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A Novel Microsurgical Procedure for Revascularization of the Vertebral Artery

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■ OBJECTIVE: A broad armamentarium of microsurgical techniques affords flexibility to surgeons when choosing a procedure that is best tailored to fit the anatomy of an individual. Herein, we report on the feasibility of using the deep cervical artery (DCA) to revascularize the vertebral artery (VA) via a DCA-V3 bypass graft.

■ METHODS: Fourteen DCAs from 7 injected cadaveric heads were located and traced. The diameter of the main trunk of the DCA was measured bilaterally at the C3 level. The proximal vertebral branches of each DCA were then severed and the main trunk of the DCA was transposed superiorly onto the V3 segment of the VA, which was also exposed bilaterally.

■ RESULTS: The DCA was identified and traced bilaterally on all specimens. The diameter of the main trunk of the DCA at the C3 level ranged from 1.03 to 2.79 mm. The mean diameter of the main trunk of the DCA at this level was found to be 1.52 ± 0.60 mm for the right side and 1.46 ± 0.54 mm for the left side. After releasing the proximal vertebral branches of the DCA, all arteries were able to be transposed to the ipsilateral VA.

■ CONCLUSIONS: Based on the mean diameter of the DCA reported in extant literature and this study, the blood flow volume of the DCA makes it a viable candidate to bypass the proximal VA.

INTRODUCTION

Vertebral artery (VA) revascularization has a wide array of indications, including vertebrobasilar ischemia, posterior circulation aneurysms, arteriovenous malformations, and iatrogenic damage to the VA.[1-3] Historically, physicians have treated vertebrobasilar pathology less aggressively than pathologies affecting major vascular structures, such as the carotid arteries (CAs), because the risk of complications including strokes and transient ischemic attacks was considered smaller.[4] However, recent studies suggest that vertebrobasilar events have morbidity rates comparable with those involving the CAs, and may even carry a higher risk for patients in the acute phase.[4] Even with advanced imaging modalities, it can be difficult to differentiate between pathologic and physiologic VA abnormalities, a fact further complicated by the potential of VA pathologies to produce no clinical symptoms.[1] Vascular surgeons and interventionalists require a diverse range of tools with which to perform VA revascularization when necessary, especially in situations of acute risk secondary to trauma or iatrogenic damage. Surgical procedures with a higher rate of VA damage include C2 pedicle screw placement and anterior approaches to the cervical spine.[5-8]

Revascularization of the VA can be performed using an endovascular or microsurgical approach. First-line treatment recommendations are often endovascular and include procedures such as endarterectomies, stenting, and embolization.[9] These procedures are associated with lower complication rates but are also dependent on multiple variables, including the type of vascular lesion affecting the patient and their tolerance of antiplatelet regimens.[10] In addition, microsurgical reconstruction of the VA has been shown to be highly effective in preventing

Key words
- Anatomy
- Bypass graft
- Deep cervical artery
- Posterior cervical triangle
- Subclavian artery
- Vertebral artery

Abbreviations and Acronyms
CA: Carotid artery
DCA: Deep cervical artery
OA: Occipital artery
SA: Subclavian artery
VA: Vertebral artery

strokes, and the use of autogenous bypass grafts can be favorably compared with endovascular endarterectomies in terms of patency rates.[11,12] This has led some surgeons to recommend a dual endovascular/microsurgical approach, especially for complex vascular cases.[13]

Bypass grafts are an effective microsurgical procedure for the revascularization of the VA. A variety of donor vessels have been used to treat atherosclerosis, aneurysms, and trauma involving the VA. The great saphenous vein and radial artery are considered to be effective donor vessels because of high postoperative patency rates and blood flow volume comparable with that of the VA.[14-18] If carotid disease is not present on the ipsilateral side, another common form of microsurgical treatment involves the transposition of the proximal VA onto the common CA.[10,19]
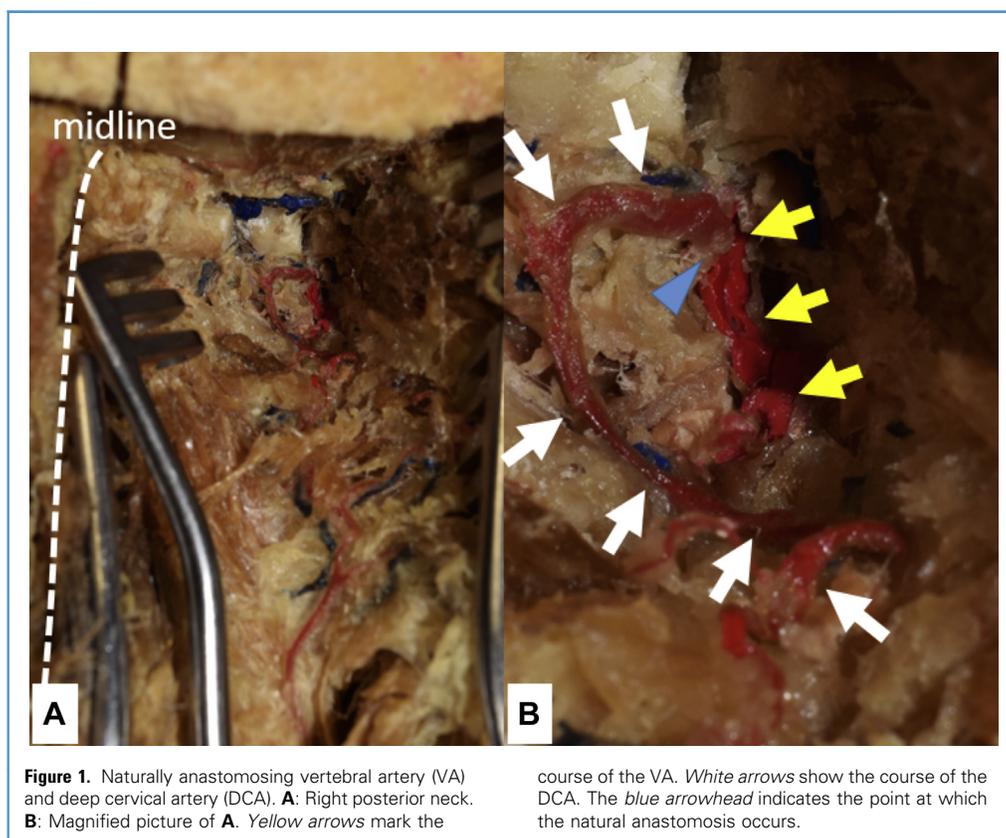
Although the use of these structures in VA bypass grafts have led to high-quality outcomes, the search for alternative donor vessels to add to the surgical armamentarium of physicians is ongoing. As early as 1985, Donaldson et al.[20] used the transverse cervical artery, a branch of the thyrocervical trunk, which itself is fed by the subclavian artery (SA), to temporarily bypass the VA. Since this report, multiple cases of an SA to VA or CA bypass have been documented.[21,22] The redirection of blood flow from the VA to the SA rather than the CA minimizes the risk of anterior intracranial ischemia.[23]
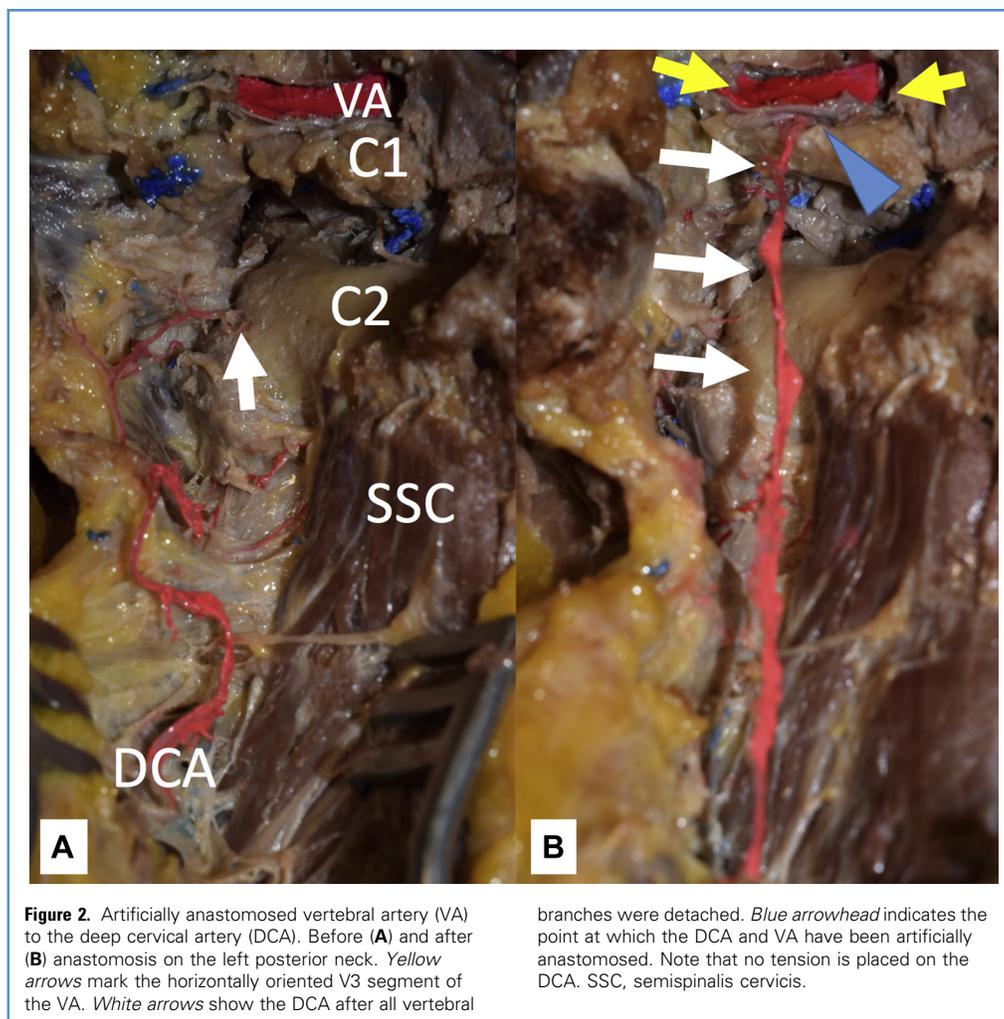
During routine cadaveric dissection of the posterior neck, we found a case in which the main trunk of the deep cervical artery (DCA) naturally anastomosed with the V3 segment of the VA (Figure 1). This finding led us to examine a new potential candidate for a VA bypass. In this study, the feasibility of using the DCA, a branch of the costocervical trunk of the SA, as a novel candidate for a VA bypass was ascertained. The DCA rises from the costocervical trunk anterior to the neck of the first rib. Traveling superiorly between the semispinalis capitis and the semispinalis cervicis, the DCA gives off branches to the nutrient foramina of the laminae of each cervical vertebra until terminating at the axis.[24]

MATERIALS AND METHODS

Fourteen DCAs from 7 injected cadaveric heads (age 56–92 years at death) were exposed using gross and microsurgical dissection techniques. Each head was fixed in a prone position. A vertical incision was made along the midline of the posterior neck from the occipital protuberance to the spinous process of C5 or C6 depending on the specimen. The skin and fat tissue were then separated from the underlying trapezius before being retracted away from the midline. A similar incision was made in the trapezius muscle and it was retracted laterally, revealing the splenius capitis, which was also transected and reflected laterally. Transitioning to a microsurgical dissection technique, a microscope (OPMI CS NC31 [Carl Zeiss, Oberkochen, Germany]) was used to isolate the injected DCA in between the semispinalis capitis, now exposed, and the semispinalis cervicis with a blunt

Figure 1. Naturally anastomosing vertebral artery (VA) and deep cervical artery (DCA). **A**: Right posterior neck. **B**: Magnified picture of **A**. *Yellow arrows* mark the course of the VA. *White arrows* show the course of the DCA. The *blue arrowhead* indicates the point at which the natural anastomosis occurs.

Figure 2. Artificially anastomosed vertebral artery (VA) to the deep cervical artery (DCA). Before (**A**) and after (**B**) anastomosis on the left posterior neck. *Yellow arrows* mark the horizontally oriented V3 segment of the VA. *White arrows* show the DCA after all vertebral branches were detached. *Blue arrowhead* indicates the point at which the DCA and VA have been artificially anastomosed. Note that no tension is placed on the DCA. SSC, semispinalis cervicis.

dissection. Once the DCA was located, it was traced superiorly to the C2 level and inferiorly to the C5-6 level (Figure 2).

After fully exposing the DCA in each specimen, a microcaliper (Mitsutoyo, Kanagawa, Japan) with a resolution of 0.01 mm and an accuracy value of $\pm$ 0.025 mm was used to measure the diameter of the DCA at the C3 level. The transverse (V3) segment of the VA was then exposed at the C1 level. The vertebral branches of the DCA were detached to allow the terminating branch to the C2 nutrient foramina to be transposed superiorly to the V3 segment of the VA (Figures 2 and 3). The DCA continued to be moved superiorly until the mechanical tension on the artery was considered excessive. This allowed for an estimate of how far the DCA could be extended superiorly beyond the V3 segment of the VA. Excess length beyond the V3 segment of the VA was recorded.

RESULTS

The DCA was identified and traced bilaterally on all specimens. The diameter of the main trunk of the DCA at the C3 level ranged from 1.03 to 2.79 mm on the right side and 1.10 to 2.61 mm on the

left. The mean diameter of the main trunk of the DCA at this level was found to be 1.52 $\pm$ 0.60 mm for the right side and 1.46 $\pm$ 0.54 mm for the left side. After releasing the proximal vertebral branches of the DCA, all arteries could be transposed to the ipsilateral VA with at least 5.0 mm of excess DCA length remaining. All anastomoses were tension free. The terminating branch of the DCA on 10 sides (71.4%) fed into the nutrient foramina of the C2 laminae. In one specimen, the DCA did not have branches to the nutrient foramina of the C2 laminae on either the right or left sides. There was no significant difference in the diameter of the main trunk of the DCA between the right and left sides (P > 0.05).

DISCUSSION

Candidate for a V3 Segment of the VA Bypass

Radial artery and great saphenous vein grafts have long been considered viable tools for the revascularization of structures critical to the posterior circulation of the brain.[25] This study explored the feasibility of using the DCA to bypass the proximal
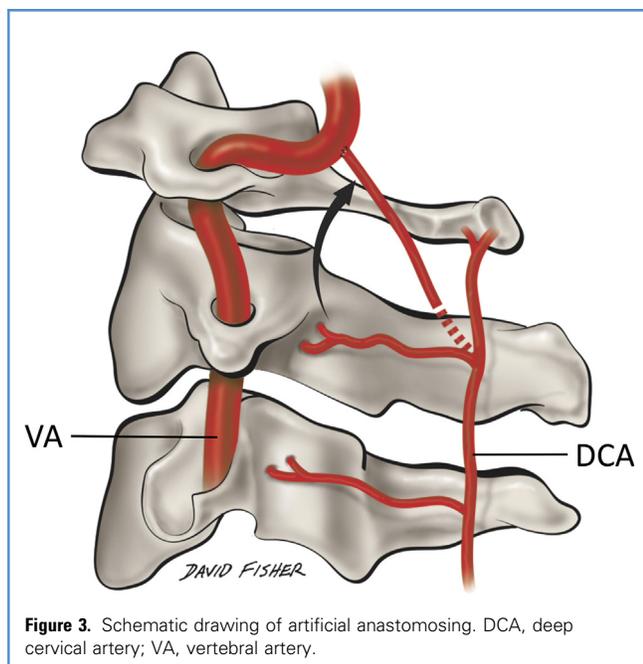
Figure 3. Schematic drawing of artificial anastomosing. DCA, deep cervical artery; VA, vertebral artery.

VA. To our knowledge, nowhere in extant medical literature has the DCA been considered as a viable graft donor in VA revascularization. For a donor vessel to be considered a high-quality candidate, the blood flow rate of the vessel must be comparable with that of the one being bypassed. According to Evans et al.,[25] grafting a high-flow vessel, such as the great saphenous vein or the radial artery, onto a relatively low-flow rate vein or artery may lead to lower patency rates and hemodynamic turbulence. Conversely, the use of a smaller vessel as a bypass donor is contingent on the flow rate being enough to sustain adequate blood flow in the revascularized structure. This reduces the risk of recurrent ischemia distal to the bypass. According to Abd el-Bary et al.,[26] the diameter of the VA along its V3 segment is approximately 4.0 mm. If a DCA-V3 bypass is to be considered feasible, the diameter of the DCA must compare favorably with that of the V3 part of the VA.

In a 2018 paper, Keser et al.[27] described the use of the suboccipital segment of the occipital artery (OA) as a means of bypassing the VA at its V3 segment. According to the authors, the OA, which in its suboccipital segment had a mean diameter of approximately 2.0 mm, could be considered a candidate for such a bypass. To our knowledge, there are no studies analyzing the blood flow rates of the DCA or its use in VA bypass; however, its mean diameter is comparable (within 0.5 mm) with that of the OA. Arslan et al.[28] described the DCA as having a mean diameter of 1.71 mm at the C3 level, which is similar to our results (approximately 1.5 mm). Although further studies are necessary to corroborate these findings, our results seem to indicate that the diameter of the DCA makes it a feasible donor candidate for a V3 segment of the VA bypass.

Surgical Approach to the V3 Segment

One potentially significant advantage of a DCA-V3 bypass is that both structures are in similar anatomic regions and are therefore accessible through a variety of surgical approaches.[29] Although anterior approaches to the VA have been used in the past, such an approach often puts critical nervous structures such as the vagus and hypoglossal nerves at risk.[5,29] Contemporary surgical literature now considers the suboccipital triangle as a more useful landmark for accessing the V3 segment of the VA.[27,30] Furthermore, Tubbs et al.[2] have also described a successful approach to the V3 segment of the VA through the posterior cervical triangle, first displacing the sternocleidomastoid and then second transecting the omohyoid and anterior scalene muscles to gain access to the VA. Such posterior or lateral approaches to the V3 segment of the VA would make the DCA a very practical candidate for bypass, especially in situations of traumatic injury to the proximal VA.

DCA-V3 Anastomosis

The feasibility of artificially anastomosing the main trunk of the DCA to the V3 segment of the VA is further supported by the histologic properties of the VA. In its sulcal segment, V3 has a thick adventitia and media. Both elastin and collagenous fibers are present in considerable quantities, providing structural elasticity and durability.[31] These characteristics make V3 an ideal candidate for a graft site. To our knowledge, no studies examining the histologic properties of the DCA have been reported. However, the natural anastomosis of the DCA with the VA discovered in one specimen in this study provides evidence to the notion that the DCA and VA, if artificially anastomosed, could remain structurally viable. The increased knowledge of the branches, regional anatomy, and variations of the VA and its surroundings will provide the surgeon with additional anatomic possibilities for anastomoses and decrease patient morbidity.[32-38]

CONCLUSIONS

The mean diameter of the DCA at the C3 level was found to be 1.52 ± 0.60 mm for the right side and 1.46 ± 0.54 mm for the left side. Each DCA was easily transferred to the ipsilateral V3 segment of the VA with at least 5.0 mm of remaining length. These results corroborate previous findings regarding the size and location of the DCA. The identification of a naturally anastomosing DCA and VA seem to indicate that the artificial anastomosis of the DCA and V3 would be structurally viable. Contingent on corroboration from future research, the findings of this feasibility study support the addition of a DCA-V3 bypass into the microsurgical armamentarium of surgeons treating vertebrobasilar pathology.

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