CASE SERIES

Endovascular sacrifice of the proximal posterior inferior cerebellar artery for treatment of ruptured intracranial aneurysms

James G Malcolm ,[1] Jonathan A Grossberg,[1] Nealen G Laxpati ,[1] Ali Alawieh ,[1,2] Frank C Tong,[3] C Michael Cawley,[1,3] Brian M Howard [1,3]

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[1]Department of Neurosurgery, Emory University School of Medicine, Atlanta, Georgia, USA
[2]Microbiology and Immunology, Medical University of South Carolina, Charleston, South Carolina, USA
[3]Department of Radiology and Imaging Sciences, Emory University, Altanta, Georgia, USA

Correspondence to
Dr Brian M Howard, Neurosurgery, Emory University School of Medicine, Atlanta GA 30322, Georgia, USA; brian.howard@emory.edu

JGM and JAG contributed equally.

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ABSTRACT

Background Ruptured aneurysms of the intracranial vertebral artery (VA) or posterior inferior cerebellar artery (PICA) are challenging to treat as they are often dissecting aneurysms necessitating direct sacrifice of the diseased segment, which is thought to carry high morbidity due to brainstem and cerebellar stroke. However, relatively few studies evaluating outcomes following VA or proximal PICA sacrifice exist. We sought to determine the efficacy and outcomes of endovascular VA/PICA sacrifice.

Methods A retrospective series of ruptured VA/PICA aneurysms treated by endovascular sacrifice of the VA (including the PICA origin) or proximal PICA is reviewed. Collected data included demographic, radiologic, clinical, and disability information.

Results Twenty-one patients were identified. Median age was 57 years (IQR 11); 15 were female. The Hunt and Hess grade was mostly 3 and 4 (18/21). Seven cases (33%) involved VA-V4 at the PICA take-off, and 14 cases (67%) involved the PICA exclusively. For VA pathology, V4 was sacrificed in all cases, while for PICA pathology, sacrificed segments included anterior medullary (4/14), lateral medullary (7/14), and tonsillomedullary (3/14) segments. Four patients went to hospice (19%). Twelve patients (57%) had evidence of stroke on follow-up imaging: cerebellar (8), medullary (1), and both (3). One patient required suboccipital decompression for brainstem compression. No aneurysm re-rupture occurred. Median discharge modified Rankin Scale score was 2.0 (IQR 2), which decreased to 1.0 (IQR 1) at median follow-up of 6.5 months (IQR 23).

Conclusions Endovascular sacrifice of V4 or PICA aneurysms may carry less morbidity than previously thought, and is a viable alternative for poor surgical candidates or those with good collateral perfusion.

INTRODUCTION

Ruptured aneurysms of the posterior intracranial circulation present a treatment challenge as they are often dissecting in morphology and intimately associated with brainstem perforators.[1] Open bypass or clip reconstruction is frequently complicated by deep location, aneurysm morphology, and the tight working corridor between the skull base, lower cranial nerves and the aneurysm, resulting in increased morbidity.[2–4] Accordingly, endovascular management may be more favorable for patients too unstable for open microsurgery, or those with dissecting lesions or surgically unfavorable anatomy. For vertebral artery (VA) aneurysms, previous studies have reported outcomes for many endovascular treatment approaches including coil embolization with or without stent assistance, flow diversion, or vessel sacrifice.[5–10] For aneurysms involving the posterior inferior cerebellar artery (PICA), endovascular options may be limited due to small vessel caliber, tortuosity, or aneurysm morphology, necessitating endovascular sacrifice of the aneurysmal segment. However, sacrifice of the V4 segment of the VA (VA-V4), including the PICA origin, or proximal PICA carries the risk of cerebellar or lateral medullary stroke.

The aim of this study was to evaluate clinical outcomes, rate of radiographic and clinically symptomatic infarction, and complications after endovascular sacrifice of ruptured aneurysms of the VA-V4 involving the PICA origin, or proximal PICA.

METHODS

A prospectively maintained database of all patients treated by the cerebrovascular and neuroendovascular surgery at a high-volume, academic, referral center for complex neurovascular disease was reviewed. All cases of aneurysmal subarachnoid hemorrhage (aSAH) from an aneurysm involving VA-V4 or PICA treated by endovascular sacrifice of the VA (including PICA origin) or proximal PICA (anterior or lateral medullary or tonsillomedullary segments) were included. Cases were excluded if VA sacrifice did not involve the PICA origin, if sacrifice was distal to the tonsillomedullary segment of the PICA, or if the PICA remained patent on follow-up imaging. The study was approved by the local institutional review board with a waiver of informed consent given the retrospective analysis of de-identified data.

Chart review and outcome measures

Relevant demographic, clinical, and radiographic data were extracted from the electronic medical record. Patient age, sex, pertinent social and family history, Hunt and Hess (H&H) grade, presence of intraventricular hemorrhage (IVH). and hydrocephalus were recorded. Aneurysm parameters were documented. Outcomes of interest included disposition and functional status (modified Rankin Scale (mRS) score) at discharge and at most recent follow-up. Complications, including strokes of the

cerebellum or brainstem, obstructive hydrocephalus from cerebellar infarction or edema requiring permanent cerebrospinal fluid diversion, need for suboccipital decompression, and typical ICU and post-procedural complications were reviewed and reported. Stroke was evaluated on CT or MRI as available.

Clinical/procedural management

All patients were managed in a dedicated neuroscience ICU. After initial stabilization, including placement of an external ventricular drain if necessary, a digital subtraction cerebral angiogram was performed. Treatment decisions were made by a multidisciplinary team including fellowship trained cerebrovascular surgeons and interventional neuroradiologists. The final treatment modality was at the discretion of the treating physician. Details of clinical decision making are noted in the Discussion. Once decided on, customary endovascular coil sacrifice was completed. Intravenous heparin was administered to keep the activated clotting time between 250 and 300 s. Rectal aspirin (300 mg) was given prior to intervention and patients were maintained on oral aspirin (81 mg or 325 mg at the discretion at the treating interventionist) starting on post-procedure day 1 to limit the risk of 'stump effect' and embolic stroke. Medical management of aSAH was conducted in the neuroscience ICU per standard of care.

Analysis of data

Continuous variables were graphed to evaluate frequency distribution. Data that were not normally distributed are presented as median and IQR.

RESULTS

From January 2012 through September 2019, 1903 patients were treated for aSAH including 107 ruptured VA-V4 or PICA aneurysms (5.6%). Of the 88 treated endovascularly, 21 patients met the inclusion criteria. Median age was 57 years (IQR 11) and 71% were female (n=15). H&H grade ranged from 1 to 4, with most being 3 (n=11, 52%) or 4 (n=7, 33%). The ruptured aneurysm involved VA-V4 in seven cases (33%), while the remaining 14 cases (67%) involved PICA exclusively. IVH was present in all patients and was limited to the fourth ventricle in 19% (n=4), while 17 (81%) patients had extension into the third and/or lateral ventricles. Hydrocephalus was identified in 19 (90%) patients, all of whom had an external ventricular drain placed. Dissecting aneurysms were the predominant morphology (n=16, 75%). The percentage of dissecting aneurysm location patterned the overall distribution of total aneurysms by location: PICA (n=11, 69%) versus VA (n=5, 31%). The distribution of PICA sacrifice was predominantly the first two segments (anterior medullary (n=4, 29%), lateral medullary (n=7, 50%)), while the tonsillomedullary (n=3, 21%) was sacrificed in the minority of cases. Clinical and aneurysm characteristics are summarized in table 1.

Table 1 shows functional outcome, discharge status, and complication data. No patient died in the hospital, but four (19%) were transferred to a hospice. All patients who were not transferred to a hospice (n=17) completed at least one follow-up clinic visit (100% of living patients, 81% of entire cohort). The median follow-up was 6.5 months (IQR 22.9 months). Thirteen patients (62%) were discharged home or to an acute rehabilitation facility (AR) (home: n=9, AR: 4), and four patients (19%) were discharged to long-term acute care. The median mRS score at discharge was 2.0 (IQR 2.0) and 1.0 (IQR 1.0) at last follow-up. An mRS score of 0–2 was achieved in 13 patients (62%) (online supplementary figure 1). All patients who presented with H&H grade 1 or 2 (n=3) were discharged home or to AR; all achieved mRS 0–2 at last follow-up and one suffered a non-debilitating stroke. Of the patients admitted with H&H grade 3, nine (82%) were discharged home or to AR; seven (64%) achieved mRS 0–2 at last follow-up, one was transitioned to a hospice (9% of the H&H grade 3 subgroup; 25% of the hospice discharges), and seven (64%) suffered a stroke.

Table 1 Patient, clinical, and aneurysm characteristics and outcomes presented by functional status, discharge location and clinical metrics

Characteristic	N (%) or median (IQR)
Age (years)	57 (11)
Sex (female)	15 (71)
Hunt and Hess grade	
1	2 (10)
2	1 (5)
3	11 (52)
4	7 (33)
5	0
Aneurysm location	
Vertebral artery	7 (33)
PICA	14 (67)
Aneurysm type	
Dissecting	16 (76)
Saccular	5 (24)
Dissecting aneurysms by location	
Vertebral artery	5 (31)
PICA	11 (69)
Intraventricular hemorrhage	
Isolated fourth ventricle	4 (19)
Fourth + third and/or lateral ventricles	17 (81)
Hydrocephalus	19 (90)
EVD placed	19 (90)
Vessel sacrificed	
Vertebral artery (V4)	7 (33)
Anterior medullary	4 (19)
Lateral medullary	7 (33)
Tonsillomedullary	3 (14)
Outcome	**n (%) or median (IQR)**
mRS at discharge	2.0 (2)
mRS at last follow-up	1.0 (1)
mRS 0–2 at last follow-up	13 (62)
Death/hospice	4 (19)
Disposition other than death/hospice	
Home	9 (43)
Acute rehab	4 (19)
LTAC	4 (19)
Stroke	12 (57)
Suboccipital decompressive craniectomy	1 (5)
Ventriculoperitoneal shunt	4 (19)

EVD, external ventricular drain; IQR, interquartile range; LTAC, long-term acute care facility; mRS, modified Rankin Scale; PICA, posterior inferior cerebellar artery; SAR, subacute rehabilitation facility.

Table 2 Outcomes by Hunt and Hess grade

	Discharge to home or AR	mRS 0–2 at last follow-up	Death/hospice	Stroke
H&H grade	n (%)			
1 (n=2)	2 (100)	2 (100)	0	1 (50)
2 (n=1)	1 (100)	1 (100)	0	0
3 (n=11)	9 (82)	7 (64)	1 (9)	7 (64)
4 (n=7)	1 (14)	3 (43)	3 (43)	4 (57)

Percentages represent the proportion of the outcome of interest as a subset of the H&H grade.
AR, acute rehabilitation facility; H&H, Hunt and Hess; mRS, modified Rankin Scale.

Patients who presented with H&H grade 4 faired worst, with only one patient (14%) discharged home or to AR, three were transitioned to hospice (43% of the H&H 4 subgroup; 75% of the hospice discharges) and four (57%) suffered a stroke. At last follow-up, three (43%) achieved mRS 0–2 (table 2).

Post-procedural cross-sectional imaging (CT and/or MRI) was available on all patients. A stroke in any location referable to the artery sacrificed (cerebellar or lateral medullary) was identified in 12 patients (57%). A cerebellar stroke was identified in eight patients (38%), while an isolated medullary stroke occurred in one patient (5%) and both cerebellar and lateral medullary strokes occurred in three patients (14%). Of the 11 cerebellar strokes, nearly all were the result of PICA sacrifice (9/11, 82%). Lateral medullary stroke was most often the result of VA sacrifice (3/4, 75%) compared with sacrifice of any PICA segment (lateral medullary: 1/4, 25%). Stroke distribution by the precise location of vessel sacrifice is shown in table 3. Of patients with no stroke (n=9), six (67%) were discharged home or to AR, 89% (n=8) achieved mRS 0–2 at last follow-up, and only one was transferred to hospice (11% of the no stroke subgroup; 25% of the hospice discharges). Of those who suffered a stroke, seven (58%) were discharged home or to AR, 42% (n=5) achieved mRS 0–2 at last follow-up, and three were transferred to hospice (25% of the stroke subgroup; 75% of the hospice discharges). Suboccipital craniectomy was required for decompression of the brainstem and fourth ventricle in one patient (5% of all patients, 8.3% of patients with any stroke) who suffered bilateral cerebellar infarction. Permanent cerebrospinal fluid diversion was required in four patients (19%), all due to communicating hydrocephalus after adequate clearance of IVH. No patient required a shunt pursuant to obstructive hydrocephalus secondary to mass effect on the fourth ventricle from cerebellar stroke (table 1).

Table 3 Stroke outcomes

Disposition by stroke outcome			
Stroke status	Discharge home or to AR	mRS 0–2 at last follow-up	Death/hospice
	n (%)		
No stroke	6 (67)	8 (89)	1 (11)
Any stroke	7 (58)	5 (42)	3 (25)
Stroke location by vessel sacrificed			
	Stroke location		
Vessel sacrificed	Any	Medulla	Cerebellum
	n (%)		
Vertebral artery (V4)	3 (43)	3 (43)	2 (29)
Anterior medullary	3 (75)	0	3 (75)
Lateral medullary	4 (57)	1 (14)	4 (57)
Tonsillomedullary	2 (67)	0	2 (67)

Percentages represent the proportion of the outcome of interest as a subset of stroke status or vessel sacrificed, as appropriate.
AR, acute rehabilitation facility; mRS, modified Rankin scale.

Representative case

The case (figure 1) is presented of a middle-aged patient who experienced acute onset headache followed by loss of consciousness and was transferred to our center with H&H grade 4 aSAH. Imaging revealed dense SAH surrounding the medulla with IVH and obstructive hydrocephalus. An external ventricular drain was placed. Angiography demonstrated a lateral medullary segment dissecting PICA aneurysm. Treatment considerations included endovascular sacrifice or surgical revascularization. The PICAs did not approximate in the midline, making a side-to-side bypass impossible. Strategies such as resection of the aneurysm with PICA re-anastomosis, occipital artery to PICA or V3 to PICA bypass were discounted due to poor H&H status, medical comorbidities, and concern for complications associated with surgery. The anterior and lateral medullary segments of the PICA were coil sacrificed. No stroke was identified on post-procedural imaging. The patient developed communicating hydrocephalus and a ventriculoperitoneal shunt was required. The patient was discharged to long-term acute care. At last follow-up, mild left hemiparesis (4+/5 diffusely) of unclear etiology was detected on examination; however, the patient had returned to work and was independent with activities of daily living (mRS 1).

DISCUSSION

PICA and VA-V4 aneurysms are relatively rare and account for a minority of aSAH cases (1.4% International Study of Ruptured Intracranial Aneurysms,[11] 5.3% Barrow Ruptured Aneurysm Trial,[1] 107/1903 or 5.6% this series). Aneurysms of the PICA and VA-V4 region can be difficult to treat surgically and are associated with worse outcomes following aSAH than aneurysms in other locations.[1] Parent vessel (PICA or VA-V4) sacrifice has been reported for patients with aSAH who are high risk for surgery or have limited or poor surgical or endovascular options due to anatomic variation. However, these studies have comprised small cohorts, are a mixed series of unruptured and ruptured aneurysms, or present larger cohorts of patients treated with a variety of techniques.[5 12 13] To our knowledge, this study is the only series of ruptured PICA and VA-V4 segment aneurysms treated exclusively by endovascular sacrifice.

In this study, which has the largest series of patients reported to undergo sacrifice of the VA-V4 segment including the PICA origin, or the proximal PICA, we report overall favorable results in a highly selected cohort of patients. While the overall rate of radiographic stroke was 57% (n=12), only one patient required suboccipital decompression. That patient sustained bilateral cerebellar infarction, which could have been cardioembolic or related to bilateral cerebellar hemispheric perfusion of the sacrificed PICA, a known variant.[14] Rather than stroke, the H&H score was seemingly correlated with overall outcome as 80% of patients with H&H 1–3 were discharged to home and 71% achieved an mRS score of 0–2 at last follow-up. These data are consistent with the published literature regarding outcomes following aSAH generally.[15]

The goal of initial management of aSAH is to eliminate the aneurysm from the circulation to prevent re-hemorrhage. However, PICA and VA-V4 segment aneurysms present unique treatment challenges that increase the procedural risk and complications which negatively affect outcomes. For endovascular treatment,

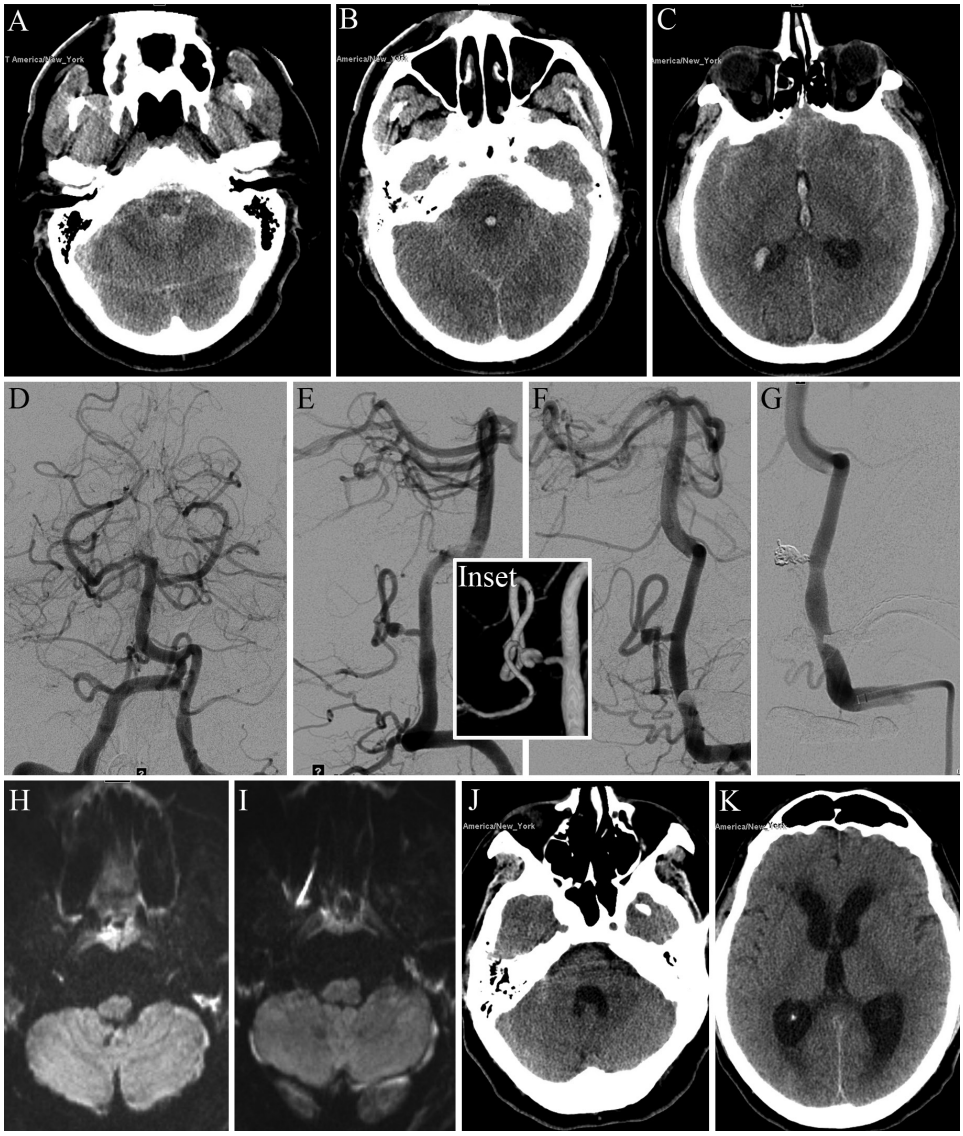

Figure 1 Case example of a patient who underwent anterior and lateral medullary segment posterior inferior cerebellar artery (PICA) sacrifice. (A–C) Axial non-contrast head CT showing perimedullary subarachnoid hemorrhage. Intraventricular hemorrhage is seen in the third and fourth ventricles with gravity-dependent layering of blood in the atrium of the right lateral ventricle. (D–F) Anteroposterior, lateral, and oblique angiograms showing a lateral medullary segment dissecting PICA aneurysm (inset: three-dimensional reconstruction). (G) Coil sacrifice of the anterior and lateral medullary segments of the left PICA. (H, I) Post-procedure day 4 MRI shows no cerebellar or medullary infarction. (J, K) Post-bleed day 12 CT shows failed external ventricular drain wean and communicating hydrocephalus.

the angulation of the PICA origin and the aneurysm neck can pose challenges for safe microcatheterization and microcatheter stability. Reconstructive endovascular treatment of dissecting fusiform aneurysms is complicated by the need for flow diversion or stent-assisted coiling and requisite dual antiplatelet therapy (DAPT) in the setting of aSAH. Whether hemorrhagic complications from DAPT are better tolerated than ischemic complications from vessel sacrifice is still unknown, but may be mitigated by next generation devices with antiplatelet coatings.

Sacrifice of the proximal PICA has historically been avoided due to the risk of infarction of either the lateral medulla, which may result in a Wallenberg syndrome or cerebellar infarction. Consequently, many aneurysms in this location are treated microsurgically in an attempt to maintain patency of the PICA. However, the variability in the location of the PICA origin on the VA, both in the craniocaudal position and with reference to the VA circumference, as well as the course of the PICA through the lower cranial nerves, render the surgical treatment of many PICA aneurysms fraught with risk.[1 12 16] In addition, complex clip reconstruction, muslin or gortex clip wrapping, or a variety of bypass techniques are often necessary to maintain PICA patency, all of which increase operative time and the technical demands of surgery to avoid collateral injury to the lower brainstem or exiting nerve roots.

Several retrospective series have reported variable results in the surgical treatment of PICA and/or VA-V4 segment aneurysms. In 2002, Ogilvy *et al* reported their series of both ruptured and unruptured posterior circulation aneurysms, most of which were ruptured and involved the PICA. They reported 'excellent or good outcomes' in 72% of patients overall, but outcomes were largely dependent on severity of illness on admission.[17] A more recent study of 49 surgically or endovascularly treated PICA/VA aneurysms, 29 of which were ruptured, reported 62% Glasgow Outcome Score 4 or 5 at follow-up.

However, outcomes by treatment modality were not clearly defined and, of 13 patients with a residual aneurysm, five subsequently died of aSAH or brainstem ischemia.[18] Horowitz and colleagues found that 66% (25/38) of patients surgically treated for PICA aneurysms developed a new postoperative neurological problem including hydrocephalus and lower cranial nerve dysfunction.[4] Another series of surgically treated VA-PICA aneurysms (n=52) reported nearly 50% new lower cranial nerve dysfunction postoperatively.[3] In a series of 37 aneurysms involving the PICA origin (VA-V4=10; PICA=27), 24 of which were ruptured, for which PICA revascularization and trapping or clip/endovascular occlusion were carried out, the mRS score was the same or improved in 77% of patients and ischemic and lower cranial nerve complications occurred in 7% and 9%, respectively.[2] However, outcomes specifically for those with aSAH were not analyzed.

Of the 22 patients with PICA aneurysms in the Barrow Ruptured Aneurysm Trial, 18 were randomized to surgery and one crossed over from coiling to surgery. A tracheostomy and/or a percutaneous gastrostomy tube was required in 50% of patients with PICA aneurysms compared with 16% in the remainder of the cohort. Likewise, 20 of the 22 patients (91%) suffered a poor outcome at discharge (mRS >2) and, despite some improvement at 1- and 3-year follow-up, 63% remained with poor functional status. Patients treated for ruptured PICA aneurysms faired statistically worse than the remainder of the cohort both at discharge and follow-up.[1]

The risk of brainstem stroke from proximal PICA or VA-V4 sacrifice may not be as high as believed, and outcome data currently available in the literature are limited.[12 13 19 20] Maimon *et al* reported two patients with ruptured dissecting PICA aneurysms who underwent coil sacrifice of the lateral medullary segment. No imaging follow-up was reported. Including a patient added from the literature, two of three patients in whom the lateral medullary segment was sacrificed made an 'excellent recovery,' while the third suffered non-specific cognitive problems.[20] A handful of more recent series demonstrate similar results. Peluso and colleagues treated 14 VA-V4 aneurysms, 13 of which were sacrificed, but only two included the PICA origin, neither of whom suffered clinical or radiographic sequelae of PICA sacrifice.[19] In a series of 76 patients with PICA aneurysms, five (7%) underwent proximal PICA sacrifice. Of the four resultant PICA territory infarctions, all were cerebellar with no permanent morbidity.[12] Most recently, in a series of 12 ruptured VA-V4 (n=10) or PICA aneurysms (n=2, one origin, one distal), two patients underwent coil sacrifice of the PICA origin, one of whom had a PICA territory cerebellar infarction on CT but was not symptomatic.[13] Interestingly, three of four patients who had a lateral medullary stroke in the present series underwent sacrifice of the VA-V4 segment, not PICA, potentially indicating the importance of VA and posterior spinal artery perforators over the contribution of the lateral medullary segment to the blood supply of the lateral medulla. Indeed, the blood supply to the medulla is divided into three main groups: anterior, lateral, and posterior. The primary supply to the anterior medulla is via perforating branches of the anterior spinal artery and the VA-V4 segment.[21 22] The lateral and posterior medulla are supplied by a combination of perforating arteries that arise from the VA-V4 segment, the lateral and tonsillomedullary segments of PICA, and the posterior spinal arteries. Both the anterior and posterior groups make reciprocal anastomotic networks with the lateral group on the surface of the medulla to, putatively, protect it from hypoperfusion.[21 22]

Study limitations/clinical decision making

At our high-volume center we are heavily biased toward a treatment strategy that results in early complete occlusion of a ruptured aneurysm while maintaining patency of the normal vasculature. Undeniably, a 57% iatrogenic stroke rate is high; however, in a highly selected subgroup of patients for whom endovascular solutions that guarantee these primary goals are impossible and for whom surgical revascularization is either high risk or thought to be technically unfeasible, VA-V4/PICA or proximal PICA sacrifice is considered.

The retrospective single-center chart design of this study, and the inherent biases thereof, is a significant limitation of this study. In general, the decision to sacrifice the PICA was made at the time of the initial angiogram by the treating interventionist on a case-by-case basis after a multidisciplinary discussion, which included a cerebrovascular surgeon. However, it is important to note that the decision tree for each case was not necessarily documented or standardized. Of the 88 total patients with ruptured VA and PICA aneurysms treated endovascularly, 67 were treated by means other than sacrifice of the PICA or its origin, which potentially adds to the selection bias. In addition, of the eight patients who underwent either clipping or bypass, six (75%) were H&H grade 3 or better and ranged in age from 31 to 53 years, indicating a strong bias toward surgery for healthy patients with low H&H grades.

In general, for saccular aneurysms, selective embolization of the aneurysm with parent artery preservation was preferred. Microsurgical clip ligation of the aneurysm or PICA revascularization via various bypass techniques in combination with PICA and/or V4 sacrifice was favored if the patient was otherwise healthy and medically stable to undergo surgery. In cases of congenitally hypoplastic or atretic VAs, in which the posterior circulation is dependent on a single VA, endovascular or surgical revascularization techniques were universally performed. For patients whose anatomy or clinical circumstance fell outside these broad parameters, the diseased artery was evaluated for sacrifice. Before sacrifice, the presence and size of potential collateral vessels were evaluated, in particular for PICA, the relative size and cerebellar cortical distribution of the superior cerebellar (SCA) and anterior inferior cerebellar arteries (AICA) were assessed and weighed against the perceived risk of surgery. However, no formalized system was used. Interestingly, although the overwhelming majority of patients who underwent PICA sacrifice had relatively large ipsilateral AICAs and SCAs, a few had relatively diminutive 'collateral vessels'. Collateral vessel size did not appear to correlate with subsequent stroke.

While patients were carefully selected for PICA or VA-V4 sacrifice, a significant weakness of this study is that we did not conform to a standardized assessment of collateralization but instead relied on the experience of senior interventionists and surgeons, which may limit the generalizability of these results. Curiously, a number—though not all—of the patients who suffered strokes had a contralateral AICA/PICA or diminutive PICA, lending some support to the idea that the PICA may commonly provide bilateral cerebellar hemispheric perfusion that is not recognized on angiography.[14] Development of a rubric by which to decide the patients who may do well after PICA sacrifice is an area for future investigation. Biases aside, in this group of patients the overall outcomes are consistent with that which would be expected for the patient's presenting H&H grade.

CONCLUSION

For ruptured VA-V4 or PICA aneurysms, endovascular sacrifice of the proximal PICA may not carry as high morbidity as previously thought. For poor surgical candidates or those with good collateral perfusion, sacrifice may be a viable alternative to open surgical strategies.

Twitter Brian M Howard @BrianHoward_MD

Contributors JGM and JAG contributed equally. Design: JGM, JAG, NGL, BMH. Data collection: All authors. Analysis: JGM, JAG, BMH. Drafting manuscript: All authors. Critical review/revision: All authors. Study supervision: JAG, BMH.

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ORCID iDs
James G Malcolm http://orcid.org/0000-0002-7545-3069
Nealen G Laxpati http://orcid.org/0000-0001-9603-9169
Ali Alawieh http://orcid.org/0000-0003-2601-8850
Brian M Howard http://orcid.org/0000-0001-9134-0817

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