Microsurgical anatomy of cerebral revascularization. Part II: Posterior circulation

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Object. Revascularization is an important component of treatment for complex aneurysms, skull base tumors, and vertebrobasilar ischemia in the posterior circulation. In this study, the authors examined the microsurgical anatomy related to cerebral revascularization in the posterior circulation and demonstrate various procedures for bypass surgery.

Methods. The microsurgical anatomy of cerebral and cerebellar vessels as they relate to revascularization procedure and techniques, including extracranial-to-intracranial bypass grafting, arterial interposition grafting, and side-to-side anastomosis, were examined by performing stepwise dissections in 22 adult cadaveric specimens. The arteries and veins in the specimens were perfused with colored silicone.

Dominant cerebral and cerebellar revascularization procedures in the posterior circulation include superficial temporal artery (STA)–posterior cerebral artery (PCA), STA–superior cerebellar artery (SCA), occipital artery (OA)–anterior inferior cerebellar artery, OA–posterior inferior cerebellar artery (PICA), and PICA–PICA anastomoses. These procedures are effective in relatively small but critical areas including the brainstem and cerebellum. For revascularization of larger areas a saphenous vein graft is used to create a bypass between the PCA and the external carotid artery. Surgical procedures are generally difficult to perform in deep and narrow operative spaces near critical vital structures.

Conclusions. Although a clear guideline for cerebral revascularization procedures has not yet been established, it is important to understand various microsurgical techniques and their related anatomical structures. This will help surgeons consider surgical indications for treatment of patients with vertebrobasilar ischemia caused by aneurysms, tumors, or atherosclerotic diseases in the posterior circulation.

KEY WORDS • microsurgical anatomy • cerebral revascularization • posterior circulation • bypass surgery

Although the usefulness of cerebral revascularization for intracranial arteriosclerotic diseases in the anterior circulation has been denied, investigators in the Cooperative Study of Extracranial–Intracranial Arterial Anastomosis17 have made no reference to the use of cerebral revascularization for intracranial arteriosclerotic diseases in the posterior circulation. No randomized trial of cerebral revascularization to treat stenoocclusive disease in the posterior circulation has been performed. Therefore, the efficacy of this procedure for arteriosclerotic diseases remains undetermined. Nevertheless, cerebral revascularization in the posterior circulation is now well recognized as an important component in the treatment of complex and giant intracranial aneurysms, especially when they involve dominant vessels in that location.

Abbreviations used in this paper: AICA = anterior inferior cerebellar artery; BA = basilar artery; CBF = cerebral blood flow; CCA = common carotid artery; ECA = external carotid artery; ICA = internal carotid artery; OA = occipital artery; PCA = posterior cerebral artery; PCoA = posterior communicating artery; PICA = posterior inferior cerebellar artery; RA = radial artery; SCA = superior cerebellar artery; STA = superficial temporal artery; VA = vertebral artery.

In this study, we examined the microsurgical anatomy associated with cerebral revascularization in the posterior circulation and demonstrated various procedures used for bypass surgery.

Materials and Methods

The microsurgical anatomy associated with cerebral revascularization, including the donor and recipient vessels and the techniques of revascularization, encompassing extracranial–intracranial bypass grafting (STA–PCA, ECA–PCA, STA–SCA, OA–AICA, and OA–PICA anastomoses), arterial interposition grafting (OA–PICA anastomosis), and side-to-side anastomosis (PICA–PICA anastomosis), were examined in stepwise dissections performed in 22 adult cadaveric specimens by using 3 to 40× magnification. Depending on the thickness of the vessel wall, 10-0, 8-0, 7-0, or 6-0 nylon threads (Ethicon, Inc., Somerville, NJ) were used for suturing. The arteries and veins of the specimens were perfused with colored silicone. Bone dissections were performed using a Midas Rex drill (Fort Worth, TX).

Results

Arterial Relationships

Table 1 shows the diameters of vessels that are frequently used for cerebral revascularization procedures.
Cerebral revascularization: posterior circulation

Posterior Cerebral Artery

The PCA arises at the basilar bifurcation, is joined by the PCoA at the lateral margin of the interpeduncular cistern, encircles the brainstem as it passes through the crural and ambient cisterns, and is distributed to the posterior portion of the hemisphere. The PCA not only supplies the posterior portion of the cerebral hemispheres, but also sends critical branches to the thalamus, midbrain, and other deeply situated structures, including the choroid plexus and the walls of the lateral and third ventricles. Each segment of the PCA is classified according to our already proposed system.64 The P_s segment is proximal to the PCoA. The P_s segment extends from the PCoA to the point at which the PCA enters the quadrigeminal cistern. The P_t segment is subdivided into equal parts: anterior (P_{2A}) and posterior (P_{2P}). The P_{2A} segment begins at the PCoA and courses between the cerebral peduncle and uncus, which form the medial and lateral walls of the ambient cistern, and then extends inferior to the optic tract and the basal vein, which crosses the roof of the cistern, to enter the proximal portion of the ambient cistern. The P_{2P} begins at the posterior edge of the cerebral peduncle, at the junction of the crural and ambient cisterns. It courses between the lateral midbrain and the parahippocampal and dentate gyri, which form the medial and lateral walls of the ambient cistern, to below the optic tract, basal vein, and geniculate bodies and the inferolateral portion of the pulvinar in the roof of the cistern, and superomedial to the trochlear nerve and temporal edge. The P_t segment begins at the posterior midbrain, courses within the quadrigeminal cistern, and ends at the anterior limit of the calcarine fissure. The P_s segment is the distal branch of the P_t segment. In this study mean diameters of the P_{2A}, P_{2P}, and P_t were 2.13, 1.73, and 1.67 mm, respectively (Table 1). The PCA gives rise to three types of branches: 1) central perforating branches to the diencephalon and midbrain; 2) ventricular branches to the choroid plexus and walls of the lateral and third ventricles and adjacent structures; and 3) cerebral branches to the cerebral cortex and the splenium of the corpus callosum. The central branches include the direct and circumflex perforating arteries, including the thalamoperforating, peduncular perforating, and thalamogeniculate arteries. The ventricular branches are the lateral and medial posterior choroidal arteries. The cerebral branches include the inferior temporal group of branches, which are divided into the hippocampal and the anterior, middle, posterior, and common temporal branches, plus the parietooccipital, calcarine, and splenial branches. The long and short circumflex, thalamoperforating, and medial posterior choroidal arteries arise predominantly from the P_t segment, and the other PCA branches most frequently arise from the P_s or P_t segment. The hippocampal, anterior temporal, peduncular perforating, and medial posterior choroidal arteries most frequently arise from the P_{3A} segment; and the middle temporal, posterior temporal, common temporal, and lateral posterior choroidal arteries most frequently arise from the P_{3P} segment. The thalamogeniculate arteries are only slightly more frequently found to arise from the P_s segment than from the P_t segment. The calcarine and parietooccipital arteries most frequently arise from the P_t segment (Fig. 1A and B).

Superior Cerebellar Artery

The SCA arises in front of the midbrain, usually from the BA near the apex, and passes below the oculomotor nerve. Its proximal portion courses medial to the free edge of the tentorium cerebelli around the brainstem near the ponto-mesencephalic junction, and its distal portion passes below the tentorium, making it the most rostral of the infratentorial arteries. All SCAs that arise as a single vessel bifurcate into two major trunks—one rostral and one caudal—most commonly near the point of maximal caudal descent of the artery on the lateral side of the brainstem. The SCA is divided into four segments: anterior pontomesencephalic, lateral pontomesencephalic, cerebellomesencephalic, and cortical. The anterior pontomesencephalic segment begins at the origin of the SCA and extends below the oculomotor nerve to the anterolateral margin of the brainstem. In this study the mean diameter of the vessel in that segment was 1.67 mm (Table 1). The lateral pontomesencephalic segment begins at the anterolateral margin of the brainstem and frequently dips caudally onto the lateral side of the pons. This segment terminates at the anterior margin of the cerebellomesencephalic fissure. The mean diameters of the rostral and caudal trunks in this segment were 1.25 and 1.15 mm, respectively. In cadavers in which there was a single trunk, the mean diameter of this segment was 1.51 mm (Table 1). The cerebellomesencephalic segment courses within the cerebellomesencephalic fissure, giving rise to branches that penetrate the fissure’s opposing walls. The cortical segment includes branches distal to the cerebellomesencephalic fissure that pass under the tentorial edge and are distributed to the tentorial surface (Fig. 1B–D).

Anterior Inferior Cerebellar Artery

The AICA originates from the BA, usually as a single trunk, and encircles the pons near the abducens, facial, and vestibulocochlear nerves. After coursing near and sending branches to nerves entering the acoustic meatus and to the choroid plexus protruding from the foramen of Luschka, the AICA passes around the flocculus on the middle cerebellar peduncle to supply the cerebellopontine fissure and the

<table>
<thead>
<tr>
<th>Artery</th>
<th>Mean Diameter (mm)</th>
<th>Standard Deviation (mm)</th>
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<tbody>
<tr>
<td>PCA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P_{2A} segment</td>
<td>2.13 ± 0.38</td>
<td>0.48</td>
</tr>
<tr>
<td>P_{2P} segment</td>
<td>1.73 ± 0.33</td>
<td>0.38</td>
</tr>
<tr>
<td>P_t segment</td>
<td>1.67 ± 0.16</td>
<td>0.29</td>
</tr>
<tr>
<td>SCA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ant pontomesencephalic segment</td>
<td>1.67 ± 0.16</td>
<td>0.38</td>
</tr>
<tr>
<td>lat pontomesencephalic segment</td>
<td>1.51 ± 0.12</td>
<td>0.29</td>
</tr>
<tr>
<td>single trunk</td>
<td>1.25 ± 0.17</td>
<td>0.29</td>
</tr>
<tr>
<td>rostral trunk</td>
<td>1.15 ± 0.17</td>
<td>0.30</td>
</tr>
<tr>
<td>caudal trunk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AICA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ant pontomesencephalic segment</td>
<td>1.34 ± 0.28</td>
<td>0.16</td>
</tr>
<tr>
<td>cortical segment</td>
<td>1.07 ± 0.29</td>
<td>0.16</td>
</tr>
<tr>
<td>PICA</td>
<td></td>
<td></td>
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<tr>
<td>ant medullary segment</td>
<td>1.84 ± 0.45</td>
<td>0.17</td>
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<tr>
<td>tonsillomedullary segment (caudal loop)</td>
<td>1.68 ± 0.38</td>
<td>0.17</td>
</tr>
<tr>
<td>OA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>at digastic groove</td>
<td>2.05 ± 0.48</td>
<td>0.21</td>
</tr>
<tr>
<td>at level of the superior nuchal line</td>
<td>2.01 ± 0.45</td>
<td>0.16</td>
</tr>
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* Values are expressed as means ± standard deviations.
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petrosal surface. It commonly bifurcates near the facial–
vestibulocochlear nerve complex to form rostral and caudal
trunks. The AICA is divided into four segments: anterior
pontine, lateral pontine, flocculonodular, and cortical. Each
segment may include more than one trunk, depending on
the level of bifurcation of the artery. In this study the mean
diameters of the anterior pontine and cortical segments
were 1.34 and 1.07 mm, respectively (Table 1). The most
common pattern is for the AICA to supply the majority of
the petrosal surface; however, overlapping of the SCA on
the upper portion of the petrosal surface and overlapping of
the PICA on the lateral portion of the suboccipital surface
are not uncommon, depending on the size of the AICA (Fig.
1C and D).

Posterior Inferior Cerebellar Artery

The PICA has the most complex, tortuous, and variable
course of the cerebellar arteries. This vessel arises from
the VA near the inferior olive and passes posteriorly around
the medulla oblongata. After it passes the lateral aspect of
the medulla, the PICA courses around the cerebellar tonsil,
enters the cerebellomedullary fissure, and passes posterior
to the lower half of the roof of the fourth ventricle. On exi-
ting the cerebellomedullary fissure, the branches of the
PICA are distributed to the vermis and the suboccipital sur-
face of the hemisphere. Most PICAs bifurcate into medi-
al and lateral trunks. The medial trunk supplies the vermis
and the adjacent portion of the hemisphere, and the later-
al trunk supplies the cortical surface of the tonsil and the
hemisphere. The PICA is divided into five segments: ante-
rior medullary, lateral medullary, tonsillomedullary, telo-
velontsillar, and cortical. The anterior medullary segment
begins at the origin of the PICA, anterior to the medulla ob-
longata, and extends backward to the inferior olivary prom-
ience, passing near the hypoglossal rootlets. The lateral
medullary segment begins at the site where the artery pass-
es the most prominent point of the inferior olive and ends at
the level of the origin of the glossopharyngeal, vagus, and
accessory nerves and extends medi-
ally across the posterior aspect of the medulla, near the cau-
dal half of the tonsil. It ends at the point at which the artery
ascends to the midlevel of the medial surface of the tonsil.
This segment commonly passes medially between the lower
margin of the tonsil and the medulla oblongata before turn-
ing rostrally along the medial surface of the tonsil. The loop
passing near the lower part of the tonsil, referred to as the
caudal loop, forms a caudally convex loop that coincides
with the caudal pole of the tonsil, but it may also course su-
periorly or inferiorly with respect to the caudal pole of the
tonsil without forming a loop. In our investigation the mean
diameter of the caudal loop, which is one of the largest dis-
tal vessels in the cerebellar arteries, was 1.68 mm (Table 1).
The telovelontsillar segment begins at the midpoint of
the PICA’s ascent along the medial surface of the tonsil
and ends at the point at which the PICA exits the fissures be-
tween the vermis and tonsil on one side and the hemisphere
on the other side to reach the suboccipital surface. This seg-
ment commonly forms a loop with a convex rostral curved, called the cranial
loop. The apex of the cranial loop usually overlies the central portion of the inferior
medullary velum. A. = artery; A.Ch.A. = anterior choroidal artery; A.I.C.A. = inferior
cerebellar artery; Bas. = basilar; Caud. = caudal; Chor. = choroidal; CN = cranial nerve; Cond. =
condylar; Fiss. = fissure; Horiz. = horizontal; L.P.Ch.A. = lateral posterior choroidal artery; M.P.Ch.A. = medial posterior choroidal
artery; P.C.A. = posterior cerebral artery; P.C.O.A. = posterior communicating artery; Pet. = petrosal; P.I.C.A. = posterior inferior cere-
bellar artery; Post. = posterior; P1, P2A, P2P, P3 = segments and subsegments of the PCA; Rost. = rostral; S.C.A. = superior cerebel-
lar artery; Str. = straight; Suboccip. = suboccipital; Sup. = superior; Tent. = tentorial; Tr. = trunk; Trans. = transverse; V. = vein; Ver. or
Vert. = vertebral.

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FIG. 2. Graft extraction. Photographs of cadaveric specimens, showing right posterior and posterolateral views of the OA. The OA arises from the posterior portion of the ECA and ends in the posterior portion of the scalp. The OA ascends to the area between the transverse process of the atlas and the mastoid process of the temporal bone, and passes horizontally backward, grooving the surface of the mastoid bone, because the vessel is covered by the sternocleidomastoid and splenius capitis muscles, and resting on the superior oblique and semispinalis capitis muscles. The OA then changes its course and runs vertically upward, pierces the fascia connecting the cranial attachment of the trapezius muscle with the sternocleidomastoid muscle, and ascends in a tortuous course in the superficial fascia of the scalp, where it divides into numerous branches that reach as high as the vertex of the skull and anastomose with the posterior auricular artery and the STA. The terminal portion of the OA is accompanied by the greater occipital nerve. Cap. = capitis; C2 = C-2 vertebra; Gr. = great; Inf. = inferior; M. = muscle; Maj. = major; N. = nerve; Obl. = oblique; Occip. = occipital; Rec. = rectus; Sag. = sagittal; Semispin. = semispinalis; Splen. = splenius; Sternocleidomast. = sternocleidomastoid.
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posite the external maxillary artery and near the lower margin of the posterior belly of the digastic muscle, and ends in the posterior portion of the scalp. At its origin, the OA is covered by the posterior belly of the digastic muscle and the stylohoid muscles. The hypoglossal nerve winds around this artery from behind and forward. Higher, the OA crosses the ICA, the internal jugular vein, and the vagus and accessory nerves. The OA ascends to the side between the transverse process of the atlas and the mastoid process of the temporal bone and passes horizontally backward, grooving the surface of the mastoid process, because the vessel is covered by the sternocleidomastoid, splenius capitis, longissimus capitis, and digastic muscles, and resting on the rectus capitis lateralis, superior oblique, and semispinalis capitis muscles. In this study the mean diameter of the OA was 2.05 mm at its exit from the digastic groove (Table 1). There the OA changes course and runs vertically upward, pierces the fascia connecting the cranial attachment of the trapezius and sternocleidomastoid muscles, and ascends in a tortuous course in the superficial fascia of the scalp, where it divides into numerous branches that reach as high as the vertex of the skull and anastomose with the posterior auricular artery and the STA. In this study the mean diameter of the OA was 2.01 mm at the level of the superior nuchal line (Table 1). The length of the OA from its exit from the digastic groove to the level of the superior nuchal line was measured in three specimens (four sides). The mean length of this segment was 81.9 mm. Its terminal portion is accompanied by the greater occipital nerve (Fig. 2).

Superficial Temporal Artery

The STA, the smaller of the two terminal branches of the ECA, appears, from its direction, to be the continuation of that vessel. The STA begins in the substance of the parotid gland, behind the neck of the mandible, and crosses over the posterior root of the zygomatic process of the temporal bone. The STA divides into two branches: frontal and parietal. The frontal branch (anterior temporal) runs tortuously upward and forward to the forehead, supplying the muscles, integument, and pericranium in this region and anastomosing with the supraorbital and frontal arteries. The parietal branch (posterior temporal) is larger than the frontal branch and curves upward and backward on the side of the head, lying superficial to the temporal fascia and anastomosing with its contralateral counterpart as well as with the posterior auricular and occipital arteries.

Procedures for Cerebral Revascularization

The STA–PCA Anastomosis. This anastomosis is performed via a subtemporal route. After positioning the temple region flat on the table, the STA is outlined either by palpation or by using a portable Doppler device. Once dissection of the STA has been completed, the temporal muscle and fascia are incised at the site of the craniotomy for the subtemporal approach. After the dura mater has been opened, the temporal lobe is elevated until the tentorial edge is identified. Care should be taken not to damage the vein of Labbé or the posterior temporal veins as they enter the transverse sinus. The PCA is dissected free from the arachnoid as the vessel courses around the cerebral peduncle. It is not necessary to expose the P1 segment of the PCA. The segment of the vessel that is isolated for temporary occlusion is the P2. A portion of the P2 segment, approximately 1.5 cm in length and having no perforating vessels, is selected for the anastomosis. Care should be taken to avoid damaging vessels that pass near the anastomotic site, including the long and short circumflex, thalamoperforating, medial and lateral posterior choroidal, hippocampal, anterior temporal, middle temporal, posterior temporal, common temporal, and peduncular perforating arteries. It may be difficult to see the PCA in the center of the operative field when the artery courses the upper portion of the cistern around the brainstem. Nevertheless, excess retraction of the temporal lobe should be avoided to protect the temporal lobe and the bridging veins. After the PCA has been exposed, the severed end of the STA is stripped of its fascial layer and a 7- to 8-mm portion of the vessel is exposed. The tip of the STA is then cut into a shape that is suitable for the anastomotic site. The recipient vessel is prepared by placing temporary clips across the vessel and performing a small arteriotomy. After two stay sutures have been placed, anastomosis of the STA to the recipient vessel is performed using 10-0 nylon interrupted sutures (Fig. 3A–C).

The ECA–PCA Anastomosis. Either a saphenous vein graft or a RA graft is used for this bypass procedure. The CCA, ICA, and ECA are exposed in the carotid triangle by making a cervical incision along the anterior aspect of the sternocleidomastoid muscle. The zygomatic arch is drilled to fashion a conduit for the graft when it is placed in the preauricular position. After a craniotomy has been performed for the subtemporal approach, dissection of the P2 segment of the PCA is performed through the subtemporal route. The P2 segment, which is thick and has the least number of side branches, is chosen and mobilized for the anastomosis. Care should be taken to avoid damaging the perforating arteries. The distal anastomosis between the P2 segment and the graft is performed in an end-to-side fashion by using interrupted 8-0 nylon sutures. After completion of the distal anastomosis, the cervical ECA is occluded proximally and distally. The graft is then pulled down through the subcutaneous tunnel. An arteriotomy, approximately 6 to 8 mm long, is made on the ECA. The graft is anastomosed to the artery in an end-to-side fashion by using 6-0 nylon sutures (Fig. 3D and E).

The STA–SCA Anastomosis. The STA–SCA anastomosis is performed in the same operative view as described for the STA–PCA anastomosis. After dissection of the STA has been completed, the tentorial edge is identified through the subtemporal space. The edge of the tentorium is elevated and sectioned to provide more exposure. The flap of the tentorium is retracted and reflected, and it is anchored to a more lateral aspect of the tentorium. Care is taken not to damage the fourth cranial nerve, which courses beneath the tentorial edge. The SCA is then identified in its lateral pontomesencephalic segment. The artery usually has no perforating branches because it courses from the lateral portion of the midbrain to the superior portion of the cerebellum. If there are branches to the brainstem, a portion of the SCA beyond the area containing the brainstem branch is selected for the anastomosis. Because the SCA frequently divides into rostral and caudal branches in this segment, the larger of the two branches is used for the anastomosis. After the SCA has been exposed, the severed end of this vessel is stripped
FIG. 3. Photographs of cadaveric specimens demonstrating an STA–PCA anastomosis on the right side (A–C) and an ECA–PCA anastomosis on the left side performed using a saphenous vein graft (D and E). A: The STA–PCA anastomosis is performed via the subtemporal route. After the dura mater has been opened, the temporal lobe is elevated until the tentorial edge is identified. Care should be taken not to damage the vein of Labbé or the posterior temporal veins as they enter the transverse sinus. The tentorial edge has been removed to expose the SCA and the fourth cranial nerve. The PCA is dissected free from the arachnoid as it courses around the cerebral peduncle. The portion of the vessel that is isolated for temporary occlusion is the P2A segment of the PCA. A portion of this segment, approximately 1.5 cm in length and having no perforating vessels, is selected for the anastomosis. Care should be taken to preserve vessels passing near the anastomotic site, including the long and short circumflex, thalamoperforating, medial and lateral posterior choroidal, (FIG. 3. continued →)
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of its fascicular layer and a 7- to 8-mm portion of the vessel is exposed. The tip of the STA is then cut into a shape that is suitable for the anastomotic site. The recipient vessel is prepared by placing temporary clips across the vessel and performing a small arteriotomy equal in length to one prepared on the SCA. After two stay sutures have been placed, anastomosis of the STA to the recipient vessel is performed using 10-0 nylon interrupted sutures (Fig. 4).

The OA–AICA Anastomosis. The course of the OA should be outlined on the scalp by using a portable Doppler device. The OA can be dissected from its point of penetration through the occipital muscle to its most distal appearance. It is important to dissect a sufficiently long piece of the OA to be able to reach the cerebellar arteries; therefore, the dissection may need to extend to the level of the mastoid process. This dissection is generally difficult because the OA is more tortuous and lies deeper than the STA. The OA is gently retracted off the field, and a lateral suboccipital craniotomy is performed from the foramen magnum to the transverse sinus and from the edge of the mastoid process to the midline. Generally, removal of the arch of C-1 is not necessary. After the dura mater has been opened, the suboccipital surface of the cerebellum can be seen. Using careful retraction of the cerebellum laterally, the AICA in the petrous surface is made visible (Fig. 5A). Anastomosis to the proximal portion of the AICA near the BA would require continuous compression of the cerebellum, compromising the collateral branches between the AICA and PICA or the AICA and SCA. Therefore, the flocculonodular (Fig. 5B and C) or cortical (Fig. 5D and E) segment of the AICA, distal to the facial–vestibulocochlear nerve complex, is selected for the anastomosis. The vessel is freed from the petrous surface of the cerebellum and is isolated. After the AICA has been exposed, the severed end of the OA is stripped of its fascial layer and a 7- to 8-mm portion of the vessel is exposed. The tip of the OA is cut into a shape that is suitable for the anastomotic site. The recipient vessel is prepared by placing temporary clips across the vessel and performing a small arteriotomy equal in length to one prepared on the AICA. After two stay sutures have been placed, anastomosis of the OA to the recipient vessel is performed using 10-0 nylon interrupted sutures. Generally, the anastomosis procedure performed for the AICA is more difficult than that for the PICA because of the depth of the operative field and the smaller diameter of the recipient vessel.

The OA–PICA Anastomosis. After dissection of the OA has been completed, a suboccipital craniotomy is performed in the manner described for the OA–AICA anastomosis. The arch of C-1 is removed, if needed. After the dura mater has been opened, the caudal loop of the PICA is exposed. The vessel is freed from the arachnoid. After the PICA has been exposed, the severed end of the OA is stripped of its fascial layer, and a 7- to 8-mm portion of the vessel is exposed. The tip of the OA is cut into a shape that is suitable for the anastomotic site. The recipient vessel is prepared by placing temporary clips across the vessel and performing a small arteriotomy equal in length to one prepared on the PICA. After two stay sutures have been placed, anastomosis of the OA to the recipient vessel is performed using 10-0 nylon interrupted sutures (Fig. 6A–C).

Short Arterial Interposition Graft Anastomosis. The STA or OA is used for an arterial graft. The OA–AICA, OA–PICA, or VA–PICA anastomosis can be performed using an interposition graft. A section of STA or OA graft material, approximately 8 cm long, is dissected from a skin flap and both severed ends of the donor vessel are stripped of the fascial layer. For an OA–PICA anastomosis the graft is placed between the OA and the caudal loop of the PICA and attached using 10-0 nylon interrupted sutures (Fig. 6D and E).

Side-to-Side Anastomosis of the PICA. This procedure is chiefly used for cerebral revascularization of the distal portion of the PICA after occlusion of its proximal portion. The proximity and parallel courses of the tonsillomedullary and the telovelotonsillar segments of the PICAs permit side-to-side anastomosis. Arteriotomies, 4 mm in length, are made in both donor and recipient arteries. The most difficult procedure is to make a tight suture on a back wall. After two stay sutures have been placed, the back wall is sutured in a continuous running fashion from the intravascular side and the anterior wall is closed with interrupted sutures (10-0 nylon). The distal portion of the artery beyond the occlusion site is supplied by the adjacent artery (Fig. 7).

End-to-End Anastomosis of the PICA. The diseased PICA segment that is involved with a tumor or aneurysm can be excised, and the remaining portions of the vessel can be directly reattached in an end-to-end fashion. The proximal and distal stumps of the PICA are anastomosed using interrupted sutures (10-0 nylon), unless the difference between the diameters of the stumps is greater than 10 mm.

Discussion

In this study, we have shown various intracranial cerebral revascularization procedures in the posterior circulation, which are considered to be routine neurosurgical techniques. We have also described the microsurgical anatomy of vessels related to these procedures. A variety of revascularization procedures associated with extracranial VA
reconstruction were excluded from this study. Extracranial VA reconstruction techniques include VA–carotid artery transposition;\textsuperscript{9,10,15} transposition of the subclavian artery to the CCA;\textsuperscript{12,18} anastomosis of a branch or the trunk of the ECA to the second portion of the VA;\textsuperscript{14,43} anastomosis of the OA to the third portion of the VA;\textsuperscript{14,43} saphenous vein bypass grafting from the subclavian artery to the VA or from the CCA to the VA distal to the area of stenosis;\textsuperscript{36,51,55} vertebral endarterectomy;\textsuperscript{1,49} a patch graft of the VA;\textsuperscript{44} and angioplasty reconstruction of the VA,\textsuperscript{35} most of which are related to vertebrobasilar insufficiency caused by stenosis or occlusion of extracranial VA.

A cerebral revascularization procedure in the posterior circulation differs from one in the anterior circulation in several ways. First, indications for bypass surgery in the posterior circulation are more ambiguous than those in the anterior circulation. This may be due to a lack of experience or to the unique hemodynamic system in the posterior fossa, where collateral flow is abundant. Second, in the posterior circulation a revascularization procedure usually deals with relatively small but critical areas including the brainstem and the cerebellum. Third, recipient vessels generally have a small diameter, which is similar to that of the cortical branch of the middle cerebral artery. A saphenous vein graft is rarely used in revascularization except for a bypass between the PCA and ECA. Finally, surgical procedures are usually difficult to perform in the deep and narrow operative space near critical vital structures such as the brainstem and cranial nerves. The OA–PICA anastomosis is performed in a relatively shallow place, but the dissection of the OA is more difficult than that of the STA. The role of intracranial bypass surgery for vertebrobasilar insufficien-
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Fig. 5. Photographs of cadaveric specimens depicting an OA–AICA anastomosis on the right side. A: The OA can be dissected from its point of penetration through the occipital muscle to its most distal location. The OA is gently retracted off the field, and a lateral suboccipital craniotomy is completed. After the dura mater has been opened, the suboccipital surface of the cerebellum can be seen. With careful retraction of the cerebellum laterally, the AICA in the petrous surface is made visible. The flocculonodular (B and C) and cortical (D and E) segments of the AICAs located distal to the facial–vestibulocochlear nerve complex are selected for the anastomoses. The vessel is freed from the petrous surface of the cerebellum and is isolated. After the AICA has been exposed, the severed end of the OA is stripped of its fascial layer, and a 7- to 8-mm portion of the vessel is exposed. The tip of the OA is then cut into a shape that is suitable for the anastomotic site. The recipient vessel is prepared by placing temporary clips across the vessel and performing a small arteriotomy equal in length to one prepared on the AICA. After two stay sutures have been placed, anastomosis of the OA to the recipient vessel is performed using 10-0 nylon interrupted sutures (arrowheads). Generally, the anastomosis procedure for the AICA is more difficult than that for the PICA because of the depth of the operative field and the smaller diameter of the recipient vessel. Sig. = sigmoid.
cy caused by atherosclerotic disease of an extracranial or intracranial VA remains unclear. Nevertheless, cerebral revascularization in the posterior circulation is well recognized as an important component in the treatment of complex and giant intracranial aneurysms and tumors, especially when these lesions involve major vessels in the posterior circulation.

**Bypass Procedures**

Four arteries—PCA, SCA, AICA, and PICA—are used as recipient vessels; all of these vessels are more or less related to perfusion of the brainstem. On the other hand, there are two types of donor graft materials: pedicled arterial grafts, such as the STA and OA, and free venous or arterial grafts, such as the saphenous vein and the STA. Selection of an anastomotic site and a graft material depends on several factors, including the patient’s symptoms (ischemic region), the site of the lesion, the collateral circulation, and the required surgical skill.

Ausman and colleagues performed the first intracranial...
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posterior circulation revascularization procedure for vertebrobasilar insufficiency in the form of an OA–PICA anastomosis in 1976. Sundt and Piepgras52 and Khodadad30 reported additional experiences with this operation. Since then, OA–PICA anastomosis has played an important role in cerebral revascularization in the posterior circulation.6,32,38,45 This procedure has several advantages. 1) A recipient vessel, usually the caudal loop of the PICA, has a rather large diameter (mean diameter 1.68 mm), thus making an anastomosis easier. 2) The lumen caliber of the donor vessel, usually the OA (mean diameter at the level of the superior nuchal line 2.01 mm), closely approximates that of the recipient vessel. 3) Bypass surgery can be performed in a shallow and wide operative field, making the procedure easier. The important technical point is to preserve perforating branches from the PICA. The disadvantage of this surgery is the dissection of the OA. This dissection is generally difficult because the OA is tortuous and runs deeply in the occipital muscles. It is important to dissect a sufficiently long piece of the OA to be able to reach the cerebellar arteries; therefore, the dissection may need to be extended to the level of the mastoid process. The mean length of the OA from the exit of the digastric groove to the level of the superior nuchal line in this study was 81.9 mm. Hamada and asso-

Fig. 7. Posterior view of a side-to-side anastomosis of PICAs in cadaveric specimens. This procedure is mainly used for cerebral revascularization of the distal portion of the PICA after occlusion of its proximal portion. The proximity and parallel courses of the tonsillomedullary and the telovelotonsillar segments of the PICAs permit their side-to-side anastomosis. Arteriotomies, 4 mm in length, are made on both donor and recipient arteries. After placement of two stay sutures, the back wall is sutured in a continuous running fashion from the intravascular side and the anterior wall is closed with interrupted sutures (arrowheads). The distal portion of the artery beyond the occlusion site (arrow) is supplied by the adjacent artery (dotted arrows).
this procedure. One reason is that the caliber of the lumen of the distal portion of the AICA is relatively smaller than those of other cerebellar vessels. Based on this study the mean diameter of the cortical segment of the AICA is 1.07 mm, causing it to be mismatched with the donor vessel and preventing it from supplying a large area. The other reason is a narrow and deep operative field. To perform the OA–AICA anastomosis as proximally as possible, it is necessary to compress the cerebellum with compromise of the collateral branch in the cerebellopontine angle.

Cerebral revascularization procedures were first performed in the lower intracranial portion of the posterior circulation and later in the upper intracranial portion, including STA–SCA and STA–PCA anastomoses. Ausman and colleagues reported the first anastomosis between an STA and the cortical segment of an SCA in 1979. After that, the technique was modified and became an anastomosis between the STA and the lateral pontomesencephalic segment of the SCA, which is now well recognized as a standard STA–SCA anastomosis procedure for cerebral revascularization in the posterior circulation. This procedure is most commonly used to treat rostral brainstem ischemia. The site of anastomosis of the SCA is located in the anterolateral margin of the brainstem. The SCA frequently dips caudally onto the lateral side of the pons. To identify the SCA near the pons, it may be necessary to cut the tentorium until the fourth cranial nerve is completely exposed. In addition, the SCA often gives rise to rostral and caudal branches in this area. The larger branch should be selected as a recipient vessel. In the present study we found the mean diameters of the rostral and caudal trunks in this segment to be 1.25 and 1.15 mm, respectively. In cadavers in which the SCA was a single trunk, the mean diameter was 1.51 mm. In this procedure, care should be taken to avoid damaging the temporal lobe by retraction, cranial nerves by dissection in the basal cistern, and perforating arteries arising from the SCA and PCA toward the brainstem. The STA–PCA anastomosis can be performed in the same operative window used to perform the STA–SCA anastomosis. It may not be necessary to cut the tentorium to expose the PCA because that vessel courses above the tentorium in the incisural space. Nevertheless, the highly positioned PCA sometimes makes an anastomotic procedure difficult. To identify the P3a segment of the PCA, which is usually thought to be a site for anastomosis, excessive retraction of the temporal lobe may be needed. A frequently seen serious complication is hematoma and/or edema caused by temporal lobe retraction. As a recipient vessel the PCA is advantageous because it can be anastomosed to the ECA by using saphenous vein or RA grafts. The mean caliber of the lumen of the P3a segment was 2.13 mm in our study, thus making it possible to anastomose the graft to the PCA.

Revascularization procedures in the posterior circulation are well recognized as important components in the treatment of complex and giant intracranial aneurysms. Techniques plays an important role in the treatment of patients with complex and giant posterior circulation aneurysms. Nevertheless, there are contraindications for endovascular treatment, including a partially thrombosed aneurysm and a wide aneurysm neck. Most of these aneurysms present treatment challenges with the use of the direct clipping procedure. Cerebral revascularization procedures are then applied to the treatment of these aneurysms. The dominant sites for saccular aneurysms in the posterior circulation are the VA–PICA junction and the top of the BA. If a giant aneurysm involves the PICA and it is impossible to spare that vessel, a minimal piece of the PICA may be removed, followed by repair of the stump vessels in an end-to-end fashion. If its removal is irreparable, consideration should be given to PICA trapping proximal to the aneurysm and/or revascularization with the aid of an OA–PICA or PICA–PICA bypass. In these procedures, it is important to preserve all viable VA and PICA perforating branches. In a previous report, one of the authors (A.L.R.) examined the microsurgical anatomy of the PICA in detail. The anterior medullary segment of the PICA gives rise to one, or two (mean one) of the perforating branches, which usually are of the short circumflex posterior type and supply the anterior, lateral, or posterior surface of the medulla oblongata. On the other hand, the tonsillomedullary segment gives rise to more perforating branches than the other segment (range 0–11 branches; mean 3.3 branches), which are either of the direct or short circumflex type, although the former is predominant. Therefore, revascularization of the distal PICA is needed unless the PICA is sacrificed at a site beyond the tonsillomedullary segment. In the case of a giant BA aneurysm the cerebral revascularization should be established, followed by ligation of the vessel proximal to the aneurysm. The bypass procedure should be selected on the basis of the degree of collateral blood flow and aneurysm location. An STA–PCA or STA–SCA bypass can be an option for patients with mild or moderate hemodynamic insufficiency of the BA, whereas an ECA–PCA bypass with a high-flow bypass graft should be used for patients with severe hemodynamic insufficiency of the BA. Nevertheless, matters concerning the evaluation of the hemodynamic status of patients, expectation of a hemodynamic change after the operation, and potential complications of a graft material remain unclear, as previously described. On the other hand, cerebral revascularization combined with endovascular techniques plays an important role in the treatment of patients with dissecting aneurysms in the posterior circulation. Iihara, et al. divided VA dissecting aneurysms into two types:...
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types: those involving the PICA and those not involving the PICA. These authors demonstrated good outcomes in patients with VA dissecting aneurysms that involve the PICA by using endovascular treatment combined with bypass surgery.

Although few cases with complications such as aneurysms have been reported, revascularization procedures are thought to be important for the treatment of complex and giant skull base tumors involving dominant vessels in the posterior circulation. Indications leading to cerebral revascularization for treatment of these tumors are almost the same as those for aneurysms. Bypass surgery should be performed with the aim of maintaining blood flow to involved territories and preventing ischemic complications.

Vertebrobasilar insufficiency occurs frequently and atherosclerosis is the predominant cause of the disease. Symptoms of vertebrobasilar stenoocclusive disease include those caused by ischemia of the brainstem and cerebellum. Dizziness, which is a common symptom in patients with vertebrobasilar disease, may be caused by ischemia of the vestibular nuclei that are fed by the most distal branch of the long circumflex arteries. Different disease processes tend to involve different portions of the vertebrobasilar circulation, and intracranial lesions cause different symptoms from extracranial lesions. The common sites of atherosclerosis in the vertebrobasilar circulation are the junction of the VA and the subclavian artery; the junction of the VA and the PICA; and the midpoint of the BA. Anticoagulation therapy has been recommended and is widely used in cases of vertebrobasilar ischemia. Many patients continue to have transient ischemic attacks in the posterior circulation, however, despite receiving anticoagulation therapy.

Although no clear guideline has been established, surgical therapy provides an alternative treatment for vertebrobasilar stenoocclusive disease, which may be effective in many cases. Ogawa and colleagues reported a change in CBF and cerebral metabolism before and after surgery, which was performed in patients with vertebrobasilar occlusive disease by using positron emission tomography. In their study, CBF, which was low in the posterior fossa preoperatively, increased significantly after STA–SCA bypass surgery. The oxygen extraction fraction, which was high preoperatively, decreased significantly not only in the posterior circulation but also throughout the entire brain following the procedure. Further evaluation of each revascularization procedure, including data on blood flow and metabolism, should be investigated to establish appropriate indications for bypass surgery in a patient with vertebrobasilar stenoocclusive disease.

The role of cerebral revascularization in the posterior circulation has been less frequently discussed than that in the anterior circulation. In particular, the role of revascularization as a treatment modality for patients with arteriosclerotic disease in the vertebrobasilar tree has not been well studied. There has been no controlled randomized study offering a comparison of medically and surgically treated patients. On the other hand, cerebral revascularization procedures combined with the endovascular technique provide another opportunity for treatment of patients with complex aneurysms. Further investigations, including the natural history of vertebrobasilar stenoocclusive disease and a change in CBF and cerebral metabolism before and after surgery, will help solve current problems related to choosing a specific therapy not only for patients with vertebrobasilar ischemia but also for those harboring aneurysms or tumors in the posterior circulation.

It is important to understand various microsurgical techniques and their related anatomical structures. It will help surgeons consider surgical indications for the treatment of patients who need cerebral revascularization.

Acknowledgments

We thank Ronald Smith, M.S., Director, and David Peace, M.S., Medical Illustrator, of the Microneurosurgery Laboratory, Department of Neurological Surgery, University of Florida, for constant support. We also thank Becky Norquist for reviewing the manuscript.

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Manuscript received April 21, 2004.
Accepted in final form August 30, 2004.
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