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Endovascular and Hybrid Treatment of Extracranial Carotid Artery Aneurysms: Long Term Results from the International Carotid Aneurysm Registry

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WHAT THIS PAPER ADDS

This study highlights the real world use of endovascular and hybrid approaches for extracranial carotid artery aneurysms based on prospectively collected multicentre data. It is the largest study to date reporting long term follow up after these treatments. The findings provide insights into procedural outcomes and long term durability and may support individualised treatment decisions and the development of future clinical guidelines for this rare vascular condition.

Objective: To evaluate the procedural and long term outcomes of endovascular treatment of extracranial carotid artery aneurysms (ECAAs).

Methods: Within the prospective international Carotid Aneurysm Registry, patients with primary ECAA treated with endovascular or hybrid therapy were analysed. Hybrid therapy involved a combination of surgical correction of proximal elongation and distal stenting. Technical approach and follow up were determined locally. The primary endpoint was ECAA exclusion. Secondary endpoints included technical success, peri-procedural complications, stent patency, long term ipsilateral stroke, and death.

Results: Between January 2014 and November 2024, 481 patients were included in the Carotid Aneurysm Registry. Of these, 42 patients (mean age 52 ± 17 years; 25 [60%] men) underwent elective endovascular ECAA exclusion ($n = 37$) or hybrid treatment ($n = 5$); 16 patients were symptomatic. One procedure was converted to open surgery due to technical failure. Thirty day outcomes revealed three ipsilateral strokes. One patient died of a stroke within 30 days. Follow up (median 65 months; interquartile range 28, 91) revealed 100% stent patency. ECAA exclusion was 95% at 12 months and 98% at a median of 65 months. One patient required additional coiling and another underwent re-stenting due to stent migration, both within the first year. During a median survival of 88 months, four patients died due to non-ECAA related causes. No ipsilateral stroke occurred in this timeframe.

Conclusion: In this registry based, prospectively collected cohort, endovascular treatment of selected ECAAs seems technically feasible and effective for aneurysm exclusion. However, this treatment comes with high peri-procedural morbidity and mortality rates. Long term outcomes showed a high stent patency rate and successful ECAA exclusion during follow up. These findings should be counterbalanced against natural course and open surgical outcome data to design a future individualised treatment algorithm for patients with ECAA.

Keywords: Endovascular treatment, Extracranial carotid aneurysm, Hybrid treatment, Registry
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INTRODUCTION

Extracranial carotid artery aneurysm (ECAA) is a rare form of arterial aneurysmal disease, accounting for < 1% of all peripheral aneurysms. The aetiology of ECAAs is diverse, ranging from traumatic or spontaneous dissection and atherosclerosis to connective tissue disorders. Most ECAAs

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remain asymptomatic and are discovered during routine imaging or screening procedures. In patients with a symptomatic ECAA, the neck mass may cause local cervical discomfort or cranial nerve compression, whereas ischaemic thromboembolic cerebral events seem infrequent.[1–4] In the absence of formal guidelines, asymptomatic ECAAs are often managed conservatively by surveillance, whereas intervention may be considered in symptomatic cases or in asymptomatic ECAAs with documented growth.[5] Although open aneurysm exclusion has traditionally been considered the gold standard for treating ECAAs, endovascular therapy has emerged as a potentially less invasive alternative. Moreover, endovascular techniques have been reported to offer a suitable option for patients with a surgically inaccessible ECAA.[6–11] However, data on mid to long term safety and efficacy of endovascular ECAA repair are lacking.[10,12] Furthermore, anatomic accessibility for endovascular repair may be challenging due to the association between ECAA and arterial tortuosity and possible angulation of the inflow and outflow route of the aneurysm.[13,14] Hybrid treatment, by either temporary intraprocedural manual straightening or by definitive surgical shortening of proximal internal carotid artery (ICA) elongation, may facilitate access of guidewires and stent positioning, but literature on this hybrid treatment is scarce, limited to small cohorts with mainly procedural outcome data.[15–17] The Carotid Aneurysm Registry (CAR) is an ongoing prospective international registry that aims to collect data on this rare pathology to support clinical decision making for ECAA treatment.[18] The purpose of this current CAR based analysis was to report the procedural and long term outcomes of endovascular and hybrid ECAA treatment.

METHODS

Patient population

A retrospective cohort analysis was conducted using prospectively collected data from the ongoing CAR. For this study, all patients with a primary ECAA who underwent endovascular or hybrid treatment between January 2014 and November 2024 were included. In CAR, clinical symptoms, aetiology, type of treatment, and follow up data are systematically recorded. Treatment decisions were made by local multidisciplinary teams. As CAR did not define uniform treatment thresholds, indications for intervention may have varied between centres. Post-carotid endarterectomy aneurysms and radiation induced ECAA cases were not included in CAR. Six patients were excluded due to lack of follow up data (Fig. 1). The registry was approved by the Medical Ethics Review Committee of the University Medical Centre Utrecht (protocol number: 12-183, updated approval: 19-280), and all participating centres obtained local institutional review board approval or exemption in accordance with national regulations.

Data collection and variables

Data on patient demographics, clinical characteristics, aneurysm characteristics, treatment modalities, procedure details, and follow up outcomes were assessed.[18] The variables of interest included age, gender, comorbidities, aneurysm size and location, treatment approach (endovascular or hybrid), technical success, and clinical and imaging outcomes. The primary endpoint was ECAA exclusion. Secondary endpoints included technical success, periprocedural complications, stent patency, and incidence of ipsilateral ischaemic stroke and death during follow up.

Definitions

The extracranial carotid artery comprises the common carotid artery, the ICA up until the skull base, and the external carotid artery. The proximal ICA was defined as extending from the carotid bulb to the carotid midpoint, whereas the distal carotid artery was delimited as extending from the midpoint to the skull base. An aneurysm was classified as either a saccular aneurysm of any size or a fusiform aneurysm with a dilatation at least 1.5 times larger than the unaffected contralateral carotid artery. Maximum size was measured by assessing its largest cross sectional diameter. This classification was based on expert consensus within the CAR study group because no formal international criteria for ECAA sizing currently exist. ECAA exclusion, the primary endpoint, was defined as complete aneurysm obliteration or blood flow stasis within the aneurysm, as confirmed by follow up imaging. Technical success was defined as the accurate positioning of the stent, ensuring sufficient overlap into proximal and distal disease free artery, sufficient sealing zone, and vessel lumen patency. Stent patency was defined as the absence of stenosis of $> 50\%$ or occlusion within the stented segment during follow up. Stroke severity (minor or major) was retrospectively classified based on documented neurological symptoms, imaging findings, and clinical outcome. Fatal stroke was defined as any stroke directly contributing to death during the periprocedural period or long term follow up. Follow up imaging based endpoints included detection of stent migration.

Procedure

The type of endovascular intervention, direct stent placement or a hybrid approach, and the antithrombotic medication prescribed were at the discretion of the treating physician. Hybrid therapy consisted of either temporary intraoperative manual straightening of the carotid artery or definitive surgical shortening of the proximal elongated ICA to facilitate guidewire access to the more distally located ECAA (Fig. 2). The choice of treatment modality was based on the individual patient characteristics and anatomic considerations. Imaging for diagnosis, treatment planning, and follow up included duplex ultrasound, computed tomography angiography imaging, or magnetic resonance angiography, depending on local protocols. The follow up schedule was determined by local clinical practice.

Statistical analysis

Descriptive statistics were used to summarise the demographic and clinical characteristics of the study population.

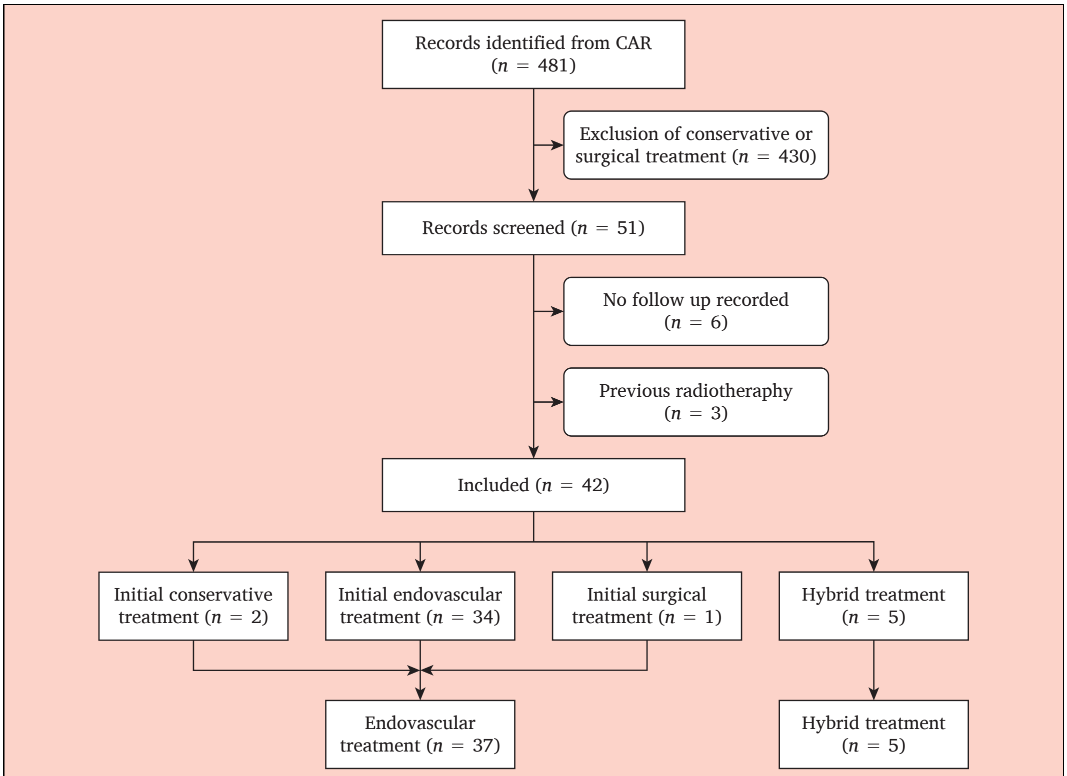

Figure 1. Flow diagram of included cases and treatment allocations from the Carotid Aneurysm Registry (CAR).

Continuous variables are presented as means with standard deviations or medians with interquartile ranges (IQRs), depending on their distribution. Categorical variables are presented as frequencies and percentages. Data were analysed using IBM SPSS for Windows, version 29.0.1 (IBM, Armonk, NY, USA). The study was not designed to compare different endovascular methods. No formal sample size or power calculation was performed because this registry based study aimed to include all eligible cases within CAR. Given the rarity of ECAA and the limited availability of data, a pragmatic approach was taken to analyse all consecutively registered patients undergoing endovascular or hybrid treatment.

RESULTS

In November 2024, 481 patients had been included in CAR (Fig. 1), of whom 42 had undergone elective endovascular

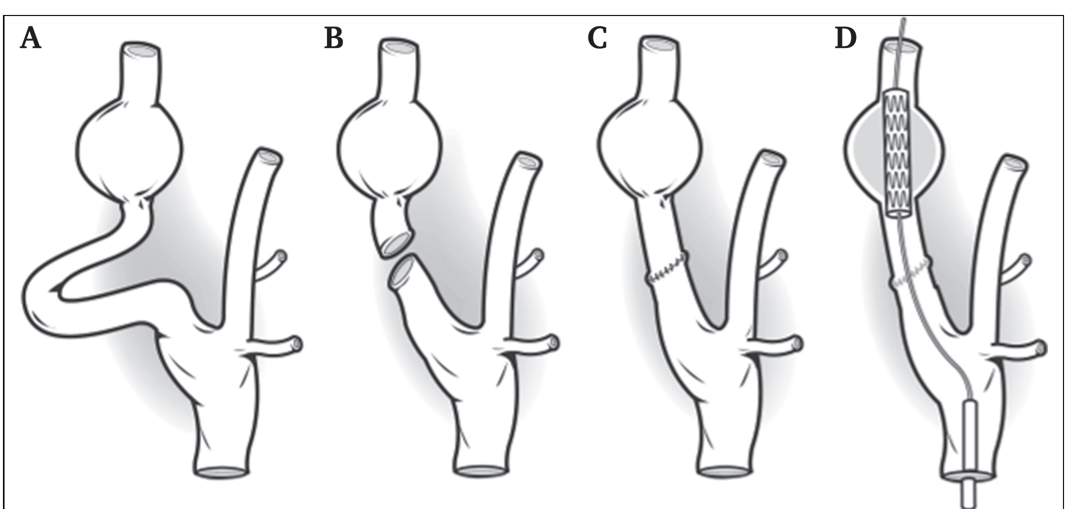

Figure 2. Hybrid approach to an extracranial carotid artery aneurysm. (A) Aneurysm located in the distal internal carotid artery (ICA). (B) Resection of a loop in the ICA. (C) Primary end to end anastomosis of the ICA. (D) Endovascular stent placement over the extracranial carotid artery aneurysm.

Table 1. Baseline and aneurysm characteristics of patients (n = 42) with extracranial carotid artery aneurysms treated endovascularly.

Patient	Sex; age − y	Size − mm; shape	Location	Main symptom	Aetiology
1	Man; 25	34; saccular	CCA	CVA	TD
2	Man; 69	7; fusiform	ICA (P)	Mass	Unknown
3	Man; 74	17; saccular	ICA (D)	TIA	Unknown
4	Woman; 65	15; saccular	ICA (D)	Asymptomatic	Unknown
5	Man; 33	15; fusiform	ICA (P)	TIA	SD
6	Woman; 52	7; fusiform	ICA (D)	Asymptomatic	CTD
7	Woman; 73	29; saccular	ICA (D)	Mass	AS
8	Woman; 71	54; fusiform	ICA (D)	Mass	Unknown
9	Man; 72	25; saccular	ICA (D)	CND	SD
10	Man; 77	44; saccular	CCA	Asymptomatic	Unknown
11	Woman; 56	10; saccular	ICA (D)	Asymptomatic	SD
12	Man; 32	20; saccular	ICA (P)	Asymptomatic	TD
13	Woman; 31	13; saccular	ICA (D)	Asymptomatic	TD
14	Man; 33	12; saccular	ICA (P)	Asymptomatic	TD
15	Man; 75	30; saccular	CCA	Asymptomatic	Unknown
16	Man; 28	15; saccular	ICA (D)	Asymptomatic	TD
17	Man; 49	8; saccular	ICA (D)	Asymptomatic	SD
18	Woman; 33	8; saccular	ICA (D)	Asymptomatic	Unknown
19	Man; 50	12; fusiform	ICA (P)	Asymptomatic	SD
20	Man; 48	12; saccular	ICA (D)	Asymptomatic	TD
21	Man; 52	25; saccular	ICA (D)	Asymptomatic	TD
22	Woman; 23	6; fusiform	ICA (D)	Asymptomatic	TD
23	Man; 75	33; saccular	ICA (P)	Asymptomatic	Unknown
24	Woman; 33	5; saccular	ICA (P)	CVA	TD
25	Man; 47	7; saccular	ICA (D)	Asymptomatic	Unknown
26	Woman; 37	8; saccular	ICA (P)	Asymptomatic	TD
27	Man; 55	11; saccular	ICA (D)	Asymptomatic	Unknown
28	Man; 74	7; saccular	ICA (D)	Asymptomatic	AS
29	Man; 56	18; saccular	ICA (D)	Asymptomatic	SD
30	Woman; 34	16; saccular	ICA (D)	Asymptomatic	CTD
31	Man; 56	19; fusiform	ICA (D)	Mass	Unknown
32	Man; 55	15; saccular	ICA (D)	Asymptomatic	TD
33	Woman; 44	9; saccular	ICA (D)	Local pain	Unknown
34	Man; 50	9; saccular	ICA (D)	CVA	Unknown
35	Woman; 80	40; saccular	ICA (D)	Asymptomatic	Unknown
36	Man; 48	10; saccular	ICA (D)	CVA	SD
37	Man; 23	16; saccular	ICA (D)	CVA	TD
38	Woman; 47	15; saccular	ICA (D)	CVA	SD
39	Woman; 74	12; saccular	ICA (D)	Asymptomatic	TD
40	Woman; 68	40; saccular	ICA (P)	Local pain	TD
41	Woman; 61	5; saccular	ICA (P)	Mass	AS
42	Man; 60	33; saccular	ICA (P)	Asymptomatic	Unknown

AS = atherosclerosis; CCA = common carotid artery; CND = cranial nerve deficit; CTD = connective tissue disease; CVA = cerebrovascular accident; (D) = distal; ICA = internal carotid artery; (P) = proximal; SD = spontaneous dissection; TD = traumatic dissection; TIA = transient ischaemic attack.

treatment. Among the 42 patients who underwent elective intervention, five received hybrid treatment, and 38 underwent elective endovascular ECAA exclusion, of whom two received endovascular intervention after initial conservative treatment due to either aneurysm growth or worsening symptoms (Fig. 1). One patient experienced a myocardial infarction during surgical treatment, after which it was decided to perform endovascular treatment at a later stage.

Baseline and aneurysm characteristics are summarised in Table 1. The mean age was 52 ± 17 years, and 25 patients (60%) were men. Eight patients (19%) experienced an ipsilateral ischaemic cerebral event at baseline. The median ECAA diameter was 15 mm (IQR 9.3, 28.0 mm), with most ECAAs located in the distal ICA (n = 28, 67%), most commonly with a saccular form (n = 35, 83%).

Treatment characteristics

Detailed treatment characteristics and outcomes of patients with notable clinical events are presented in Table 2. Fourteen patients were treated with bare metal stents (BMSs) and 15 with covered stents, whereas a smaller number received flow diverting stents (FDSs) (n = 4). All hybrid procedures involved the use of BMSs. Stent type was not documented in four cases. The most commonly used devices included Viabahn (Gore, Flagstaff, AZ, USA; n = 7), Carotid

Table 2. Treatment characteristics and outcomes of patients with extracranial carotid artery aneurysms (ECAAs) treated with endovascular therapy.

Patient	Stent type	Antithrombotic therapy	30 d outcomes	Long term outcomes	Follow up – mo
1	Covered	DAPT	Major ipsilateral stroke	–	48
3	FDS	Clopidogrel	Fatal ipsilateral stroke	–	0
7	Covered	NR	Conversion	–	1
10	Covered	Aspirin	–	Death	12
29	Hybrid, BMS	DAPT	–	New ECAAs	220
30	BMS	DAPT	–	Death	88
32	BMS + coils	DAPT	–	Death	92
35	Covered	DAPT	Minor stroke	Death	36
49	Hybrid, BMS	Clopidogrel	–	Aneurysm growth	74
40	FDS	DAPT	–	Stent migration	64

BMS = bare metal stent; DAPT = dual antiplatelet therapy; ECAA = extracranial arterial aneurysm; FDS = flow diverting stent; NR = not reported.

Wallstent (Boston Scientific, Natick, MA, USA; $n = 4$), and Precise (Cordis, Miami Lakes, FL, USA; $n = 3$). Dual antiplatelet therapy was the most common regimen at discharge ($n = 27$), whereas others received single antiplatelet therapy with aspirin ($n = 3$), clopidogrel ($n = 4$), or ticagrelor ($n = 1$). Antiplatelet therapy was undocumented or unknown in seven patients. One technical failure occurred where stent placement was not possible due to severe tortuosity of the carotid artery. The patient was converted to conventional open reconstruction without stent placement, and the aneurysmal segment was resected with end to end anastomosis. The five cases treated with hybrid therapy had a severely tortuous proximal ICA. The extent of tortuosity was not formally quantified but was observed based on imaging, aligning with the operator's discretion. In three of these patients, the carotid artery was manually straightened during the catheterisation. Surgical shortening of the proximal ICA was performed in the other two patients.

Short term outcomes (≤ 30 days after the procedure)

Within 30 days, three patients developed an ipsilateral stroke (one ischaemic and two haemorrhagic). One patient experienced a minor ischaemic stroke due to in stent thrombosis while taking dual antiplatelet therapy. The patient fully recovered without residual symptoms, and no re-interventions were required. The second patient developed a major haemorrhagic stroke following heparin administration for suspected ischaemia. Initial symptoms mimicked a stroke, but no new findings were seen on imaging. After treatment, the patient experienced a haemorrhagic cerebrovascular event and subsequently died; the event was classified as a fatal stroke. One patient experienced a haemorrhagic transformation of an earlier ischaemic stroke, which required a craniotomy; this was classified as a major stroke, and the patient recovered in moderately good condition. Access related complications consisted of a false aneurysm of the right groin ($n = 1$); cervical bleeding ($n = 1$) which required surgical correction; and groin ($n = 1$) or cervical haematoma ($n = 3$) which required no further intervention.

Long term outcomes

The median follow up was 65 months (IQR 28, 91 months). No ipsilateral ischaemic stroke was reported during long term follow up. Among patients with available follow up imaging, stent patency was 100%. ECAA exclusion was 95% at 12 months and 98% at the median of 65 months. One patient required additional ECAA coiling within one year, due to growth of the aneurysm sac. Stent migration in one case resulted in the need for three additional, separate stent placements over the years. Additionally, one patient developed two small new aneurysms proximal to the stent, 16 years after the initial hybrid treatment. These new aneurysms were assessed to pose a low risk of thromboembolism, leading to a decision for conservative monitoring, with no observed growth in two years. During the follow up period, four patients died at varying time points due to non-ECAA related causes, such as pneumonia, malignancy, and other non-cardiovascular conditions, with a median survival of 88 months.

DISCUSSION

This study currently represents the largest, multicentre cohort with the longest follow up of endovascular or hybrid ECAA treatment in 42 patients, demonstrating a high technical success rate and effective exclusion of the aneurysm sac. However, the peri-operative morbidity and peri- and post-operative mortality rates were higher than previously reported.[10,19–21]

The increased use of advanced imaging techniques has led to more frequent ECAA detection, particularly smaller, asymptomatic lesions.[22] The absence of evidence based guidelines poses a challenge in selecting the optimal treatment for individual patients. Previous literature, comparing surgical and endovascular ECAA repair, reported similar short term mortality and cerebrovascular event rates. However, the lack of long term data prevented direct comparisons between surgical and endovascular outcomes over time. This study addresses some of the limitations of the previous literature by adding long term outcome data on endovascular and hybrid treatment.[1,11,23,24]

In this series, the incidence of peri-procedural cerebral ischaemic events (7%) and peri-operative mortality rate (2%) appeared higher than previously pooled results. Previous studies have mostly consisted of small retrospective case series, which may have been subject to selection and publication bias.[10,23,25] The higher rates observed in this study may be related to the inclusion of complex clinical scenarios in a real world, multicentre setting. The overall post-operative mortality rate was 10% (four patients); however, these deaths were not directly related to the ECAA or its treatment. These findings underline the heterogeneity of ECAA cases and the need for carefully individualised decision making.

For 30 day survivors, the long term patency rate was 100%, with no cerebrovascular events reported during follow up. This finding is consistent with previous studies, which have reported patency rates between 93.2% and 100%, along with low cerebrovascular complication rates during short to midterm follow up.[2,10,12,26] Complete aneurysm exclusion was achieved in most cases, with one patient requiring staged additional coiling, which corresponds with the previous literature.[10,25] However, one patient experienced stent migration, necessitating three additional, separate stent placements over the years. Despite this complication, the patient remained free from cerebrovascular incidents during the follow up period. The exact cause of the stent migration in this particular patient remained unclear and warrants further research. Most published studies report no instances of stent migration during follow up.[2,27] Only isolated cases have been reported in the literature.[28,29] Possible risk factors could include poor stent wall apposition due to vessel tortuosity, as seen in carotid artery stenting for stenosis, or continuous mechanical stress in the mobile cervical segment.[30,31]

The post-operative antithrombotic therapy in this study varied between single and dual antiplatelet regimens, based on the discretion of the surgeon and local guidelines. Due to the small sample size, stratification and trend analysis regarding the number and type of complications was not feasible.

ECAA location and accessibility should be considered when selecting the optimal treatment approach. The highly elongated and tortuous inflow track in patients with ECAA is associated with challenging endovascular exclusion due to difficulties in navigating and accessing the affected area.[14,32,33] This series reported one technical failure where stent placement was not possible due to a tortuous carotid artery. A hybrid approach, to facilitate access, seems to be a feasible option for such cases. Existing literature has discussed multiple endovascular approaches for the treatment of ECAAs, including overlapping BMSs, covered stents, and FDSs; the use of the latter has proven to be an effective modality for intracranial aneurysms and has shown promise for safe ECAA exclusion in recent reports on ECAA treatment.[34,35] In this series, only four patients were treated with FDSs, possibly due to its more recent use in ECAA treatment. Additionally, the small available FDS diameters, which often do not align with the average size of the extracranial carotid arteries, may limit their use. It has been suggested that covered stents would result in better exclusion of the aneurysm sac; however, the superior flexibility of some BMSs could be useful for navigating the tortuous carotid branch and has shown equally good results for ECAA exclusion.[2,15,27] As the number of different stents and subsequent events was too small, a statistical comparison was not conducted.

This study was limited by the use of observational registry data with heterogeneous management approaches and variable follow up durations. In addition, detailed information on stent design and dimensions (length and diameter) was not consistently captured in the registry and could therefore not be included in the analysis. However, the CAR design aims to provide an accurate representation of current disease management, thereby enhancing the generalisability of these findings. Most patient data were entered into the registry shortly after treatment, and follow up information was added prospectively to provide a real world patient cohort. These findings highlight the need for a better understanding of patient specific and anatomic factors to optimise patient selection for endovascular ECAA repair. Of note, most of the patients in this registry underwent treatment for an asymptomatic ECAA. In general, a conservative approach is considered most appropriate for patients with asymptomatic ECAAs. While clear intervention thresholds on, for example, ECAA diameter are still lacking, the debate should question which ECAA patients would truly benefit from ECAA exclusion. For now, these results should be counterbalanced against prospective follow up data in conservatively treated ECAA patients. In order to create a future individualised patient approach, a clear framework for weighing the risks of intervention against those of conservative management is clearly needed. Further data collection through collaborative efforts such as CAR is essential to validate these findings and continue advancing personalised care for this rare disease.

Conclusions

In this registry based cohort, endovascular treatment appears technically feasible and effective for the (staged) exclusion of selected ECAAs. In this heterogeneous cohort, the peri-procedural morbidity and mortality rates were higher than previously reported in the literature. Of relevance, in patients surviving the 30 day period after ECAA exclusion, long term follow up revealed no recurrent stroke and a 100% stent patency rate. These preliminary findings should be carefully counterbalanced by natural course outcome data to design a future treatment algorithm for patients with ECAA.

CONFLICT OF INTEREST

None.

FUNDING

None.

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejvs.2025.11.055.

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