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Original Article

Emergent salvage of the vertebral artery with flow diverter pipeline stent following vessel laceration: Systematic literature review and illustrative case example

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ABSTRACT

Background: Iatrogenic injury to neck vasculature is a potentially life-threatening complication of spine surgery. We present an illustrative case describing the use of the Pipeline™ Embolization Device (PED) in the emergent reconstruction of the vertebral artery (VA) following vessel laceration. In addition, we document a systematic review concerning the use of the PED in acute to chronic iatrogenic injury of the internal carotid or VAs.

Methods: This study was a systematic literature review and illustrative case example.

Results: A 73-year-old woman underwent anterior cervical discectomy and fusion (ACDF) surgery complicated by left VA injury. The incision was promptly packed and pressure held while the vessel was salvaged using a Pipeline™ stent. At 6 months follow-up, the patient had no residual symptoms. A systematic review identified 11 publications meeting study criteria, in which 16 patients were reported to have an injury to the internal carotid or VAs. Patients were grouped into acute, subacute, and chronic cohorts. In the acute group, the majority of patients experienced injury during transsphenoidal resection or ACDF procedures. All cases in the acute group received immediate intervention with the deployment of a PED device. One patient experienced continued contrast extravasation, necessitating vessel sacrifice through superficial temporal artery-middle cerebral artery bypass. All patients recovered to their neurologic baseline. In the subacute and chronic groups, two patients experienced complications, with the majority going on to recover to their neurologic baseline.

Conclusion: PED placement is a viable management strategy for restoring anatomic integrity to head-and-neck vasculature following acute iatrogenic injury.

Keywords: Flow diverter technology, Iatrogenic vascular injury, Internal carotid artery, Pipeline embolization device, Vertebral artery

INTRODUCTION

Iatrogenic injury to the internal carotid or vertebral arteries (VAs) is a rare and potentially life-threatening complication of endoscopic endonasal or spinal decompression/fusion procedures.[3,5] Repair of these injuries is remarkably challenging due to the risk of acute deterioration;[3] therefore, prompt intervention is necessitated in such cases to mitigate adverse outcomes. Primary management generally includes tamponade of the vessel through packing or

hemostatic agent application, followed by definitive repair through coil embolization (vessel sacrifice) or stenting.[3]

The Pipeline™ Embolization Device (PED, Covidien/Medtronic, Irvine, CA) belongs to a class of flow-diverting stents, which utilizes a 48-strand cobalt chromium and platinum tungsten braided mesh design to provide radial force in the redirection of blood flow away from aneurysms.[16] This technology has shown promise in the treatment of large and wide-neck aneurysms, yet its utility has not been explored in the context of other vascular pathology. In this systematic literature review and case example, we aim to consolidate the existing literature while assessing the viability, safety profile, and outcomes associated with the use of the PED for the management of acute iatrogenic injury to the internal carotid or VAs.

MATERIALS AND METHODS

A systematic literature review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 guidelines[12] with two independent reviewers. Two databases were searched: PubMed and Ovid MEDLINE. PubMed was searched on December 9, 2023, with the following search terms: ((Internal carotid artery [ICA] injury) OR (VA injury)) AND ((((flow diverter) OR (flow diversion)) AND (pipeline stent)) OR (PED). Ovid was searched on December 12, 2023, with the following search strategy: ((VA OR carotid artery, internal OR (vertebral* adj1 arter*).mp) AND (exp Stents OR stent*.mp)) AND ((injur* OR iatrogen*).mp) AND (((flow* OR diver* OR pipeline*) adj2 stent*).mp) AND (((intraop* OR intra-op* OR Neurosurg* OR surg* OR iatrogen*) adj2 injur*).mp).

Articles were then screened by title and/or abstract based on the proper inclusion and exclusion criteria. Articles included were any original-research articles in the English language discussing the use of flow diverter pipeline stenting to salvage iatrogenic injury to the ICA or VA in adult patients. Articles were excluded if they were review papers, meta-analyses, letters/editorials, abstracts published from academic conferences, studies on non-human animals, non-clinical studies, or discussed the use of pipeline flow diverter stents in non-traumatic aneurysm dissection, general aneurysm repair, or traumatic (non-iatrogenic) vessel injury. Articles were then imported and screened through Rayyan, a web-based screening tool.[11]

Following an initial screening, the same two reviewers carefully conducted a full-text analysis of the articles, and any conflicts were discussed between the reviewers. Data extraction had the following primary outcomes: (1) patient demographics, including the number of patients in each study and the age and biological sex of each patient; (2) description of injury, including the location of the injury, primary pathology, and surgery type; (3) symptoms at presentation, including angiographic findings and the interval between injury and treatment; and (4) outcome. Other outcome data collected included procedural complications, anticoagulation details, follow-up period, and description of stent(s). Publications were then separated into three groups: Those undergoing treatment for acute, subacute, or chronic iatrogenic vascular injury. The acute group was defined as vessel compromise necessitating immediate intervention (<24 h), whereas subacute was defined as any injury repaired within 1 month, and chronic was defined as any injury repaired beyond 1 month. A good outcome was defined as minimal or no neurological deficits at follow-up. The details of the screening process are shown in Figure 1.

RESULTS

Illustrative case example

A 73-year-old woman with a medical history notable for antiphospholipid syndrome underwent anterior cervical discectomy and fusion (ACDF) surgery at the C6-C7 vertebral level at a community hospital, which was complicated by injury to and dissection of the left VA. The patient's incision site was packed, whereupon she received two units of packed red blood cells (pRBCs) and was transferred to our institution. On arrival, a diagnostic cerebral angiogram was performed, which revealed active extravasation of contrast and confirmed injury to the proximal V2 segment of the left VA at the C6 vertebral level [Figure 2a].

The decision was made to salvage the vessel using the PED, in which she received 6000 units of heparin intravenously (IV), along with an eptifibatide bolus and 90 mcg/kg drip. A benchmark guide catheter was then placed in the origin of the left VA, and the injured segment was traversed through a Headway™ 27 microcatheter (MicroVention, California, USA) over an Aristotle® 0.14 microwire (Scientia Vascular, Inc, Utah, USA). A 4.25 mm×16 mm Pipeline™ flow diverting stent (Medtronic, California, USA) was delivered through the microcatheter and deployed across the injured segment. Contrast injection through the guiding catheter revealed no further extravasation and patency of the VA [Figure 2b].

The patient was taken promptly to the operating room for hemostasis and closure of the ACDF incision. Intraoperatively, she required hemodynamic support with a transfusion of three additional units of pRBCs and norepinephrine. The patient then recovered well with close monitoring in the neurointensive care unit and experienced no complications. She was extubated on postoperative day one with no neurological deficits and transitioned to dual antiplatelet therapy, including oral aspirin and apixaban (81 mg and 5 mg daily by mouth, respectively). She was then

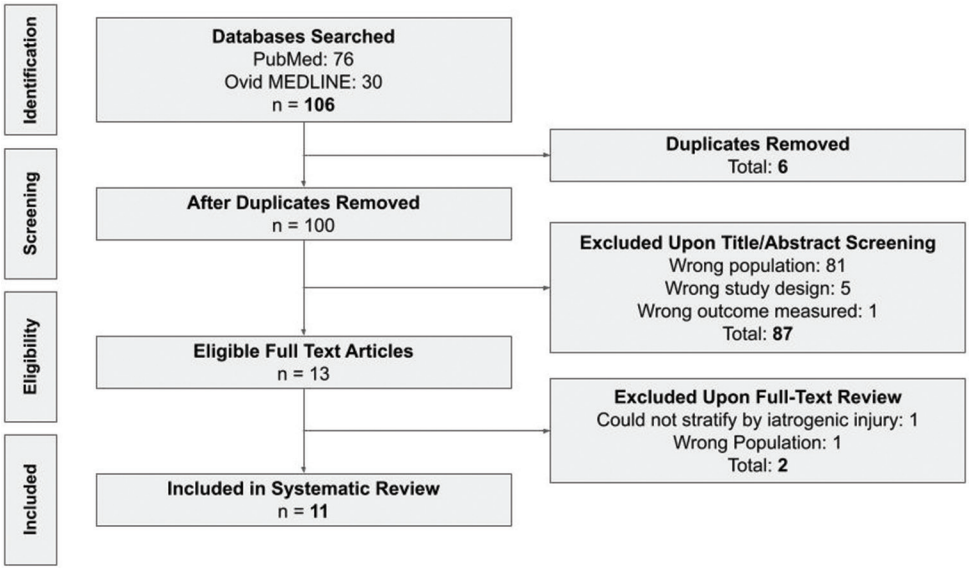

Figure 1: Flow diagram demonstrating the literature review process as outlined by the preferred reporting items for systematic reviews and meta-analyses 2020 guidelines.

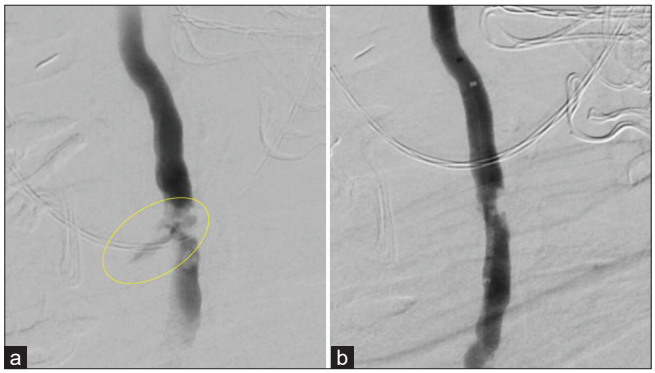

Figure 2: Cerebral angiogram demonstrating (a) extravasation of contrast following iatrogenic injury to the proximal V2 segment of the vertebral artery and (b) successful placement of Medtronic pipeline flow diverting stent placement with salvage of the artery. Yellow circle indicates active contrast extravasation.

discharged on postoperative day 3 to the outside location for completion of the ACDF, and no further complications were encountered. At 6 months follow-up, she was noted to have no focal deficits. Angiography at that time redemonstrated the healed VA with excellent apposition of the PED and no evidence of aneurysm [Figure 3].

Literature review

Eleven publications with sixteen patients were identified for this review [Figure 1]. Including the current case, four patients were identified for inclusion in the acute group [Tables 1 and 2], eleven were identified for inclusion in the subacute group [Tables 3 and 4], and two were identified for inclusion in the chronic group [Tables 5 and 6].

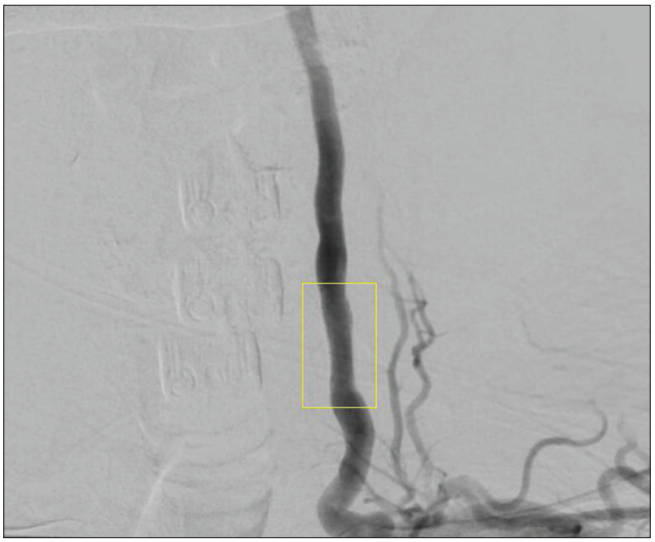

Figure 3: Six-month postoperative angiography demonstrating the healed vertebral artery with excellent apposition of the pipeline embolization device (PED) and no evidence of aneurysm. The yellow box indicates PED.

In the acute group (n = 4), the average age for vascular injury was 66.5 (range, 61–73) years with a female predominance (ratio, 4:0). One patient experienced an injury to the petrous of the ICA while undergoing transsphenoidal surgery (TSS) for a clival tumor whereas another patient experienced an injury to an unspecified portion of the ICA while undergoing TSS for a pituitary adenoma. One patient experienced an injury to the cavernous ICA during PED placement for a prior pseudoaneurysm (PA), and the last patient experienced

Table 1: Patient demographics and details of acute iatrogenic vascular injury/treatment modality.

Author, year	Case number	Sex	Age	Primary pathology	Surgery type	Location	Angiographic finding	The interval between injury and treatment	Anticoagulation	Stent type
Shakir *et al.*, 2014	1	F	61	Clival tumor	TSS	Petrous ICA	Active contrast extravasation	Immediate	Prasugrel for 12 months, aspirin indefinitely	4 mm×12 mm Jostent with 4.5 mm×18 mm PED; second PED placed over the first
Amuluru *et al.*, 2016	2	F	69	Prior PA	PED placement	Cavernous ICA	CCF	Immediate	Loaded with aspirin 325 mg and ticagrelor 90 mg daily prior to PED placement; discharged on aspirin and ticagrelor	5 mm×16 mm, 5 mm×14 mm, 5 mm×12 mm, 5×18 mm PEDs
Griauzde *et al.*, 2017	3	F	63	Pituitary adenoma	TSS	ICA, unspecified	Active contrast extravasation	Immediate	*	Vessel sacrificed with delayed STA-MCA bypass; vessel occlusion for adjunct treatment
Current case	4	F	73	Cervical stenosis	C6-C7 ACDF	V2 segment of VA	Active contrast extravasation	Immediate	6000 u of heparin with eptifibatide bolus and 90 mcg/kg drip intraoperatively, discharged to the outside institution on ticagrelor	4.25 mm×16 mm PED

*Not reported in the literature. M: Male, F: Female, TSS: Transsphenoidal surgery, ICA: Internal carotid artery, PED: Pipeline embolization device, CCF: Cavernous-carotid fistula, ACDF: Anterior cervical discectomy and fusion, STA-MCA: superficial temporal artery to middle cerebral artery, VA: vertebral artery, PA: pseudoaneurysm

Table 2: Results of acute iatrogenic repair with PED.

Author, year	Case number	Follow-up period (months)	Imaging at follow-up	Obliteration/Repair	Complications	*Outcome
Shakir *et al*., 2014	1	1	CT angiography demonstrated wide stent patency with no flow restriction	Complete	None	Good
Amuluru *et al*., 2016	2	12	Angiography demonstrated stasis of intra-aneurysmal flow with complete resolution of CCF.	Complete	None	Good
Griauzde *et al*., 2017	3	†	None	Vessel sacrificed with delayed STA-MCA bypass secondary to continued contrast extravasation.	None	Good
Current case	4	3	Angiography demonstrated excellent apposition of the PED and no evidence of an aneurysm.	Complete	None	Good

*Good outcome is defined as greatly improved or no neurological deficits at follow-up. †Follow-up was immediate. CCF: Cavernous carotid fistula; STA-MCA: Superficial temporal artery to middle cerebral artery bypass; PED: Pipeline embolization device, CT: Computed tomography

an injury to the V2 segment of the VA during ACDF for cervical stenosis. All patients were found to have active extravasation of contrast on angiography, barring case 2, who were found to have a cavernous-carotid fistula. All cases were deemed emergent due to the risk of hemodynamic instability. The time interval between injury and treatment was immediate in all cases. In one case, PED placement resulted in continued contrast extravasation, which necessitated vessel sacrifice through a delayed superficial temporal artery-middle cerebral artery (STA-MCA) bypass. No complications were reported, and all patients experienced good neurologic outcomes. The average follow-up time was 5.3 (range, 1–12) months.

In the subacute group (n = 11), the average age at vascular injury was 55.3 (range, 21–77) years with a male predominance (ratio, 5:2). Seven patients experienced vascular injury while undergoing TSS, six being for pituitary adenoma and one being for Rathke cleft cyst. Three patients underwent decompression for cervical stenosis, with two patients experiencing vascular injury during C1/C2 fixation and one during ACDF. Five patients experienced injury to the cavernous ICA, whereas one experienced injury to segment V2 of the VA, and another experienced injury to segment V3 of the VA. Three patients experienced injury to an unspecified portion of the ICA. All patients were found to have a PA on angiography. The time interval between injury and treatment ranged from 1 to 15 days. Two patients had an immediate postoperative complication, including type I endoleak, resolved with balloon angioplasty, and incomplete parent vessel apposition, resolved with a third PED placement. All cases resulted in complete PA obliteration, with ten patients experiencing a good neurologic outcome. One death was reported. The average follow-up time was 10.1 (range, 3–30) months. Proportions of injury location, primary pathology, and procedure type in patients receiving PED placement for the treatment of subacute iatrogenic vascular injury are shown in Figure 4.

In the chronic group (n = 2), age was reported in one patient, who was 78 years old at the time of injury. Both patients experienced vascular injury while undergoing TSS for pituitary adenoma. One patient experienced injury to the cavernous ICA, whereas the second experienced injury to an unspecified portion of the ICA. Both patients were found to have a PA on angiography. The time interval between injury and treatment was 20 years in both cases. No complications were reported; complete or near-complete obliteration of the PA was achieved. Both patients experienced a good neurologic outcome. Follow-up time ranged from 1 day to 12 months.

DISCUSSION

We report the seventeenth iatrogenic injury of the ICA or VA treated with a PED and the fourth use of a PED in the acute setting.[1,2,4,6,8-10,13-15,17] No complications were reported in the acute group, with two patients experiencing vessel laceration during TSS for a skull base mass, one during repair of a prior PA, and the last during ACDF. All cases recovered

Table 3: Patient demographics and details of subacute iatrogenic vascular injury/treatment modality.

Author, year	Case number	Sex	Age	Primary pathology	Surgery type	Location	Angiographic finding	The interval between injury and treatment	Anticoagulation	Stent type
Ambekar *et al.*, 2014	5	M	47	Cervical stenosis	Posterior C1-C2 fixation	V3 segment of VA	30-mm PA	2 days	Clopidogrel 75 mg daily for 6 months, followed by aspirin indefinitely	5 mm×18 mm PED
Nerva *et al.*, 2014	6	*	*	Pituitary adenoma	TSS	Cavernous ICA	20-mm PA	4 days	Loaded with aspirin 325 mg and clopidogrel 75 mg daily prior to PED placement	4 mm×14 mm PED
	7	*	*	Pituitary adenoma	TSS	Cavernous ICA	3-mm PA	15 days	Loaded with aspirin 325 mg and clopidogrel 75 mg daily prior to PED placement	4 mm× 14 mm PED with telescoping PED
Dolati *et al.*, 2015	8	M	71	Cervical stenosis	Posterior C1-C2 fixation	V3 segment of VA	†PA	1 day	*	3 mm×16 mm PED
Shakir *et al.*, 2016	9	*	*	Cervical stenosis	C3-C7 ACDF	V2 segment of VA	0.5 mm× 0.85 mm PA	1 day	*	4 mm×18 mm and 4 mm×20 mm PEDs
Sylvester *et al.*, 2016	10	M	21	Pituitary adenoma	TSS	ICA, unspecified	3-mm PA	15 days	*	PED, unspecified
Griauzde *et al.*, 2017	11	F	49	Chordoma	Transnasal resection	ICA, unspecified	†PA	Short-term follow-up, unspecified	*	4 mm×25 mm and 4.25 mm×16 mm PEDs
Liu A *et al.*, 2021	12	M	60	Pituitary adenoma	TSS	ICA, unspecified	†PA	Short-term follow-up, unspecified	*	4.5 mm×20 mm PED
Sami *et al.*, 2018	13	*	*	Pituitary adenoma	TSS	Cavernous ICA	3-mm PA	Several days, unspecified	Loaded with aspirin 325 mg and clopidogrel 75 mg daily prior to PED placement; aspirin continued indefinitely, clopidogrel stopped after 6 months	4.25 mm×14 mm PED
Nariai *et al.*, 2020	14	M	62	Rathke cleft cyst	TSS	Cavernous ICA	2.9 mm×2.1 mm PA	3 days	6000u of heparin intraoperatively with 3.75 mg prasugrel and 100 mg aspirin daily for 12 months	4.75 mm×16 mm PED
Liu *et al.*, 2021	15	F	77	Pituitary adenoma	TSS	Cavernous ICA	1.4 mm×2 mm PA	5 days	Loaded with aspirin 325 mg and prasugrel 5 mg daily prior to PED placement; aspirin 81 mg indefinitely	4.75 mm×14 mm Flex, 5 mm× 14 mm Flex, and 5 mm×12 mm Flex PEDs

*Not reported in the literature. †Size unspecified. M: Male, F: Female, TSS: Transsphenoidal surgery, ICA: Internal carotid artery, VA: Vertebral artery, PA: Pseudoaneurysm, PED: Pipeline embolization device, ACDF: Anterior cervical discectomy and fusion

Table 4: Results of subacute iatrogenic injury repair with PED.

Author, year	Case number	Follow-up period (months)	*Obliteration/ Repair	Complications	†Outcome
Ambekar *et al*., 2014	5	10	Complete	None	Good
Nerva *et al*., 2014	6	N/A	Complete	Type I endoleak	Death secondary to aneurysmal re-rupture
	7	4	Complete	None	Good
Dolati *et al*., 2015	8	3	Complete	None	Good
Shakir *et al*., 2016	9	9	Complete	None	Good
Sylvester *et al*., 2016	10	16	Complete	None	Good
Griauzde *et al*., 2017	11	6	Complete	None	Good
	12	5	Complete	None	Good
Sami *et al*., 2018	13	6	Complete	None	Good
Nariai *et al*., 2020	14	12	Complete	None	Good
Liu *et al*., 2021	15	30	Complete	Incomplete parent vessel apposition	Good

*As observed at the time of follow-up. "Complete" indicates complete obliteration of pseudoaneurysm. †Good outcome defined as greatly improved or no neurological deficits at follow-up. N/A: Not applicable, PED: Pipeline embolization device

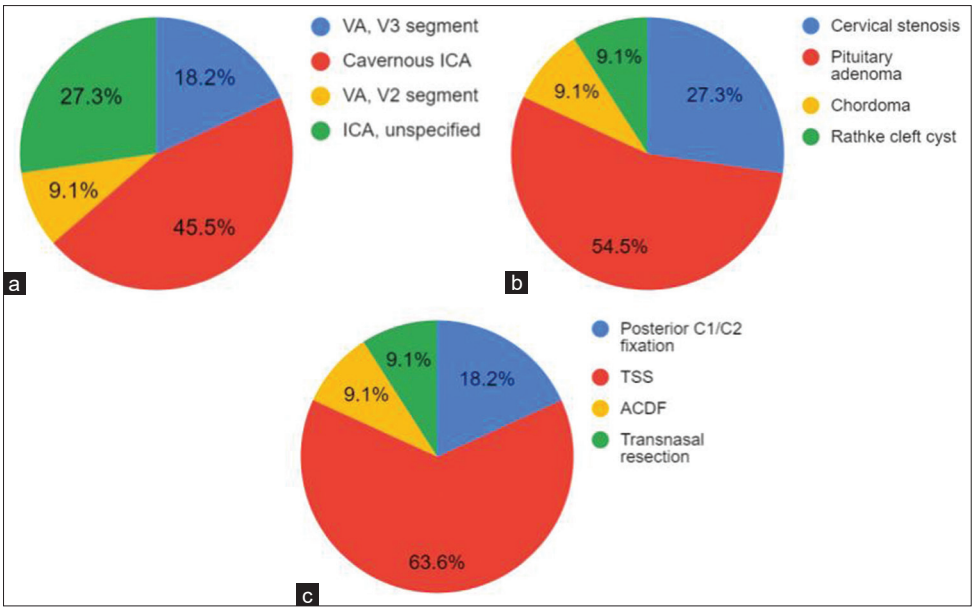

Figure 4: (a) Location of vessel injury, (b) primary pathology, and (c) procedure type in patients receiving pipeline embolization device placement for the treatment of following subacute iatrogenic vascular injury. VA: Vertebral artery, ICA: Internal carotid artery, TSS: Transsphenoidal surgery, ACDF: Anterior cervical discectomy and fusion.

to neurologic baseline despite one patient undergoing delayed STA-MCA bypass due to continued extravasation of contrast following PED placement. It must be noted that the successful treatment with PED may depend on the degree of vessel laceration, as the flow diverter was inherently designed to control blood flow across a closed cavity, such as an aneurysm. Thus, the resolution of active bleeding may be due to tamponade from the original procedure or the added structural integrity of the PED across the injured vessel.

All patients in the subacute group underwent PED placement for the obliteration of a PA, in which two complications and 1 death occurred. Nonetheless, the majority of patients in this group experienced full neurologic recovery at the time of follow-up. In the chronic group, no complications were reported, and both patients recovered to their neurologic baseline following obliteration of a PA through PED placement. Altogether, PED placement has demonstrated high fidelity in salvaging

Table 5: Patient demographics and details of chronic iatrogenic vascular injury/treatment modality.

Author, year	Case number	Sex	Age	Primary pathology	Surgery type	Location	Angiographic finding	The interval between injury and treatment	Anticoagulation	Stent type
Sylvester *et al*., 2016	16	F	78	Pituitary adenoma	TSS	ICA, unspecified	5-mm PA	20 years	*	PED, unspecified
Sami *et al*., 2018	17	*	*	Pituitary adenoma	TSS	Cavernous ICA	6-mm PA	20 years	Loaded with aspirin 325 mg and clopidogrel 75 mg daily prior to PED placement; aspirin continued indefinitely, clopidogrel stopped after 6 months	5 mm×20 mm, 5 mm×18 mm, and 5 mm×35 mm PEDs

*Not reported in the literature. M: Male, F: Female, TSS: Transsphenoidal surgery, ICA: Internal carotid artery, PA: Pseudoaneurysm, PED: Pipeline embolization device

the ICA or VA via reconstitution of vessel architecture. Historically, vessel sacrifice has been established as a viable strategy for restoring hemodynamic stability in the presence of adequate collateral blood flow; however, flow diversion allows for the preservation of critical vasculature in high-risk cases.

Current literature regarding the management and outcomes of iatrogenic injury to the ICA or VA remains limited. Although rare overall, the cavernous segment of the ICA appears to be the most common site of iatrogenic injury during endoscopic endonasal surgery. Conventional treatment modalities include covered stent placement or coil embolization,[5] which do not fully address the remarkable challenge of ICA repair. Further, the need for improved clinical outcomes has led to the advent of flow diverter technology. PED placement is gaining marked popularity, as this treatment avenue allows surgeons to salvage a vessel that may have otherwise been sacrificed. The disadvantages of this technology must be acknowledged, including a significant chance of PA rebleeding as thrombosis is delayed.[5] As such, the employment of a flow diverter does not provide an immediate cure for vessel pathologies such as PA but rather encourages thrombosis over time.

Within the context of iatrogenic VA injury, drilling and instrumentation significantly increase the risk of vessel compromise during anterior cervical spine operations.[3] Conventionally, tamponade/packing or hemostatic agent application is the preferred primary management strategy for VA injury, with secondary management including coiling or stenting.[3,7] Direct tamponade of the VA provides a significant risk of cerebral ischemia due to occlusion of the vessel, hypovolemic shock (if stasis is not achieved), or the development of PA.[3] Therefore, immediate cessation of bleeding by tamponade or packing is recommended, which should be followed by definitive vascular repair. Although traditional vascular repair typically includes coiling or stenting, salvage of the VA through vessel occlusion or embolization has also been reported in the literature, although to a lesser degree than in ICA salvage.[3,5,7]

Flow diverter technology is promising in the management of acute iatrogenic vascular injury to the internal carotid or VAs. Distinct advantages of this technology include enhanced endothelialization that may limit the duration of dual antiplatelet therapy (through advancements in stent coatings) and the preservation of critical vasculature. However, dual-antiplatelet therapy is currently required for 6 months following treatment. Altogether, the Pipeline™ stent should be heavily considered as a definitive intervention in the management of acute injuries to head and neck vessels.

Table 6: Results of chronic iatrogenic injury repair with PED.

Author, year	Case number	Follow-up period (months)	*Obliteration/repair	Complications	†Outcome
Sylvester *et al*., 2016	16	0.03	Complete	None	Good
Sami *et al*., 2018	17	12	Near complete	None	Good

*As observed at the time of follow-up. "Complete" indicates complete obliteration of pseudoaneurysm. †Good outcome defined as greatly improved or no neurological deficits at follow-up. PED: Pipeline embolization device

Limitations

The current work is limited by several variables intrinsic to observational studies, chiefly being small sample size. In addition, the timeline between vascular injury and PED placement varied widely, as some PAs were not diagnosed until several years following the patient's initial procedure. Considering that the ICA and VA are significantly different anatomically, the conclusions of this review are limited by the lack of homogenous data available in the literature. The cohort of 17 patients remains significantly small, in larger cohort studies are recommended to elucidate the efficacy of PED placement for acute iatrogenic injury of head and neck vasculature.

CONCLUSION

In this illustrative case and systematic review, we report the promising use of the PED in the context of ICA or VA injury and a range of acute to chronic pathology, resulting in high technical success rates with salvage of critical vasculature. In the current literature, iatrogenic injury commonly occurs to the cavernous segment of the ICA during transsphenoidal resection but may also occur to the VA in posterior cervical instrumentation and/or ACDF procedures. Further, we found that PED placement may be a vital modality for restoring anatomical integrity to the ICA or VA during acute injury, with the majority of patients experiencing optimal clinical outcomes and a complete or near-complete return to the neurologic baseline.

Ethical approval

The Institutional Review Board approval is not required as this report contained fewer than two patients, so ethical approval was not required by the University of Oklahoma Health Science Center's Institutional Review Board.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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