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INTERVENTIONAL RADIOLOGY

ORIGINAL ARTICLE

Flow-diverting stents in the management of extracranial carotid artery aneurysms

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PURPOSE

This study aims to investigate the indications and therapeutic efficacy of flow-diverting stents (FDSs) in the management of extracranial carotid artery aneurysms (ECAAs) and dissections.

METHODS

A retrospective analysis was conducted on 18 patients treated for ECAAs with an FDS between 2010 and 2024. Patient demographics, aneurysm characteristics, procedural details, and clinical and radiologic follow-up outcomes were extracted from medical records. Procedures were performed under general anesthesia using standard endovascular techniques. Patients received preoperative and postoperative antiplatelet therapy and were fully anticoagulated during the procedure. Follow-up assessments included digital subtraction angiography or computed tomography angiography at 6–12 months and clinical evaluations to monitor symptom resolution and complications.

RESULTS

Eighteen patients, with an average age of 46.44 ± 17.54 years, underwent 19 endovascular interventions. Technical success was achieved in all cases. Single stent deployment was used in 15 aneurysms, and telescopic stent deployment in 7. Total occlusion of the aneurysm was achieved in 94.4% of cases. One patient required retreatment due to the separation of two overlapped telescopic stents. All patients were discharged within 2 days post-procedure, with symptomatic patients experiencing the complete resolution of symptoms. No complications or adverse events were reported during the follow-up period.

CONCLUSION

The endovascular treatment of ECAAs with FDSs appears to be a safe and effective alternative, achieving high technical success and positive clinical outcomes.

CLINICAL SIGNIFICANCE

The use of FDSs for treating ECAAs significantly improves patient outcomes with minimal complications.

KEYWORDS

Carotid artery, stenting, flow diverter, aneurysm, neuroendovascular treatments

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Extracranial carotid artery aneurysms (ECAAs) account for <1% of all peripheral arterial aneurysms.[1] The most common etiologies of ECAAs include atherosclerosis and dissection with or without trauma.[2] These aneurysms are often diagnosed incidentally during examinations for other pathologic processes and are mostly asymptomatic.[3] Although the risk of ECAA rupture and exsanguination is minimal, complications such as thrombosis, embolization, and nerve compression frequently indicate the need for repair.[4,5]

In cases where ECAAs are located more distally in the internal carotid artery (ICA) and near the base of the skull, endovascular therapy is recommended. Despite the lack of consensus, various types of stents are available for the endovascular treatment of ECAAs. Coated stents

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are often avoided in tortuous carotid arteries due to their stiffness and lack of maneuverability during the procedure.[3] However, flow-diverting stents (FDSs) have proven to be more effective in treating extracranial aneurysms and dissections.[4,6]

This study aims to investigate the indications and therapeutic efficacy of FDSs in the management of ECAAs and dissections.

Methods

The Institutional Review Board of Ege University Faculty of Medicine approved this retrospective study (protocol number: 24-8T/23, date: 26.06.2024). Informed consent was not required due to this study's retrospective and observational nature. All identifiable details were anonymized during data collection and analysis to ensure patient confidentiality.

We conducted a retrospective analysis on a cohort of 18 patients treated in two institutions for ECAAs using FDSs between 2010 and 2024. Patient demographics, aneurysm characteristics, procedural details, and clinical and radiologic follow-up outcomes were extracted from medical records. These cases were confirmed angiographically using computed tomography (CT) and magnetic resonance imaging. Inclusion criteria encompassed patients diagnosed with cervical ICA aneurysms, irrespective of aneurysm etiology and presentation. Patients with aneurysms located outside the cervical ICA were excluded.

Main points

- The study achieved a 100% technical success rate in treating extracranial carotid artery aneurysms (ECAAs) with flow-diverting stents (FDSs), as all 19 endovascular interventions in 18 patients were successfully performed without peri-procedural complications.
- Follow-up imaging indicated a 94.4% total occlusion rate of aneurysms, with 17 out of 18 patients showing complete occlusion. Only one patient required retreatment due to the separation of two overlapped telescopic stents, which was successfully addressed with a third stent.
- All symptomatic patients experienced the resolution of their symptoms post-treatment.
- The study reported no complications or adverse events, such as transient ischemic attack or stroke, during the follow-up period, indicating a safe profile for FDSs in ECAA treatment.

All procedures were performed under general anesthesia using standard endovascular techniques. The choice between single or telescopic stent deployment was based on aneurysm morphology, size, and the presence of associated vascular lesions. Antiplatelet therapy was administered preoperatively and continued postoperatively in accordance with institutional protocols. Patients were pre-loaded for 5 days with antiplatelet medication (300 mg/day of aspirin and 75 mg/day of clopidogrel). In cases of resistance to clopidogrel, 10 mg/day of prasugrel was used. Platelet function was measured using multiple electrode aggregometry (Multiplate® Analyzer; Roche Diagnostics, Munich, Germany). All tests were undertaken 1 day before the endovascular procedure. According to the consensus opinion of the Working Group on High On-Treatment Platelet Reactivity, platelet aggregation (adenosine diphosphate) values >47 U (the normal range in the absence of an antiaggregant is 57–113 U, as reported by the manufacturer) is considered indicative of nonresponsiveness or hyporesponsiveness (resistance).[7]

All patients were fully anticoagulated with intravenous heparin during the procedure. Post-procedure, dual antiplatelet therapy was continued for 6–12 months, and aspirin was continued for the patient's lifetime.

A 6 or 7 Fr introducer was placed in the groin region for the vascular intervention, followed by navigation into the common carotid artery proximal to the dissection. A microwire inside a microcatheter was then crossed through the dissection segment. An FDS of the appropriate diameter and length was selected according to the measurements made from three-dimensional angiography. After the microcatheter was placed in the lesion, Pipeline (Medtronic, Irvine, CA, USA), Derivo (Acandis, Pforzheim, Germany), and Surpass Evolve (Stryker Neurovascular, Kalamazoo, MI) stents were used.

Technical success was defined as the accurate placement and deployment of the FDS in the targeted segment of the cervical ICA without peri-procedural complications. Digital subtraction angiography or CT angiography was performed routinely at 6 and 12 months after stent deployment. Total occlusion of the aneurysm on imaging was defined as the absence of residual filling. Clinical follow-up assessments were performed to monitor symptom resolution and potential complications.

No statistical comparisons were made in this descriptive study. Summary statistics are reported as median and range for continuous variables or frequency counts and percentages for categorical variables.

Result

A total of 18 patients, comprising 8 men (45%) and 10 women (55.5%), underwent 19 endovascular interventions. The average age was 46.44 ± 17.54 years, ranging from 8 to 68 years. Six cases were discovered incidentally during imaging investigations for other pathological processes, whereas the other patients presented with various symptoms (Table 1).

Clopidogrel resistance was detected in three patients; they were re-loaded with prasugrel. All patients were treated with FDSs. Technical success was achieved in all cases (100%) (Figures 1-4). Single stent deployment was utilized in 15 locations, whereas telescopic (dual) stent deployment was employed in 7 aneurysms. Imaging follow-up indicated that the total occlusion of the aneurysm was achieved in 17 out of 18 patients (94.4%). One patient required retreatment (patient 16) due to the separation of two overlapped telescopic stents, resulting in residual filling. When evaluated retrospectively, it was thought that the stent separation was caused by insufficient manipulation during initial stent deployment and leaving the short overlapped segment. This was successfully addressed with a third stent. Notably, aneurysm occlusion persisted in subsequent follow-ups.

All patients were discharged on postoperative day 1 or 2. Clinically, symptom resolution was observed in symptomatic patients, including the complete disappearance of neck pain and swallowing difficulties. No complications or adverse events (transient ischemic attack or stroke) were reported during the follow-up period.

Discussion

Our study found that FDSs are highly effective in treating ECAAs. Among the 18 patients who underwent 19 endovascular interventions, technical success was achieved in all cases, with 94.4% (17 out of 18) of aneurysms showing total occlusion on follow-up imaging. One patient required retreatment due to the separation of two telescopic stents. Clinical outcomes were positive, with symptomatic patients experiencing the resolution of symptoms, and no complications

Table 1. Summary of patients with ECAAs treated with an FDS

No/age (year)/ sex	Etiology	Presentation	Aneurysm: side/ geometry/length/ diameter/neck	Associated vascular lesions	FDS name/size	Radiologic follow-up	Clinical follow-up
1/8/F	Fall	Swallowing difficulties, neck mass	R/saccular/6 cm/3 cm/0.5 cm	None	Pipeline/5 × 30 mm (two telescopic)	1-year CTA: total occlusion	Disappearance of symptoms
2/45/M	Unknown	TIA	L/fusiform/2 cm/0.9 cm/1.5 cm	None	Pipeline/5 × 30 mm	1- year CTA: total occlusion	No complaint
3/21/M	Fall (suicide)	Incidental (polytrauma)	R/saccular/1.5 cm/1.5 cm/0.5 cm L/fusiform/3.5 cm/2 cm/2.5 cm	Aortic transection treated with stent graft	Pipeline/5 × 30 mm each	6-month CTA: total occlusion	No complaint
4/54/F	Unknown	Neck mass	R/saccular/2.8 cm/2.2 cm/1 cm	None	Pipeline/5 × 30 mm (two telescopic)	6-month CTA: total occlusion	No complaint
5/ 65/M	Unknown	Incidental	L/saccular/1.6 cm/0.5 cm/1 cm	None	Pipeline/5 × 30 mm	1-year CTA: total occlusion	No complaint
6/68/F	Unknown	Neck mass	R/saccular/3 cm/3 cm/1.3 cm	None	Pipeline/5 × 30 mm	6-month CTA: total occlusion	No complaint
7/35/F	Unknown	Acute neck pain	L/fusiform/2.5 cm/1.5 cm/2 cm	R narrowing of cervical ICA due to long segment dissection	Pipeline/5 × 30 mm	12-month CTA: total occlusion	No complaint
8/45/M	Unknown	TIA	L/two saccular/2.5 cm/1.5 cm/1 cm and 1.2 cm/1.2 cm/0.7 cm	None	Pipeline/5 × 30 mm (two telescopic)	24-month CTA: total occlusion	No complaint
9/64/F	Unknown	Incidental	L/saccular/0.8 cm/0.8 cm/0.4 cm	L cavernous ICA aneurysm 15 mm in diameter	Pipeline/5 × 30 mm	15-month CTA: total occlusion	No complications
10/65/F	Fibromuscular dysplasia	Incidental	R/Saccular/0.3 cm/0.3 cm/0.3 cm	Two intracranial aneurysms 6 mm and 4 mm in diameter	Pipeline/5 × 30 mm	6-month CTA: total occlusion	No complications
11/51/F	Unknown	Syncope	R/saccular/0.5 cm/0.3 cm/0.4 cm L/fusiform/1.5 cm/0.8 cm/0.5 cm	Two intracranial aneurysms 1.3 cm and 0.5 cm in diameter	Pipeline/4.5 × 20 mm (R) Surpass/ 5 × 50 mm (L)	38-month DSA: total occlusion	No complaint
12/16/M	Unknown	Right transient hemiparesis 8 months before	L/fusiform/4 cm/1.5 cm/ 3 cm	None	Derivo/5.5 × 50 mm (two telescopic)	6-month DSA: apparently diminished aneurysm. 36-month CTA: almost total occlusion with minimal neck filling	No complaint
13/33/M	Unknown	Acute stroke, mechanical thrombectomy 4 weeks before	L/fusiform/1.5 cm/1 cm/1.5 cm	Dissecting stenosis involving whole prepetrous ICA segment	Surpass/5 × 20 mm and Derivo/ 5 × 50 mm (telescopic)	30-month DSA: aneurysm occlusion with 50% long segment stenosis	No complaint
14/48/F	Unknown	Incidental	R/saccular/0.9 cm/0.9 cm/0.5 cm L/fusiform/3 cm/1 cm/2.5 cm	Cavernoma in cervical spinal cord	Pipeline/5 × 30 mm in each	6-month DSA: total occlusion	No complaint
15/52/F	Unknown	Incidental	R/saccular/1.5 cm/1.5 cm/0.5 cm	Occluded L ICA	Pipeline/5 × 30 mm	12-month Doppler US: total occlusion	No complaint
16/61/M	Unknown	Neck pain	R/fusiform/2.5 cm/1.5 cm/0.6 cm	Three intracranial aneurysms 5, 6, and 15 mm in diameter	Derivo/4.5 × 30 and 5.5 × 30 mm (telescopic) Derivo/5.5 × 50 mm (retreatment)	6-month DSA: residual filling due to separation of overlapped stents. Retreatment with third stent. 18-month DSA: total occlusion	No complaint
17/54/F	Connective tissue disorder	Neck pain	R/saccular/1 cm/1 cm/0.4 cm and 0.9 cm/0.8 cm/0.4 cm L/saccular/2 cm/1 cm/0.5 cm	None	Pipeline/4.75 × 30 mm in each.	6-month CTA: total occlusion	Neck pain subsides
18/51/M	Fibromuscular dysplasia	Neck pain	R/fusiform/1 cm/0.8 cm/0.8 cm L/fusiform/1 cm/0.9 cm/0.7 cm	None	Derivo/5 × 30 mm (two telescopic in R) Derivo/5 × 30 mm (L)	6-month DSA: total occlusion	Neck pain subsides

F, female; M, male; ECAAs, extracranial carotid artery aneurysms; FDS, flow-diverting stent; TIA, transient ischaemic attack; L, left; R, right; ICA, internal carotid artery; CTA, computed tomography angiography; DSA, digital subtraction angiography; US, ultrasound.

Figure 1. Patient 1: Chronic traumatic aneurysm **(a)**. Magnetic resonance imaging shows a huge mass compressing the esophagus and laryngeal air passage. **(b)** Subtracted computed tomography (CT) angiography reveals the aneurysm with extensive wall calcification. **(c)** Angiography demonstrates a huge aneurysm arising from the pre-petrous segment of the right internal carotid artery. **(d)** One-year follow-up CT angiography confirms the disappearance of the aneurysm and shrinkage of the mass.

or adverse events were reported during the follow-up period.

ECAAs can arise from various etiologies, including atherosclerosis, trauma, infections, and inflammatory conditions.[2] Many cases, similar to those in our study, can be idiopathic.[8] Giannopoulos et al.'s[9] systematic review found trauma to be the cause in 54.3% (38 out of 70) of cases. Similar to our study, the literature indicates that neurological symptoms occur in approximately 42% to 51% of ECAA cases.[10-12] Given the high morbidity associated with ECAAs, treatment is recommended upon diagnosis, especially if symptomatic.[13,14] Untreated ECAAs can lead to distal embolization (particularly in true aneurysms) or exert a mass effect on adjacent structures (particularly in false aneurysms).[15,16]

Several therapeutic strategies have been proposed for managing ECAAs, including surgical, endovascular, and conservative therapies. In addition, there is a case report of a complex ECAA treated with both endovascular and open surgical approaches.[17] However, the optimal treatment modality remains controversial due to the lack of established guidelines. Open surgery for ECAA treatment has a 2.6% peri-procedural mortality rate, and cranial nerve injury occurs in 11.8% to 26% of cases.[2,9] Moreover, open surgery can be risky if the aneurysm's location and patient suitability are not optimal. Attigah et al.[18] classified aneurysms into high (type I) and very low (type V) positions, with these positions being more suitable for endovascular treatment. In an observational study by Choi et al.[19] involving 41 patients treated with surgical, conservative, or endovascular methods, surgical treatment was preferred for Attigah type I ECAAs at their institution (64.0% vs. 40.0%, $P = 0.09$), and both surgical and endovascular treatments were deemed safe.

A meta-analysis by Galyfos et al.[20] involving 374 patients with 383 ECAAs (220 were treated with open surgery and 81 with endovascular methods) found similar 30-day mortality rates for open surgery and endovascular treatments [4% vs. 0%; pooled odds ratio (OR), 2.67; 95% confidence interval (CI), 0.291–24.451]. Stroke and transient ischemic attack rates were also comparable (5.5% vs. 1.2%; pooled OR, 1.42; 95% CI, 0.412–4.886), but cranial injury was more common in open surgery (14.5% vs. 0%; OR, 3.98; 95% CI, 1.178–13.471).[20] The literature also shows that the perioperative stroke rate for endovascular treatment ranges from 2% to 3.1%.[9,10] Similarly, Ni et al.[21] demonstrated in a study with a 2-year follow-up that no deaths or neurological adverse events occurred.

Endovascular modalities described in the literature include covered stenting,[12] bare metal stenting,[2] multiple stent techniques (telescoping stenting, overlapped stenting),[22] and stent-assisted coiling[14] for treating ECAAs. Self-expanding carotid stents have traditionally been used for treating carotid atherosclerosis in high-risk patients due to their positive effects on coronary atherosclerosis. Recently, these stents have also been employed to address spontaneous dissections or those caused by trauma or angioplasty.[4,8,23] However, mechanical tests reveal that self-expanding carotid stents tend to stiffen, with bending stiffness increasing non-linearly as deflection rises.[24] This stiffness makes these stents less suitable for use in a distal cervical or petrous ICA, where sharp angulation at the skull base occurs. Furthermore, carotid stents with large cell designs are highly porous and may lack sufficient radial force to seal a false lumen or induce thrombosis in a pseudoaneurysm.[25]

In our study, we used FDSs for all cases. Although there are limited reports on the use of FDSs,[4,5,25-28] they offer several advantages over traditional closed- and open-cell stents. Kurre et al.[28] reported their experience with stent placement for acute ICA dissections in 73 patients presenting with acute ischemia, using FDSs in approximately 30% of cases. They reported excellent success rates (100%) for justified reconstructions of the cervical ICA and a low complication rate (8%), with no new ischemic symptoms in treated dis-

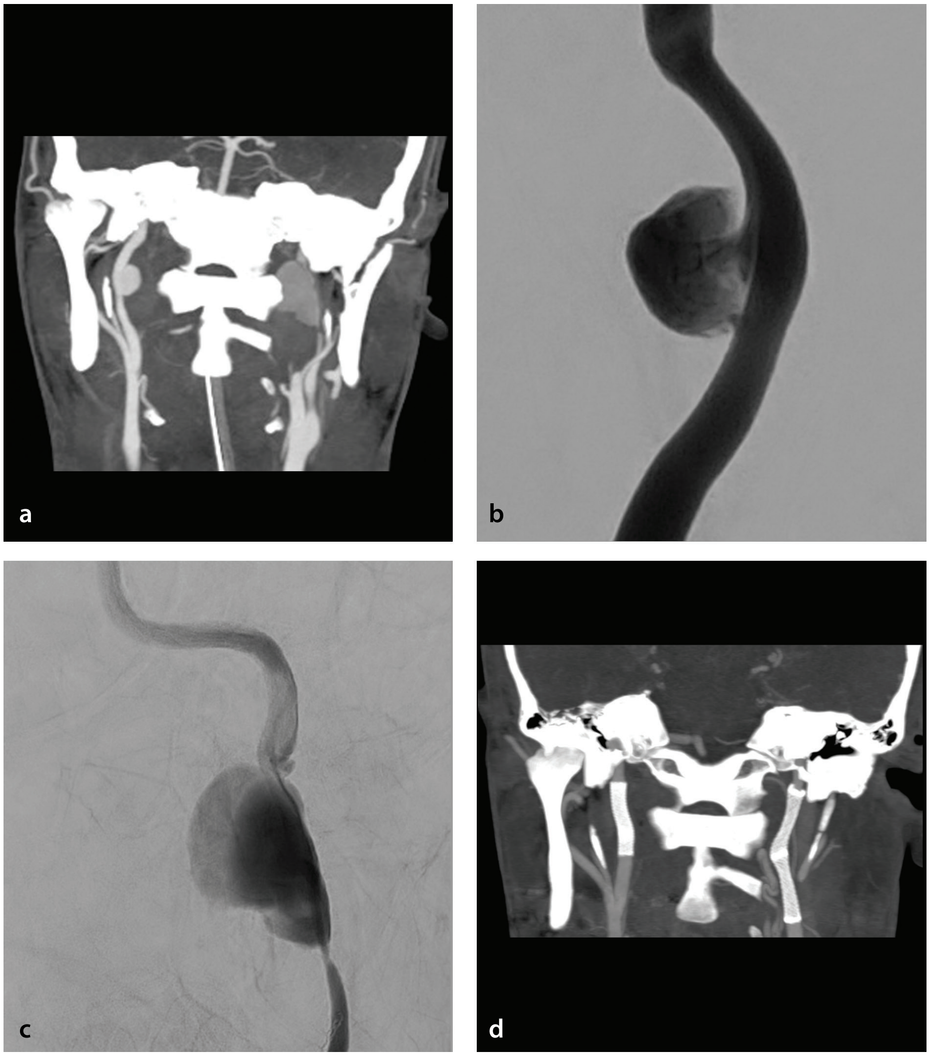

Figure 2. Patient 3: Bilateral acute traumatic dissecting aneurysms. **(a)** Computed tomography (CT) angiography reveals a bilateral high-cervical internal carotid artery (ICA) dissection accompanied by saccular (R) and fusiform (L) aneurysms. **(b, c)** Angiograms show more clearly the anatomy of the right **(b)** and left **(c)** cervical ICA aneurysms. **(d)** Six-month control CT angiography confirms the disappearance of both aneurysms and the normal calibration of the dissected segments.

sections.[28] Similarly, Hilditch et al.[5] treated seven young patients with symptomatic extracranial ICA dissection using FDSs, with no serious perioperative complications. None of the patients experienced recurrent ischemic events following ICA reconstruction, and no postprocedural in-stent stenosis was observed.

FDSs are approved for the treatment of wide-necked intracranial aneurysms and are potentially suitable for treating dissections with or without aneurysms at the skull base due to several unique features. The softer and more flexible characteristics of FDSs provide greater durability against stent fracture in the highly mobile high-cervical ICA transition at the skull base. FDSs are low-porosity woven tubes, offering three times the vessel wall coverage compared with traditional intracranial stents.[25] The higher metal coverage of the parent vessels (30%–50%) of FDSs can improve the closure of a dissection flap or pseudoaneurysm and reduce continued blood flow into a false lumen. This can also reduce recurrent embolic events, providing an advantage over braided stents, which generally offer less metal coverage.[29] In addition, FDSs facilitate the neo-intimal remodeling of the parent artery. Another significant feature of the FDS is its greater flexibility and adaptable radial force compared with traditional self-expanding carotid stents, allowing easier accommodation to sharp angulation at the skull base.

Despite the advantageous properties of FDSs in treating ECAAs with or without dissection, certain factors may limit their future use. Notably, some features of the extracranial cervical vessel structure, such as high lumen pressures and frequent positional changes due to neck movement, pose a higher risk of stent migration compared with intracranial vessels.[30] Both proximal migration in the anterior and posterior circulation and the spontaneous shortening of FDSs have been reported.[31] In our series, we encountered the separation of two overlapped telescopic stents in only one patient. Another concern is the need for dual antiplatelet agents 6–12 months following FDS placement, complicating the management of any medical conditions requiring surgery.[26]

Another significant limitation of FDSs in cervical segments is the parent artery diameter, as current flow diverters are recommended for vessel diameters of up to 5.2–5.75 mm, designed to open approximately 0.25 mm above their nominal diameter, with the largest available size being approximately 5.25 mm. For arteries measuring wider than 5.75 mm, other adjunctive endovascular techniques should be considered. For example, Amuluru et al.[4] and Rahal et al.[32] reported concurrent anchoring strategies with FDS deployment in cases where the distal cervical ICA measured ≥5.25 mm. To ensure adequate coverage of the aneurysm neck and to cover long segment dissection, if any, we intentionally used multiple FDSs in a telescoping configuration in six patients. Tsang et al.[26] also highlighted the use of the telescoping method in six of the seven cases in their series.

This study has several limitations that should be considered when interpreting the findings. The retrospective, non-randomized design may introduce recall bias and limit the establishment of causal relationships. The small sample size because of the low incidence of ECAAs limits the study's power. The etiology and aneurysm type also differed in each case. Additionally, some patients did not have a long enough follow-up period. Although these limitations require cautious interpretation, they also point to opportunities for future research to address these constraints and enhance our understanding of the subject.

In conclusion, considering the patient's condition and the characteristics of the aneurysm, the endovascular treatment of ECAAs with FDSs appears to be a safe and feasible alternative.

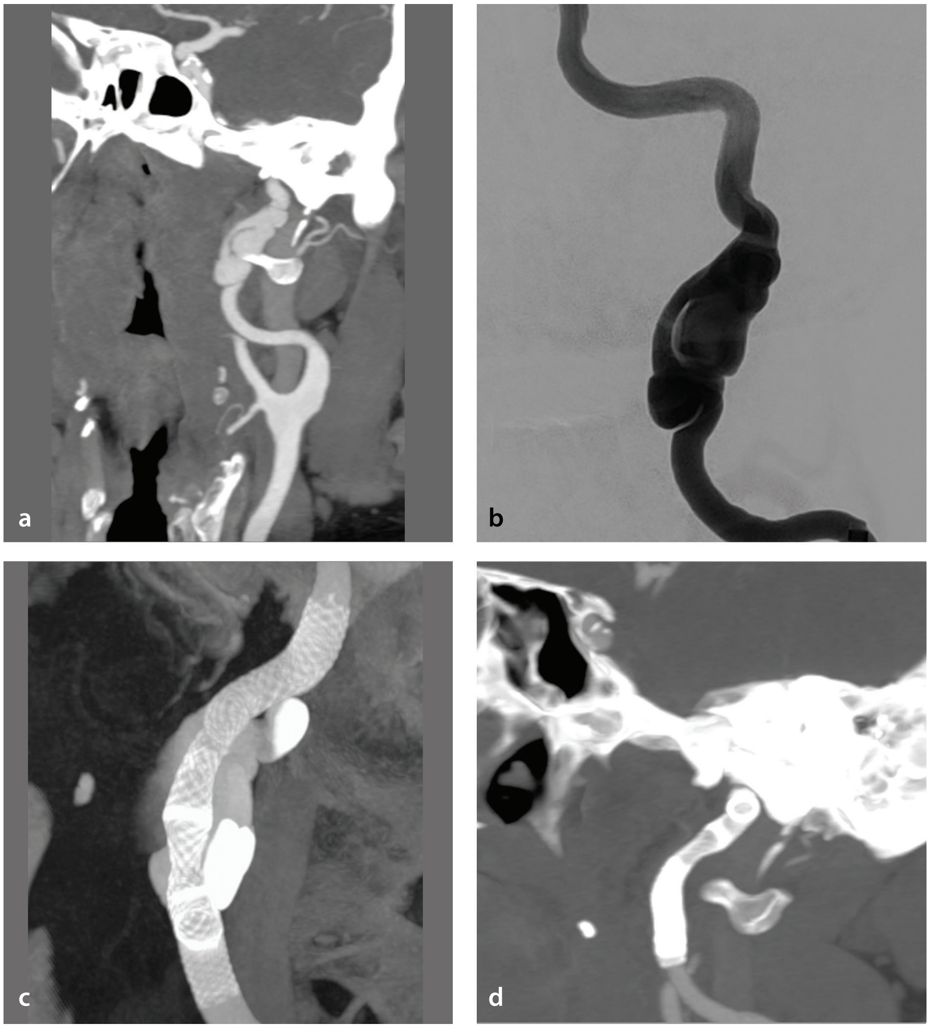

Figure 3. Patient 8: Chronic dissecting aneurysms in the high-cervical segment of the left internal carotid artery. Computed tomography (CT) angiography **(a)** and digital subtraction angiography **(b)**. **(c)** Cone-beam CT after telescopic flow-diverting stent implantation in the dissected segment. **(d)** Twenty-four-month control CT angiography confirms aneurysm occlusion and the reconstruction of the dissected segment.

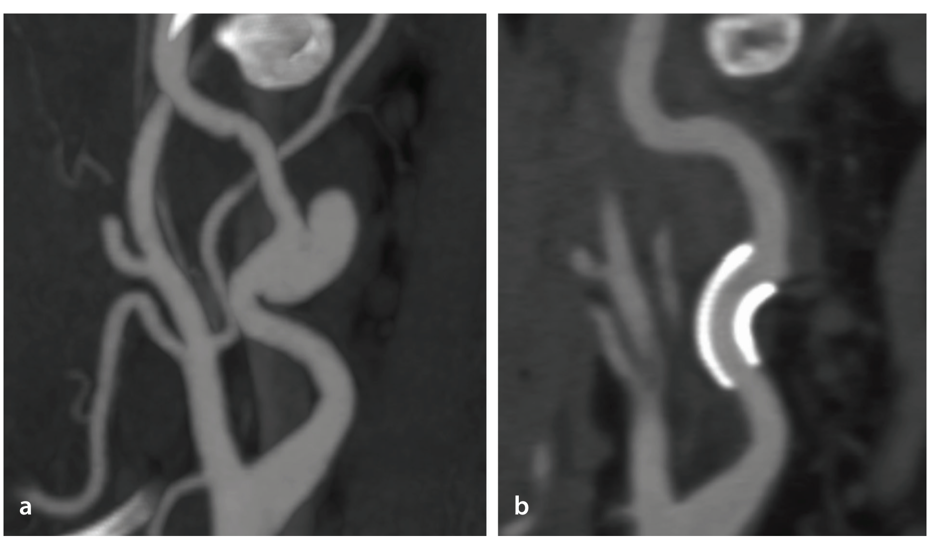

Figure 4. Patient 2: Sausage-shaped, presumably dissecting aneurysm located in the left cervical internal carotid artery (ICA). **(a)** Computed tomography (CT) angiography shows an aneurysm located in the low cervical ICA. **(b)** One-year control CT angiography confirms occlusion of the aneurysm.

Footnotes

Conflict of interest disclosure

The authors declared no conflicts of interest.

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