Article published online: 2022-09-09

Flow Diversion for the Treatment of Petrous Internal Carotid Artery Aneurysms

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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*

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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Access this article online
Website: www.asianjns.org
DOI: 10.4103/ajns.AJNS_119_18
Quick Response Code:

How to cite this article: Ghali MG, Binning M. Flow diversion for the treatment of petrous internal carotid artery aneurysms. Asian J Neurosurg 2019;14:1058-62.

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.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Cohen JE, Grigoriadis S, Gomori JM. Petrous carotid artery pseudoaneurysm in bilateral carotid fibromuscular dysplasia: Treatment by means of self-expanding covered stent. Surg Neurol 2007;68:216-20.
2. Mori R, Murayama Y, Irie K, Takao H, Ebara M, Ishibashi T, *et al.* Endovascular treatment of large petrous internal carotid artery aneurysm associated with chronic otitis media: Case report. No Shinkei Geka 2006;34:415-9.
3. Bergés C, Pollak A, Valavanis A, Fisch U. Gradual facial palsy and intrapetrous internal carotid aneurysm: A case report. Skull

Base Surg 1993;3:164-9.
4. Gupta SK, Gupta OP, Singh MM, Varma DN, Kesharwani R. Giant aneurysm of the internal carotid artery in the carotid canal. J Laryngol Otol 1979;93:299-305.
5. Hamamoto Filho PT, Machado VC, Macedo-de-Freitas CC. A giant aneurysm from the petrous carotid presenting with isolated peripheral facial palsy. Rev Assoc Med Bras (1992) 2013;59:531-3.
6. Ravon R, Bouquier JJ, Dupuy JP, Bokor J, Feiss P, Vidal J, *et al.* Case of giant intra-petrous and intra-cavernous internal carotid aneurysm in a child. Neurochirurgie 1976;22:621-6.
7. Er U, Fraser K, Lanzino G. Isolated unilateral sixth nerve palsy as a presenting symptom of cerebral aneurysms. Report of two cases. Neuroradiol J 2007;20:81-4.
8. Gibson RD, Cowan IA. Giant aneurysm of the petrous carotid artery presenting with facial numbness. Neuroradiology 1989;31:440-1.
9. Date I, Sugiu K, Ohmoto T. A giant thrombosed aneurysm of the petrous carotid artery presenting with cavernous sinus syndrome: Case report. Skull Base Surg 1999;9:65-70.
10. Coley SC, Clifton A, Britton J. Giant aneurysm of the petrous internal carotid artery: Diagnosis and treatment. J Laryngol Otol 1998;112:196-8.
11. Lynch JC, Amaral MA, Pareira A. Giant aneurysm of the petrous portion of the carotid artery. J Neurol Neurosurg Psychiatry 1983;46:685-7.
12. Lee SH, Jang JH, Kim KH, Kim YZ. Stent-assisted coil embolization of petrous ICA in a teenager with neurofibromatosis. J Cerebrovasc Endovasc Neurosurg 2015;17:252-6.
13. Costantino PD, Russell E, Reisch D, Breit RA, Hart C. Ruptured petrous carotid aneurysm presenting with otorrhagia and epistaxis. Am J Otol 1991;12:378-83.
14. Lubicz B, Gauvrit JY, Leclerc X, Lejeune JP, Pruvo JP. Giant aneurysms of the internal carotid artery: Endovascular treatment and long-term follow-up. Neuroradiology 2003;45:650-5.
15. Sasaki T, Hori E, Sakai S, Fuji T, Takata H. A case of traumatic petrous portion internal carotid artery aneurysm treated by endovascular parent artery occlusion. No Shinkei Geka 2010;38:739-44.
16. Singh H, Thomas J, Hoe WL, Sethi DS. Giant petrous carotid aneurysm: Persistent epistaxis despite internal carotid artery ligation. J Laryngol Otol 2008;122:e18.
17. Takeshita T, Horie N, So G, Ujifuku K, Hayashi K, Morikawa M, *et al.* Ruptured giant thrombosed aneurysm at the internal carotid artery successfully treated with endovascular internal trapping following emergent balloon occlusion test: A case report. No Shinkei Geka 2012;40:61-6.
18. Cheng KM, Chan CM, Cheung YL, Chiu HM, Tang KW, Law CK. Endovascular treatment of radiation-induced petrous internal carotid artery aneurysm presenting with acute haemorrhage. A report of two cases. Acta Neurochir (Wien) 2001;143:351-5.
19. Cross DT 3rd, Moran CJ, Brown AP, Oser AB, Goldberg DE, Diego J, *et al.* Endovascular treatment of epistaxis in a patient with tuberculosis and a giant petrous carotid pseudoaneurysm. AJNR Am J Neuroradiol 1995;16:1084-6.
20. Anson JA, Lawton MT, Spetzler RF. Characteristics and surgical treatment of dolichoectatic and fusiform aneurysms. J Neurosurg 1996;84:185-93.
21. Ferroli P, Bisleri G, Nakaji P, Albanese E, Acerbi F, Polvani G, *et al.* Endoscopic radial artery harvesting for U-clip EC-IC bypass in the treatment of a giant petrous internal carotid artery aneurysm: Technical case report. Minim Invasive Neurosurg 2009;52:186-9.
22. Johnston SC, Halbach VV, Smith WS, Gress DR. Rapid development of giant fusiform cerebral aneurysms in angiographically normal vessels. Neurology 1998;50:1163-6.
23. Sánchez-Legaza E, Vallejos Miñarros J, Herrero Riquelme S. Giant petrous carotid aneurysm. Acta Otorrinolaringol Esp 2011;62:406-7.
24. Rathore YS, Chandra PS, Kumar R, Singh M, Sharma MS, Suri A, *et al.* Monitored gradual occlusion of the internal carotid artery followed by ligation for giant internal carotid artery aneurysms. Neurol India 2012;60:174-9.
25. Delrue F, De Vuyst D, d'Archambeau O. Giant multisaccular aneurysm of petrous and cervical internal carotid artery. JBR-BTR 2002;85:126-7.
26. Guirguis S, Tadros FW. An internal carotid aneurysm in the petrous temporal bone. J Neurol Neurosurg Psychiatry 1961;24:84-5.
27. Glassock ME 3rd, Smith PG, Bond AG, Whitaker SR, Bartels LJ. Management of aneurysms of the petrous portion of the internal carotid artery by resection and primary anastomosis. Laryngoscope 1983;93:1445-53.
28. Morantz RA, Kirchner FR, Kishore P. Aneurysms of the petrous portion of the internal carotid artery. Surg Neurol 1976;6:313-8.
29. Berenstein A, Ransohoff J, Kupersmith M, Flamm E, Graeb D. Transvascular treatment of giant aneurysms of the cavernous carotid and vertebral arteries. Functional investigation and embolization. Surg Neurol 1984;21:3-12.
30. Depauw P, Defreyne L, Dewaele F, Caemaert J. Endovascular treatment of a giant petrous internal carotid artery aneurysm. Case report and review of the literature. Minim Invasive Neurosurg 2003;46:250-3.
31. Reid TL, Cornnell B, Murtagh FR, Cahill DW. Port wine nevus associated with ipsilateral saccular aneurysms: Treatment by intraarterial balloon trapping. Surg Neurol 1985;23:541-4.
32. Halbach VV, Higashida RT, Hieshima GB, Dowd CF, Barnwell SL, Edwards MS, *et al.* Aneurysms of the petrous portion of the internal carotid artery: Results of treatment with endovascular or surgical occlusion. AJNR Am J Neuroradiol 1990;11:253-7.
33. McGrail KM, Heros RC, Debrun G, Beyerl BD. Aneurysm of the ICA petrous segment treated by balloon entrapment after EC-IC bypass. Case report. J Neurosurg 1986;65:249-52.
34. Lawton MT, Hamilton MG, Morcos JJ, Spetzler RF. Revascularization and aneurysm surgery: Current techniques, indications, and outcome. Neurosurgery 1996;38:83-92.
35. Spetzler RF, Fukushima T, Martin N, Zabramski JM. Petrous carotid-to-intradural carotid saphenous vein graft for intracavernous giant aneurysm, tumor, and occlusive cerebrovascular disease. J Neurosurg 1990;73:496-501.
36. Couldwell WT, Zuback J, Onios E, Ahluwalia BS, Tenner M, Moscatello A. Giant petrous carotid aneurysm treated by submandibular carotid-saphenous vein bypass. Case report. J Neurosurg 2001;94:806-10.
37. Willinsky R, Lasjaunias P, Pruvost P, Boucherat M. Petrous internal carotid aneurysm causing epistaxis: Balloon embolization with preservation of the parent vessel. Neuroradiology 1987;29:570-2.
38. Lempert TE, Halbach VV, Higashida RT, Dowd CF, Urwin RW, Balousek PA, *et al.* Endovascular treatment of pseudoaneurysms with electrolytically detachable coils. AJNR Am J Neuroradiol 1998;19:907-11.
39. Mericle RA, Lanzino G, Wakhloo AK, Guterman LR, Hopkins LN. Stenting and secondary coiling of intracranial

internal carotid artery aneurysm: Technical case report. Neurosurgery 1998;43:1229-34.

40. Ponce FA, Albuquerque FC, McDougall CG, Han PP, Zabramski JM, Spetzler RF. Combined endovascular and microsurgical management of giant and complex unruptured aneurysms. Neurosurg Focus 2004;17:E11.
41. Mascitelli JR, De Leacy RA, Oermann EK, Skovrlj B, Smouha EE, Ellozy SH, *et al.* Cervical-petrous internal carotid artery pseudoaneurysm presenting with otorrhagia treated with endovascular techniques. J Neurointerv Surg 2015;7:e25.
42. Alexander MJ, Smith TP, Tucci DL. Treatment of an iatrogenic petrous carotid artery pseudoaneurysm with a symbiot covered stent: Technical case report. Neurosurgery 2002;50:658-62.
43. Auyeung KM, Lui WM, Chow LC, Chan FL. Massive epistaxis related to petrous carotid artery pseudoaneurysm after radiation therapy: Emergency treatment with covered stent in two cases. AJNR Am J Neuroradiol 2003;24:1449-52.
44. Gross BA, Moon K, Ducruet AF, Albuquerque FC. A rare but morbid neurosurgical target: Petrous aneurysms and their endovascular management in the stent/flow diverter era. J Neurointerv Surg 2017;9:381-3.
45. Colby GP, Lin LM, Huang J, Tamargo RJ, Coon AL. Utilization of the Navien distal intracranial catheter in 78 cases of anterior circulation aneurysm treatment with the Pipeline embolization device. J Neurointerv Surg 2013;5 Suppl 3:iii16-21.
46. Kadkhodayan Y, Shetty VS, Blackburn SL, Reynolds MR, Cross DT 3rd, Moran CJ. Pipeline embolization device and subsequent vessel sacrifice for treatment of a bleeding carotid pseudoaneurysm at the skull base: A case report. J Neurointerv Surg 2013;5:e31.
47. Moon K, Albuquerque FC, Ducruet AF, Crowley RW, McDougall CG. Resolution of cranial neuropathies following treatment of intracranial aneurysms with the Pipeline embolization device. J Neurosurg 2014;121:1085-92.
48. Lerat J, Orsel S, Mounayer C, Riva R, Roudaut PY, Patron V, *et al.* Peripheral facial paralysis and bilateral carotid pseudoaneurysms of petrous localization: A case report. Skull Base Rep 2011;1:133-8.
49. Paullus WS, Pait TG, Rhoton AI Jr. Microsurgical exposure of the petrous portion of the carotid artery. J Neurosurg 1977;47:713-26.
50. Brandt TW, Jenkins HA, Coker NJ. Facial paralysis as the initial presentation of an internal carotid artery aneurysm. Arch Otolaryngol Head Neck Surg 1986;112:198-202.
51. Lazorthes G. Vascularisation Et Circulation Cerebrales. Paris: Masson Et Cie.; 1961. p. 13.
52. Vasović L, Arsić S, Vlajković S, Jovanović I, Jovanović P, Ugrenović S, Andjelković Z. Otic artery: a review of normal and pathological features. Med Sci Monit 2010;16:RA101-9.
53. Natarajan SK, Lin N, Sonig A, Rai AT, Carpenter JS, Levy EI, *et al.* The safety of Pipeline flow diversion in fusiform vertebrobasilar aneurysms: A consecutive case series with longer-term follow-up from a single US center. J Neurosurg 2016;125:111-9.
54. Murthy SB, Shah S, Venkatasubba Rao CP, Bershad EM, Suarez JI. Treatment of unruptured intracranial aneurysms with the pipeline embolization device. J Clin Neurosci 2014;21:6-11.
55. Murthy SB, Shah S, Shastri A, Venkatasubba Rao CP, Bershad EM, Suarez JI. The SILK flow diverter in the treatment of intracranial aneurysms. J Clin Neurosci 2014;21:203-6.
56. O'Kelly CJ, Spears J, Chow M, Wong J, Boulton M, Weill A, *et al.* Canadian experience with the Pipeline embolization device for repair of unruptured intracranial aneurysms. AJNR Am J Neuroradiol 2013;34:381-7.
57. Yu SC, Kwok CK, Cheng PW, Chan KY, Lau SS, Lui WM, *et al.* Intracranial aneurysms: Midterm outcome of pipeline embolization device – A prospective study in 143 patients with 178 aneurysms. Radiology 2012;265:893-901.
58. Amuluru K, Al-Mufti F, Singh IP, Prestigiacomo C, Gandhi C. Flow diverters for treatment of intracranial aneurysms: Technical and clinical updates. World Neurosurg 2016;85:15-9.
59. Szikora I, Berentei Z, Kulcsar Z, Marosfoi M, Vajda ZS, Lee W, *et al.* Treatment of intracranial aneurysms by functional reconstruction of the parent artery: The Budapest experience with the pipeline embolization device. AJNR Am J Neuroradiol 2010;31:1139-47.
60. Byrne JV, Beltechi R, Yarnold JA, Birks J, Kamran M. Early experience in the treatment of intra-cranial aneurysms by endovascular flow diversion: A multicentre prospective study. PLoS One 2010;5. pii: e12492.
61. Sahlein DH, Fouladvand M, Becske T, Saatci I, McDougall CG, Szikora I, *et al.* Neuroophthalmological outcomes associated with use of the Pipeline embolization device: Analysis of the PUFS trial results. J Neurosurg 2015;123:897-905.
62. Appelboom G, Kadri K, Hassan F, Leclerc X. Infectious aneurysm of the cavernous carotid artery in a child treated with a new-generation of flow-diverting stent graft: Case report. Neurosurgery 2010;66:E623-4.