospital stay and other postoperative complications were recorded.

### **Laboratory and imaging tests**

Biochemical parameters, such as complete blood count (CBC), electrolyte levels, renal function tests (creatinine and urea), and C-Reactive Protein (CRP) levels, were analyzed preoperatively and postoperatively. Doppler ultrasonography was used to evaluate the presence of restenosis, and cardiac complications were monitored using electrocardiography (ECG) during the postoperative period.

### **Results**

This retrospective study aimed to evaluate the efficacy and safety of primary closure during CEA in 130 patients. The patients were 90 males (69%) and 40 females (31%) with a mean age of  $69.54 \pm 5.42$  years. The demographic data of the patients are shown in Table 1. Asymptomatic restenosis was detected in five patients (3%) at the 12<sup>th</sup> month of postoperative follow-up, but no clinically significant symptoms were observed in

these patients. In addition, three patients (2.3%) developed TIA in the postoperative period, and these episodes resolved completely within one month.

At the end of 1 year, one patient (0.8%) developed myocardial infarction and was managed with appropriate cardiovascular therapy. Amalosis fugax was observed in one patient (0.8%). Furthermore, among surgical complications, hematoma developed in four patients (3%), but none of these patients required revision surgery. Regarding nerve damage, two patients (1.5%) had hypoglossal nerve damage and one patient (0.8%) had marginal mandibular nerve damage. All nerve injuries showed partial recovery in the months following surgery. The postoperative complications are shown in Table 2. In terms of early mortality, there were no deaths in any of the patients during the first month of follow-up.

## **Discussions**

Carotid endarterectomy is the gold standard surgical procedure for the treatment of carotid artery diseases. CEA is an effective treatment option to prevent recurrent stroke in patients with symptomatic carotid artery stenosis. This effective treatment is associated with stroke and mortality rates of less than 3% [6-9]. These results demonstrate the reliability and clinical preference of this method. However, the differences between surgical techniques and surgeon experience play a decisive role in the postoperative outcomes. Differences between long-standing surgical closure methods are increasingly being discussed in terms of their impact on patient clinical outcomes. In this context, the first comparison of primary carotid artery closure and patch angioplasty dates back to 1964. These early studies provided an important starting point for understanding the effects of artery closure methods on postoperative hemodynamics and complications [10]. In our study, we aimed to evaluate our results using the primary closure technique, which began in the late 19<sup>th</sup> century.

In the study by Rockman et al. [11], primary closure was reported to have more unfavorable postoperative outcomes than patch closure and eversion techniques. The authors suggested that this method was associated with higher restenosis rates and long-term complication risks. However, in the same study, surgeons, particularly those with little surgical experience, tended to prefer the primary closure method. This causes confusion in the literature regarding the safety and efficacy of this method [11]. In our study, asymptomatic restenosis was detected in five patients (3%) at 1 year. The results obtained in this study suggest that primary closure is a safe option, with low restenosis and postoperative complication rates. However, the better results compared to the

findings of Rockman et al. [11] suggest that surgeon experience and patient selection criteria play a critical role in the success rate of this method.

Kapoor et al. [12] analyzed intraoperative EEG data and emphasized that selective shunting with primary closure yielded similar results to routine patch angioplasty and shunting. In particular, this study shows that primary closure may be a neurologically safe option and that this method provides neurologic protection equivalent to routine patch angioplasty. This finding suggests that the primary closure technique may be a safe alternative, particularly when used in combination with selective shunting.

One possible complication of patch closure is pseudoaneurysm development. In a study conducted by Hertzner et al. [13] on 917 cases, it was reported that three patients developed pseudoaneurysms and required surgical repair. Curiously, it has been reported that no such complications were observed in the primary closure group without patching. This finding suggests that the patch closure method should be carefully evaluated for its safety. Although patch application has hemodynamic advantages, the risks of such complications should not be ignored. In our study, no false aneurysm development was observed in patients who underwent primary closure. However, large-scale, long-term studies are necessary for a clearer understanding of the differences between primary and patch closures. Such studies will allow us to better understand the risks of complications associated with surgical techniques and patient outcomes.

Stenting remains a good treatment option for carotid artery stenosis [14-16]. In the literature, several studies have demonstrated that CEA offers a more cost-effective treatment option compared with carotid artery stenting [17, 18]. Although we aimed to differentiate between surgical techniques, the materials used in both stents and different surgical techniques cause a significant cost. In addition to being cost-effective, CEA using the primary closure technique offers successful clinical outcomes in the postoperative period, making this method a more attractive option. This finding supports the idea that primary closure is an advantageous alternative in terms of both economic and clinical outcomes. In a single-center study by Zagzoog et al. [19], it was reported that primary and patch closure techniques have similar risk profiles, and both methods offer equally robust surgical approaches that can be safely applied in CEA procedures. This study suggests that the choice of closure technique can be determined by surgeon preference and patient characteristics and reveals that there is no significant clinical difference between the two methods. In another study, Clagett et al. [20] reported that primary closure significantly reduced the clamp time and increased restenosis (12.9% vs. 1.7%). These results suggest that primary closure may be a more effective option in terms of the operative time and surgical complexity. However, the choice of surgical

technique should be based on individual considerations for each patient, and further prospective studies are required.

Primary closure appears to be a safe, low complication rate, and economical option for CEA. When compared with different closure methods in the literature, primary closure has been reported to shorten the surgical time, maintain hemodynamic stability, and accelerate postoperative recovery. However, patient selection, surgeon experience, and the effects of additional surgical techniques should be considered. Although the findings showed that the short-term results of the primary closure technique are favorable, prospective studies based on long-term follow-up data in larger patient populations are necessary. Such studies will allow us to better understand the long-term safety and efficacy of primary closure and will guide the choice of the surgical technique.

### **Limitations**

This study had some limitations owing to its retrospective design. First, retrospective data collection may have introduced potential biases in patient selection and data validation. Second, our patient group represented a single-center population; therefore, the results obtained may not be fully generalizable to the general population. Furthermore, multicenter and prospective studies involving large patient populations are necessary to evaluate the long-term efficacy and safety of primary closure.

In conclusion, this study provides data demonstrating the efficacy and safety of the primary closure technique for CEA. In our study, we observed low complication rates, minimal nerve damage, and limited postoperative events with primary closure. It was also found to be advantageous in terms of surgical time and cost. These findings suggest that primary closure can be used as a safe and effective alternative in selected patient groups. However, multicenter prospective studies are needed to better understand the long-term results of this method and to validate it in different patient populations.

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**Authors contributions:** O.A. and E.K. constructed the main idea and hypothesis of the study. O.A. and E.K. developed the theory and arranged/edited the material and method section. O.A. has done the evaluation of the data in the Results section. Discussion section of the article written by O.A. and E.K. reviewed, corrected and approved. In addition, all authors discussed the entire study and approved the final version.

**Conflict of interest:** No conflict of interest was declared by the authors.

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**Table 1.** Patient characteristics

<b>Characteristic</b>	<b>Values</b>
Mean age at the time of surgery (years)	69.54±5.42
Gender n (%) - Male	90 (69%)
Gender n (%) - Female	40 (31%)
Hypertension n (%)	60 (46%)
Hyperlipidaemia n (%)	45 (35%)
Coronary Artery Disease n (%)	50 (38%)
Atrial Fibrillation n (%)	20 (15%)

**Table 2.** Postoperative complications

<b>Complications</b>	<b>Values</b>
Restenosis (3%)	5 patients
Transient Ischemic Attack (TIA) (2.3%)	3 patients
Myocardial Infarction	1 patient (after 1 year)
Amaurosis Fugax	1 patient
Hematoma	4 patient
Hypoglossal Nerve Damage	2 patient
Marginal Mandibular Nerve Injury	1 patient
Early Mortality	0 patient

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