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Review Article

Flow Diversion for the Treatment of Petrous Internal Carotid Artery Aneurysms

Abstract

Petrous internal carotid artery (ICA) aneurysms are rare and pose a unique management dilemma. They are most commonly fusiform. They are difficult to treat surgically and typically not amenable to selective aneurysmal obliteration. The advent of flow diverters, such as the Pipeline endovascular device, has offered a new approach to these historically challenging lesions. The unique utility of flow diversion in treatment of petrous ICA aneurysms is reviewed and discussed.

Keywords: *Aneurysm, endovascular, flow diversion, internal carotid artery, petrous, pipeline*

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Introduction

Aneurysms of the petrous segment of the internal carotid artery (ICA) are rare and may result from congenital, infectious, or traumatic etiologies,[1,2] with the vertical portion most commonly affected.[3] Unruptured petrous intracranial aneurysms are frequently asymptomatic, but may present with cranial neuropathies,[4-9] Horner's syndrome,[10] pulsatile tinnitus,[11,12] otalgia,[11] traumatic intracranial aneurysms,[13] and/or audible bruit.[14] Ruptured petrous ICA aneurysms may cause massive epistaxis[13,15-19] and hemorrhagic shock or hemorrhagic otorrhagia.[15] They pose a unique management dilemma, especially when giant or infectious[6,16,19-25] and are difficult to treat surgically, due to the inherent challenges of microsurgical access to the carotid canal of the petrous bone.[26,27] Endovascular approaches may also prove challenging, typically as the consequence of therapeutically-unamenable morphology, but occasionally due to size considerations as well.

Historical background

Historically, petrous ICA aneurysms were managed by parent vessel ligation or surgical trapping,[6,11,28] following balloon test occlusion.[10,14,29,30] Endovascular treatment of unruptured petrous ICA aneurysms was first performed in the 1980s, using detachable balloons[29,31,32] and balloon occlusion in conjunction with bypass (superficial temporal artery-middle cerebral artery and cervical-petrous saphenous vein graft),[33,34] a versatile and useful adjunct in the treatment of these and other complex lesions.[35,36] Hemorrhagic petrous ICA aneurysms have been successfully treated with balloon parent vessel occlusion,[37] which may also be accomplished using coils. Selective aneurysmal sac obliteration was also achieved using balloons, coils, or stent-assisted coiling in the 1990s.[32,38,39]

Concurrent surgical and endovascular therapy has been used for petrous ICA aneurysms.[40] Prior to the advent of flow-diverting stents, covered stents were successfully used in the treatment of petrous ICA aneurysms, including ruptured lesions, in the 2000s.[1,41-43] While very effective, these stents are stiff and difficult to navigate through tortuous anatomy. The advent of flow diversion has offered an exciting new endovascular approach for these historically challenging aneurysms. The off-label use of pipeline embolization device (PED) for fusiform petrous ICA aneurysms has proven effective in several reports.[44-48] We propose that petrous ICA aneurysmal morphology and unique anatomy render flow diversion an excellent therapeutic option for these lesions.

Anatomy of the petrous internal carotid artery: Clinical implications and endovascular considerations

The cervical segment of the ICA transitions into the petrous segment upon entering the

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carotid canal. It averages 5 mm in diameter, is comprised of an initial vertical portion approximately 10–11 mm in length,[49] is related posteriorly and anteriorly to the jugular foramen and Eustachian tube, respectively, and terminates as the genu, lying anteroinferomedial to the cochlea and anteromedial (in most cases) to the geniculate ganglion, and turning as the horizontal segment to run anteromedially for ~20 mm before transitioning into the lacerum segment. This sharp bend renders use of covered stents challenging (e.g., stenting) and the frequent fusiform morphology of aneurysms in the petrous ICA makes selective aneurysmal obliteration/primary coiling not possible. Flow diverters are thus ideal for navigating the petrous ICA at the genu and bridging the fusiform lesions found here.

Aneurysmal dilation of the petrous segment of the ICA may cause facial paralysis due to the proximity of the genu to the geniculate ganglion and facial nerve.[3,50] The geniculate ganglion is within approximately 6–7 mm of the genu of the petrous ICA and is found posterolaterally, posteriorly, and laterally to the same in approximately 3/5, 1/3, and 1/6 of individuals, respectively.[49] The greater superficial petrosal nerve runs along the anterosuperior margin of the carotid canal and damage to it may result in alacrima. The horizontal portion of the petrous segment of the ICA is crossed medially by the abducens nerve and is located posterior to and below the Gasserian ganglion in Meckel's cave, accounting for not infrequently observed abducens palsy.[7,44] Also in close relation to the petrous ICA is the vestibulocochlear nerve, running within the internal acoustic meatus, damage to which may underlie tinnitus or hearing loss in these patients.[10,11]

Branch arteries from the petrous ICA are found in approximately two fifths of anatomical specimens, typically arising from its horizontal aspect. These have historically included the vidian and caroticotympanic arteries, though the latter were not found in an anatomical dissection study by Paullus *et al.*,[49] who found the vidian artery most commonly, followed in frequency by periosteal arteries.[51] The otic artery represents an exceedingly rare persistent anastomosis between the carotid and vertebrobasilar circulations, characteristically anastomosing with the lower basilar trunk.[52] The clinical significance of these branches is that they may fill the ICA in retrograde fashion in cases of spontaneous or interventional parent vessel occlusion of the cervical ICA. The clinical inconsequence of compromise of these branches, when they are present, renders this effect with use of PED unimportant.

The petrous ICA is surrounded by venous and neural plexi. The former is present in 76% of individuals and represents a lateral extension of the cavernous sinus. It exhibits a variable extent of lateral extension, on average 7.6 mm into the carotid canal. The peripetrous ICA venous plexus may fistulize with the artery and contribute to aneurysmal persistence/progression and/or recurrence in untreated/treated cases. The peripetrous ICA neural plexus is comprised of two trunks from the carotid nerve, variably sending nerve fibers to accompany arteries and cranial nerves IV-VI, as well as the deep petrosal nerve, which joins the greater superficial petrosal nerve to form the vidian nerve. Petrous ICA aneurysms may thus cause a Horner's syndrome by disruption of these nerve fibers.[10]

Treatment of petrous internal carotid artery aneurysms using flow diversion

Flow-diverting stents are microcatheter-delivered self-expanding flexible metallic stents designed to induce aneurysmal thrombosis and reconstitution of the parent vessel without occlusion of parent arterial branches via a modest reduction of intra-aneurysmal flow. PED was approved in April of 2011 for large or giant wide-necked Intracranial aneurysms arising from petrous segment of the ICA distally as far as the superior hypophyseal segment of this vessel.

The experience with PED in fusiform aneurysms has been complete or partial occlusion in most cases,[52] with 100% complete occlusion in all lesions involving the vertebrobasilar circulation.[53] The occlusion rate with flow diverters is excellent (80%–85% for PED and ~82% for SILK device;[54-57]). The mortality rate is ~5% (lower for PED and higher for SILK[55,58]). Rupture or delayed hemorrhage from PED in a petrous ICA aneurysm might be catastrophic, especially given the requirement for lifelong antiplatelet therapy, and require treatment with parent vessel sacrifice. Compromise of side branches, a principal concern with the use of flow diverters,[54,59] is of no clinical consequence in the petrous segment of the ICA. Furthermore, the use of flow diverters precludes the future ability to coil saccular aneurysms,[60] which represent a small fraction of petrous segment ICA aneurysms. Thus, several of the disadvantages with use of PED are not applicable in the petrous segment of the ICA. Moreover, use of PED is associated with decreased intervention time and radiation and contrast exposure in comparison to endovascular coiling.[45]

PED has been used in the treatment of petrous ICA aneurysms in 11 patients.[44-48,61] Five of these cases were in the context of larger studies and did not provide specific case data.[45,61] Among the other five cases, three patients were treated with a combination of PED and coiling and two were treated with PED alone, one of whom bore a ruptured pseudoaneurysm and experienced recurrent bleeding 12 days following intervention requiring parent vessel occlusion [Table 1]. Resolution or improvement in symptoms and aneurysmal obliteration was achieved in the remaining cases.

Gross *et al.*[44] recently reported on a case series of patients with petrous ICA aneurysms. Of these lesions, eight were fusiform with only two having an identifiable neck. Three of these were successfully treated with flow diversion in

Table 1: Petrous internal carotid artery aneurysms treated with Pipeline. Six cases reported in the literature did not provide demographic or specific diagnostic or outcome data (Colby *et al*., 2013; Salhein *et al*., 2015). *reported by Moon and colleagues in 2014 and in a later series in 2017. HIV, human immunodeficiency virus; ICA, internal carotid artery; PED, Pipeline endovascular device

Author (s)	Age, Gender	Presentation	Imaging	Intervention	Outcome
Gross *et al*., 2017	Not provided	Asymptomatic	Not provided	PED + coil	Stable at 1 mo. follow-up
		Abducens palsy	Not provided	PED + coil	Abducens palsy resolved, aneurysm obliterated
		*Trigeminal and abducens palsy	Large petrous ICA aneurysm from genu to proximal half of horizontal portion	PED + coil	Facial numbness and abducens palsy improved; aneurysm obliterated
Moon *et al*., 2014	64, M	*Visual field cut, facial numbness, abducens palsy	Large petrous ICA aneurysm from genu to proximal half of horizontal portion	PED + coil	Facial numbness and abducens palsy improved; aneurysm obliterated
Kadkhodayan *et al*., 2013	50, F	Malignant external otitis, bitemporal osteomyelitis; hemorrhagic otorrhagia	Small petrous ICA pseudoaneurysm in vertical portion	PED	Rebleeding 12 days after PED, required parent vessel occlusion
Lerat *et al*., 2011	64, F	Left facial paralysis	Bilateral large petrous ICA pseudoaneurysms; 1 on the left, 2 on R	PED - 1 on left side, 2 on right side	Facial paralysis resolved; right aneurysm obliterated; 5 mm neck remnant in left aneurysm at 6 mo. follow-up

conjunction with coil embolization. For two patients having follow-up, both had resolution of cranial nerve palsies and complete obliteration of the aneurysm. Other patients successfully treated endovascularly underwent parent vessel occlusion with low-flow bypass, balloon-assisted coiling (complete occlusion without recurrence >2 years follow-up), and stent-assisted coiling (near-complete occlusion).[44] Lerat *et al*.[48] report on a 64-year-old female with sudden onset left facial paralysis and bilateral petrous ICA aneurysms treated successfully with PED. Facial paralysis improved and aneurysmal obliteration occurred completely on the right side with a neck remnant identified on the left. Moon *et al*.[47] describe the case of a 64-year-old male with visual field cut, facial numbness, and diplopia secondary to lateral rectus palsy found to have petrous ICA aneurysm and treated with coiling and PED.

Kadkhodayan *et al*.[46] report on a 50-year-old female with malignant external otitis and bilateral temporal osteomyelitis and brisk bleeding from the left ear found to have an infectious petrous ICA pseudoaneurysm. PED was attempted after bleeding transiently ceased, but proved inadequate with rebleeding occurring after 12 days rendering parent vessel occlusion necessary. Thus, while PED appears effective and promising for treating petrous ICA aneurysms, its use may be limited in pseudoaneurysms and ruptured lesions in which persistent and rebleeding remains a significant risk, requiring more aggressive treatment.[46] While previous investigators have successfully used flow-diverting stents in the treatment of mycotic aneurysms of the ICA,[62] those lesions were unruptured.

Conclusion

Flow diversion is an ideal treatment for petrous ICA aneurysms, specifically unruptured lesions of complex morphology. Other options for treating petrous ICA aneurysms are challenging, not possible, less effective, and/or carry substantial risks. Furthermore, several of the disadvantages of PED, occlusion of side vessel branches and preclusion of future coil embolization, do not apply to the petrous segment of the ICA, lacking major branches, with aneurysms most commonly fusiform and not amenable to selective aneurysmal sac embolization to begin with. In addition, flow diversion is the best option in patients with bilateral petrous ICA aneurysms and morphology unfavorable to selective aneurysmal sac obliteration. Finally, use of PED in petrous ICA aneurysms has proven effective in many reports, except for one group's experience with a ruptured pseudoaneurysm which had initially transiently ceased, but then resumed, to bleed. While flow diversion appears promising for petrous ICA aneurysms, further experience with PED alone (i.e., without concurrent coiling) is required to make a stronger assertion.

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Conflicts of interest

There are no conflicts of interest.

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