Original Paper

Anchoring Pipeline Flow Diverter Construct in the Treatment of Traumatic Distal Cervical Carotid Artery Injury

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Keywords

Carotid dissection · Pseudoaneurysm · Pipeline Embolization Device

Abstract

Background: Traumatic extracranial internal carotid artery (ICA) dissections are uncommon and can be difficult to treat. Thinning of adventitia and dilatation may occur following arterial dissection, thus resulting in a fusiform pseudoaneurysm, which can subsequently cause bleeding, expanding, or pulsatile hematoma. Currently, medical management with anticoagulation remains the first line of treatment and yields good outcomes in 75% of cases with a mortality rate of 3–4%. Endovascular intervention is indicated with failure of medical therapy, progressive enlargement of a traumatic pseudoaneurysm, acute flow-related infarcts due to vessel occlusion, or when anticoagulation is contraindicated due to risk of pseudoaneurysm rupture and hemorrhage. Recognized interventional treatments include parent artery occlusion with or without revascularization, endovascular coil embolization, and covered stenting.

Summary: A wide variety of endovascular stents are available that are capable of opening a stenosed vessel while obliterating the associated false lumen and providing a scaffold for embolization of the pseudoaneurysm. The use of the Pipeline Embolization Device (PED) in the management of traumatic intracranial pseudoaneurysms has been described. However, there are few reports on the usage of the PED for treating traumatic extracranial ICA dissection and/or pseudoaneurysms. However, a potential complication of the use of PED in the extracranial ICA is a hypothetical tendency to migrate in a mobile vessel. Thus, the risk of migration of the PED has encouraged practitioners to adopt strategies to limit this risk. **Key Messages:** We describe different techniques employed to anchor the flow-diverting construct within tortuous, mobile vessels.

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Introduction

Traumatic extracranial internal carotid artery (ICA) dissections are uncommon and can be difficult to treat [1]. Thinning of adventitia and dilatation may occur following arterial dissection, thus resulting in a fusiform pseudoaneurysm, which can subsequently cause bleeding, expanding or pulsatile hematoma, dysphagia, hoarseness, or hypotension [2]. Currently, medical management with anticoagulation remains the first line of treatment and yields good outcomes in 75% of cases with a mortality rate of 3–4% [3].

Endovascular intervention is indicated with failure of medical therapy, progressive enlargement of a traumatic pseudoaneurysm, acute flow-related infarcts due to vessel occlusion, or when anticoagulation is contraindicated due to risk of pseudoaneurysm rupture and hemorrhage [4]. Recognized interventional treatments include parent artery occlusion with or without revascularization, endovascular coil embolization, and covered stenting [2]. A wide variety of endovascular stents are available that are capable of opening a stenotic vessel while obliterating the associated false lumen and providing a scaffold for embolization of the pseudoaneurysm [4–10].

Traditional carotid stents have typically been the mainstay of treatment for most proximal and midcervical ICA dissections. However, the use of traditional carotid stents in the management of flow-limiting dissections and/or pseudoaneurysms involving tortuous parent arteries, such as the distal cervical or petrous ICA, can be technically challenging. The relative rigidity of the carotid stent delivery system limits the ability to manipulate the system within acute angulations of the parent vessel [11].

The Pipeline Embolization Device (PED) (ev3 Neurovascular, Irvine, CA, USA) has become an increasingly useful tool in the neurointerventionalist's repertoire in managing distal ICA disease. Stent reconstruction of dissections involving the petrous segment of the carotid artery is challenging due to the abrupt angulation of the vessel, which is fixed by the osseous skull base. Although the use of the PED in the management of traumatic intracranial pseudoaneurysms has been described, there are few reports on the usage of the PED for treating traumatic extracranial ICA dissections and/or pseudoaneurysms [1, 3, 12].

The PED is a low-porosity, highly flexible stent that renders it suitable for treating distal cervical ICA traumatic dissections and/or pseudoaneurysms. However, a potential complication of the use of PED in the extracranial ICA is a hypothetical tendency to migrate in a mobile vessel.

Thus, the risk of migration of the PED has encouraged practitioners to adopt strategies to limit this risk [13–15]. Herein, we describe the successful use of flow diversion in the management of different presentations of traumatic distal cervical ICA dissections. Additionally, we demonstrate different techniques employed to anchor the flow-diverting construct within a tortuous, mobile vessel. The subjects have given their informed consent and the study protocol has been approved by our Institute's Committee on Human Research.

Case 1

Clinical Presentation

An elderly patient presented after being struck by a vehicle while riding a bicycle. The patient denied recollection of the episode, and was witnessed to have lost consciousness briefly after the accident. The patient reported waking up on the ground with severe cervical, left thigh, left knee, and left elbow pain. On presentation to the hospital, the patient was hemodynamically stable and on exam was found to have multiple superficial injuries, a mildly displaced fracture through the left olecranon with intraarticular extension, and a left ligamentous knee injury. Neurologically, the patient was intact at the time of initial evaluation.

Fig. 1. **a** MRI brain DWI image showing punctate foci of infarcts in the watershed distribution between the anterior and middle cerebral artery territories. **b** DSA in left oblique view showing arterial dissection involving the distal cervical and petrous ICA with decreased anterograde flow. **c** Postintervention DSA showing recanalization of the parent vessel with PED and Wallstent construct. **d** Reconstructed dyna-CT showing the PED-Wallstent construct with PED navigating the tortuous cervical petrous junction and telescoped Wallstent within the straight cervical segment. **e** Three-month follow-up DSA showing resolution of dissection with anterograde flow through the patent stent construct.

Within 24 h of admission, the patient demonstrated a fluctuating mental status, word-finding and comprehension difficulties, and the National Institute of Health Stroke Scale (NIHSS) score fluctuated between 1 and 8. Computerized tomographic angiography (CTA) and computerized tomography perfusion (CTP) of the brain were obtained. The CTA revealed gradual tapering of the extracranial left ICA with a linear filling defect within the proximal petrous left ICA, suggesting arterial dissection. CTP showed an increased mean transit time and perfusion deficits of the entire left hemisphere. The findings of decreased blood flow, without a definite decrease in blood volume suggested a large ischemic penumbra. The MRI (Fig. 1a) demonstrated scattered areas of restricted diffusion consistent with flow-related infarcts in a watershed distribution between the left anterior cerebral and middle cerebral artery territories.

Intervention and Outcome

The patient was taken to the angiography suite where a dissection of the left ICA was confirmed, involving the distal cervical ICA at the skull base and extending to involve the vertical and horizontal petrous segments (Fig. 1b). There was delayed anterograde flow to the left anterior circulation, with poor collateral flow via a transophthalmic external-to-internal carotid collateral, and a small posterior communicating artery. Although the patient's altered mental status was a nonspecific finding, the decision was made to attempt recanalization of the vessel due to the patient's word-finding difficulty, the poor anterograde flow and the findings on the MRI. The risks of recanalization were considered, which included propagating further embolic material and completely occluding the vessel. The risk of reperfusion injury was thought to be minimal given the punctate nature of the infarcts.

During the procedure, a Neuron MAX 0.088-inch ID guide catheter (Penumbra, Alameda, CA, USA) was placed into the proximal cervical left ICA. An initial dose of 11 mg of intra-arterial abciximab (ReoPro) was administered through the left carotid artery guide catheter. Through the guide catheter, a 150-cm, 3.2-Fr, 0.027-inch ID Marksman microcatheter (Covidien, Irvine, CA, USA) was used as the delivery microcatheter. Due to the tortuosity of the cervical-petrous ICA junction, a 5 × 30 mm PED was deployed extending from the horizontal petrous segment proximally into the distal cervical ICA across the dissection. Restoration of TICI grade 3 antegrade intracranial flow through the PED into the left anterior circulation was obtained. However, the proximal aspect of the PED was slightly smaller than the cervical parent vessel which measured 5.4 mm. Thus, the decision was made to deploy a larger carotid stent in order to anchor the PED. Both the Marksman microcatheter and Navien intermediate catheter were removed. A 3.5- to 5.5-mm FilterWire EZ (Boston Scientific, Marlborough, MA, USA) was used for embolic protection. Over this, a 10 × 37 mm Carotid Wallstent (Stryker Neurovascular, MN, USA) was deployed from the vertical petrous segment proximally into the distal cervical segment of the left ICA, well positioned within the proximal lumen of the PED. Noncontrast dynaCT confirmed optimal stent positioning (Fig. 1c–d).

Postoperatively, the patient was loaded with aspirin 325 mg and clopidogrel 600 mg and was placed on aspirin 325 mg and clopidogrel 75 mg daily. Neurological examinations at 24 and 48 h remained unchanged. The patient was fully alert, oriented and fluent without aphasia. Extraocular movements were intact. Pupils were OS 4 mm and OD 2 mm bilaterally; the face was symmetric, and the tongue deviated slightly towards the right. There was no pronator drift of the right upper extremity, and the left upper extremity could not be fully assessed due to elbow immobilization, but bilateral deltoid and finger grip strength was full. The strength in bilateral lower extremities was full proximally and distally. The patient was observed closely in the surgical ICU where the patient remained neurologically stable.

Postprocedure carotid Doppler scans were performed at 48 h demonstrating patency of the left ICA. The patient was discharged from the hospital in stable condition. At the 3-month follow-up examination, the patient was neurologically intact. A 3-month follow-up angiogram demonstrated stable PED-Wallstent construct position without evidence of migration (Fig. 1e). TICI grade 3 flow was seen through the construct. The patient was continued on clopidogrel for 6 months, after which it was discontinued.

Case 2

Clinical Presentation

A middle-aged patient presented to the emergency room as a pedestrian struck by an automobile. The patient had a brief loss of consciousness and presented with a Glasgow Coma Score of 15. The patient sustained multiple injuries including a comminuted proximal left humerus fracture, bilateral acetabular fractures, comminuted fracture of the left symphysis pubis extending to the inferior pubic ramus, fracture of the pars interarticularis of the C2 vertebral body on both sides, urethral tear, and a colonic contusion. The CTA of the neck demonstrated an intimal flap within the cervical right ICA, consistent with arterial dissection (Fig. 2a). On examination, the patient was awake, confused but able to follow simple commands. The patient demonstrated no gaze preference, with normal cranial nerve function and normal visual field testing. The left upper and lower extremity strength was limited due to pain, but the patient demonstrated no focal weakness. There was no clinical evidence of embolic phenomenon or ischemia, and the patient was not a candidate for either antiplatelet or anticoagulation given the extent of additional injuries. Thus, treatment of the dissection was deferred until the remaining course of polytrauma was managed. During the hospitalization, the patient underwent open reduction and internal fixations of the left humeral and left acetabular fractures. A digital subtraction angiogram (DSA) on posttrauma day 7 revealed development of a pseudoaneurysm at the distal cervical right ICA (Fig. 2b, c). A repeat CTA on posttrauma day 20 revealed progressive enlargement of the pseudoaneurysm (Fig. 2d). At this point, no additional surgical procedures were planned, and thus the patient was cleared for dual-antiplatelet therapy, and the decision was made to treat the enlarging pseudoaneurysm with flow diversion.

Intervention and Outcome

Preoperatively, the patient was loaded with aspirin 325 mg and clopidogrel 600 mg and was placed on aspirin 325 mg and clopidogrel 75 mg daily for 6 days. A 6-Fr, 0.070-inch ID Envoy MPD guide catheter was used to access the right ICA. Through a 3.2-Fr, 0.027-inch ID Marksman microcatheter, 2 PEDs (4 × 25 mm, 4 × 16 mm) were deployed across the neck of the pseudoaneurysm. Finally, a third PED, which was slightly

Fig. 2. **a** CTA in coronal plane showing an intimal flap and a small pseudoaneurysm at the cervical petrous junction of the right ICA. DSA in unsubtracted lateral view (**b**) and subtracted oblique view (**c**) showing the pseudoaneurysm along with proximal severe stenosis. **d** CTA on posttrauma day 20 showing enlarging progression of the pseudoaneurysm. **e** Immediate post-PED DSA showing improved stenosis and delayed opacification of the pseudoaneurysm. **f** Seven-month follow-up DSA showing exclusion of the pseudoaneurysm and vessel reconstruction.

oversized to the parent vessel, was prepared with the goal of deploying across the proximal end of the flow diverter construct in order to prevent PED construct migration. A 4.75×18 mm PED was telescoped through the construct with the distal end of the third stent across the stenotic segment of the dissection flap. There was good apposition of the PED construct to the vessel wall across the dissection and the stenotic segment, with successful reconstitution of the cervical and petrous segments of the right ICA with immediate contrast stagnation into the pseudoaneurysm (Fig. 2e).

The patient tolerated the procedure well and was discharged in stable condition to a rehabilitation facility on posttrauma day 29. On the 7-month follow-up DSA, there was no further filling of the pseudoaneurysm, and there was complete reconstruction of the cervical and petrous ICA with normal antegrade flow (Fig. 2f).

Discussion

Arterial dissection occurs due to disruption of the vascular intima and subsequent hemorrhage into the vessel wall, which can lead to thrombus formation and embolic artery-to-artery infarcts [4, 5, 16–18]. In addition to flow-limiting stenosis and embolic artery-to-artery

phenomena, traumatic arterial dissection can lead to pseudoaneurysm formation in up to 86% of patients [3]. Additionally, the development of a traumatic ICA pseudoaneurysm carries a reported incidence of 1.2–2.7% in all patients with blunt or penetrating trauma of the neck [19–27]. Traumatic pseudoaneurysm formation has been associated with a 12.2% risk of acute cerebral ischemia, and has an overall mortality of 20–30%. Permanent neurological deficits attributable to central nervous system ischemia are extremely high at 37–58% [28–30].

The current standard of care for cerebrovascular dissection consists of therapeutic anticoagulation or antiplatelet therapy, as both lead to significant rates of dissection resolution [18, 31]. The CADISS study compared antiplatelet treatment with anticoagulation treatment for cervical artery dissection. This was a randomized clinical trial and meta-analysis, which found an equivalent efficacy between antiplatelet therapy and therapeutic anticoagulation [32, 33]. Concerning atherosclerotic intracranial arterial stenosis, studies have shown that medical therapy is superior to endovascular intervention, which is associated with a high risk of morbidity and mortality [34]. Any endovascular intervention of cerebrovascular disease must be strictly compared with the benefits of medical management.

Medical management of cervical ICA dissections with anticoagulation or antiplatelet therapy yields good clinical outcomes in 70% of cases, with a reported complete recanalization rate of 51.4% [3, 35]. However, in a subset of patients, the dissection will progress despite optimal medical therapy. Surgical or endovascular intervention is indicated in certain patients, such as those with failed medical management, flow-limiting stenosis, enlarging pseudoaneurysm, or contralateral occlusion [5, 13–16, 18, 31]. Although successful and clinically reasonable in certain cases, the techniques presented herein are experimental approaches, and medical management remains first-line therapy.

Surgical options include extracranial-intracranial bypass in the setting of flow failure, bypass grafting, direct repair, and ligation of the ICA for pseudoaneurysm repair [16, 36, 37]. Endovascular repair is now emerging as a favored therapeutic option given its demonstrated safety and positive clinical and radiographic outcomes. Furthermore, it obviates the need for vessel ligation or flow occlusion which would be poorly tolerated in patients without sufficient collateralization or in those with contralateral disease [16]. Endovascular therapy remains second-line therapy after conservative medical management due to the low risk of recurrent stroke in those with dissection. Endovascular intervention is also considered when the risk of pseudoaneurysmal rupture is too high to consider anticoagulation [4, 31, 36]. However, a recent meta-analysis observed a mortality benefit in patients who underwent endovascular stenting for cervicocranial artery dissection compared to those who received conservative therapy (i.e., antiplatelets or anticoagulation) [38]. Although this was an observational, nonrandomized study, further studies are necessary to elucidate the possible role of endovascular intervention as a first-line therapy for dissection.

Numerous endovascular stents are now available, each with technical and mechanical properties which optimize usage for various situations such as recanalization of a stenosed vessel, obliteration of false lumina, scaffolding for embolization of pseudoaneurysm, or for prohibiting migration of coils in wide-necked intracranial aneurysms [4–10, 39]. Despite the variety of endovascular stents available, several aspects of traditional carotid stents and stents designed for assisted-intracranial aneurysm embolization may render them unsuitable for the treatment of distal cervical petrous ICA dissections or pseudoaneurysms. Traditional self-expandable carotid stents have been used in certain high-risk populations for carotid atherosclerosis given their beneficial effect in coronary atherosclerosis [40, 41]. These carotid stents have more recently also been used to treat spontaneous dissections or those secondary to trauma or angioplasty [6, 42–44]. However, mechanical testing of several commercially available self-expandable memory alloy carotid stents has demonstrated a general “stiff-

ening” behavior, with a nonlinear increase in bending stiffness with progressive increase in maximum deflection [45]. Thus, the relative inflexibility of these traditional carotid stent systems may render them unsuitable within the distal cervical or petrous ICA, where there is acute angulation at the skull base. Intracranial stents used for assistance in intracranial aneurysm embolization are highly porous because of their large cell design. As a result, these stents may not possess enough radial force to exclude false lumen or provide enough flow diversion to promote thrombosis of the pseudoaneurysm [3].

Flow-diverting stents, such as the PED, have several features that may allow their usage in the treatment of distal cervical petrous ICA dissections and/or pseudoaneurysms. Compared to traditional self-expandable carotid stents, flow diverters possess a greater flexibility and adaptable radial force, allowing them to more easily conform to acute angulation at the skull base. Additionally, flow-diverting stents are low-porosity woven tubes with 3 times the vessel wall coverage of traditional intracranial stents, thus providing an increased potential for pseudoaneurysm thrombosis [3].

There are only a few reports on the usage of PEDs in the treatment of extracranial carotid steno-occlusive disease [3, 46, 47]. Brzezicki et al. [3] reported on 11 patients with 13 carotid dissections. Complete revascularization (<10% residual stenosis) was achieved in 91% of vessels, and 50% of pseudoaneurysms were completely or near completely obliterated immediately after PED deployment.

While the aforementioned features of the PED are advantageous for the treatment of distal cervical and petrous ICA steno-occlusive disease, other aspects may limit its prospective use; namely, the risk of PED stent migration within a voluminous vessel such as the cervical ICA. Proximal migration of PEDs has been described in cases of placement within both anterior and posterior circulations [48–55]. Spontaneous shortening of PEDs has also been described [56]. Certain features of the extracranial cervical vasculature such as higher luminal pressures, and frequent positional changes with neck movement may confer a higher risk of migration than in intracranial vessels [57].

We have demonstrated 2 successful anchoring strategies employed to prevent PED migration in the treatment of distal cervical ICA steno-occlusive disease. In both cases, the flexibility of a PED was necessary to navigate the tortuosity of the posterior genu of the petrous ICA. However, despite the deployment of the maximal diameter PED (5 mm) in our first case, the stent construct was still undersized, as the distal cervical ICA measured >5 mm. Thus a 10 × 37 mm Carotid Wallstent (Stryker Neurovascular) was manipulated into the proximal aspect of the PED and extended proximally into the distal cervical left ICA, providing adequate anchoring of the PED. In the second case, the final PED deployed (4.75 × 18 mm) was purposely oversized relative to the parent vessel by 18%, in order to accommodate the larger cervical ICA. In addition, aggressive wire manipulation with a Synchro-2, 0.014-inch guidewire with a J-shaped distal tip was performed to maximally dilate the proximal stent construct. In addition to the strategies described here, Rahal et al. [58] described a method of anchoring the PED construct by using a 6 × 30 mm Solitaire FR detachable stent (ev3 Neurovascular) in a successful treatment of 2 patients with extracranial dissections. PEDs are designed to open approximately 0.25 mm beyond their nominal diameter, such that the largest presently available diameter would be around 5.25 mm. Thus, PED deployment along with concomitant anchoring strategies may potentially be expected in cases that employ a maximal-diameter 5.0-mm PED extending to within a distal cervical ICA measuring ≥5.25 mm.

The main limitations of our study include small sample size, ongoing long-term follow-up, and the retrospective nature of the study. Dissecting vessels with sharp angulations or with tortuous courses presents a technical challenge for stent placement. Flexible flow-diverting stents, such as the PED, represent a feasible option for management of distal cervical

and petrous ICA dissections. As with every new device and new application of a device, a larger prospective study is needed to fully assess the safety and efficacy of treatment of carotid dissections with PEDs. However, due to the limited patient population that requires endovascular intervention for carotid dissections, a larger multicenter cohort study with long-term efficacy and stent durability is required.

Disclosure Statement

There are no competing interests. This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Author Contributions

Fawaz Al-Mufti, MD: Acquisition of data, analysis and interpretation, draft of the manuscript, critical revision of the manuscript for important intellectual content. Krishna Amuluru, MD: Acquisition of data, analysis and interpretation, draft of the manuscript, critical revision of the manuscript for important intellectual content. William Roth, MD: Acquisition of data, analysis and interpretation, draft of the manuscript, critical revision of the manuscript for important intellectual content. Chirag Gandhi: Acquisition of data, analysis and interpretation, draft of the manuscript, critical revision of the manuscript for important intellectual content. Charles J. Prestigiacomo, MD: Acquisition of data, analysis and interpretation, draft of the manuscript, critical revision of the manuscript for important intellectual content, study supervision.

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