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. Successful PICA reimplantation depends on the anatomy of the recipient artery, specifically the presence of medullary perforators on the proximal P₁ 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 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 as the anatomy of the recipient artery, specifically the presence of medullary perforators on the proximal P₁ 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 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 as the anatomy of the recipient artery, specifically
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.\textsuperscript{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.\textsuperscript{4} Twenty classic far-lateral approaches using a hockey-stick skin incision were completed to access the V\textsubscript{4} 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 [P\textsubscript{1}] and lateral medullary [P\textsubscript{2}])\textsuperscript{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.:\textsuperscript{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\textdegree 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.\textsuperscript{3} The Pearson correlation coefficient was calculated to assess the statistical correlation between the lengths of P\textsubscript{1} and P\textsubscript{2} 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...
in all specimens (20 PICAs; Figs. 2 and 3). Two hypoplastic PICAs and 1 extradural PICA (originating from the V₂ segment of the VA) were excluded from the statistical analysis. The number and type of perforating arteries from the P₁ and P₂ 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 P₁ and P₂ segments was short circumflex. There were no direct perforators in the P₁ 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 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 P₁ or P₂ lengths and either of the buffer lengths measured. Similarly, no correlation was identified when the sum of P₁ and P₂ length was used. When the PICAs without P₁ 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., P₁, P₂, and P₃).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° and ≥ 90° around the brainstem before entering the parenchyma, respectively.¹⁸ According to Lister et al., P₁ gives rise to an average of 1 perforator (the most common short circumflex type), P₂ gives rise to an average of 1.8 perforators, and P₃ has the most perforators (an
cumflex perforators in the P1 and P2 segments. Although least common perforating type. 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 limited mobility. 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. 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, 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.

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

<table>
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<tr>
<th>Specimen</th>
<th>P1 Length (mm)</th>
<th>Direct</th>
<th>Short Circ</th>
<th>Long Circ</th>
<th>P2 Length (mm)</th>
<th>Direct</th>
<th>Short Circ</th>
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<th>Along-VA Buffer (mm)</th>
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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.
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 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 wall18 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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References


Anatomy of PICA reimplantation

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

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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, Tayebi Meybodi. Study supervision: Benet, Lawton, Feng.

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