Microsurgical treatment of posterior inferior cerebellar aneurysms based on angioarchitecture supplemented by high-resolution vessel wall MRI: a case series report

Zixiao Yang,1,2,3,4 Jianping Song,1,2,3,4 Kai Quan,1,2,3,4 Peiliang Li,1,2,3,4 Qingzhu An,1,2,3,4 Yuan Shi,1,2,3,4 Peixi Liu,1,2,3,4 Guo Yu,1,2,3,4 Yanlong Tian,1,2,3,4 Liangfu Zhou,1,2,3,4 Wei Zhu1,2,3,4

ABSTRACT

Background  Surgical treatment of posterior inferior cerebellar artery (PICA) aneurysms is challenging because many are nonsaccular and atherosclerotic. We report our tailored approach to PICA aneurysms, which is based on angioarchitecture supplemented by high-resolution vessel wall MRI (HR-VW MRI) findings.

Methods  From March 2010 to September 2020, 27 patients with 29 PICA aneurysms underwent surgical treatment in our institution. Since October 2016, HR-VW MRI has been used for aneurysmal wall assessment. Clinical characteristics, radiological data and surgical outcomes were analysed.

Results  Nineteen proximal PICA aneurysms (vertebral artery (VA), P1, P2 and P3) were treated using the far-lateral approach. Ten distal PICA aneurysms (P4, P5) were treated using the suboccipital midline approach. Direct clipping or clip reconstruction was achieved in 19 aneurysms. Ten were trapped in conjunction with extracranial–intracranial or intracranial–intracranial bypass, including three occipital artery-PICA reimplantations, three PICA-VA reimplantations, two PICA-PICA side-to-side anastomoses, one PICA-PICA reimplantation and one PICA-PICA reanastomosis. All aneurysms were eventually completely obliterated and all bypasses remained patent. At the last follow-up, 26 patients (96.2%) achieved a good outcome (modified Rankin Scale score <3). Eight patients underwent HR-VW MRI. Among these, the six aneurysms with focal wall enhancement required bypass and the two with negative enhancement were successfully clipped.

Conclusion  PICA aneurysms have a higher frequency of complex features such as large or giant size and fusiform or dissecting morphology. Favourable outcomes were achieved with individualised microsurgical strategies based on angioarchitecture. HR-VW MRI may be used as a promising technique to predict aneurysmal atherosclerosis.

INTRODUCTION

Posterior inferior cerebellar artery (PICA) aneurysms account for 3%–4% of all cerebrovascular aneurysms.1 Compared with aneurysms in other locations, PICA aneurysms are more likely to be fusiform. After rupture, they are associated with higher incidence of lower cranial nerve dysfunction and tracheostomy/percutaneous endoscopic gastrostomy placement.2–4 Although endovascular treatment can allow PICA preservation, selective aneurysm coiling may not be possible in up to 79% of fusiform aneurysms.5 Stent-assisted coiling may preserve the circulation but can place patients at risk of unpredictable rebleeding.6 Furthermore, distal PICA segment aneurysms can be difficult to access via an endovascular approach and direct PICA occlusion may result in infarction and death.7

Key messages

What is already known on this topic

⇒ Posterior inferior cerebellar artery (PICA) aneurysms have a higher frequency of complex features, and surgical treatment is still challenging because of anatomic variability, lower cranial nerves interference, diverse aneurysmal morphology and atherosclerosis.

What this study adds

⇒ Surgical strategies for treatment of PICA aneurysms consists of aneurysm clipping and various bypass modalities, such as occipital artery-PICA, PICA-vertebral artery and PICA-PICA bypass. Favorable outcome could be achieved if a PICA aneurysm is treated with proper surgical strategy. The selection of surgical strategies is mainly based on the assessment of aneurysmal morphology and enhancement pattern on high-resolution vessel wall MRI (HR-VW MRI).

How this study might affect research, practice or policy

⇒ The aneurysmal enhancement patterns on HR-VW MRI may be used as a promising imaging biomarker to predict atherosclerosis of PICA aneurysms and help surgical strategy selection.
Therefore, microsurgical treatment may be required for the treatment of complex PICA aneurysms. This approach can be challenging because of anatomic variability, interference of lower cranial nerves, diverse aneurysmal morphology and size, and presence of atherosclerosis, calcification, and intraluminal thrombosis, all of which must be assessed preoperatively. However, previously developed angioarchitecture-based surgical algorithms do not take aneurysmal wall structure into account despite its impact on treatment selection. High-resolution vessel wall MRI (HR-VW MRI) has shown promise in identifying aneurysmal wall inflammatory reaction and atherosclerosis and may be useful in surgical planning. Therefore, we have developed tailored operative techniques for PICA aneurysms that are based on digital subtraction angiography (DSA) angioarchitecture characteristics, including morphology, location and wall structure. This study describes our evaluation process, surgical strategy and outcomes.

METHODS

Complex PICA aneurysms

The PICA is divided into five segments: anterior medullary (P1), lateral medullary (P2), tonsillomedullary (P3), telovelotonsillar (P4) and cortical (P5). Aneurysms located on any of these five segments are considered true PICA aneurysms. Most arise at the vertebral artery (VA)-PICA junction. Those located at the VA-PICA junction and on segments P1–P3 are classified as proximal. P4 and P5 aneurysms are classified as distal and share similar surgical strategies.

A complex PICA aneurysm that cannot be secured by simple coiling or clipping may have one or more of the following features: giant (≥25 mm) or large (10–25 mm) size, atherosclerotic wall structure, dissecting or fusiform morphology, wide neck, and recurrence after previous coiling or clipping. Since October 2016, we have used HR-VW MRI in the preoperative evaluation of unruptured PICA aneurysms. The imaging was acquired using fat-suppressed three-dimensional fast spin-echo (FSE) CUBE T1-weighted sequences. Wall enhancement on gadolinium-enhanced imaging was classified as negative (no wall enhancement) or focal wall enhancement (FWE, strong enhancement of only a part of the wall), as previously described. FWE has been verified as a promising radiological marker of atherosclerotic plaque formation. We considered that FWE indicated a complex aneurysm since atherosclerotic plaque is often considered a feature of complex aneurysms. Bacterial, iatrogenic and traumatic aneurysms and those arising from an anterior inferior cerebellar artery-PICA variant were excluded.

Surgical strategy

Our PICA aneurysm surgical strategy is illustrated in figure 1. Angioarchitecture was carefully evaluated before surgery with DSA. For proximal PICA aneurysms, the far-lateral approach was used to provide wide exposure of the VA and PICA branch point, which enables clear identification and dissection of the aneurysm and perforators. The dentate ligament was transected to promote PICA and brainstem-spinal cord junction mobility, reducing the incidence of lower cranial nerve injury. The craniotomy was extended across the midline for distal PICA exposure if a PICA-PICA bypass was needed. For distal PICA aneurysms, a suboccipital midline approach was used. The aneurysm was exposed by starting dissection at P3 and proceeding distally. If the aneurysm was hidden deep in a cerebellar fissure, neuronavigation was used for localisation.

After aneurysm exposure and inspection, direct clipping or clip reconstruction was preferentially performed. If the aneurysm was unclippable due to complexity, bypass and trapping was considered, especially for proximal aneurysms associated with critical brainstem perforators. We preferred intracranial–intracranial (IC-IC) bypass over extracranial–intracranial (EC-IC) bypass when possible. PICA-PICA side-to-side bypass was the first choice for proximal aneurysms if possible. If not, ipsilateral PICA (P3) to contralateral (P3) reimplantation was attempted (figure 2). Alternatively, PICA-VA end-to-side reimplantation (figure 3) was performed if the PICA and intracranial
VA had sufficient length for anastomosis without critical perforators or occipital artery (OA)-PICA dissection of aneurysm (red arrows). (F–I) Using the suboccipital midline approach, the aneurysm was exposed adjacent to cranial nerves (CN) XI and XII. After temporary clipping of the proximal PICA, the aneurysm was trapped by clipping the proximal and distal PICA. A contralateral P3-ipsilateral P3 end-to-side bypass was performed for vascular reconstruction. (J–M) DSA showed aneurysm obliteration (red arrows) and bypass patency.

Patients

From March 2010 to September 2020, 45 consecutive patients with PICA aneurysm were treated in our institution. Among them, 27 patients treated surgically with 29 PICA aneurysms were enrolled in this study. Clinical data regarding age, sex, symptoms, radiological imaging, surgical complications and modified Rankin Scale (mRS) score outcomes were prospectively collected.

Statistical methods

Statistical analyses were performed using SPSS software V.20.0 (IBM). The independent Student’s t-test was used to compare continuous data. Fisher’s test and the χ² test were used to compare categorical data. A p<0.05 was considered significant.
RESULTS

Patient characteristics

Patient characteristics are shown in table 1 (for detailed information, please see online supplemental table). The mean patient age was 49.8±11.9 years (range 29–67). Nineteen patients were female and eight were male. The most common symptoms were headache in 16 patients (59.3%), dizziness in 10 (37.0%), unconsciousness in 7 (25.9%) and focal neurological deficit in 3 (11.1%). Thirteen patients (48.1%) presented with aneurysmal subarachnoid haemorrhage. The Hunt-Hess grade was I in five patients (38.5%), II in three patients (23.1%), III in four patients (30.8%) and IV in one patient (7.7%). Sixteen patients (59.3%) underwent surgery in the hybrid operating room of our hospital.

Twenty-five patients (92.6%) had a single PICA aneurysm and 2 (cases 9 and 14) had multiple PICA aneurysms. Case 9 had a P3 and a P4 segment aneurysm. Case 14 had 5 PICA aneurysms, including 3P2 segment aneurysms which were coiled first, and 2P5 segment aneurysms which were surgically clipped (online supplemental figure 1). Two patients (cases 5 and 17) had a single PICA aneurysm and a concomitant internal carotid artery ophthalmic segment aneurysm that was clipped before PICA aneurysm clipping. Case four harboured a concomitant cerebellar arteriovenous malformation unrelated to the aneurysm.

PICA aneurysm features and surgical strategy

Twenty-nine PICA aneurysms were treated surgically. Among these, 15 were on the left (51.7%), and 14 on the right (48.3%). Nineteen were proximal (5 VA–PICA, 6P1, 5P2, 3P3) and 10 were distal (4P4, 6P5). PICA aneurysm features and microsurgical strategies are summarised in table 2. Nineteen aneurysms were saccular (mean size 8.6±2.9 mm (range, 4.0–16.0)), five were fusiform (mean size 18.0±4.3 mm (range, 11.0–22.0)) and five were dissecting (mean size 10.2±4.7 mm (range, 4.0–15.0)). Cases 18 and 24 presented with a recurrent saccular and a recurrent fusiform aneurysm after coiling, respectively. Eleven patients (37.9%) had a large aneurysm (diameter 10–25 mm) and 2 (6.9%) had a giant aneurysm (diameter ≥25 mm).

All 10 distal aneurysms were treated by direct clipping (nine saccular aneurysms) or trapping (one fusiform aneurysm). Among the 19 proximal aneurysms, 9 (47.4%) were treated by clipping and 10 (52.6%) by trapping combined with bypass (7 IC-IC and 3 EC-IC, table 2, figure 1).

Table 1 Patient characteristics

| Characteristic                  | N=27 |
|--------------------------------|------|
| Age (years)                    | 49.8±11.9 years |
| Sex                            |      |
| Female                         | 19 (70.4%) |
| Male                           | 8 (29.6%)  |
| Side                           |      |
| Right                          | 13 (48.1%) |
| Left                           | 14 (51.9%) |
| Symptom                        |      |
| Headache                       | 16 (59.3%) |
| Dizziness                      | 10 (37.0%) |
| Unconsciousness                | 7 (25.9%)  |
| Focal neurological deficit     | 3 (11.1%)  |
| No symptom                     | 1 (3.7%)   |
| Rupture history                |      |
| Unruptured                     | 14 (51.9%) |
| Ruptured                       | 13 (48.1%) |
| No of PICA aneurysms           |      |
| Single                         | 25 (92.6%) |
| Multiple                       | 2 (7.4%)   |

PICA, posterior inferior cerebellar artery.
Surgical complications and outcomes

Complete aneurysm obliteration was observed in 25 patients (92.6%). The other two patients (cases 18 and 27, 7.4%) exhibited near-complete obliteration that later thrombosed completely. All patients were interviewed at follow-up with a mean follow-up period of 59.0±42.7 months. Postoperative transient lower cranial nerve dysfunction (cough and hoarseness) was observed in one patient with a P1 aneurysm who underwent PICA-VA reimplantation (case 21). No ischaemic complications were observed. At the last follow-up, 26 patients (96.2%) achieved a good outcome (mRS score <3). Compared with before surgery, mRS score was worse at last follow-up in only one patient (case 21, figure 3); the other 26 had improved (n=21, 77.8%) or stable (n=5, 18.5%) scores (table 2). All 10 patients who underwent bypass showed angiographic bypass patency. No aneurysm recurrences were observed.

Relationship between aneurysmal wall enhancement and surgical strategy

Because of the rarity of the PICA aneurysms, only eight patients with a single proximal unruptured PICA aneurysm were scanned by HR-VW MRI since October 2016 as a pilot study. Mean aneurysm size was larger as measured by HR-VW MRI than as measured by DSA with significant difference (15.8±10.9 mm vs 17.7±11.2 mm; p=0.0023). Wall enhancement on HR-VW MRI was negative in two aneurysms and FWE in six, and the latter tended to have a larger size and morphologic characteristics unfavourable for clipping (66.7% were fusiform or dissecting). We selected clipping as the primary strategy in the two aneurysms with negative wall enhancement and planned bypass with aneurysm trapping in the six aneurysms (two PICA-PICA side to side, two PICA-VA and two OA-PICA; table 3) that demonstrated FWE because of atherosclerotic plaque and calcification. The intraoperative surgical strategies were consistent with the preoperative strategies selected based on aneurysm angioarchitecture and wall assessment. Figure 5 illustrates two typical cases.

DISCUSSION

Aneurysmal wall assessments in the prediction of the surgical strategy

Surgical treatment of PICA aneurysms can achieve good results (tables 1 and 2) and the individualised surgical strategy varies according to the aneurysm’s segmental location and morphology (figure 1). However, although DSA remains the gold standard for aneurysm diagnosis and angioarchitecture assessment, it does not provide the aneurysmal wall structure data that HR-VW MRI does. We found a significant difference between DSA and HR-VW MRI aneurysm size measurements, with MRI arriving at a larger size. For aneurysms with FWE, bypass surgery should be considered and prepared for as there is a high possibility that atherosclerotic plaque will hinder clipping. This finding has encouraged us to include HR-VW MRI in future surgical planning. In our study, the intraoperative surgical strategies were consistent with preoperative assessment (table 3, figure 5).

Bypass surgery for pica aneurysms

Although clipping is generally considered the first option, this may be difficult for PICA aneurysms because of complex morphology. Bypass surgery is an important technique, especially for proximal aneurysms (figure 1). IC-IC bypass was our preferred technique because of its lower risk of cerebrospinal fluid leak and no need for graft harvesting. PICA-PICA bypass was preferred because the distal PICA tolerates prolonged temporary occlusion. If the contralateral PICA is not close enough for bypass, we have successfully transected the ipsilateral P3 distal to the aneurysm and anastomosed it to the contralateral P3 in an end-to-side fashion with a favourable outcome (case 20, figure 2). Moreover, if the VA-PICA junction is in a high position, PICA-VA reimplantation can be achieved instead of PICA-PICA bypass (figure 3). The collateral perfusion of the contralateral VA is usually sufficient, so ischaemic risk during VA temporary occlusion is low. However, the lower cranial nerves may be closely related to the VA and hinder the operation (case 21). Aneurysm resection and PICA-PICA end-to-end reanastomosis could be attempted if the remaining parent PICA is long enough, but with
### Table 3  Aneurysm wall assessment and surgical strategies

| Case | Sex | Location | Morphology | HR-VW MRI Enhancement* | Size (mm)† | Size (mm)‡ | Atherosclerosis | Surgical strategy | mRS before surgery | mRS at last follow-up |
|------|-----|----------|------------|------------------------|------------|------------|-----------------|-------------------|---------------------|----------------------|
| 15   | Male| P1       | Saccular   | Negative               | 13.6       | 14.8       | None            | Reconstructive clipping | 3                   | 0                    |
| 16   | Female| VA-PICA | Dissecting | FWE                   | 15.7       | 16.1       | Atherosclerosis | Aneurysm trapping OA-PICA bypass | 1                   | 0                    |
| 17   | Female| P1       | Saccular   | Negative               | 5.0        | 5.1        | None            | Direct clipping           | 0                   | 0                    |
| 21   | Female| VA-PICA | Saccular   | FWE                   | 8.2        | 11.4       | Severe atherosclerosis | Aneurysm trapping PICA-VA bypass | 0                   | 2                    |
| 24   | Male| VA-PICA | Fusiform   | FWE                   | 9.3        | 11.9       | Atherosclerosis, calcification | Aneurysm trapping OA-PICA bypass | 1                   | 0                    |
| 25   | Female| VA-PICA | Saccular   | FWE                   | 11.2       | 14.5       | Atherosclerosis | Aneurysm trapping PICA-PICA side-to-side bypass | 1                   | 0                    |
| 26   | Male| P1       | Fusiform   | FWE                   | 37.9       | 41.0       | Atherosclerosis | Aneurysm trapping PICA-PICA side-to-side bypass | 0                   | 0                    |
| 27   | Male| VA-PICA | Fusiform   | FWE                   | 25.8       | 27.0       | Severe atherosclerosis | Aneurysm trapping PICA-VA bypass | 1                   | 0                    |

*Negative indicates no wall enhancement; (strong enhancement of only part of the wall).
†Size as measured by DSA.
‡Size as measured by HR-VW MRI.

DSA, digital subtraction angiography; FWE, focal wall enhancement; HR-VW MRI, high-resolution vessel wall MRI; mRS, modified Rankin Scale; OA, occipital artery; PICA, posterior inferior cerebellar artery; VA, vertebral artery.
a high risk of occlusion. Therefore, OA-PICA bypass, a moderate-flow EC-IC bypass, was considered the last resort if IC-IC bypass was difficult (figure 4).

LIMITATIONS
Since PICA aneurysms are rare, the number of enrolled patients was small and bias may have been introduced. Current HR-VW MRI research is limited and HR-VW MRI resolution is not high enough to determine the exact distribution of the atherosclerosis. The value of HR-VW MRI may be less applicable and more ambiguous in ruptured aneurysms than unruptured aneurysms. The HR-VW MRI concept for making surgical decisions is still speculative and in need of further research. Nonetheless, we believe that future developments in HR-VW MRI aneurysm assessment will contribute to advances in surgical treatment.

CONCLUSION
PICA aneurysms have a high frequency of complex features and require tailored surgical strategies. Surgical modalities included direct clipping, clip reconstruction, trapping with bypass surgery. Aneurysmal wall enhancement patterns on HR-VW MRI may assist with surgical planning. We recommend bypass surgery for aneurysms showing FWE. Favourable outcomes were achieved with individualised microsurgical strategies.

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Contributors ZY: conceptualisation, data curation, methodology, software, formal analysis, visualisation, writing-original draft preparation. JS: conceptualisation, methodology, validation, data curation, formal analysis, visualisation, writing-reviewing and editing, funding acquisition, supervision. KO: visualisation, data curation, software. PeiLi: visualisation, data curation. QA: visualisation, data curation. YS: software, validation. PeiL: software, data curation. GY: validation, data curation. YT: software, validation. LZ: writing-reviewing and editing, project administration. WZ: conceptualisation, Writing-reviewing and editing, supervision, project administration, funding acquisition, responsible for the overall content as the guarantor

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ORCID iDs Jianping Song http://orcid.org/0000-0003-3411-1457
Kai Quan http://orcid.org/0000-0002-6483-2434
Peiliang Li http://orcid.org/0000-0002-7854-9162
Qingzhu An http://orcid.org/0000-0001-9192-2841
Wei Zhu http://orcid.org/0000-0003-4993-2212

REFERENCES
1 Rodríguez-Hernández A, Zador Z, Rodríguez-Mena R, et al. Distal aneurysms of intracranial arteries: application of numerical...
nomenclature, predilection for cerebellar arteries, and results of surgical management. World Neurosurg 2013;80:103–12.
2. Williamson RW, Wilson DA, Abla AA, et al. Clinical characteristics and long-term outcomes in patients with ruptured posterior inferior cerebellar artery aneurysms: a comparative analysis. J Neurosurg 2015;123:441–5.
3. Tokimura H, Yahamata H, Kamezawa T, et al. Clinical presentation and treatment of distal posterior inferior cerebellar artery aneurysms. Neurosurg Rev 2011;34:57–67.
4. Bohnstedt BN, Ziemba-Schnoebelen M, et al. Distal posterior inferior cerebellar artery aneurysms: clinical features and outcome of 80 patients. World Neurosurg 2014;82:702–13.
5. Czabanka M, Ali M, Schmiedek P, et al. Vertebral artery-posterior inferior cerebellar artery bypass using a radial artery graft for hemorrhagic dissecting vertebral cerebellar aneurysms: surgical technique and report of 2 cases. J Neurosurg 2011;114:1074–9.
6. Suh SH, Kim BM, Park SI, et al. Stent-assisted coil embolization followed by a stent-within-a-stent technique for ruptured dissecting aneurysms of the intracranial vertebrobasilar artery. Clinical article. J Neurosurg 2009;111:48–52.
7. Chalouhi N, Jabbour P, Starke RM, et al. Endovascular treatment of proximal and distal posterior inferior cerebellar artery aneurysms. J Neurosurg 2013;118:991–9.
8. 2020;11:4. Cancela Caro P, Blanco MO, et al. Modified “Extended” Suboccipital Subtonsillar Clipping of a Ruptured Proximal Pica Aneurysm: Technical Note with Relevant Anatomical Demonstration. World Neurosurg 2018;117:301–8.
9. Nussbaum ES, Mendez A, Camarata P, et al. Surgical management of fusiform aneurysm of the posterior periorferior cerebellar artery. Neurosurgery 2003;53:831–5.
10. Lewis SB, Chang DJ, Peace DA, et al. Distal posterior inferior cerebellar artery aneurysms: clinical features and management. J Neurosurg 2002;97:56–66.
11. Lehto H, Harati A, Niemelä M, et al. Seventy aneurysms of the posterior inferior cerebellar artery: anatomical features and value of computed tomography angiography in microneurosurgery. World Neurosurg 2014;82:1106–12.
12. Kawashima M, Takase Y, Matsushima T. Surgical treatment for vertebral artery-posterior inferior cerebellar artery aneurysm: special reference to the importance of the cerebellomedullary fissure dissection. J Neurosurg 2013;118:460–4.
13. Kanou Y, Arita K, Kuriyama K, et al. Dissecting aneurysm of the posterior inferior cerebellar artery: Acta Neurochir 2000;142:1105–11.
14. Deora H, Nayak N, Dixit P, et al. Surgical management and outcomes of aneurysms of posterior inferior cerebellar artery: Location-Based approaches with review of literature. J Neurosci Rural Pract 2015;1:304–9.
15. Dehdashti AR. How I do it: side to side posterior inferior cerebellar artery – posterior inferior cerebellar artery bypass procedure. Acta Neurochir 2013;155:2121–5.
16. Bohnstedt BN, Zimba-Davis M, Edwards G, et al. Treatment and outcomes among 102 posterior inferior cerebellar artery aneurysms: a comparison of endovascular and microsurgical clip ligation. World Neurosurg 2015;83:784–93.
17. Quan K, Song J, Yang Z, et al. Validation of wall enhancement as a new imaging biomarker of unruptured cerebral aneurysm. Stroke 2019;50:1570–3.
18. Kanemoto Y, Michiwaki Y, Maeda K, et al. Multidisciplinary treatments of true posterior inferior cerebellar artery aneurysms: single-center retrospective study and treatment algorithm. World Neurosurg 2020;139:e45–51.
19. Abia AA, McDougall CM, Breshears JD, et al. Intracranial-to-intracranial bypass for posterior inferior cerebellar artery aneurysms: options, technical challenges, and results in 35 patients. J Neurosurg 2016;124:1275–86.
20. Singh RK, Behari S, Kumar V, et al. Posterior inferior cerebellar artery aneurysms: anatomical variations and surgical strategies. Asian J Neurosurg 2012;2:7–11.
21. Song J, Park JE, Chung J, et al. Treatment strategies of ruptured posterior inferior cerebellar artery aneurysm according to its segment. Surg Neurol Int 2017;8:155.
22. Matsushima K, Matsuo S, Komune N, et al. Variations of occipital Artery-Posterior inferior cerebellar artery bypass: anatomic consideration. Oper Neurosurg 2018;14:563–71.
23. Tayebi Meybodi A, Lawton MT, Feng X, et al. Posterior inferior cerebellar artery reimplantation: buffer lengths, perforator anatomy, and technical limitations. J Neurosurg 2016;125:909–14.
24. Zhou Y, Kato Y, Otubangna OT, et al. The true distal posterior inferior cerebellar artery aneurysm: clinical characteristics and strategies for treatment. Minim Invasive Neurosurg 2010;53:9–14.
25. Bacigaluppi S, Bergui M, Crobeddu E, et al. Aneurysms of the medullary segments of the posterior-inferior cerebellar artery: considerations on treatment strategy and clinical outcome. Neuroradiology 2013;34:529–36.
26. Petró O, Sejkorová A, Bradač O, et al. Safety and efficacy of treatment strategies for posterior inferior artery aneurysms: a systematic review and meta-analysis. Acta Neurochir 2018;160:2415–28.
27. Viswanathan GC, Menon G, Nair S, et al. Posterior inferior cerebellar artery aneurysms: operative strategies based on a surgical series of 27 patients. Turk Neurosurg 2014;24:30–7.
28. Raijansamy D, Yasuhir Y, Kyosuke M, et al. Transcandynal fossa approach to unruptured vertebral artery and vertebral Artery-Posterior inferior cerebellar artery aneurysms: surgical outcome. World Neurosurg 2018;119:e783–91.
29. La Pira B, Sturiale CL, Della Pera GM, et al. Surgical approach to posterior inferior cerebellar artery aneurysms. Acta Neurochir 2018;160:295–9.
30. Soeane P, Kalb S, Clark JC, et al. Far-Lateral approach without drilling the occipital condyle for vertebral Artery-Posterior inferior cerebellar artery aneurysms. Neurosurgery 2017;81:268–74.
31. Abe H, Miki K, Kobayashi H, et al. Unilateral posterior cerebellomedullary fissure approach for occipital artery to posterior inferior cerebellar artery bypass during aneurysmal surgery. Neurol Med Chir 2017;57:284–91.
32. Fatehi M, Rizzuto MA, Prakash S, et al. Functional outcomes after treatment of posterior inferior cerebellar artery aneurysms. Cereus 2020;12:e11746.
33. Pilipenko Y, Eliava S, Okishev D, et al. Vertebral artery and posterior inferior cerebellar artery aneurysms: results of microsurgical treatment of eighty patients. Surg Neurol Int 2019;10:227–.
34. Rennert RC, Strickland BA, Ravina K, et al. Efficacy and outcomes of posterior inferior cerebellar artery (pica) bypass for proximal pica and vertebral Artery-PICA aneurysms: a case series. Oper Neurosurg 2018;15:395–403.
35. Ravina K, Strickland BA, Rennert RC, et al. Fusiform vertebral artery aneurysms involving the posterior inferior cerebellar artery origin associated with the sole angiographic anterior spinal artery origin: technical case report and treatment paradigm proposal. J Neurosurg 2018;1–7.
36. Naruddu A, Xu R, Vajkoczy P. Decision making in surgery for Nonsaccular posterior inferior cerebellar artery aneurysms with special reference to intraoperative assessment of collateral blood flow and neurophysiological function. Oper Neurosurg 2018;14:422–31.
37. Foster MT, Hervadkvar A, Patel HC. Posterior inferior cerebellar Artery/Vertebral artery subarachnoid hemorrhage: a comparison of saccular vs dissecting aneurysms. Neurosurgery 2018;82:93–8.
38. Bonda DJ, Labib M, Katz JM, et al. Intracranial bypass of posterior inferior cerebellar artery aneurysms: indications, technical aspects, and clinical outcomes. Oper Neurosurg 2017;13:886–95.
39. Sejkorová A, Petró O, Mulino M, et al. Management of posterior inferior cerebellar artery aneurysms: what factors play the most important role in outcome? Acta Neurochir 2017;159:549–58.
40. Edjlali M, Gentic J-C, Régent-Rodriguez C, et al. Does aneurysmal wall enhancement on vessel wall MRI help to distinguish stable from unstable intracranial aneurysms? Stroke 2014;45:3704–6.