The V₃ segment of the vertebral artery as a robust donor for intracranial-to-intracranial interpositional bypasses: technique and application in 5 patients

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The V₃ segment of the vertebral artery (VA) has been studied in various clinical scenarios, such as in tumors of the craniocervical junction and dissecting aneurysms. However, its use as a donor artery in cerebral revascularization procedures has not been extensively studied. In this report, the authors summarize their clinical experience in cerebral revascularization procedures using the V₃ segment as a donor. A brief anatomical description of the relevant techniques is also provided.

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KEY WORDS far-lateral approach; interpositional bypass; extended retrosigmoid approach; anastomosis; posterior fossa vascular insufficiency syndrome; aneurysm; vascular disorders; surgical technique

A VARIETY of bypasses are available to revascularize the cerebral circulation, including first-generation, low-flow extracranial-intracranial (EC-IC) bypasses with scalp arteries (e.g., occipital artery [OA]^{1,11,12} or superficial temporal artery [STA]); second-generation, high-flow EC-IC bypasses with interposition grafts that connect the cervical carotid artery (e.g., external carotid artery [ECA]) to intracranial recipients;^{9,17,23,31} and third-generation intracranial-intracranial (IC-IC) bypasses that use adjacent intracranial arteries as donors to nearby recipients. While the range and versatility of these bypasses give the neurosurgeon great flexibility for most indications, unusual cases with complex pathology and unfavorable anatomy might eliminate classic bypass choices. Alternative donor arteries are needed when previous surgery, radiation therapy, or intraoperative injury prevents the use of scalp arteries or cervical carotid arteries as donors. The internal maxillary artery and the V₃ segment of the vertebral artery (VA) are examples of alternative donor arteries.^{8,14,27,35} The V₃ segment has been used in a variety of bypasses to treat posterior circulation vascular insufficiency syndrome,^{7,24} complex vertebrobasilar aneurysms,^{2,18,27,35} and skull base tumors.^{29,35} The V₃ segment is an attrac-

tive donor because of its large size and tolerance to temporary occlusion with a competent contralateral VA, but it is located deep within the suboccipital muscular triangle and surrounded by complex anatomy that is unfamiliar to many neurosurgeons. We describe the surgical technique for accessing the V₃ segment and our experience with the V₃ (suboccipital) segment as a donor site for IC-IC interpositional bypasses.

Methods

The study was approved by the institutional review board and performed in compliance with Health Insurance Portability and Accountability Act regulations. The prospective database of the vascular neurosurgery service at the University of California, San Francisco, was queried, and patients for whom the V₃ segment was used as a donor site in the bypass were identified. Medical records were retrospectively reviewed, as were preoperative and postoperative images, angiograms, and technical considerations.

Bypasses using the V₃ segment were considered IC-IC interpositional bypasses and differentiated from EC-IC interpositional bypasses based on the need for a second in-

ABBREVIATIONS AICA = anterior inferior cerebellar artery; EC = extracranial; ECA = external carotid artery; IC = intracranial; ICA = internal carotid artery; MCA = middle cerebral artery; OA = occipital artery; PCA = posterior cerebral artery; PICA = posterior inferior cerebellar artery; PSA = posterior spinal artery; RAG = radial artery graft; SCA = superior cerebellar artery; SCM = sternocleidomastoid; STA = superficial temporal artery; SVG = saphenous vein graft; VA = vertebral artery.

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cision remotely. Most EC-IC interpositional bypasses use the cervical carotid artery and require a neck incision and a tunnel for the graft between sites. IC-IC interpositional bypasses are typically interpositional bypasses that are entirely intracranial, but also include those that have the donor vessel within the intracranial surgical field without a second remote site.

Surgical Technique for V₃ Exposure

Patient position, skin incision, and craniotomy depend on the recipient site, and the exposure needed to access it. With the posterior inferior cerebellar artery (PICA), anterior inferior cerebellar artery (AICA), superior cerebellar artery (SCA)/posterior cerebral artery (PCA), and middle cerebral artery (MCA) as possible recipients, a variety of positions and incisions are used depending on the approach, which might be a far-lateral, extended retrosigmoid, subtemporal, or pterional craniotomy, respectively. Any incision over the retromastoid region will access the suboccipital triangle and the V₃ segment.

The suboccipital triangle lies in the third or deep muscular layer of the craniocervical junction and is exposed by elevating the superficial and intermediate muscular layers. An incision along the superior nuchal line and the crest of the mastoid process exposes the underlying muscles. The first or superficial muscular layer consists of the sternocleidomastoid (SCM) muscle laterally and trapezius muscle medially, with both muscles inserting at the superior nuchal line (Fig. 1A). The posterior border of the SCM muscle is elevated anteriorly to expose the posterior edge of the mastoid process. The second or intermediate muscular layer is formed by the splenius capitis, semispinalis capitis, and longissimus capitis muscles (Fig. 1B and C). The distal or posterior intermuscular course of the OA runs under the splenius capitis, emerging between the splenius and semispinalis muscles, and then continuing on top of the semispinalis muscle (Fig. 1C).

The muscles of the suboccipital triangle—superior oblique capitis, inferior oblique capitis, rectus capitis posterior major, and rectus capitis posterior minor muscles—form the third or deep layer of muscles (Fig. 1D). The suboccipital triangle contains the V₃ segment of the VA coursing toward the sulcus arteriosus of the C-1 vertebra, usually buried beneath a fat pad. The V₃ segment is divided into 3 subsegments: 1) a foraminal part (V_{3f}), consisting of the proximal V₃ passing through the C-1 transverse foramen; 2) a sulcal part (V_{3s}), running along the sulcus arteriosus of C-1; and 3) a dural part (V_{3d}), between the sulcus arteriosus and its dural entrance (Fig. 1E).³³ V_{3s} is the optimal site for a donor anastomosis because the VA projects posteriorly here as a prominent bulge, and this layer-by-layer, lateral-to-medial dissection maximizes the length of artery exposed. The V_{3d} segment can also be exposed through a far-lateral approach without this layer-by-layer technique by dissecting laterally from the midline to its dural entrance and into the sulcus arteriosus.

The atlantomastoid line is a useful guide to localize the V₃ segment before actually seeing it. This line runs between the tip of the mastoid process and the C-1 posterior tubercle in the midline, and the VA bulge is usually found in the middle of the line or just lateral to the mid-

point (46% of the distance from mastoid tip; Fig. 1F). This landmark is relatively independent of patient positioning because it relies on 2 bony landmarks, and these landmarks are palpable before skin incision and in all stages of surgical exposure.³⁴ The belly of the superior oblique muscle is another practical guide to the VA bulge that is available during the dissection.³⁴ After finding the tip of the C-1 transverse process and ascending approximately 2 cm along the medial edge of the superior oblique muscle, the VA bulge will be found 1 cm medially along the atlantomastoid line.

The V₃ segment can give rise to a large muscular branch (artery of Salmon), an extradural PICA, and an extradural posterior spinal artery (PSA; Fig. 1G and H).^{3,5,28} An extradural PICA and PSA both have surgical importance and must be preserved. The V₃ segment is invested in an abundant venous plexus (Fig. 1D).

Surgical Technique for V₃ Bypass

The distal anastomosis in the intracranial space is the more difficult one and is therefore performed first. After completing this anastomosis, the proximal end of the graft is brought into the suboccipital triangle and trimmed appropriately. A length of 15–20 mm of the V₃ segment is available for completing the proximal end of the bypass. Circumferential exposure allows full control of the artery and application of the proximal and distal clips. The foraminal segment of the V₃ (V_{3f}) can be exposed and mobilized by unroofing the foramen transversarium of C-1 with a diamond drill bit, in cases of limited proximal control, atherosclerotic plaque, arterial dissection, or external bony compression. The V₃ segment is enveloped in a rich venous plexus that can bleed extensively during its exposure. Bipolar cautery, packing with oxidized cellulose, and injection with fibrin glue can be used to induce hemostasis.³⁵ Prominent muscular branches from the V₃ segment can be recognized in preoperative angiography and divided as needed.

Large V₃ segments may not be occluded completely with temporary clips; permanent aneurysm clips are more effective. The V₃ segment shares more common features with the cervical carotid artery in its wall characteristics than an intracranial artery and therefore requires an excisional arteriotomy (as with an aortic punch) rather than an incisional arteriotomy. After trapping a 10- to 15-mm-long segment of the donor artery and making a small arteriotomy, an aortic punch is used to excise a circular piece of the wall. An atherosclerotic plaque may warrant endarterectomy before proceeding with the anastomosis (Case 1). The anastomosis is sutured using 8-0 monofilament nylon or 7-0 Prolene, depending on wall thickness.

Results

During a 19-year period, a total of 441 bypasses were performed by the senior author (M.T.L.) for various cerebrovascular lesions, of which 5 (1.1%) used the V₃ segment of the VA as the donor site (Table 1). Of these 5 patients, there were 2 women and 3 men with a mean age of 56.6 years (range 41–65 years). Indications for bypass included 2 basilar trunk aneurysms, 1 V₄ segment aneurysm, and

FIG. 1. Cadaveric dissection of the left craniocervical junction. **A:** The superficial muscular layer is composed of the trapezius and SCM muscles attached to the superior nuchal line. **B:** Immediately underneath the SCM muscle's insertion, the splenius capitis muscle inserts laterally into the mastoid process and just below the superior nuchal line, and its belly descends medially to the cervical spinous processes in the midline. (*continued*)→

FIG. 1. C: The semispinalis capitis muscle inserts medial to the splenius capitis, also just below the superior nuchal line, with fibers that descend vertically and slightly laterally to insert on transverse processes of cervical vertebrae. The OA courses between the splenius capitis superficially and the semispinalis capitis deeply. It may pass under or over the longissimus capitis muscle. **D:** The deep muscular layer comprises 4 muscles, 3 of which compose the suboccipital triangle through which the V_3 segment passes: the superior oblique, inferior oblique, and rectus capitis posterior major muscles. The superior oblique muscle runs from the inferior nuchal line to the transverse process of the atlas and forms the superolateral border; the inferior oblique muscle runs from the transverse process of the atlas to the spinous process of the axis in the midline and forms the inferior border; and the rectus capitis posterior major runs from the inferior nuchal line to the spinous process of the axis and forms the superomedial border. The rectus capitis posterior minor muscle runs parallel and medial to the rectus capitis posterior major and attaches to the posterior tubercle of C-1 vertebra. The V_3 segment of the VA is embedded in a rich venous plexus. **E:** Three subsegments of the V_3 are V_{3a} , or the foraminal part (black double arrow dashed line); V_{3s} , or the sulcal part (yellow double arrow dashed line); and V_{3d} , or the dural part (green double arrow dashed line). The red dashed line shows the dural cuff around the VA that marks the V_3 - V_4 transition. The C-1 nerve intimately accompanies the V_3 segment. **F:** The atlantomastoid line (blue double arrow line) is a useful guide for localization of the V_3 segment. The dorsal bulge of the V_3 (yellow star) lies almost at 40%–50% of a line projected from the mastoid tip to the posterior C-1 tubercle. Another guide is the superior oblique muscle. The VA bulge can be found about 10 mm from the medial border of the superior oblique muscle (green arrow). **G:** The artery of Salmon is a large branch from the V_3 found in one- to two-thirds of cases that supplies the adjacent muscles and has an anastomosis with the deep muscular branch of the occipital artery to the suboccipital muscles. **H:** Dissection of the left craniocervical area showing the relationship between the V_3 and the surrounding nerves. The C-1 nerve pierces the dura just inferior to the VA and courses inferior to the VA in the sulcus arteriosus. There might be a communicating branch from the accessory nerve to the C-1 nerve (McKenzie nerve). Note the extradurally originating PSA. a. = artery; ant. = anterior; IOM = inferior oblique muscle; m. = muscle; maj. = major; min. = minor; n. = nerve; occ. = occipital; post. = posterior; proc. = process; RCP = rectus capitis posterior; SOM = superior oblique muscle; XI = 11th cranial nerve. Figure is available in color online only.

2 patients with ischemic conditions from atherosclerosis or carotid sacrifice. The procedures included V_3 -PICA, V_3 -AICA, V_3 -SCA, and V_3 -MCA bypasses. Radial artery grafts (RAGs) were used in 3 patients and saphenous vein grafts (SVGs) in 2 patients.

The far-lateral craniotomy in the park-bench position was used when the PICA was the recipient artery; the extended retrosigmoid craniotomy in the lateral position was used when the AICA was the recipient. A combined approach in the lateral position with far-lateral and subtemporal craniotomies was used when the SCA was the recipient, and a combined approach in the lateral position with far-lateral and pterional craniotomies was used when the MCA was the recipient. Early access to the cisterna magna obviates the need for lumbar drainage. Incision of the tentorium posterior to the entrance of the trochlear nerve increases the exposure window for SCA anastomosis. The full range of table rotation was needed to access both the suboccipital triangle and the ambient or sylvian cisterns for SCA/PICA or MCA bypasses, respectively.

Illustrative Cases

Case 4: V_3 - M_2 Bypass

This 65-year-old man presented with a history of squamous cell carcinoma involving the left side of the neck that was resected during multiple surgical stages and required free flap transpositions. The patient was also treated with radiation therapy to the neck, which resulted in delayed occlusion of the left common, internal, and external carotid arteries (Fig. 2). He presented to his neurologist with episodes of dizziness, drop attacks, right-hand weakness, transient visual field deficits, and limb-shaking transient ischemic attacks. MRI demonstrated watershed infarcts in the left hemisphere, and angiography confirmed complete carotid occlusion with poor collateral flow from the anterior and left posterior communicating arteries. Hemodynamic insufficiency was diagnosed, and bypass surgery was recommended. Bypass options included a left subcla-

vian artery-MCA bypass, but the graft would traverse a complex prior surgical site; a right MCA-left MCA bonnet bypass, but this long graft has a low patency rate; and a V_3 -MCA bypass, which was selected.

The patient was placed in the lateral position, and the skin was incised with an inverted J-shaped incision starting behind the left mastoid process, extending up to the superior temporal line, and curving forward to the hairline. The V_3 segment was exposed in the suboccipital triangle using layer-by-layer muscle dissection. A pterional craniotomy exposed a suitable M_2 recipient, and an RAG was anastomosed end-to-side to an M_2 branch. Next, the V_3 segment was isolated between permanent aneurysm clips, an arteriotomy was made, and an endarterectomy was performed to remove an atheromatous plaque at the donor site. The proximal end of the RAG was anastomosed to the VA, and bypass patency was confirmed by indocyanine green video angiography. The patient tolerated the surgery well, and postoperative angiography confirmed bypass patency. The patient's ischemic symptoms resolved, and he remains without new strokes at the 18-month follow-up.

Case 5: V_3 -AICA Bypass

A 41-year-old woman presenting with imbalance and dysarthria was diagnosed with a pontine infarct. The patient was treated with warfarin and aspirin, and she suffered a second pontine stroke while undergoing medical management. Angiography showed bilateral VA occlusions, both terminating just distal to the PICA (Fig. 3). Her right posterior communicating artery supplied the basilar quadrifurcation with no retrograde filling of the basilar trunk. Cerebral revascularization with an OA-AICA bypass or a V_3 -AICA bypass was recommended to augment the pontine circulation, but the OA was very small. An extended left retrosigmoid craniotomy²² with complete skeletonization of the sigmoid sinus exposed the AICA in the cerebellopontine cistern, and a recipient site was se-

TABLE 1. Summary of clinical features of the patients treated with cerebral revascularization using the V₃ segment as a donor in this study

Case No.	Age (yrs), Sex	Preop Status	Preop mRS Score	Pathology	Position/Approach/ Intervention	Bypass Status	Outcome/mRS Score
1	54, F	Progressive gait instability, imbalance, diplopia	3	Giant, dolichoectatic basilar artery trunk aneurysm	Park bench/rt FL + ST/V ₃ -RAG-SCA bypass + proximal aneurysm occlusion	Patent	Initially stabilized, but symptoms progressed w/ aneurysm growth/3
2	58, M	Diabetic & hypertensive; multiple previous episodes of posterior circulation stroke, presenting w/ ataxia, confusion, double vision, lt abducens nerve paresis, blurred vision, overall cognitive decline	4	Giant dolichoectatic, thrombotic basilar trunk aneurysm	Park bench/rt FL + torcular + ST/V ₃ -SVG-SCA bypass + proximal aneurysm occlusion	Occluded SVG graft in postop angiography (allograft SVG)	Alert, oriented, no limb paresis, sent to physical therapy/4
3*	65, M	Hunt & Hess Grade III SAH, seizure	4	Fusiform rt VA aneurysm, SAH	Park bench/rt FL/VA-RAG-PICA bypass + aneurysm trapping	Patent	Aspiration pneumonia + sepsis/6
4	65, M	Stage 3 chronic kidney disease, hypertensive, chronic obstructive pulmonary disease; history of neck squamous cell carcinoma; multiple episodes of dizziness & rt-hand weakness + transient visual field cuts	3	Postradiation lt carotid artery occlusion, hemodynamic insufficiency	Lat/rt PT/V ₃ endarterectomy + V ₃ -RAG-MCA bypass	Patent	Ischemic symptoms resolved, neurologically stable/3
5	41, F	Dysarthria & disequilibrium, unable to walk unassisted	4	Basilar artery insufficiency	Park bench/rt ExRS/V ₃ -SVG-AICA bypass†	Patent	Ischemic symptoms resolved/1

ExRS = extended retrosigmoid; FL = far lateral; mRS = modified Rankin Scale; PT = pterional; SAH = subarachnoid hemorrhage; ST = subtemporal.

* Previously reported by Czabanka et al.

† The initial procedure was an OA-AICA bypass, but the OA was injured during harvest.

lected on the flocculo-peduncular a₃ segment of the AICA. The V₃ segment was exposed in the suboccipital triangle at the inferior edge of the surgical field.³⁴ The patient's peripheral vascular disease prevented the use of an RAG, and an SVG was used instead. The V₃-AICA bypass was completed, and its patency was confirmed both intra- and postoperatively, with marked improvement of brainstem circulation seen on angiography (Fig. 3). The patient's symptoms resolved after surgery; she was placed on a regimen of daily aspirin, and has had no further stroke at the 18-month follow-up.

Discussion

Indications for a V₃ Bypass

Our anatomical review, technical description, and clinical applications are intended to increase familiarity with this often-forgotten donor site that can be incorporated in bypasses for complex aneurysms of the vertebrobasilar circulation, vascular insufficiency of the posterior and anterior circulations, and skull base tumors that require sacrifice of an intradural V₄.^{29,35}

Deliberate occlusion of one VA afflicted with a dissecting aneurysm is generally tolerated, except when the contralateral VA is hypoplastic or absent, and balloon test occlusion of the pathological VA, with or without cerebral blood flow studies (e.g., Xe CT), reveals insufficient blood flow to the basilar circulation. Preserving adequate blood

flow to the distal posterior circulation is critical, and preserving flow to the PICA is also important if the arterial dissection incorporates the PICA origin. The OA-PICA bypass is an excellent bypass option for dissections proximal to the PICA's origin because retrograde blood flow to the distal VA may provide sufficient blood flow to the entire posterior circulation. However, the OA is difficult to harvest, may be damaged during exposure, or may be too small to adequately supply the entire posterior circulation.² The OA-PICA bypass is not a good solution for VA dissections that incorporate the PICA origin or lie distal to it. In these cases, a V₃-V₄ interpositional bypass may be needed.

Dolichoectatic aneurysms¹⁶ of the basilar trunk are sometimes treated with proximal or distal aneurysm occlusion and revascularization of the upper posterior circulation (i.e., SCA or PCA) using the STA as a donor.¹⁰ When the STA is not available or does not have sufficient caliber at the anastomotic depth, the V₃ offers a favorable alternative because it provides robust flow and can be incorporated into the exposure of the proximal basilar trunk.¹⁶ The MCA-PCA bypass has been important in the management of dolichoectatic basilar aneurysms, but the orbitozygomatic approach used for this bypass does not expose the aneurysm's inflow, in the way that a far-lateral-subtemporal approach for a V₃-SCA bypass does.

Vascular insufficiency syndromes due to progressive atherosclerosis, postradiation stenosis, or deliberate arteri-

FIG. 2. Case 4. VA-RAG-MCA bypass. **A and B:** Parasagittal FLAIR sequence (A) showing parietooccipital watershed infarcts (red arrow) due to occlusion of the left common carotid artery (CCA) and ICA (B) in a 65-year-old man following surgery and radiotherapy for squamous cell carcinoma in the neck. **C:** Anteroposterior digital subtraction angiogram of the right ICA showing weak cross-filling of the left anterior circulation. **D:** A left VA angiogram did not show reconstitution of the anterior circulation through the posterior communicating artery. **E–M:** Intraoperative images of a V₃-RAG-M₂ bypass showing exposure of the M₂ (white arrow, E) after the sylvian fissure split, and end-to-side anastomosis to the RAG (F and G). The V₃ segment is exposed (green star, H) using the atlantomastoid line (dashed double-arrow yellow line, H). VA arteriotomy is performed (I) and endarterectomy is completed due to a large atheromatous plaque (J). End-to-side anastomosis is completed between the RAG and the V₃ segment (K and L). Completed bypass (M). **N–P:** Digital subtraction (N and O) and CT (P) angiograms confirm the patency of the bypass with successful reconstitution of blood flow in the left MCA territory (red arrows in P show the RAG). tub. = tubercle. Figure is available in color online only.

al sacrifice (e.g., Hunterian ligation for complex lesions)^{6,18} may require atypical donor sites, particularly when the cervical carotid arteries are not available as donors. The V₃ segment provides an alternative donor artery for a variety of bypasses involving diverse recipients, not restricted to the posterior circulation, like our V₃-MCA bypass.^{6,18,27}

Skull base tumors may encase the VA or internal carotid artery (ICA) and may require arterial sacrifice as part of their treatment.^{29,30,35} Radical tumor resection with carotid sacrifice can often be managed with a high-flow ECA-MCA bypass, but pathology in the cervical segment of the ICA artery might eliminate this option. Although

bonnet bypass from the contralateral ICA is an option, it is prone to occlusion due to its length, the use of a saphenous vein graft, and caliber mismatch with the recipient MCA. The V₃ segment is often available in these cases for a V₃-MCA bypass. Foramen magnum or clival tumors encasing a dominant VA may similarly require bypass after planned or inadvertent occlusion, and the V₃ segment provides several bypass options, such as a V₃-V₄ bypass.³³

Previous Reports

The use of the V₃ segment as a donor artery for cerebral revascularizations is not a novel concept.^{2,4,6,14,15,18,21,}

FIG. 3. Case 5. VA-SVG-AICA bypass. A 41-year-old woman presented with recurrent posterior circulation infarcts and symptoms of vascular insufficiency syndrome. **A:** Axial T2-weighted MR image showing a pontine infarct (red arrow). **B–D:** Right VA (anteroposterior view, B) and left VA (anteroposterior and lateral views, C and D, respectively) angiograms showing bilateral VA occlusion just past the origin of the PICA. The posterior communicating arteries failed to effectively contribute to the posterior circulation blood flow (not shown). **E:** An OA-AICA bypass was contemplated, but, on exposure, the OA was found to be diminutive. **F:** An extended retrosigmoid exposure was completed with isolation of the post-meatal loop of the AICA. **G–J:** Using an SVG, a bypass was completed between the V₃ segment and the AICA. **K and L:** Postoperative anteroposterior (K) and lateral (L) angiograms showing the patency of the bypass (red arrows) and good reconstitution of blood flow in the posterior circulation. VII = 7th cranial nerve; VIII = 8th cranial nerve; IX = 9th cranial nerve; X = 10th cranial nerve. Figure is available in color online only.

^{25–27} Hadeishi et al. reported a V₃-M₂ bypass in a patient in whom the ipsilateral carotid artery was not usable because of local neck infection.⁶ Others have reported the use of

the “extradural VA” to revascularize the intradural VA without much elaboration on the details of exposure and patient positioning.^{4,18,27} Table 2 summarizes the previous

TABLE 2. Summary of previous studies reporting on the use of the V₃ segment of the VA as a donor for intracranial revascularization

Authors & Year	No. of Patients	Pathology	Intervention	Comments	Reported Outcome
Hadeishi et al., 1996	1	Irradiated cervical squamous cell carcinoma causing bleeding rt ICA + neck infection	V ₃ -RAG-M ₂ bypass	V ₃ required an endarterectomy; op performed in supine position; no STA available due to prior irradiation, ipsilateral ECA was not favorable because of neck infection (infected salivary fistula)	Patent bypass, no neuro deficit postop; postop CT showed rt SCA & PCA hemorrhagic infarcts (embolus from VA)
Evans et al., 2004	6	Rt fusiform VA incorporating PICA origin	Rt V ₃ -SVG-V ₄ + rt V ₃ -SVG-PICA bypass + aneurysm trapping & excision		KPS Score 90 (CN VIII deficit)
		Rt giant fusiform VA aneurysm compressing brainstem	Rt V ₃ -SVG-V ₄ bypass + aneurysm trapping & excision; rt VA was dominant		KPS Score 80; recovered CN VIII & X deficits
		Lt fusiform VA aneurysm	Lt V ₃ -SVG-V ₄ bypass + aneurysm trapping & excision		KPS Score 90; recovered CN X & XII deficits
		Lt fusiform VA aneurysm	Lt V ₃ -SVG-V ₄ bypass + aneurysm trapping & excision		KPS Score 90
		Lt ruptured VA-BA fusiform aneurysm	Lt V ₃ -RAG-PCA bypass + bilateral VA occlusion		KPS Score 0 (death)
		BA & bilat VA dolichoectatic aneurysms	Lt V ₃ -RAG-PCA bypass + coil occlusion of rt VA		KPS Score 90
Miele et al., 2005	1	Giant rt ICA aneurysm	Rt STA-MCA bypass (insufficient flow) + rt V ₃ -SVG-MCA bypass	Rt common carotid artery was occluded 20 yrs earlier	No complications
Czabanka et al., 2011	2	Ruptured fusiform dissecting rt VA aneurysm involving rt PICA origin	Rt V ₃ -RAG-PICA bypass + trapping of rt VA + clipping of PICA origin	Failed endovascular coiling, damaged OA during surgical exposure; PICA-PICA bypass was not possible due to small contralateral PICA	GOS Score 4, patent bypass; 23 ml/min bypass blood flow rate
		Ruptured rt V ₄ fusiform aneurysm + small lt VA presenting w/ Hunt & Hess Grade III SAH	Rt V ₃ -RAG-PICA bypass + trapping of VA proximal to PICA origin		Patent bypass; aspiration pneumonia + sepsis; family decided to withdraw support
Kubota et al., 2013	1	Bilat fusiform VA aneurysms; rt aneurysm involved a medullary perforator, but none involving PICA	Rt V ₃ -RAG-V ₄ bypass + aneurysm excision + OA-perforator bypass	Planned proximal occlusion of lt aneurysm	No postop complications
Kubota et al., 2014	2	Lt VA dissecting aneurysm incorporating PICA origin	Lt OA-PICA + V ₃ -OAG-V ₄ bypass		Transient dysphagia, no neuro deficit on discharge
		Bilat fusiform VA aneurysms	Bilat OA-PICA + lt V ₃ -RAG-V ₄ bypasses + rt VA trapping		No neuro deficits
Osorio et al., 2014	1	Cerebellopontine angle meningioma + iatrogenic V ₃ injury	V ₃ -V ₃ reanastomosis		No complications
Saito et al., 2014	1	Bilat VA aneurysms + posterior circulation stroke	Rt V ₃ -RAG-V ₄ bypass + rt OA-PICA bypass + proximal occlusion of 1 aneurysm	Lt VA aneurysm observed	No complications
Saito et al., 2016	2	Bilat VA dissecting/fusiform aneurysms	Lt V ₃ -RAG-V ₄ + aneurysm trapping + lt OA-PICA bypass	Rt lesion observed	mRS Score 2; cerebellar infarct + transient lower CN deficit
		Bilat VA dissecting/fusiform aneurysms	Lt V ₃ -RAG-V ₄ bypass + aneurysm trapping	Rt lesion observed	mRS Score 1; dysphagia

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TABLE 2. Summary of previous studies reporting on the use of the V₃ segment of the VA as a donor for intracranial revascularization

Authors & Year	No. of Patients	Pathology	Intervention	Comments	Reported Outcome
Yang et al., 2014*	13	Aneurysm (n = 4); tumor (n = 1)	V ₂ -V ₃ -SVG-PCA		mRS Score 1 (n = 1); Score 2 (n = 1); Score 3 (n = 1); Score 6 (n = 2)†
		Aneurysm (n = 3)	V ₂ -V ₃ -RAG-PCA		mRS Score 2 (n = 2); Score 4 (n = 1)
		Aneurysm (n = 2)	V ₂ -V ₃ -SVG-V ₄		mRS Score 1 (n = 2)
		Ischemia (n = 2)	V ₂ -V ₃ -RAG-MCA		mRS Score 1 (n = 2)
		Tumor (n = 1)	V ₂ -V ₃ -SVG-MCA		mRS Score 6

BA = basilar artery; CN = cranial nerve; GOS = Glasgow Outcome Scale; KPS = Karnofsky Performance Scale; mRS = modified Rankin Scale; neuro = neurological; OAG = occipital artery graft.

* In this series, the V₂-V₃ segment was exposed by unroofing the C-1 foramen transversarium and used as the donor site.

† One of the patients with an mRS score of 6 underwent bypass for tumor treatment.

reports on the use of the suboccipital VA as a donor artery for intracranial revascularization procedures. In a recent publication, Yang et al. reported their experience on the use of the extradural VA as a donor for various intracranial recipients.³⁵ They suggest the lateral position as the most favorable position for exposing the VA, and they strongly recommend unroofing the C-1 foramen transversarium to get an adequate length of the V₂-V₃ exposed.³⁵

Our small case series shows the versatility of the V₃ segment as a donor for IC-IC bypass to a variety of recipient arteries in the posterior and anterior circulations and its adaptability to different patient positions. Unlike Yang et al., we did not find it necessary to expose the V_{3f} or the V₂ segment of the VA to prepare the donor site. Furthermore, while this donor site seems natural for lesions in the posterior circulation, patient positions and surgical approaches can be modified for remote recipients in the sylvian cistern as well. The V₃ segment can be exposed through a variety of patient positions, depending on the recipient location.

Rationale for a V₃ Bypass

The simplest and shortest bypass with the fewest anastomoses is usually the best option.¹⁹ Interpositional bypasses using the V₃ segment are complex because they require graft harvest and 2 anastomoses. Harvesting an RAG or SVG with patients in the lateral and park-bench positions is not as straightforward as in the supine position. Traditional orientations are changed, some limbs may be inaccessible, and the harvest can be awkward. These disadvantages of V₃ bypasses can be overcome with careful preparation and attention to positioning. However, if the V₃ segment is affected by the pathology (e.g., dissection), it cannot be used as a donor vessel.

Some advantages of a V₃ bypass are the robustness of the donor artery, its accessibility when dissecting the suboccipital triangle using efficient landmarks, and its proximity to key recipient sites (e.g., AICA, PICA). This last factor shortens the graft length and likely improves its long-term patency. Exposure of the extracranial carotid arteries may seem simpler than exposure of the V₃ seg-

ment, but the lateral or three-quarter prone position may compromise ECA exposure or render the proximal anastomosis awkward to suture. Another advantage of the V₃ segment is its tolerance to temporary occlusion without ischemic complications, because the contralateral VA supplies the posterior circulation during the cross-clamping in most patients.¹⁹ In the patient with a single carotid artery who requires revascularization of the anterior circulation,¹⁸ use of the VA can eliminate the risks associated with temporary occlusion of the vital carotid artery, although it may increase the risk of atheroembolic events of the posterior circulation.^{6,13,20,32} Table 3 summarizes the relative advantages and disadvantages of the use of the V₃ segment as a donor.

Study Limitations

This descriptive study reports a limited case series with a relatively short period of patient follow-up. Currently, the use of the V₃ segment as a donor may be only justified in patients with no other, simpler revascularization option. Larger numbers of patients with longer follow-up periods are required to validate the V₃ as a high-flow donor artery

TABLE 3. Advantages and disadvantages of the V₃ segment as a donor for intracranial revascularization

Advantages	Disadvantages
Accessibility of V ₃ in different patient positions	Anatomical complexity
Presence of clear landmarks for exposure	Difficult to control surrounding venous plexus
Mostly tolerates long-term clipping	Need for an interposition graft
Short distance to recipients (higher long-term patency)	Extra risk of atheroembolic events in the posterior circulation when the VA is used as a donor to revascularize the anterior circulation
High flow	

for routine use and its results relative to other donors, such as the ECA.

Conclusions

Exposure of the V₃ segment of the VA can be performed safely if the neurosurgeon is familiar with local anatomy and efficient dissection techniques are used. The inclusion of these bypass strategies in the cerebrovascular literature may provide unique advantages when addressing complex cases. The V₃ segment is a versatile donor for multiple recipients in the intracranial circulation and can be applied to tumors, aneurysms, and vascular insufficiency syndromes. The V₃ segment might not be a first-line bypass option, but it should be considered when confronted with complex lesions or complex patients for whom common or traditional donors are not suitable.

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

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