Vertebro-Basilar Junction Aneurysms: A Single Centre Experience and Meta-Analysis of Endovascular Treatments

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Key words: giant aneurysms, vertebrobasilar junction, endovascular treatment, flow diverter

SUMMARY – *Vascular lesions of the vertebrobasilar junction (VBJ) are challenging in neurosurgical practice, and their gold-standard therapy is still under debate. We describe the operative strategies currently in use for the management of these complex vascular lesions and discuss their rationale in a literature meta-analysis and single centre blinded retrospective study. The single centre study included a review of initial presentation, angiographic features and clinical outcome (with modified Rankin Scale [mRS] scores) over a long-term follow-up. In our series, small aneurysms were effectively treated by endosaccular coil embolization, whereas a strategy including flow-diverter devices combined with endosaccular coil embolization was the option of choice in large and giant aneurysms, leading to satisfactory outcomes in most cases. Our Medline review showed that endovascular treatment was chosen in most VBJ cases, whereas the microsurgical option was assigned to only a few cases. Among the endovascular treatments, the most common techniques used for the treatment of VBJ aneurysms were: coiling, stent-assisted coiling and flow diversion. Our study highlights that aneurysm morphology, location and patient-specific angio-architecture are key factors to be considered in the management of VBJ aneurysms. Most case series, including our own, show that parent artery reconstruction using a flow-diverter device is a feasible and successful technique in some cases of giant and complex aneurysms (especially those involving the lower third of the basilar artery) while a "sit back, wait and see" approach may represent the safest and most reasonable option.*

Introduction

Giant aneurysms of the vertebrobasilar junction (VBJ) are complex and usually lethal lesions, if ruptured, due to massive intracranial haemorrhage. The International Study of Unruptured Intracranial Aneurysms (ISUIA) reports that the rupture rate for VBJ aneurysms significantly increases with the diameter of the lesions. A cumulative rupture rate of 50% at five years has been reported for VBJ aneurysms with a diameter of > 25 mm¹⁻⁸. It is very tempting to customize and apply treatment even to incidentally diagnosed cases because

of the high risk of rupture and its fatal consequences. However, management of the lesions is extremely challenging and the morbidity and mortality rate associated with the treatment itself is high⁹⁻¹¹.

We searched the Medline database for all articles published since 2004 on the treatment of VBJ aneurysms, and performed a meta-analysis of success rates associated with different endovascular or microsurgical approaches. Then, we compared the results from the literature with our endovascular experience of ten cases, suggesting the rationale for various techniques that provided a successful treatment outcome.

Material and Methods

A retrospective review of our database was conducted by the first author (FG) over a five-year period from November 2006 to September 2011. Data on ten patients with VBJ vascular lesions treated by the local interventional neuroradiologist (ED) were retrieved and assessed blindly by the authors not involved in their management (MG and DGI). The management of each patient was guided by the intention to treat. Research ethics board permission was granted for retrospective analysis (Table 1).

In addition, the first author conducted an extensive Medline review for all articles published since 2004 on the treatment of VBJ aneurysms and performed a meta-analysis of success rates associated with different endovascular or microsurgical approaches (Table 2). Then, the results of our literature search were compared with our experience.

Case Series

The patient group included four men and six women (age range: 44-79 yrs; average: 57 yrs) (Table 2). In 30% of cases, the clinical presentation involved a subarachnoid haemorrhage (SAH) from ruptured small aneurysms. One large aneurysm and one giant lesion were discovered as incidental findings. In one case of giant aneurysm, cranial nerve deficit due to brainstem compression occurred, and, in the remaining cases, headache and dizziness were the prominent symptoms.

All patients underwent digital subtraction angiography (DSA): in seven cases out of ten, a vertebrobasilar fenestration was angiographically depicted and in all those cases an aneurysm was also found. Briefly, in four cases the VBJ fenestration was associated with a small aneurysm (< 1 cm), in two cases with a large aneurysm (1-2.5 cm) and in one case (10%) with a giant aneurysm (> 2.5 cm). In the remaining three cases (one small aneurysm and two giant aneurysms) no fenestration was found.

All endovascular procedures were performed under general anaesthesia and via a right femoral artery approach using a 6F femoral artery sheath and a 6F guiding catheter (Envoy, Cordis). Three treatment strategies were adopted:

1. Coil embolization (50%)
2. Coils and covered stent placement (10%)
3. Flow diversion device placement (40%)

In all patients presenting ruptured small aneurysms with VBJ fenestration (Cases 4-7-8), and in another two cases of non-ruptured small aneurysms (Cases 2-3), only coils were used to treat the lesions. In these subjects (Cases 2-3-4-7-8), a microcatheter was navigated in proximity to the neck of the aneurysm and coils were delivered into the lesion until optimal aneurysm occlusion was obtained. Stenting and coiling was used only in one case (Case 1) characterized by a VBJ fenestration associated with a large aneurysm. In this case, the left vertebral artery (VA) was cannulised with a 6F guiding catheter and a microcatheter was navigated to the left posterior cer-

Table 1 Data obtained in 10 patients undergoing endovascular treatment for vertebro-basilar junction aneurysms.

Case Nos.	Age (years)*	Type of Aneurysm	Fenestration	Pre-op mRS Score	Treatment Strategy	Post-op mRS Score (at last FU)	Last FU (months)
1	68	Large	yes	2	II	0	12
2	48	Small	yes	4	I	2	60
3	47	Small	yes	4	I	0	48
4	80	Large	yes	3	I	1	lost
5	43	Giant	no	3	III	0	12
6	58	Small	no	3	III	0	36
7	46	Small	yes	3	I	0	24
8	79	Small	yes	4	I	1	12
9	60	Giant	no	4	III	2	12
10	44	Giant	yes	3	III	0	12

*Age at the time of treatment, FU: follow-up.

Table 2 Medline literature meta-analysis.

<i>Authors</i>	<i>Year of publication</i>	<i>No. of patients</i>	<i>Fenestration</i>	<i>Treatment modality</i>	<i>Outcome</i>
Current series	2014	10	Yes	Endovascular: Coil embolization (50%), Coils and covered stent placement (10%) Flow diversion device placement (40%)	9 Good 1 Dependent
Trivelato et al.	2014	8	Yes	Endovascular: Stent-assisted coiling (55.5%), Selective coiling (33.3%), Balloon-assisted coiling (11.1%)	7 Good 1 Aneurysm rupture
Gupta et al.	2013	4	Yes	Endovascular: Balloon remodelling technique	75% Good 25% No follow-up
Itami et al.	2013	10	Yes	Endovascular: Coil embolization with or without balloon remodelling	9 Good 1 Dependent
Meckel et al.	2013	10 (8 giant)	No	Endovascular: Flow diversion contralateral vertebral artery sacrifice and adjunctive coiling	6 Good 4 Deaths
Shi X et al.	2013	3	No	Microsurgery: Far-lateral, transcondylar approach	Good
Chalouhi et al.	2013	2	No	Endovascular: Flow diversion	Good
Graziano et al.	2013	1	No	Endovascular: 1. Coiling 2. Coiling+Onyx and VA occlusion	Partial recovery
Kalani et al.	2013	11 (7 VBJ)	No	Microsurgery: Extracranial-intracranial bypass and vessel occlusion	6 Good 5 Deaths
Kan et al.	2012	1	Yes	Endovascular: Stent-assisted coiling	Good
Liu et al.	2012	2	No	Endovascular: 1. Intra-arterial thrombolysis 1. Stenting vertebral artery associated with a coil occlusion of the other vertebral artery	1 Death 1 Good
Consoli et al.	2012	2	Yes	Endovascular: Flow diversion	Good
Binning et al.	2011	1	No	Endovascular: Flow diversion	Good
Ponce et al.	2011	11	No	Microsurgery: Clipping during cardiac standstill	4 Deaths 7 Partial recovery
Gruber et al.	2010	1	Yes	Endovascular: Stent-assisted coiling	Good
Bentura et al.	2010	1	No	Microsurgery: Clipping	Good
Marhold et al.	2010	1	No	Microsurgery/Endovascular: High flow bypass and coiling (SVG from VA to SCA Coiling of bilateral VAs above PICA)	Partial recovery
Albanese et al.	2009	1	Yes	Endovascular: Stenting and balloon-assisted coiling in the dominant limb of the fenestration. Sacrifice of the non-dominant vertebral artery with coils and Onyx.	Good
Wakhloo et al.	2008	1 of 30	No	Endovascular: Stent-assisted coiling	1 Death
Peluso et al.	2007	7	Yes	Endovascular: Coiling (balloon assistance, stent, limb occlusion)	4 Good; 2 Died; 1 Dependent
Greenberg et al.	2007	1	Yes	Endovascular: Stent-grafts placement and VA coils occlusion	100% Good
Nakau et al.	2007	1	Yes	Endovascular: Coiling	Aneurysm perforation + parent artery thrombosis
Fujimoto et al.	2007	2	Yes	Endovascular: Coiling	Good
Kai et al.	2006	2	Yes	Endovascular: Coiling; 1 limb sacrificed in 1 patient	Good
Peltier et al.	2006	1	Yes	Endovascular: Coiling	Good
Ricci et al.	2005	1 (giant)	No	Microsurgery: Posterolateral approach plus contralateral artery control with balloon inflation and clipping	Good
Zenteno et al.	2005	3	No	Endovascular: Stenting alone	1 Temporary visual defect 2 Good
Kubo et al.	2005	1	Yes	Endovascular: Coiling	Good
Burkelko et al.	2004	1	Yes	Endovascular: Stent-grafts placement	Good
Yoon et al.	2004	4	Yes	Endovascular: Coiling	3 Good 1 Vertebral thrombosis

Figure 1 Pre and post-treatment and one year f/u DSA showing Case 6. The left VA was cannulated as usual with a 6Fr Envoy delivery catheter, a microcatheter with microguide were navigated over the aneurysm. Through the microguide, a Leo stent was placed along the aneurysm and the middle third of the BA. Another Leo stent was then inserted immediately along the left VA in a telescoping fashion to augment support. Afterwards, three Silk flow diverters were placed covering the neck of the giant aneurysm. Then, the right VA was cannulated and three GDC coils were delivered. The right VA was then occluded with coils.

ebral artery. A Neuroform EZ (Stryker) stent was placed across the neck of the lesion and nine coils were used to occupy the aneurysm sac. In all the remaining patients (Cases 5-6-9-10), a flow diverter was positioned to treat these complex lesions. Following the induction of general anaesthesia and immediately before the procedure, a 3000 IU bolus of heparin (or more, according to the patient's weight) was administered intra-arterially. In particular, in Case 5, a Pipeline embolization device (PED, Covidien) was used as the sole endovascular intervention. The VA was cannulised with a 6F delivery catheter. Via a coaxial system, a microcatheter was navigated distally to the aneurysm under roadmap guidance. The PED was then introduced and deployed through a combination of forward pressure and retraction technique, with the goal of covering the aneurysmal sac and the diseased arterial segment. In Case 6, the left VA was cannulised as usual. Through a microguide, a LEO stent (Balt Extrusion) was placed along the aneurysm and the middle third of the basilar artery (BA). Another LEO stent was then inserted along the left VA in a telescoping fashion for enhanced support. Subsequently, three SILK flow diverters (Balt Extrusion) were placed covering the neck of the giant aneurysm. Then, the right VA was cannulised and a microcatheter was navigated into the aneurysm and three coils were delivered. The right vertebral artery was then occluded with coils (Figure 1). In the Case 9, a scaffold was constructed using three LEO stents along the BA and the right VA. Inside this channel, three SILK stents were deployed.

Then, through the left VA, a microcatheter was navigated into the aneurysm and coils were delivered to occlude the aneurysm and the left VA (Figure 2). In the last case (Case 10), a flow diverter and coils were used to treat a giant aneurysm associated with VBJ fenestration (Figure 3). The VA was cannulised and, via a coaxial system, a microcatheter was navigated to the tip of the BA, passing through the left arm of the fenestration, under roadmap guidance. The PED was then introduced and deployed. Then, a microcatheter was navigated into the aneurysm sac passing through the right VA, and coils were delivered. Finally, a microcatheter was advanced along the right arm of the fenestration and the PED was deployed in the same fashion as the first one (Table 1, Figure 3).

Results

In our clinical series, there was a slight prevalence (60% of cases) of aneurysm occurrence in female subjects. In 70% of cases, a VBJ fenestration was associated with an aneurysm (four small; two large and one giant); in 90% of these cases the aneurysm was small (Table 1). Looking at the symptomatology, in 30% of cases an SAH occurred and, in all cases, the ruptured aneurysm was small. No intra-procedural or non-procedure-related complications were observed. In the cases treated with flow diverter devices, the patients received dual antiplatelet therapy three to seven days before the procedure. Dual antiplatelet therapy was continued for one month after the procedure.

Aspirin therapy was stopped four months after endovascular treatment. In all cases, a brain CT scan was performed after the procedure. Long-term follow-up evaluation was performed in nine of ten (90%) patients: one patient was lost during the follow-up period (Table 1, Case 4). All patients underwent a follow-up DSA six months after treatment (with or without CT or MRI), and one and two-year post-treatment evaluation was carried out with a CT or MR scan, in some cases combined also with a new DSA. Flow diverter placement (Cases 5-6-9-10) was technically successful, and at the end of each procedure variable degrees of slower flow and contrast stagnation were observed in the aneurysm sac (Figures 3 and 4). In our series the intra-procedural mortality rate was 0%, and the morbidity rate was 10%. This accounts for one patient (Case 9) initially treated for a giant dissecting aneurysm of the VBJ, whose angio-MR study at two-year follow up showed an increase in the aneurysmal mass and a reduction of the blood flow in the basilar artery (Figure 2, Table 1). Even though the increase was minimal and the aneurysm was angiographically occluded, this patient's condition progressively declined with occurrence of lower cranial nerve palsy and hemiparesis syndrome. A subsequent brain CT scan revealed an enlargement of the ventricular cavities and an intra-arterial thrombosis: the patient underwent ventricular shunt placement and was ultimately admitted to the Rehabilitation Unit.

With the aim to describe and summarize the state-of-the-art of treatment for VBJ aneurysms, we did an extensive PubMed review of the last ten years (from 2004 to date) in search of the medical literature regarding the strategy adopted for treating these challenging lesions (Table 2). We found 85 cases in all, described in 29 studies, most of them as reports of single cases^{19,20,23,25-29,31-33,35,37,38}. VBJ fenestration was associated in more than half of the cases, 56 cases, confirming the high incidence of aneurysm in the VBJ affected by a fenestration^{12-14,16,19,22,28,30-32,34-39}. Thorough evaluation revealed a high prevalence of endovascular treatment instead of microsurgery. A microsurgical strategy was reported in four studies for a total of 26 cases treated^{16,18,24,25}. In two cases a combined endovascular-microsurgical approach was applied with good success^{26,33}. However, the microsurgical strategy was chosen in very specialized neurovascular centres with the employment of a dedicated neurosurgical-neuroanaesthetist team and specific expertise (cardiac

standstill, EC-IC bypass, combined techniques, etc.). Coiling with or without balloon assistance or stenting was performed in most of the cases (39 in number) stent alone or balloon remodeling in eight cases and four cases respectively^{12-14,19,21,27-31,34-39}. In those cases, moreover, one or both limbs of VAs were sacrificed with coiling. In 17 cases a flow diversion technique was applied for the treatment of VBJ aneurysms with a good outcome apart from four deaths^{15,17,22,23}.

Discussion

The management of giant aneurysms in the VBJ is extremely challenging and associated with a high rate of morbidity and mortality. For this reason, different factors should be critically considered in the selection of the most appropriate treatment strategy, including: the preoperative clinical and neurological status of the patient and/or evaluation of the features of the aneurysm, its related vascular structures and the parental artery collateral circulation¹⁻⁶.

According to the literature, in the setting of a VBJ fenestration there is a greater incidence of aneurysm formation, approximately 35%¹³. Thus, when there is a vertebrobasilar junction aneurysm, an associated fenestration should be strongly suspected and as, most authors have reported, the proximal aspect of the fenestration is the most common site of aneurysm formation.

Surgery was the conventional mode of treatment of such aneurysms in the pre-endovascular era. Microsurgical clipping requires a customized surgical approach widely exposing the aneurysm, parent vessel and arterial perforators. Although this strategy can ensure a durable and complete aneurysm exclusion from the circulation with preservation of the parent vessels, exposing these vascular lesions and clipping them could be technically challenging due to irregularities in the aneurysms and vessel anatomy. Moreover, access to the VBJ is difficult and hampered by the petrous bone and the direct proximity of the aneurysm to the brain stem, perforating arteries and lower cranial nerves makes the approach dangerous. Selected cases may benefit from indirect therapies, such as proximal arterial occlusion and aneurysm trapping, with or without flow replacement, but these procedures may increase the operative risk and compromise the post-operative outcome^{4,5,10,40,41,46,50}. In some other situations combined endovascular/microsurgi-

Figure 2 A-D) Pre- and post-treatment DSA and Angio-MR in Case 9. In this case, a scaffold was constructed using three LEO stents along the BA and the right VA. Inside this channel, three SILK stents were deployed. Then, through the left VA, coils were delivered to occlude the aneurysm and the left VA. E) At the six month f/up, the study revealed a more stagnant flow with a patent basilar artery. F) At 24 months, the flow had become more stagnant not only inside the lesion but also in the basilar artery.

cal strategies have proved complementary and very efficient, allowing satisfactory aneurysm occlusion^{26,33}.

Endovascular techniques have progressively evolved over the last few decades and are nowadays considered a valid line of defence against some of the most complex cerebrovascular pathologies^{42-45,49}. The well-known challenges correlated with the surgical treatment of vertebro-basilar system (VBS) aneurysms, and the geometry of the posterior arteries, considered favourable for endovascular navigation, have

made endovascular embolization a valuable tool for a relatively safe and less hazardous management of such lesions^{47,48}. There are, however, certain restrictions and limitations involved in the endovascular approach. It is extremely important to understand the anatomy of the region with a clear depiction of the aneurysm sac, neck and its relationship to the fenestration (if present) and the parent artery microanatomy.

In recent years, flow diverter devices have been developed to provide a diversion of the flow into the parent artery, away from the an-

eurysm⁵¹⁻⁵⁵. A series of flow diverter devices can be placed and overlapped to aid in aneurysm thrombosis or to extend the overall construct length for particularly long aneurysms. Adjunctive coil placement may enhance aneurysm thrombosis⁵⁶. The results so far have been promising: Lylyk et al. reported angiographically-documented occlusion rates of 56%, 93%, and 95% at three, six and 12 months respectively, whereas the investigators of the recently conducted Pipeline Embolization Device for the Intracranial Treatment of Aneurysms (PITA) trial reported a 93% occlusion rate at six months⁵⁶⁻⁵⁷. The porosity of the stent is thought to allow for continued blood flow through perforating arteries, given the demand of these vessels. However, recent studies have highlighted some concerns in terms of late parent vessel thrombosis, perforating vessel infarction or aneurysm rupture, in particular for vascular lesions located at the posterior fossa⁵⁸⁻⁶¹. Indeed, although the use of flow diverters in the anterior circulation may be useful for internal carotid artery aneurysms, below the anterior choroid artery, aneurysms of the posterior fossa are quite different. The perforator-rich region of the VBS makes the use of flow diverters in this region an entirely different matter. Despite the initial widespread enthusiasm for the use of these devices in such cases, few reports on such usage have been published to date. For example, only 6% of the aneurysms in the PITA trial were located in the VBS⁵⁷.

In our clinical series, an initial complete occlusion or successful embolization was observed in all ten patients during the long-term follow-up period. In brief, all patients with small aneurysms were managed with endosaccular coiling embolization, without immediate or long-term complications in 100% of cases. On the other hand, large and giant aneurysms were treated with flow diverter devices, combined or not with coil embolization. In one case of a giant aneurysm involving more than one third of the parent artery, a late vessel thrombosis was reported.

Like our database analysis, our Medline review showed that the most common techniques used for the treatment of VBJ aneurysms were: coiling, stent-assisted coiling and flow diversion. In particular, stent-assisted coiling with or without one VA sacrifice was the most used procedure. Compared to microsurgery, this is less demanding and invasive and, among the other endovascular options, it is the one able to offer the most satisfactory aneurysm occlusion

with preservation of the blood flow in the parent artery and in the perforating vessels. However, in situations such as giant aneurysms and very tortuous vessels, this technique may not be feasible. Conversely, flow diversion has the advantage of being employed in very demanding and complex vessel and aneurysm angio-architecture, providing successful results. Thus concerns arise in the usage of flow diversion in the VBS; due to the high number of perforating arteries related to this area, it may be employed in particular situations as a treatment of last resort.

Take-Home Messages

Our database and Medline review yielded the following considerations:

- 1 In small aneurysms involving the VBJ traditional coiling or stent-assisted coiling therapy remains a valuable option to achieve successful results.
- 2 In large or giant aneurysms with small necks and involving less than one third of the BA, overlapping flow diverter devices in a telescopic fashion, coupled with endosaccular coil embolization may be an efficient and comprehensive treatment strategy. Indeed, associating endosaccular aneurysm coiling with the use of flow diverters seems to be useful in avoiding this initial scaring effect.
- 3 In large or giant aneurysms with wide necks and involving more than one third of the basilar artery, a thrombotic evolution may occur soon or even several months after endovascular treatment. Accordingly, although the poor natural history might justify every kind of therapeutic attempt, a "wait and see" strategy may actually represent the most reasonable behaviour in elective cases. In emergency cases, external ventricular shunt placement may be more than enough.

Study Limitations

The main limitation of this study is the fact that it is based on a single centre series, thus our review includes a relatively small number of subjects. Nonetheless the lack of large case series in the international literature makes the study useful for future meta-analyses. Moreover, the rigorous blinded retrospective assessment of the clinical and radiological outcomes by authors not involved in the initial treatment guarantees a fair appraisal of the techniques discussed.

Figure 3 Pre- and post-treatment DSA showing Case 10. Kissing saccular aneurysms at the VBJ with fenestration. Two flow diverters were deployed to treat the lesions, one for each side of the fenestration; coils were then delivered into the aneurysm sac passing through the right VA.

Conclusions

Vertebrobasilar junction (VBJ) aneurysms, especially giant ones, pose major challenges in neurosurgical practice. A carefully selected operative strategy is the key for a safe treatment with long-term benefit. In smaller lesions traditional endovascular methods still play an important role for a successful treatment, whereas in some other complex lesions, flow diverters could provide more definitive and durable results compared to other endovascular

strategies. However, their judicious application in clinical practice is essential to ensure the safest treatment.

For further progress in the management of these complex cases, it will be essential to better understand how the perforator vessels and intralesional thrombi formation are influenced by flow diverter devices. It would also be valuable to define a cut-off in the extension of basilar artery involvement which may or may not cause the risk of potential intra-arterial thrombosis.

References

- 1 LeRoux PD, Winn HR. Surgical decision making for the treatment of cerebral aneurysms. In: Winn HR, Youmans (Eds). *Neurological Surgery*. 5th ed. Vol 2. Philadelphia: Saunders; 2004. p. 1793-1812.
- 2 Peluso JP, van Rooij WJ, Sluzewski M, et al. Aneurysms of the vertebrobasilar junction: incidence, clinical presentation, and outcome of endovascular treatment. *Am J Neuroradiol*. 2007; 28 (9): 1747-1751. doi: 10.3174/ajnr.A0654.
- 3 Wiebers DO, Whisnant JP, Huston J 3rd, et al. Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. *Lancet*. 2003; 362 (9378): 103-110. doi: 10.1016/S0140-6736(03)13860-3.
- 4 Weir BL, Disney L, Karrison T. Sizes of ruptured and unruptured aneurysms in relation to their sites and the ages of patients. *J Neurosurg*. 2002; 96 (1): 64-70. doi: 10.3171/jns.2002.96.1.0064.
- 5 Spetzler RF, Riina HA, Lemole GM Jr. Giant aneurysms. *Neurosurgery*. 2001; 49 (4): 902-908. doi: 10.1097/00006123-200110000-00022.
- 6 Drake CG. Giant intracranial aneurysms: experience with surgical treatment in 174 patients. *Clin Neurosurg*. 1979; 26: 12-95.
- 7 Drake CG. The treatment of aneurysms of the posterior circulation. *Clin Neurosurg*. 1979; 26: 96-144.
- 8 Wiebers DO, Whisnant JP, Huston J 3rd, et al. Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. *Lancet*. 2003; 362 (9378): 103-110. doi: 10.1016/S0140-6736(03)13860-3.
- 9 Collice M, Arena O, D'Aliberti G, et al. Aneurysms of the vertebrobasilar junction area: preliminary experience in endovascular and surgical management. *Acta Neurochir (Wien)*. 1997; 139 (2): 124-133. doi: 10.1007/BF02747192.
- 10 Sanai N, Tarapore P, Lee AC, et al. The current role of microsurgery for posterior circulation aneurysms: a selective approach in the endovascular era. *Neurosurgery*. 2008; 62 (6): 1236-1249; discussion 1249-1253. doi: 10.1227/01.neu.0000333295.59738.de.
- 11 Cantore G, Santoro A, Guidetti G, et al. Surgical treatment of giant intracranial aneurysms: current viewpoint. *Neurosurgery*. 2008; 63 (4 Suppl 2): 279-289; discussion 289-290. doi: 10.1227/01.NEU.0000313122.58694.91.
- 12 Trivelato FP, Abud DG, Nakiri GS, et al. Basilar artery fenestration aneurysms: endovascular treatment strategies based on 3D morphology. *Clin Neuroradiol*. 2014. [Epub ahead of print]. doi: 10.1007/s00062-014-0336-0.
- 13 Gupta V, Ahuja CK, Khandelwal N, et al. Treatment of ruptured saccular aneurysms of the fenestrated vertebrobasilar junction with balloon remodeling technique. A short case series and review of the literature *Interv Neuroradiol*. 2013; 19 (3): 289-298.
- 14 Itami H, Sugiu K, Hiramatsu M, et al. Endovascular treatment of basilar artery aneurysms associated with fenestration. *No Shinkei Geka*. 2013; 41 (7): 583-592.
- 15 Meckel S, McAuliffe W, Fiorella D, et al. Endovascular treatment of complex aneurysms at the vertebrobasilar junction with flow-diverting stents: initial experience. *Neurosurgery*. 2013; 73 (3): 386-394. doi: 10.1227/01.neu.0000431472.71913.07.
- 16 Shi X, Qian H, Singh KC, et al. Surgical management of vertebral and basilar artery aneurysms: a single center experience in 41 patients. *Acta Neurochir (Wien)*. 2013; 155 (6): 1087-1093. doi: 10.1007/s00701-013-1656-6.
- 17 Chalouhi N, Tjoumakaris S, Dumont AS, et al. Treatment of posterior circulation aneurysms with the pipeline embolization device. *Neurosurgery*. 2013; 72 (6): 883-889. doi: 10.1227/NEU.0b013e31828ba984.
- 18 Kalani MY, Zabramski JM, Nakaji P, et al. Bypass and flow reduction for complex basilar and vertebrobasilar junction aneurysms. *Neurosurgery*. 2013; 72 (5): 763-775; discussion 775-6. doi: 10.1227/NEU.0b013e3182870703.
- 19 Kan P, Abba AA, Dumont TM, et al. Double-Barrel Stent-assisted coiling of a Basilar artery Fenestration aneurysm. *J Neuroimaging*. 2012. [Epub ahead of print].
- 20 Graziano F, Russo VM, Wang W, et al. 3D computational fluid dynamics of a treated vertebrobasilar giant aneurysm: a multistage analysis. *Am J Neuroradiol*. 2013; 34 (7): 1387-1394. doi: 10.3174/ajnr.A3373.
- 21 Liu XC, Shi MC, Wang SC. Endovascular treatment for ischemic stroke induced by vertebrobasilar junction artery dissection: 2 case reports. *Vasc Endovascular Surg*. 2012; 46 (1): 58-61. doi: 10.1177/1538574411419374.
- 22 Consoli A, Renieri L, Nappini S, Ricciardi F, et al. Endovascular treatment with 'kissing' flow diverter stents of two unruptured aneurysms at a fenestrated vertebrobasilar junction. *J Neurointerv Surg*. 2013; 5 (2): e9. doi: 10.1136/neurintsurg-2011-010188.
- 23 Binning MJ, Natarajan SK, Bulsara KR, et al. SILK flow-diverting device for intracranial aneurysms. *World Neurosurg*. 2011; 76 (5): 477.e1-6. doi: 10.1016/j.wneu.2011.03.050.
- 24 Ponce FA, Spetzler RF, Han PP, et al. Cardiac standstill for cerebral aneurysms in 103 patients: an update on the experience at the Barrow Neurological Institute. *Clinical article. J Neurosurg*. 2011; 114 (3): 877-884. doi: 10.3171/2010.9.JNS091178.
- 25 Bentura JE, Figueiredo EG, de Monaco BA, et al. Vertebrobasilar artery junction aneurysm associated with fenestration. *Arq Neuropsiquiatr*. 2010; 68 (2): 312-314. doi: 10.1590/S0004-282X2010000200031.
- 26 Marhold F, Rosen CL. Novel technique to improve vessel mismatch when using saphenous vein bypass grafts for intracranial revascularization procedures. *J Neurosurg*. 2010; 112 (6): 1227-1231. doi: 10.3171/2009.9.JNS09367.
- 27 Gruber TJ, Ogilvy CS, Hauck EF, et al. Endovascular treatment of a large aneurysm arising from a basilar trunk fenestration using the waffle-cone technique. *Neurosurgery*. 2010; 67 (3 Suppl operative): ons140-144; discussions ons 144.
- 28 Albanese E, Russo A, Ulm AJ. Fenestrated vertebrobasilar junction aneurysm: diagnostic and therapeutic considerations. *J Neurosurg*. 2009; 110 (3): 525-529. doi: 10.3171/2008.9.JNS08170.
- 29 Wakhloo AK, Mandell J, Gounis MJ, et al. Stent-assisted reconstructive endovascular repair of cranial fusiform atherosclerotic and dissecting aneurysms: long-term clinical and angiographic follow-up. *Stroke*. 2008; 39 (12): 3288-3296. doi: 10.1161/STROKEAHA.107.512996.
- 30 Peluso JP, van Rooij WJ, Sluzewski M, et al. Aneurysms of the vertebrobasilar junction: incidence, clinical presentation, and outcome of endovascular treatment *Am J Neuroradiol*. 2007; 28 (9): 1747-1751. doi: 10.3174/ajnr.A0654.
- 31 Greenberg E, Katz JM, Janardhan V, et al. Treatment of a giant vertebrobasilar artery aneurysm using stent grafts. Case report. *J Neurosurg*. 2007; 107 (1): 165-168. doi: 10.3171/JNS-07/07/0165.
- 32 Nakau H, Nagatani H, Nakau R, et al. An aneurysm located at a fenestration of the vertebrobasilar junction successfully treated with Guglielmi detachable coils. *No Shinkei Geka*. 2007; 35 (3): 267-272.
- 33 Ricci G, Ricci A, Gallucci M, et al. Combined endovascular and microsurgical approach in the treatment of giant paraclinoid and vertebrobasilar aneurysms. *J Neurosurg Sci*. 2005; 49 (1): 1-6.
- 34 Kai Y, Hamada J, Morioka M, et al. Endovascular treatment of ruptured aneurysms associated with fenestrated basilar artery. Two case reports. *Neurol Med chir (Tokyo)*. 2006; 46 (5): 244-247. doi: 10.2176/nmc.46.244.
- 35 Peltier J, Gayet JB, Toussaint P, et al. Terminovertebral aneurysm arising from basilar artery fenestration. *Neurochirurgie*. 2006; 52 (1): 52-56. doi: 10.1016/S0028-3770(06)71170-5.

- 36 Fujimoto K, Kawai S, Yonezawa T, et al. Basilar trunk aneurysms with associated fenestration treated by using Guglielmi detachable coils: two case reports. *J Stroke Cerebrovasc Dis.* 2007; 16: 84-87. doi: 10.1016/j.jstrokecerebrovasdis.2006.10.004.
- 37 Kubo M, Hachein-Bey L, Varelas PN, et al. Ruptured saccular aneurysm of distal vertebral artery fenestration managed with Guglielmi detachable coils and intraventricular tissue plasminogen activator. *Surg Neurol.* 2005; 63: 244-248; discussion 248. doi: 10.1016/j.surneu.2004.02.038.
- 38 Burbelko MA, Dzyak LA, Zorin NA, et al. Stent-graft placement for wide-neck aneurysm of the vertebrobasilar junction. *Am J Neuroradiol.* 2004; 25 (4): 608-610.
- 39 Yoon SM, Chun YI, Kwon Y, et al. Vertebrobasilar junction aneurysms associated with fenestration: experience of five cases treated with Guglielmi detachable coils. *Surg Neurol.* 2004; 61 (3): 248-254. doi: 10.1016/S0090-3019(03)00485-3.
- 40 Ponce FA, Albuquerque FC, McDougall CG, et al. Combined endovascular and microsurgical management of giant and complex unruptured aneurysms. *Neurosurg Focus.* 2004; 17 (5): E11. doi: 10.3171/foc.2004.17.5.11.
- 41 Chen L, Kato Y, Sano H, et al. Management of complex, surgically intractable intracranial aneurysms: the option for intentional reconstruction of aneurysm neck followed by endovascular coiling. *Cerebrovasc Dis.* 2007; 23 (5-6): 381-387. doi: 10.1159/000101460.
- 42 Koebbe CJ, Veznedaroglu E, Jabbour P, et al. Endovascular management of intracranial aneurysms: current experience and future advances. *Neurosurgery.* 2006. 59 (5 Suppl 3): S93-102; discussion S3-13.
- 43 Gonzalez NR, Duckwiler G, Jahan R, et al. Challenges in the endovascular treatment of giant intracranial aneurysms. *Neurosurgery.* 2006. 59 (5 Suppl 3): S113-124; discussion S3-13.
- 44 Guglielmi G, Viñuela F, Duckwiler G, et al. Endovascular treatment of posterior circulation aneurysms by electrothrombosis using electrically detachable coils. *J Neurosurg.* 1992; 77 (4): 515-524. doi: 10.3171/jns.1992.77.4.0515.
- 45 Standhardt H, Boecher-Schwarz H, Gruber A, et al. Endovascular treatment of unruptured intracranial aneurysms with Guglielmi detachable coils: short- and long-term results of a single-centre series. *Stroke.* 2008. 39 (3): 899-904. doi: 10.1161/STROKEAHA.107.496372.
- 46 Hoh BL, Putman CM, Budzik RF, et al. Combined surgical and endovascular techniques of flow alteration to treat fusiform and complex wide-necked intracranial aneurysms that are unsuitable for clipping or coil embolization. *J Neurosurg.* 2001; 95 (1): 24-35. doi: 10.3171/jns.2001.95.1.0024.
- 47 Gonzalez NR, Dusick JR, Duckwiler G, et al. Endovascular coiling of intracranial aneurysms in elderly patients: report of 205 treated aneurysms. *Neurosurgery.* 2010; 66 (4): 714-720; discussion 720-721. doi: 10.1227/01.NEU.0000367451.59090.D7.
- 48 Fiorella D, Albuquerque FC, Woo H, et al. Neuroform stent assisted aneurysm treatment: evolving treatment strategies, complications and results of long term follow-up. *J Neurointerv Surg.* 2010; 2 (1): 16-22. doi: 10.1136/jnis.2009.000521.
- 49 Liebman KM, Severson MA 3rd. Techniques and devices in neuroendovascular procedures. *Neurosurg Clin N Am.* 2009; 20 (3): 315-340. doi: 10.1016/j.nec.2009.01.002.
- 50 Ashley WW, Amin-Hanjani S, Alaraj A, et al. Flow-assisted surgical cerebral revascularization. *Neurosurg Focus.* 2008; 24 (2): E20. doi: 10.3171/FOC/2008/24/2/E20.
- 51 Fiorella D. Pipeline in clinical practice in 2011. *Neuroradiology.* 2012; 54 (4): 277-278. doi: 10.1007/s00234-011-0957-9.
- 52 Fargen KM, Frei D, Fiorella D, et al. The FDA approval process for medical devices: an inherently flawed system or a valuable pathway for innovation? *J Neurointerv Surg.* 2013; 5 (4): 269-275. doi: 10.1136/neurintsurg-2012-010400.
- 53 Nelson PK, Lylyk P, Szikora I, et al. The pipeline embolization device for the intracranial treatment of aneurysms trial. *Am J Neuroradiol.* 2011; 32 (1): 34-40. doi: 10.3174/ajnr.A2421.
- 54 Wagner A, Cortsen M, Hauerberg J, et al. Treatment of intracranial aneurysms. Reconstruction of the parent artery with flow-diverting (Silk) stent. *Neuroradiology.* 2012; 54 (7): 709-718. doi: 10.1007/s00234-011-0949-9.
- 55 Leonardi M, Cirillo L, Toni F, et al. Treatment of intracranial aneurysms using flow-diverting silk stents (BALT): a single centre experience. *Interv Neuroradiol.* 2011; 17 (3): 306-315.
- 56 Lylyk P, Miranda C, Ceratto R, et al. Curative endovascular reconstruction of cerebral aneurysms with the pipeline embolization device: the Buenos Aires experience. *Neurosurgery.* 2009; 64 (4): 632-642; discussion 642-643; quiz N6. doi: 10.1227/01.NEU.0000339109.98070.65.
- 57 McAuliffe W, Wycoco V, Rice H, et al. Immediate and midterm results following treatment of unruptured intracranial aneurysms with the pipeline embolization device. *Am J Neuroradiol.* 2012; 33 (1): 164-170. doi: 10.3174/ajnr.A2727.
- 58 Fiorella D, Hsu D, Woo HH, et al. Very late thrombosis of a pipeline embolization device construct: case report. *Neurosurgery.* 2010; 67 (3 Suppl Operative): onsE313-314; discussion onsE314. doi: 10.1227/01.NEU.0000383875.08681.23.
- 59 Siddiqui AH, Abila AA, Kan P, et al. Panacea or problem: flow diverters in the treatment of symptomatic large or giant fusiform vertebrobasilar aneurysms. *J Neurosurg.* 2012; 116 (6): 1258-1266. doi: 10.3171/2012.2.JNS111942.
- 60 Munich SA, Tan LA, Keigher KM, et al. The Pipeline Embolization Device for the treatment of posterior circulation fusiform aneurysms: lessons learned at a single institution. *J Neurosurg.* 2014; 1-8. doi: 10.3171/2014.7.JNS132595.
- 61 Lall RR, Crobeddu E, Lanzino G, et al. Acute branch occlusion after Pipeline embolization of intracranial aneurysms. *Clin Neurosci.* 2014; 21 (4): 668-672. doi: 10.1016/j.jocn.2013.07.011.

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