Posterior inferior cerebellar artery reimplantation: buffer lengths, perforator anatomy, and technical limitations

Ali Tayebi Meybodi, MD, Michael T. Lawton, MD, Xuequan Feng, MD, PhD, and Arnau Benet, MD

Skull Base and Cerebrovascular Laboratory, Department of Neurological Surgery, University of California, San Francisco, California

OBJECTIVE Reimplantation of the posterior inferior cerebellar artery (PICA) to the vertebral artery (VA) is a safe and effective bypass option after deliberate PICA sacrifice during the treatment of nonsaccular and dissecting aneurysms at this location. However, the anatomy and limitations of this technique have not been studied. The goal of this study was to define the surgical anatomy and buffer lengths specific to the proximal segment of the PICA related to 2 variations of PICA reimplantation: 1) reimplantation “along-VA” (simulating a dissecting VA aneurysm), and 2) reimplantation “across-VA” (simulating a nonclippable, proximal PICA aneurysm).

METHODS Ten cadaver heads (20 sides) were prepared for surgical simulation. Twenty far-lateral approaches were performed. The PICA was mobilized and reimplanted onto the VA according to 2 different paradigms: 1) transposition along the axis of the VA (along-VA) to simulate a dissecting VA, and 2) transposition perpendicular to the axis of the VA (across-VA) to simulate a nonclippable, proximal PICA aneurysm. The buffer lengths provided by mobilization of the artery in each paradigm were measured and the anatomy of perforator branching on the proximal PICAs was analyzed.

RESULTS The PICA was reimplanted in all surgical simulations. The most common perforating artery on the P_1 and P_2 segments was the short circumflex type. No direct perforator was found on the P_1 segment. The mean buffer length with reimplantation along the VA axis was 13.43 ± 4.61 mm, and it was 6.97 ± 4.04 mm with reimplantation across the VA. The PICA was less maneuverable when it was reimplanted across the VA, due to perforator branches of the PICA (P_3 segment).

CONCLUSIONS The buffer lengths measured in this study describe the limitations of PICA reimplantation as a revascularization procedure for nonsaccular aneurysms in this location. PICA reimplantation is a revascularization option for dissecting VA aneurysms incorporating the PICA origin that are < 13 mm in length, and for nonsaccular proximal PICA aneurysms that are < 6 mm in diameter. The final decision to reimplant the PICA depends on careful inspection of perforator anatomy that is not visible preoperatively on angiography, as well as an assessment of technical difficulty intraoperatively.

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KEY WORDS reimplantation; posterior inferior cerebellar artery; far-lateral craniotomy; dissecting aneurysm; vertebral artery; vascular disorders

ANEURYSMS affecting the vertebral artery (VA) and posterior inferior cerebellar artery (PICA) can be challenging, especially when the aneurysm is non-saccular, the PICA originates from the aneurysm base, or the parent artery is dissected. Repair of these aneurysms often sacrifices the PICA, in which case a bypass might be indicated and PICA reimplantation might be a consideration.^{5,7,11,12,17,19,25} Successful PICA reimplantation depends on the anatomy of the recipient artery, specifically

the presence of medullary perforators on the proximal P_1 segment that might tether the PICA, and the extra length proximally that allows the PICA to be transposed (buffer length). Although reimplantation of the PICA to the VA has been previously reported^{5,10,12,15,19,23} and included in our own clinical series of 35 intracranial-to-intracranial bypasses for PICA aneurysms, the anatomy and limitations of this procedure have not been studied. Variables such as number, size, and type of the PICA perforators, as well

ABBREVIATIONS PICA = posterior inferior cerebellar artery; VA = vertebral artery.

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as buffer lengths, are critically important. However, they cannot be easily visualized on preoperative angiography and therefore have not been quantified. Morphometric analysis in cadaveric specimens is needed to appreciate these factors.^{1,2,7,12,14,17,18,24}

In this study, we sought to define the specific proximal PICA anatomy and buffer lengths related to 2 variations of PICA reimplantation: 1) reimplantation “along-VA” (simulating a dissecting VA aneurysm), and 2) reimplantation “across-VA” (simulating a nonclippable, proximal PICA aneurysm). We performed surgical simulations via a far-lateral approach using cadavers to maximize the surgical applicability of our findings.

Methods

Ten cadaver heads without cranial disease were prepared for surgical simulation using our customized formula.⁴ Twenty classic far-lateral approaches using a hockey-stick skin incision were completed to access the V₄ segment and the VA-PICA junction. The posterior third of the occipital condyle was removed to facilitate access to the lateral gutter of the cerebellomedullary region. After opening the dura, the first 2 segments of the PICA (anterior medullary [P₁] and lateral medullary [P₂])²⁰ were examined. The lengths of each segment, as well as the number and type of perforating branches, were recorded. Perforators were described according to the nomenclature proposed by Lister et al.:¹⁸ direct, short circumflex, and long circumflex perforators. However, to avoid ambiguity and errors in classification, a perforating artery was labeled as direct only if the parent artery lay on the brainstem surface, with the perforator branch directly entering

the brainstem at the same level. Otherwise, it was categorized as a short circumflex perforator, unless the course of the artery included a > 90° turn around the brainstem, in which case it would be considered as long circumflex.

Next, the origin of the PICA was cut from the VA and mobilized in 2 different fashions relative to the VA. To recreate the surgical scenario in which the PICA originates from a fusiform VA aneurysm but the artery itself is intact, the PICA was mobilized as far along the VA axis as possible (either down or up, relative to the origin of the PICA on the VA). This allowed measurement of the length of the VA that could be sacrificed and still allow the PICA to be transposed and reimplanted (along-VA paradigm; Fig. 1A). In the across-VA paradigm, it was assumed that the proximal PICA was aneurysmal and needed to be excised, whereas the VA was considered disease free. Thus, the PICA was pulled perpendicularly across the axis of the VA to measure the buffer length of the PICA available for excision, while still allowing reimplantation (Fig. 1B). Care was taken to prevent undue tension to the perforating branches and the PICA while mobilizing the artery. Length measurements were taken using a stereotactic system (Stryker), as defined by our team.³ The Pearson correlation coefficient was calculated to assess the statistical correlation between the lengths of P₁ and P₂ segments and the buffer length provided in each paradigm. The Student's t-test was used to compare the means of buffer lengths among different groups of branching configuration of perforators.

Results

Reimplantation of the PICA was successfully performed

FIG. 1. A schematic drawing showing the 2 different paradigms and buffer lengths analyzed in the present study. **A:** Along-VA reanastomosis. **B:** Across-VA reanastomosis. The blue areas represent the aneurysmal part of the respective artery. Double arrows show the mobilization paradigm of the PICA. AICA = anterior inferior cerebellar artery; SCA = superior cerebellar artery. Printed with permission from the Skull Base and Cerebrovascular Laboratory, University of California, San Francisco. Copyright Arnau Benet. Published with permission. Figure is available in color online only.

in all specimens (20 PICAs; Figs. 2 and 3). Two hypoplastic PICAs and 1 extradural PICA (originating from the V_2 segment of the VA) were excluded from the statistical analysis. The number and type of perforating arteries from the P_1 and P_2 segments, the lengths of these 2 segments, and buffer length measurements performed under 2 different paradigms (along-VA vs across-VA mobilization) are reported in Table 1. The most common perforator type in both the P_1 and P_2 segments was short circumflex. There were no direct perforators in the P_1 segments. In 1 PICA, a short circumflex perforator originated 3 mm from the origin of the artery, which precluded across-VA mobilization. In 4 other cases, the first perforator origination pattern allowed ≤ 3 mm of buffer length. These cases were collectively named as early branching pattern of perforators. Early branching did not significantly affect the buffer length in the along-VA paradigm (i.e., average buffer length provided by along-VA mobilization in PICAs with early branching vs PICAs without early branching; $p > 0.05$).

The average buffer length provided by mobilization of

FIG. 3. Across-VA mobilization of the PICA (paradigm B). Far-lateral exposure of the right cerebellomedullary angle. After excising the available buffer length of the PICA, it is reimplanted on its origination site respecting its perforator branch. D.r. = dural ring; IX = ninth cranial nerve; X = 10th cranial nerve; XI = 11th cranial nerve; XII = 12th cranial nerve. Figure is available in color online only.

FIG. 2. Along-VA mobilization of the PICA (paradigm A). **A:** Far-lateral exposure of the left cerebellomedullary angle. One short circumflex perforator originates from the P_1 segment. The curved blue arrow shows the planned mobilization of the PICA. **B:** The origin of the PICA is clipped and cut, and the artery is mobilized proximally along the VA and reimplanted. Two other clips are placed on the presumed aneurysmal segment of the VA. No tension was imposed on the perforators or the PICA. Circ. = circumflex; orig. = origin; Perf. = perforator; PSA = posterior spinal artery; X = 10th cranial nerve; XI = 11th cranial nerve. Figure is available in color online only.

the PICA along the axis of the VA was 13.43 mm (range 5–22 mm; SD 4.61) and the average buffer length perpendicularly across the VA was 6.97 mm (range 0–16.4 mm; SD 4.04). No strong correlation was found between P_1 or P_2 lengths and either of the buffer lengths measured. Similarly, no correlation was identified when the sum of P_1 and P_2 length was used. When the PICAs without P_1 segments were excluded, the mean buffer length was increased along-VA (14.57 mm), whereas it was decreased across-VA (6.88 mm); these differences were not significant ($p > 0.05$).

Discussion

Brainstem perforators and the buffer lengths of the PICA are the major features that determine the mobility of the recipient artery and feasibility of PICA reimplantation. The present study provides information about the anatomy of the proximal PICA that impacts the feasibility of PICA reimplantation in 2 clinical settings encountered regularly in practice—namely, the fusiform VA dissection and the nonclippable, proximal PICA aneurysm. Studies by Durward and Hamada et al. each reported PICA reimplantation in the case of VA dissection.^{8,12} They emphasized the need to mobilize the artery “in a gentle fashion” to prevent overtension of the brainstem perforators.^{8,12} However, the impact of the branching pattern of the perforators on the feasibility of PICA reimplantation has not been addressed in previous reports.^{8–10,12,22,23}

Brainstem-perforating arteries branching from the PICA originate from the medullary segments (i.e., P_1 , P_2 , and P_3).¹⁸ Lister et al. have subdivided these perforators into 3 types: direct perforators that course straight to the brainstem and short and long circumflex perforators that travel $< 90^\circ$ and $> 90^\circ$ around the brainstem before entering the parenchyma, respectively.¹⁸ According to Lister et al., P_1 gives rise to an average of 1 perforator (the most common short circumflex type), P_2 gives rise to an average of 1.8 perforators, and P_3 has the most perforators (an

TABLE 1. Characteristics of the anterior and lateral medullary segments and buffer lengths of the PICAs examined in the present study

Specimen	P ₁ Length (mm)	Direct	Short Circ	Long Circ	P ₂ Length (mm)	Direct	Short Circ	Long Circ	Along-VA Buffer (mm)	Across-VA Buffer (mm)
1	0	0	0	0	7	0	0	0	5	10
2	14	0	0	1	21	0	1	0	7	9
3	4	0	0	0	10	1	0	0	15.7	7.5
4	4	0	0	0	6	0	0	0	12.5	6
5	15	0	2	0	10	0	2	0	22	10
6	0	0	0	0	7.1	0	1	0	7.6	1
7	0	0	0	0	8	0	0	0	12.1	6
8	7.5	0	0	1	7.8	1	0	0	16.4	2
9	11.8	0	1	0	9.9	0	1	0	16.3	4.5
10	12.5	0	0	0	4	0	0	1	9	11
11	16.5	0	1	1	14	0	0	0	10.3	9
12	4.5	0	0	0	5.3	0	0	0	11.9	6.8
13	9.8	0	1	0	5.2	0	1	0	15.1	0*
14	6	0	1	0	5.6	0	1	0	17	3
15	11.4	0	0	0	7.3	0	1	0	19.5	16.4
16†	0	0	0	0	0	0	0	0	14.2	3
17	3.2	0	0	0	7.7	0	1	0	16.8	4.3
Mean ± SD	7.07 ± 5.7		NA		8.05 ± 4.5		NA		13.43 ± 4.61	6.97 ± 4.04

Circ = circumflex; NA = not applicable.

* In this artery, early branching precluded any mobilization according to the across-VA paradigm.

† The PICA originated proximally from the VA without a P₁ or P₂ segment but was still mobile enough to give rise to extra length for reimplantation.

average of 3.3). They reported that the short circumflex perforator was the most common perforating type stemming from P₁ and P₂ segments. Shrontz et al. stated that more brainstem perforators arise from the distal cisternal portion of the PICA (P₂ and P₃) than the proximal cisternal segment (P₁); these authors considered the proximal cisternal segment to be the most suitable site to perform anastomosis.²⁴

In the present study, the least common perforator type in both P₁ and P₂ was the direct type (only 2 direct perforators from all P₂ segments examined and no direct perforators from P₁). This finding is different from that of Lister et al., who reported that the long circumflex type was the least common perforating type.¹⁸ Such a discrepancy may be due to our strict criteria for categorizing direct perforators. To avoid ambiguity, we designated a perforator as direct only when it was directly coursing toward the adjacent brainstem, without coursing around the brainstem. Using the criteria defined by Lister et al., a short circumflex perforator that travels a very short distance (e.g., < 10°) around the brainstem before entering the parenchyma may be easily mistaken for a direct perforator and vice versa.

Reimplantation Along the VA

Good mobility of the PICA along the VA (mean buffer length 13.43 mm) resulted from an absence of direct perforating branches in the P₁ segment and few short circumflex perforators in the P₁ and P₂ segments. Although we did not measure perforator lengths, the mobility of the PICA along the VA is related to the length of perforating arteries originating from the mobilized segments (i.e., P₁

and P₂). We did not mobilize the P₃ segment due to its numerous direct perforating branches to the brainstem. However, in 1 exception (Specimen 14; Table 1), without P₁ and P₂ segments and with a relatively lengthy P₃ segment, mobilization of the cisternal portion of the PICA was performed without tension to the perforators. A direct perforating artery from P₁ tethers the PICA to the medulla, and any mobilization of the PICA along the brainstem is limited. On the other hand, even a short PICA can give rise to a sizable buffer length for reimplantation along the VA, because a circumflex perforator will allow movement of the first segment. In the majority of the PICAs we studied, the perforating branches from the first 2 segments of the artery were circumflex types (Fig. 2B).

The results of our study may provide important information to guide preoperative decision making. Dissecting VA aneurysms are an average of 11.1 ± 6.5 mm in length.⁶ The maximum distance required for a PICA to be transposed along a VA (aneurysmal) is nearly half the length of the aneurysm. Considering the buffer length found in this study (13.43 ± 4.61 mm), most dissecting intradural VA aneurysms are amenable to PICA reimplantation after trapping the aneurysm. Of note, a nondiseased segment of the VA should be chosen for reimplantation,⁵ a property that is verified only after the arterial wall is inspected intraoperatively. Perforator anatomy is not typically visualized preoperatively on angiography; therefore, limitations related to direct perforators must also be determined intraoperatively. Also, if the reimplantation site is selected distal to the aneurysm, depth of the operative field may add complexity to the technique and must be considered before attempting the reimplantation.

Reimplantation Across the VA

The mean buffer length available for reimplantation across the VA was 6.97 mm, which is substantially shorter than the buffer length measured for reimplantation along the VA. Therefore, mobilization of the PICA across the VA is more limited than mobilization along the VA (Fig. 3). This difference is due to: 1) the distance between the origin of the PICA and the origin of the first perforating branch, and 2) the length of the perforating branches along the cisternal segment of the artery. The former parameter limits the absolute available buffer length available for excision and the latter controls the mobility of the PICA from its primary position. However, if the first perforating branch originates early along the course of the PICA (the first factor), the available buffer length of the PICA will be greatly limited. Although we did not measure the distance from the origin of the PICA to the origin of the first perforating branch, such a limiting configuration occurred in 5 (29%) of our specimens. In the remainder, a minimum buffer length of 4.5 mm was available (Table 1).

Aneurysms of the proximal PICA range greatly in size,²¹ with a mean diameter < 10 mm and most of them located at the VA-PICA junction.^{13,16,21,26} This pathology makes PICA reimplantation a viable option when there is a nonclippable, proximal PICA aneurysm that measures < 6.9 mm in length (the mean across-VA buffer length). However, nonclippable PICA aneurysms > 6.9 mm may be optimally treated using other revascularization procedures, e.g., a side-to-side anastomosis to the contralateral PICA.

Several reports have described reconstruction of the PICA after resection of its proximal portion,^{11,12} but the resected length of the PICA was not stated. For example, Hamada et al. used the superficial temporal artery as an interposition graft to reconstruct the PICA in a case of VA aneurysm with an adherent proximal PICA along the wall of the aneurysm.¹¹ The results of our study may provide important information about the feasibility of a reimplantation without an interposed graft or extracranial-intracranial bypass.

The use of preoperative angiographic studies may help neurosurgeons decide whether a nonclippable, proximal PICA aneurysm is amenable to trapping and reimplantation. But again, preoperative angiography may not visualize proximal perforator anatomy. Our results should be considered as a rough guide. The reimplantation technique must be carefully applied only after considering the specific anatomy of the aneurysm, its relationship to perforators and cranial nerves, the technical difficulty of the anastomosis, and the feasibility of easier options.

Conclusions

Although PICA reimplantation is a less common technique of revascularization in the PICA territory,¹⁹ it can be considered in certain cases where other options (e.g., PICA-PICA bypass, excision-reanastomosis, or occipital artery-to-PICA anastomosis) are not favorable.^{11,19} This revascularization technique maintains the original vascular pattern and avoids harvesting distant donor arteries. However, PICA reimplantation is not always a good

choice; the anatomical limitations imposed by perforators and the condition of the VA wall^{5,8} must be taken into account. The PICA anatomy and buffer lengths measured in this study might help guide the choice of revascularization technique used with PICA aneurysms and further clarify the role of this reimplantation technique in the current practice of cerebrovascular surgery.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Benet, Tayebi Meybodi, Lawton. Acquisition of data: Tayebi Meybodi, Feng. Analysis and interpretation of data: Benet, Tayebi Meybodi. Drafting the article: Benet, Tayebi Meybodi, Feng. Critically revising the article: all authors. Reviewed submitted version of manuscript: Benet, Lawton, Feng. Approved the final version of the manuscript on behalf of all authors: Benet. Statistical analysis: Benet, Tayebi Meybodi. Administrative/technical/material support: Benet, Lawton. Study supervision: Benet, Lawton, Feng.

Correspondence

Arnau Benet, Department of Neurological Surgery, University of California, San Francisco, 505 Parnassus Ave., M-779, San Francisco, CA 94143. email: arnaubenet@gmail.com.