Microsurgical anatomy of the posterior circulation

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Context: The microsurgical anatomy of the posterior circulation is very complex and variable. Surgical approaches to this area are considered risky due to the presence of the various important blood vessels and neural structures. **Aims:** To document the microsurgical anatomy of the posterior circulation along with variations in the Indian population. **Materials and Methods:** The authors studied 25 cadaveric brain specimens. Microsurgical dissection was carried out from the vertebral arteries to the basilar artery and its branches, the basilar artery bifurcation, posterior cerebral artery and its various branches. Measurements of the outer diameters of the vertebral artery, basilar artery and posterior cerebral artery and their lengths were taken. **Results:** The mean diameter of the vertebral artery was 3.4 mm on the left and 2.9 mm on the right. The diameter of the basilar artery varied from 3-7 mm (mean of 4.3 mm). The length varied from 24-35 mm (mean of 24.9 mm). The basilar artery gave off paramedian and circumferential perforating arteries. The origin of the anterior inferior cerebellar artery (AICA) varied from 0-21 mm (mean 10.0 mm) from the vertebrobasilar junction. The diameter of the AICA varied from being hypoplastic i.e., < 0.5 mm to 2 mm (mean 1.0 mm). The superior cerebellar artery (SCA) arises very close to the basilar bifurcation, in our series (1-3 mm from the basilar artery bifurcation). The diameter of the SCA varied from 0.5-2.5 mm on both sides. The posterior cerebral artery (PCA) is divided into four segments. The PCA gave rise to perforators (thalamoperforators, thalamogeniculate arteries, circumflex arteries and peduncular arteries), medial posterior choroidal artery, lateral posterior choroidal artery and cortical branches. In 39 specimens the P1 segment was found to be larger than the posterior communicating artery, in six specimens it was found to be equal to the diameter of the posterior communicating artery and in five specimens it was found to be smaller than the posterior communicating artery diameter (fetal circulation). **Conclusions:** The authors have documented the various anomalies as well as the differences of the anatomy in this area in the Indian population as compared to the Western literature.

Key words: Basilar artery, microsurgical anatomy, posterior cerebral artery, posterior circulation, superior cerebellar artery

The posterior circulation of the brain constitutes the vertebrobasilar system and its branches. The microsurgical anatomy of the posterior circulation is very complex and variable. Surgical approaches to this area are considered risky due to the presence of the various important blood vessels and neural structures. It is important for neurosurgeons to understand the microsurgical anatomy of the posterior circulation in order to treat pathologies in this area safely and confidently. Apart from the vascular pathologies like aneurysms and arteriovenous malformations, surgery in this area may be required for tumors, epilepsy surgery and for revascularization procedures.

Many authors have described the anatomy of the posterior circulation in detail. The works of Yasargil and Rhoton stand out due to their attention to detail and vivid description. There is a paucity of Indian literature in this regard. The aim and objective of the authors was to examine and document the microsurgical anatomy of the posterior circulation in a group of Indian cadavers.

Materials and Methods

The authors studied 25 cadaveric brain specimens. The age of the cadavers ranged from 40 to 84 years with a mean of 58.96 years. The cadavers were embalmed with a mixture of 10% formaldehyde, 55% methanol, 15 g of sodium borate, 15 g of sodium citrate, 15% glycerine, 5% phenol, 15% water and 5 ml eosin to make 1 liter of arterial embalming fluid. About eight liters of this fluid was injected into the arterial system of each cadaver using a pump. The brain was subsequently delivered carefully in toto from the cadavers. Microsurgical dissection was carried out from the vertebral arteries to the basilar artery

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and its branches, the basilar artery bifurcation, posterior cerebral artery and its various branches. Microscopic dissection was done using the Serwell-Operating Microscope under 5x to 20x magnification. The arteries were painted with water color after dissection and digital photographs taken through the operating microscope. Particular attention was paid to the perforators in this area and the branches of the vertebrobasilar system. The posterior cerebral artery (PCA) was dissected up to the P3-P4 junction. Measurements of the outer diameters of the vertebral artery (VA), basilar artery (BA) and PCA were taken. Lengths of the BA and various divisions of the PCA were also noted. The PCA beyond the P3-P4 junction i.e., the cortical branches, was not dissected as the study was restricted to the cisternal anatomy. Meticulous dissection was done to distinguish the small perforators from the arachnoid strands under higher magnification. Documentation of the vascular anatomy and its variations was also done using a digital camera.

Results

Vertebral artery (VA)

Only 15 VAs could be studied in the 25 cadavaric specimens acquired by the authors. In ten specimens the VA was cut during the separation of the specimen from the skull. The mean diameter of the VA was 3.4 mm on the left and 2.9 mm on the right. One specimen showed a left hypoplastic VA (less than 0.5 mm). Both the VAs were found to meet at the pontomedullary junction or up to 10 mm below it, at a mean distance of 2.7 mm below the pontomedullary junction. In no specimen was the junction of the VA above the pontomedullary sulcus. The angle of the fusion between the two VAs was found to be from 40°-80° (mean of 51°). No fenestration or duplications of the VA were seen in the specimens. The right and left VAs are usually different in caliber. The VAs on both the sides were equal in diameter in eight instances. The right was larger than the left in six and the left was larger than the right in one case. In our study, the anterior spinal artery originated from the VA 5-7 mm proximal to the vertebrobasilar junction on the right side (mean of 6 mm) and 4-8 mm (mean 6 mm) on the left side.

The posterior inferior cerebellar artery (PICA)

The PICA is the most distal branch of the VA. Only 11 PICAs could be studied on each side out of the 25 cadaveric specimens. The diameter of the PICA ranged from less than 0.5 mm (hypoplastic) to 2.5 mm (mean 1.23 mm) on the right side and less than 0.5 mm to 2 mm (mean 1.2 mm) on the left side. The site of origin of the PICA from the vertebral artery is variable and this to some extent determines its course. In our study the site of origin varied from 6 mm to 19 mm (mean 12 mm) proximal to the vertebrobasilar junction on the right side and 10-20 mm (mean 13 mm) on the left side.

Basilar artery (BA)

The BA begins at the junction of the two vertebral arteries, courses upward in the prepontine cistern in a shallow groove in the surface of the pons and it ends by bifurcating into the two PCAs. In 13 specimens (52%) the BA was curvaceous and elongated and in the rest it was straight. The diameter of the BA varied from 3-7 mm (mean of 4.3 mm). The length varied from 24-35 mm (mean of 24.9 mm). The origin of the BA was at the pontomedullary sulcus or up to 10 mm (mean 3.1 mm) below it. The bifurcation was 2-11 mm (mean 5.6 mm) below the mamillary bodies. No fenestrations, duplications or hypoplasia of the BA were noted. The BA gave off paramedian and circumferential perforating arteries that supply most of the pons and the mesenchephalon. The other larger branches included the anterior inferior cerebellar artery (AICA) and the superior cerebellar artery (SCA) and some times the internal auditory artery. The paramedian branches are the small branches that leave the BA and immediately pierce the pons. These were one to five (mean 3.5) in number on the right side and one to seven (mean 3.8) on the left side. The circumferential arteries go laterally and course around the pons and supply the lateral portion of the pons and the cerebellar peduncles. These range from one to five (mean 3.25) in numbers on the right side and one to seven (mean 3.4) in number on the left side. Thalamoperforators were seen to rarely arise from the basilar artery bifurcation. In one specimen a large thalamoperforator could be seen arising on the right side and in another from the left side of the midline and supplying the thalamo-geniculate area. Otherwise most of the thalamoperforators are seen to arise from the P1 portion of the PCA.

AICA

The origin of the AICA varied from 3-21 mm (mean 10.35 mm) from the vertebrobasilar junction on the right side and from 0-17 mm (mean 9.5 mm) from the vertebrobasilar junction on the left side. The diameter of the AICA varied from being hypoplastic i.e., less than 0.5 mm on the right side to 2 mm (mean 0.9 mm) and then again from less than 0.5 mm (hypoplastic) to 2 mm on the left (mean 1.11 mm). The AICA courses backwards from the pons and may cross the fourth cranial nerve dorsally or ventrally as it passes from the prepontine cistern to the cerebellopontine cistern. It passes along the flocculus of the middle cerebellar peduncle to supply the lips of the cerebellopontine fissure and petrosal surface. It commonly bifurcates near the faciovestibulocochlear complex to form the rostral and the caudal trunk. This bifurcation in our series was seen to occur from 8 mm from its origin to a very distal bifurcation on the right side (mean 7.8 mm) and on the left from 0-25 mm (mean 8.2 mm) from the origin. The *rostral trunk* follows the seventh and eighth cranial nerves towards the internal auditory meatus for a variable distance before looping beneath the cerebellum, while the *caudal trunk* traverses inferomedially near the brainstem to reach the inferior cerebellar surface. Duplication of AICA was noted in six instances - two on the right and four on the left. Whenever there was duplication the rostral portion of the AICA was seen to be nerve-related while the caudal portion was nerve unrelated. The AICA also gave rise to perforating arteries to the brainstem. We found one to two (mean 1.4) small perforators and 1.75 large circumflex perforators on the the right side and a mean of 2.3 small perforators and a mean of 2.0 large perforators on the left side.

The AICA was found to be larger than the PICA in nine occasions; the AICA was equal to PICA in four occasions and the AICA was smaller than PICA in eight cases in our series.

SCA

The SCA is the most consistent branch of the BA in terms of origin and location among the arteries of the posterior circulation.[1] The SCA arose very close to the basilar bifurcation in our series - 1 to 3 mm from the basilar artery bifurcation (mean 1.45 mm on the right side and 1.33 mm on the left side). In one instance the left SCA took origin from the P1 segment of the PCA [Figure 1].

The diameter of the SCA varied from 0.5 mm to 2.5 mm on both sides (mean 1.4 mm on the right side and 1.6 mm on the left side). There were no instances of hypoplasia or aplasia of the SCA. The SCA origin lies within the interpeduncular cistern and it is separated from the PCA by the occulomotor nerve. It encircles the brainstem in a groove between the pons and the midbrain. It passes below the trochlear nerve and above the trigeminal nerve. The proximal portion courses medial to the free edge of the tentorium and the distal part passes below the tentorium making it the most rostral of the infratentorial arteries.

After passing above the trigeminal nerve it enters the cerebellomesenchephalic fissure. On leaving the cerebellomesenchephalic fissure it branches again medial to the tentorial edge and supplies the tentorial surface. Within the ambient cistern on the lateral side of the brainstem, the artery makes a shallow caudal loop and then divides into lateral and medial branches or the caudal and rostral trunks respectively. The SCA arose as a single trunk in 42 out of 50 specimens and as a double trunk in eight specimens [Figure 2]. The bifurcation of SCA into the rostral (medial) and caudal (lateral) trunks occurred at a mean distance of 8.6 mm on the right side and 7 mm on the left side from the origin of the SCA [Figure 3]. The bifurcation, however, can be very proximal, almost at the origin itself where it is duplicated or it can also be at a very distal point from the origin. The SCA gives off perforating branches to the brainstem and the cerebellar peduncles. We found two to nine thalamoperforators originating from the SCA on each side. In addition one to four circumflex perforators were seen on either side arising from the SCA which supply the lateral portion of the brainstem and cerebellar peduncles.

The SCA divides into two trunks i.e., the rostral and the caudal trunk. *The rostral (medial) trunk* supplies the vermis and paravermian area and the *caudal trunk (lateral)* supplies the hemispheres on the suboccipital surface.

PCA

The PCA arises at the basilar bifurcation and is joined by the posterior communicating artery (PComA) at the lateral margin of the interpeduncular cistern. It encircles the brainstem passing through the crural and ambient cisterns to reach the quadrigeminal cistern. It is divided into four segments P1 to P4.

The P1 segment: The P1 segment also called the precommunicating segment extends from the basilar bifurcation to the junction with the PComA. The average length of the P1 was 5-10 mm (mean 6.8 mm) on the right side and 6-11 mm (mean 7.5 mm) on the left side. The average diameter of the PCA was 2-3.5 mm (mean 2.76 mm) on the right side, 1-3.5 mm (mean 2.5 mm) on the left side. In 39 specimens the P1 segment was found to be larger than the PComA, in six specimens it was found to be equal to the diameter of the PComA and in five specimens it was found to be smaller than the PComA diameter. In the latter case which is referred to as the fetal pattern of circulation, the PCA arises predominantly from the internal carotid artery (ICA). A fetal pattern of circulation was seen on both sides in only one case [Figure 4]. In the fetal pattern of circulation the P1 was generally longer than in the normal pattern of circulation. Two main types of perforators were seen to arise from the P1 segment.

1. Thalamoperforating arteries: These arise from the superior and posterior surface of the P1 and course superiorly and posteriorly and they divide into numerous branches that terminate in the interpeduncular fossa, posterior perforating substance, cerebral peduncles, mamillary bodies and posterior midbrain [Figure 5]. These perforators were seen to arise as a bunch of small arteries or as large stem arteries which would later divide into a tuft of smaller perforators. On an average one to four small thalamoperforators (mean 2.0) were seen to arise from both sides of P1 and one to four (mean 2.0) large thalamoperforators were seen to arise from either P1 segment.
2. Circumflex perforating arteries: These encircle the brainstem for a variable distance before entering the diencephalon and mesenchephalon and are divided into long and short groups depending on how far they course around the brainstem. About one to two circumflex arteries were seen to arise from the P1 segment on either side. Sometimes the medial

posterior choroidal artery (MPCA) was seen to arise from the P1 segment. In our specimens thalamoperforators were rarely seen to arise from the upper segment of the BA. However, the upper segment of the BA gave rise to pontine branches.

The P2 segment: The P2 segment of the PCA extends from the junction of the PComA to the point where the common temporal origin takes place. The length of the P2 segment varied from 12-28 mm (mean 19.9 mm) on the right side and 10-28 mm (mean 18.44 mm) on the left side. The P2 anterior begins at the PComA and courses between the cerebral peduncle and uncus that forms the medial and lateral wall of the crural cistern inferior to the optic tract and basal vein that crosses the roof of the cistern to enter the proximal portion of the ambient cistern. The P2 posterior commences at the posterior edge of the cerebral peduncle at the junction of the crural and ambient cistern and courses between the lateral midbrain and parahippocampal and dentate gyrii which forms the medial and lateral wall of the ambient cistern below the optic tract and basal vein and geniculate bodies and inferolateral part of the pulvinar in the roof of the cistern superomedial to the trochlear nerve. Basically, the different branches of the P2 segment are as following.

1. Thalamogeniculate arteries: These arise from the P2 beneath the lateral thalamus and penetrate the part of the roof of the ambient cistern formed by the geniculate body and surrounding area. About three to five (mean 3.5) were seen on the right side and one to seven (mean 4.0) on the left side arising from the P2 segment.
2. Peduncular perforating arteries: These were one to six in number on the right side and one to seven on the left side with a mean of 3.0 on both the sides. These arose from the P2 segment and pass directly from the PCA into the cerebral peduncle. They supply the corticospinal, corticobulbar pathways as well as the substantia nigra, red nucleus and other structures of the tegmentum.
3. Circumflex branches: As previously described these run parallel and medial to the PCA and may be short or long. About one to two circumflex branches could be seen arising from the P2 segment apart from one to two circumflex branches from the P1 segment on both the left and right side.
4. MPCA: One to two were seen to arise from the P2 segment on both the sides.
5. Lateral posterior choroidal artery (LPCA): One to two could be seen arising from either side from the P2 segment.

The common temporal origin, which forms the distal limit of the P2 segment, consists of the inferior temporal group of arteries, which arise from the PCA. Detailed dissection of these cortical arteries was not done as the authors concentrated on the cisternal anatomy of the posterior circulation.

The P3 segment: The P3 segment of the PCA extends from the inferior temporal artery or common temporal artery origin to the origin of the parieto-occipital and calcarine arteries. It is also termed the quadrigeminal segment. The segment of the PCA beyond this is termed as P4 segment and was not dissected.

The average length of the P3 segment varied from 13-38 mm (mean 22.4 mm on the right and 20.9 mm on the left). A single LPCA was usually seen to arise from the P3 segment. Peduncular arteries vary from none to four on the right side and two to five on the left side (mean 3.5 on the right and 3.8 on the left). Thalamogeniculate perforators ranged from none to six on the right side and one to eight on the left side with a mean of 4.0 on either side. Cortical branches too ranged from none to four on both sides with a mean of 3.0 cortical branches from the P3 segment.

MPCA

The MPCA has a variable origin. It arose from the P1 segment in 38.6% cases and from P2 in 61.4% cases. There was a single MPCA in 43 cases and duplications

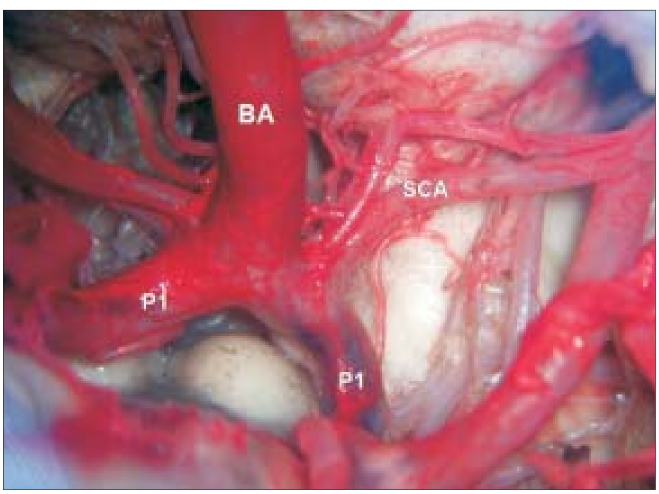

Figure 1: Left superior cerebellar artery arising from the P1 segment of the posterior cerebral artery

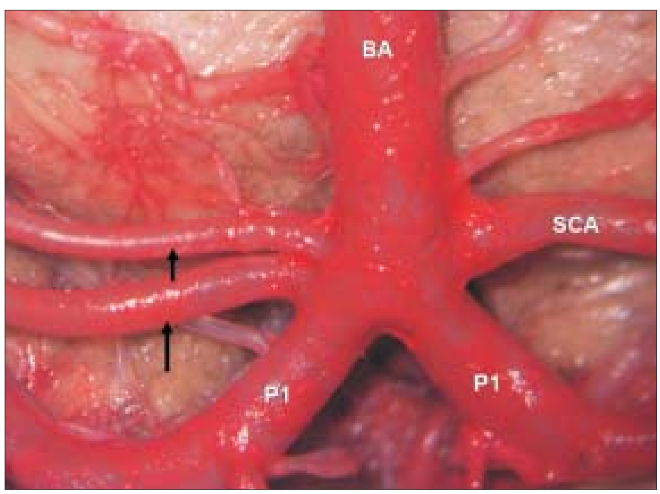

Figure 2: Duplicate origin of the right superior cerebellar artery (black arrows)

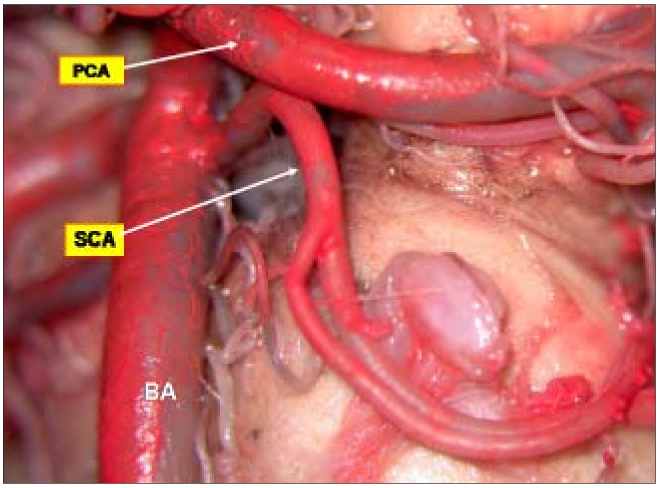

Figure 3: Branching of the left superior cerebellar artery into rostral and caudal trunks

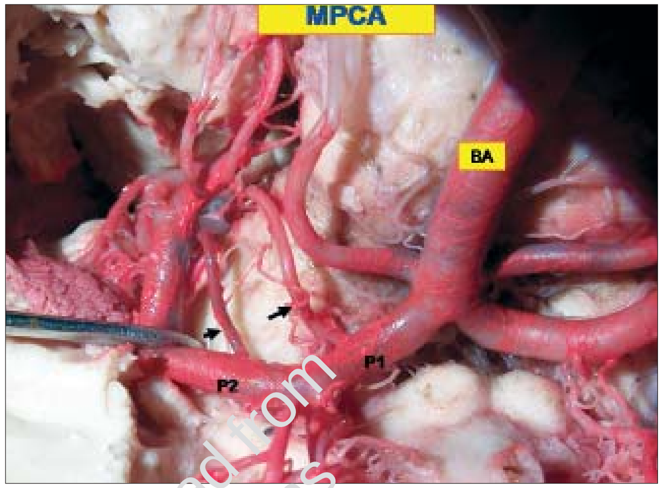

Figure 6: Medial posterior choroidal arteries arising from the P1 and P2 segments of the posterior cerebral artery

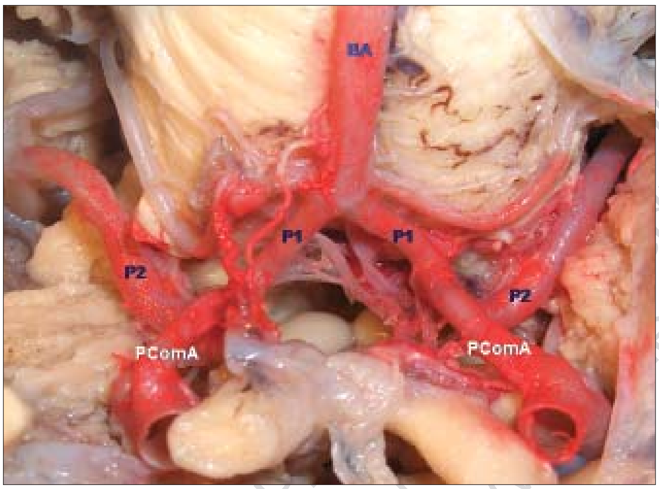

Figure 4: Bilateral fetal circulation

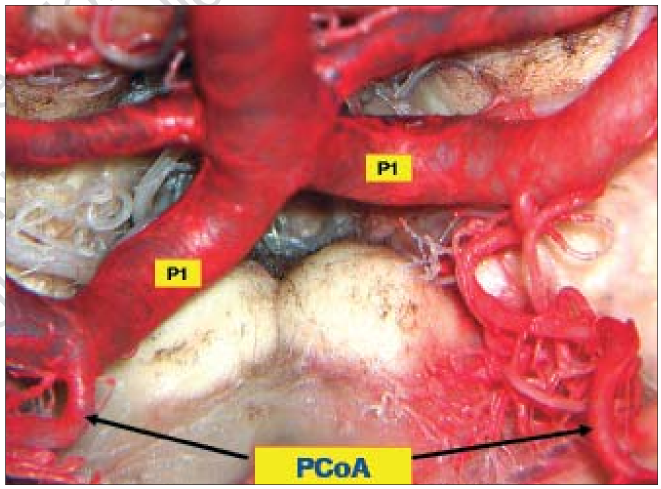

Figure 7: Posterior communicating arteries with perforators

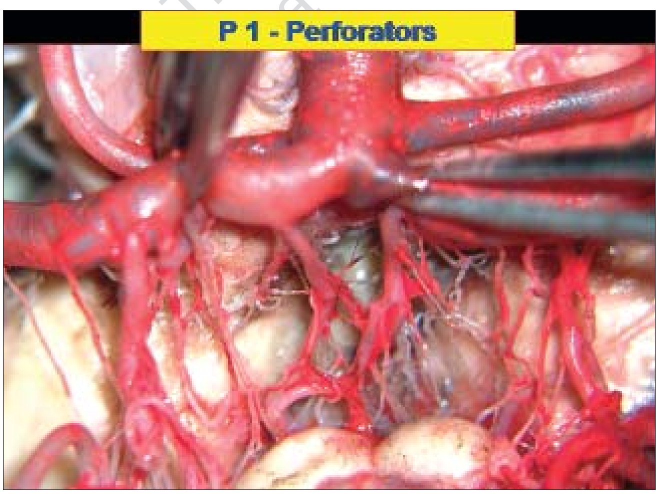

Figure 5: Multiple thalamoperforators arising from the P1 segment of the posterior cerebral artery

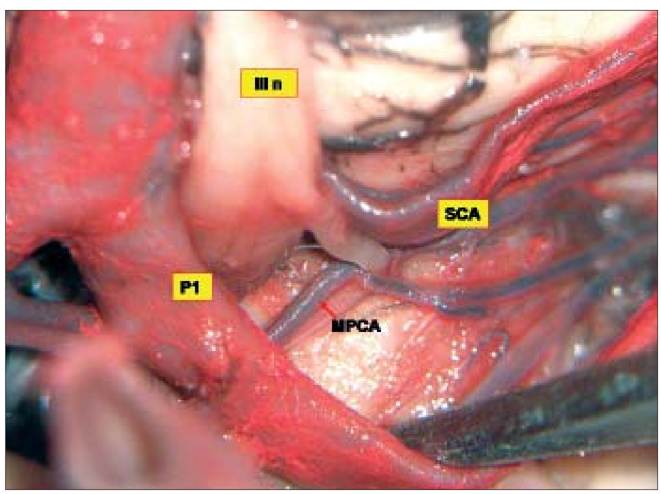

Figure 8: Third nerve fascicle entrapped by the branches of the medial posterior choroidal artery

were noted in seven cases [Figure 6]. No cases of triplication or aplasia were seen. After arising from the posteromedial aspect of the PCA the MPCA encircles the midbrain medial to the PCA distributing branches to the peduncle, tegmentum, geniculate body and colliculi. It passes the pulvinar and turns forwards lateral to the pineal gland to enter the roof of the third ventricle between the thalami and ends at the foramen of Monroe in the choroid plexus.

LPCA

The LPCA too has a variable origin. It was seen to arise from P_2 in 62% of cases, from the P3 segment of the PCA in 34% of the cases and from the common temporal artery origin in 4% cases. The number of LPCAs in each hemisphere ranged from one to two. Single LPCA was seen in 32 cases and double LPCA was seen in nine cases. From its origin the LPCA courses laterally into the lateral choroid fissure and to supply the choroid plexus of the temporal horn.

Posterior communication artery (PComA)

The PComA forms the lateral boundary of the circle of Willis. The diameter of the PComA varied from hypoplastic (less than 0.5 mm) to 4 mm (fetal circulation) on the right side (mean 1.25 mm) and 0.5 mm to 3 mm (mean 1.125 mm) on the left side. Length of the PComA ranged from 8 mm to 18 mm on both sides with a mean of 12.13 mm on the right side and 11.88 mm on the left side. The main branches from the PComA were the perforators which arose from the superior and lateral surfaces of the PComA and coursed superiorly to penetrate the tuber cinereum, premamillary part of the floor of the third ventricle and the posterior perforating substance of the interpeduncular fossa [Figure 7]. The PComA branches ranged from two to 15 on both sides with a mean of 7.8 on the right side and 5.7 on the left side. As in the P1 segment there are basically two types of perforators: Small, fine delicate perforators and stem artery which would then divide into tuft of perforators.

Discussion

The microsurgical anatomy of the posterior circulation, especially the cisternal anatomy is of importance to the cerebrovascular surgeons in surgical approaches to the various pathologies in this region. Apart from aneurysms and arteriovenous malformations, the neurosurgeon may be called upon to operate other pathologies like tumors in this area, for epilepsy surgery, posterior temporal lobectomies and posterior cerebral revascularization procedures.

Vertebral artery (VA)

Many anomalies of the VA have been described by various authors. Fenestrations, duplications, complete atresia and ending of one of the VAs as the PICA and the other continuing as the BA are some of the variations reported.[1] However, in our series we could not find any such variations. Several small branches to the anterolateral, lateral and posterolateral medulla have been reported.[1]

PICA

The PICA has a variable site of origin and this might determine its course. Most commonly it arises 14-16 mm below the vertebrobasilar junction in the anterior medullary cistern. It forms a caudal loop around the cerebellar tonsil to enter the cisterna magna. It has been reported by Yasargil *et al* that in 35% of the cases the artery will extend a few mm lower than the tonsil or the foramen magnum. Hence, the position of the caudal loop as seen on the angiography is not an entirely reliable sign to assess tonsilar herniation.[1] The PICA is present as a single vessel in 90% of the cases, duplicated in 6% and absent in 4% according to the studies of Fuji and Rhoton.[1] No such variations were noted in our study.

The basilar artery (BA)

The BA begins in the area of the pontomedullary sulcus by the union of the two VAs and courses upwards in the prepontine cistern in a shallow groove on the surface of the pons. With increasing age the BA becomes more tortuous and elongated and the bifurcation may lie much more superiorly. In the series of Yasargil *et al* only 25% of the arteries were seen to run in a straight course.[1] However, in our study 74% of the cases the artery was found to be in the midline in a straight course and in the rest it was seen to be deviated from the midline with a tortuous course. Various anomalies like fenestrations, duplications (persistence of the paired basilar arteries of the embryo), persistence of carotidobasilar anastomosis such as premature trigeminal, optic, hypoglossal or proatlantic arteries etc have all been described.[1] In our series, however, we could not find any such anomalies. The BA gives off paramedian and circumferential perforating arteries that supply most of the pons and mesenchephalon in addition to the larger branches like the AICA, the SCA and the internal auditory artery.[1] The same was also noted in our series. Two twig arteries arising from the proximal portion of the BA supplying and penetrating the anteromedial medulla were seen in the series of Yasargil *et al*.[1] This could not be noted in our series.

AICA

The origin of the AICA from the BA is variable. Yasargil *et al* have found solitary AICA in 58%, duplicated in 20%, triplicated in 20% and rarely absent in 2%.[1] In our series solitary was found to be in 78% and duplicated AICA was seen in 22%. The AICA arose from the lower third of the BA in 7.14%, from the middle third in 60.7%

and from the upper third in 32.14%. This was in contrast to the findings of Yasargil *et al* who have noted 84% of the AICAs arising from the lower third of the BA and 16% from the middle third. In the cerebellopontine cistern the AICA bifurcates into two main trunks: The rostral and caudal trunks. The rostral trunk is generally also referred to as the nerve-related trunk due to its relation to the VII-VIII nerve complex. Rich anastomoses exist between the peripheral branches of the SCA, AICA and PICA. There is usually an inverse relationship between the AICA and the PICA in their diameter which was noted in our series.[1,2] The AICA is commonly exposed during surgeries of the cerebellopontine angle. Aneurysms of the AICA are rare. The AICA may be displaced or may be involved in the vestibular schwannomas of the cerebellopontine angle. Great care must be taken to preserve the AICA. An injury or occlusion of the AICA may result in ischemia or infarctions of the brainstem and cerebellar peduncles, rather than cerebellar hemispheric infarctions. The recovery of patients from surgical injuries to the AICA is possible because of the adequacy of the collateral circulations from the SCA and PICA as mentioned above.

SCA

The SCA is the most consistent artery of the posterior circulation in terms of origin and location.[2] Usually the SCA arises from just below the basilar bifurcation and sometimes directly from the P1 segment of the PCA [Figure 1]. The SCA frequently has points of contact with the occulomotor, trochlear and trigeminal nerve.[2] The bifurcation of SCA into two major trunks, rostral and caudal according to Rhoton *et al* is 0.6 to 34 mm [average 19 mm] from the origin. In our series it was at a mean of 8.6 mm from the origin on the right and at a mean of 7 mm on the left. Six cases of duplicate origin of the SCA could be seen and the rostral and the caudal trunks were formed by the duplications rather than the divisions of the same later. The perforating branches of the SCA are divided into direct and circumflex type. Direct perforators have a straight course to enter the brainstem while the circumflex perforators wind around the brainstem before terminating in it. Rhoton *et al* have noted two to five perforating branches. In our series none to ten perforators were noted arising from the SCA. The commonest perforators were the circumflex type in our series. Constant cortical supply of the SCA is to the tentorial surface. It supplies the majority of the tentorial surface and frequently the adjacent parts of the petrosal surface. The SCA is seen to have points of contacts with the occulomotor, trochlear and trigeminal nerves.

Occulomotor nerve: The proximal part of the SCA passes below and is separated from the PCA by the occulomotor nerve. This position of the occulomotor nerve between the PCA and SCA is nearly constant. In one of our cases one of the fascicles of the occulomotor nerve was seen to be entangled among the branches of the MPCA resulting in traction on the former [Figure 8]. The authors hypothesize that this could be one of the causes of congenital anisocoria. Sunderland suggests that the occulomotor nerve may occasionally be constricted between the PCA and SCA.[2] Marinkovic and Gibo have also noted the presence of vessels which penetrate the nerve trunk itself in addition to the above phenomenon.[3]

Trochlear nerve: This nerve may come in contact with the SCA in almost all cases at the cerebellomesencephalic fissure.

Trigeminal nerve: The SCA encircles the brainstem above the trigeminal nerve making a shallow caudal loop on the lateral side of the pons. The contact between the SCA and the trigeminal nerve occurs at the most prominent caudally projected loops. Some of the SCAs may have a contact with the trigeminal nerve and may involve the main rostral or caudal or both the rostral and caudal trunks. The point of contact of the SCA is usually the superior or superomedial aspect of the nerve and often a few fascicles of the nerve are indented or distorted by the vessels. This was seen in 12% of cases in the Rhoton *et al* study. The significance of these contacts in trigeminal neuralgia has been studied by many authors.[2]

The situation of the BA bifurcation is an important determinant of the initial course of the SCA. The level of the bifurcation of the BA is normal if the bifurcation occurs at the ponto mesenchephalic junction, high if it occurs above it and low if it occurs below this. In our study the bifurcation was at the normal position in 56% of the cases, in 44% of cases above it and in none of the cases below it. In Rhoton's study, 18 of 25 i.e., 72% were normal, 24% were high and 4% were low-lying BA bifurcations. A transsylvian approach is required to approach the high basilar artery bifurcation while for the low and normal bifurcations, a surgeon can adopt the sub temporal approach.

PCA

The PCA arises as the terminal branch of the bifurcation of the BA. It is joined by the PComA at the lateral margin of the interpeduncular cistern. It is distributed to the posterior part of the cerebral hemisphere and supplies the posterior part of the cerebral hemispheres, thalamus, midbrain and deeper structures including the choroid plexus of the lateral and third ventricles.

PCA segments:

P1 segment: The P1 segment also called as the precommunicating segment extends from the basilar bifurcation to the junction of PCA with PComA. The branches of the P1 segment include the thalamoperforators, the circumflex perforators, the MPCA, etc. In one instance the SCA was seen to arise from the P1 segment. Embryologically, it arises from the ICA. With development, the P1 segment of PCA usually enlarges to form a major connection between the BA and PCA with subsequent reduction in the size of the PComA. Persistence of the fetal type of posterior cerebral circulation where the P1 was smaller than PComA, was seen by Saeki and Rhoton in 22% of cases (unilateral in 20% and bilateral in 2%). Yasargil *et al* reported 67.5% cases of the adult type and 24.5% of fetal type and an equal representation in 8% of the cases. Kameyama and Okinaka reported similar results.[1] In our study the fetal type of circulation was seen in 10%, the adult type of circulation in 78% of cases with an equal representation in 12% of cases.

P2 segment: The P2 segment begins at the PComA and lies within the crural and ambient cisterns and terminates lateral to the posterior edge of the midbrain where the origin of the inferior temporal arteries takes place. The P2 segment is further divided into anterior (P2A) and posterior halves (P2P).[1,4-6] Rhoton *et al* have found P2A and P2P to be 25 mm long together, whereas in our study it has been around 19 mm in length. It helps in identifying the origins of the branches. The branches of these segments include:

1) Peduncular perforating arteries: These peduncular branches penetrate the cerebral peduncles.
2) Thalamogeniculate arteries.
3) Apart from perforating branches the P2 segment also gives rise to branches to the ventricular and choroid plexus branches i.e., MPCA and LPCA in different cases.
4) The common temporal origin gives rise to inferior temporal branches such as the anterior temporal artery, middle temporal artery and posterior temporal arteries.

P3 segment: The P3 segment or the quadrigeminal segment of the PCA which proceeds posteriorly from the origin of the inferior temporal arteries continues to curve around the mesenchephalic tectum until it pierces the quadrigeminal cistern and reaches the lateral geniculate body under the pulvinar thalami. Rhoton *et al* have noted the average length of the P3 segment to be 2 cm. The P3 segment in our series had a mean length of 22.4 mm on the right and 20.9 mm on the left.

The branches of the P3 segment include [a] Peduncular perforating arteries, [b] the thalamogeniculate arteries, [c] the cortical branches which may be from none to four in number with a mean of 3.0 in our study which included the inferior temporal branches, the posterior callosal arteries, the calcarine and parietooccipital arteries etc.

P4 segment: The PCA, after the origin of the parietooccipital and calcarine arteries, is called the P4 segment.

Branches of the PCA:

The following are the branches of the PCA:

a] Perforating branches to the diencephalon and midbrain
b] Ventricular branches of the choroid plexus and walls of the lateral and third ventricle and adjacent structures and
c] Cerebral branches to the cerebral cortex and splenium of the corpus callosum.

a) *The perforating branches*

The perforating branches or the central branches of the PCA are divided into two groups: The direct perforating branches and the circumflex arteries.[4] Direct perforating branches are those which originate from the PCA and directly go to the brainstem. They include thalamoperforating branches, thalamogeniculate branches and peduncular perforating arteries. The first one arises from the P1 segment; while the latter two arise from the P2 and P3 segments of the PCA.

The circumflex branches encircle the brainstem for a variable distance before entering the diencephalon and mesencephalon. They are divided into long and short, depending upon the course around the brainstem.[4]

1] The thalamoperforating arteries: These arise from the initial part of the PCA i.e., the P1 segment. They enter the interpeduncular fossa that is surrounded by cerebral peduncles laterally and to the rostral pons caudally and mamillary bodies rostrally. They then penetrate the posterior perforating substance and supply the portions of the midbrain, thalamus, pre-tectum and subthalamic regions.[7] Marinkovic *et al* have studied the thalamoperforators (posterior thalamoperforating arteries or interpeduncular thalamoperforating arteries) in detail.[7] They have found that the thalamoperforating arteries vary in number from none to ten with an average of 2.0, while in our study a mean of 2.0 was found on both sides which conform to the Western literature. Rhoton *et al* have reported that the majority of the thalamoperforating arteries originated from the middle third of the P1 segment of the PCA. However, such a disposition was not noted in our series and we found the perforators to be distributed all along the P1 segment. Marinkovic *et al* have also reported that most of the perforating branches arose from the P1 segment and only 5.8% of these perforating branches originated from the P2 segment.[7] In our study no thalamoperforators were seen to arise from the P2 segment. Rhoton *et al* have noted that some of the thalamoperforators originated from the posterior and lateral surface of the upper 1 cm of the basilar artery. In our studies no specimen revealed any thalamoperforators from the BA bifurcation except in one case where a large thalamoperforator was seen arising from the basilar tip. In our study thalamoperforators (interpeduncular perforators) were seen to originate from the P1 segment and the SCA only. These perforators arose as either as a large stem artery or as very fine arteries. Marinkovic *et al* have also reported common stem origin of the perforating arteries in 88.4% of the cases. These stems were arc-like or S-shaped. Their proximal part as a rule was convex towards the opposite side and ran just above the bifurcation of the BA. The branching of these common stem arteries was usually complex. The thalamoperforating arteries always arose from the posterosuperior aspect of the P1 and very rarely from the anterior surface of the P1. The origin of thalamoperforators was not necessarily symmetrical on both sides, which was also noted by Rhoton *et al*.[4] Thalamoperforators supply the anterior and part of the posterior thalamus, subthalamus and medial part of the upper midbrain including the substantia nigra, red nucleus, occulomotor and trochlear nuclei, the occulomotor nerve, mesencephalic reticular formation, pretectum, rostro medial part of the floor of the fourth ventricle and posterior portion of the internal capsule. Occlusion of the thalamoperforating arteries depending upon the size of infarction or ischemia may produce a variety of focal syndromes including contralateral hemiplegia, cerebellar ataxia and tremor along with ipsilateral occulomotor nerve paresis (Nothnagel's syndrome).[3]

The microsurgical anatomy of this area is very important, especially in the surgical treatment of cerebral aneurysms of the posterior circle of Willis. It is well know that posterior circulation aneurysms usually arise from the basilar bifurcation or from the P1 segment of the PCA or from the PComA and P1 junction.[7] Hence it is imperative that great care should be taken during surgery in this area to preserve the interpeduncular perforating arteries.

2. *Peduncular perforating arteries:* These are one to seven in number (mean 3.0), usually arise from the P2 segment and pass directly from the P2 segment of the PCA into the cerebral peduncle. They supply the corticospinal and corticobulbar pathways as well as the substantia nigra, red nucleus and other structures of the tegmentum. They may also send branches to the occulomotor nerve.[3]
3. *Circumflex branches:* The circumflex groups of arteries arise from the P1 or P2 segment of the PCA. They are one to four in number with a mean of 2.0. They are divided into short or large circumflex arteries. The short circumflex branches reach as far as geniculate bodies while the long may reach the colliculi. These branches course medial to the P2 and MPCA and send branches to the cerebral peduncle. The short circumflex arteries send branches to the interpeduncular fossa and posterior perforating substance; while the long circumflex arteries also referred to as quadrigeminal artery or collicular artery pass around the brainstem to reach the quadrigeminal cistern and supply the quadrigeminal bodies. They encircle the midbrain medial to the PCA and send small rami to the cerebral peduncle and geniculate bodies and occasionally, to the tegmentum, pulvinar and quadrigeminal plate. They may arise from the P1 or P2. Duvernoy in 1978 consistently saw an accessory quadrigeminal artery paralleling the course of the quadrigeminal artery and supplying the lateral aspect of the superior colliculus.[1] However in our study, this was not noted.
4. *Thalamogeniculate arteries:* The thalamogeniculate arteries arise directly from the P2 segment or the P3 segment beneath the lateral thalamus and penetrate the part of the roof of ambient cistern formed by the geniculate bodies and the surrounding area. Rhoton *et al* reported most of the thalamogeniculate arteries to arise from the P2 segment.[4] However, in our series we found that an equal number arose from the P2 segment as well as the P3 segment of the PCA. These were seen to arise individually unlike the thalamoperforators which usually were seen to arise as large stem perforators with complex division. Milisavljevic *et al* noted large stem perforators in only 26.67% of the cases.[8] They have studied thalamogeniculate perforators of the PCA in great detail.[8] They found the thalamogeniculate perforators to originate also from the anterior temporal, medial temporal, common temporal arteries and other cortical arteries like calcarine or parietooccipital arteries. According to the literature available the numbers of thalamogeniculate arteries can vary greatly.[8] Zeal and Rhoton have reported one to seven (mean 2.4) in number, while Milisavljevic *et al* have reported two to 12 with a mean of 5.7. The number in our series too conformed to the latter ranging from two to 12 with a mean of 7.75. Aneurysms of the distal PCA may affect the thalamogeniculate arteries in several ways in the same ways as described for the thalamoperforators. Vasospasm of the thalamogeniculate arteries may also occur after SAH. Thalamogeniculate arteries may also be injured during surgery in this area for tumors and other lesions. All these may lead to ischemia of the area supplied by the thalamogeniculate arteries i.e. the medial geniculate body, portions of the subthalamus, a large region of the thalamus and part of the posterior limb of the internal capsule. This may result clinically in the Dejerine-Roussy thalamic syndrome characterized by disturbance in the sensation, thalamic pain, slight hemiparesis and homonymous hemianopia.[8] Usually (66.67%), anastomosis may be present between thalamogeniculate arteries but may not connect all arteries. Hence it is important that the thalamogeniculate arteries are spared during

operations in this area. It is also unlikely that occlusion of a single thalamogeniculate artery would produce the complete syndrome because of the anastomosis. Hence, usually this syndrome is caused by the occlusion of the PCA proximal to the origin of all these thalamogeniculate arteries.[8]

b) Ventricular and choroid plexus branches

These constitute the MPCA and LPCA.

1. *MPCA:* The MPCA has a variable origin. Lang and Kapplinger have described that the artery originated from the P2 segment in 83.3% of cases and from P1 in 9.4%, from both P1 and P2 in 1.2% cases and from the distal PCA segments in 7.1% cases.[1] Zeal and Rhoton also confirmed these findings.[1] In their series the MPCA arose from the P2 in 71% of cases, from P1 in 12% of cases, from P3 in 4% and P4 in 13%. The same authors report a single MPCA in 54%, duplication in 32% and triplication in 14%.[1] In our series the MPCA arose from P1 in 38.6% and from P2 in 61.4% of the cases. It was seen as a single artery in 86% and seen to be duplicate in 14%.
2. *The LPCA:* The LPCA too has a variable origin. Zeal and Rhoton have found the origin of the LPCA to be from P2 in 51%, P3 in 30%, P4 in 15% and rarely from the MPCA (in 4%). Herthem *et al* have noted that the origin of the LPCA was from the P2 segment in 24%, P3 segment in 41%, the parietooccipital artery in 13%, the splenial artery in 12%, posterior temporal artery in 6%, the common inferior temporal trunk in 2% and hippocampal artery in 2%.[6] In our series the LPCA was seen to arise from the P2 in 62%, from P3 in 34% and in 4% from the common temporal origin. The number of LPCAs usually vary from one to nine with a mean of three to four according to Galloway and Greitz.[1] In our series too we found one to two LPCAs in the specimens with a mean of 1.5.

c) Cortical branches

The cortical branches of the PCA were not studied in detail as it was beyond the purview of this study. However, the cortical branches include the inferior temporal arteries, which include the hippocampal arteries, anterior, middle, posterior and common temporal arteries; the posterior callosal or splenial artery; the parietooccipital arteries and the calcarine artery.

PComA: The PComA which forms the lateral boundary of the Circle of Willis is seen to arise from the posteromedial surface of the supraclinoid portion of the ICA within a few mm of the anterior portion of the carotid cistern, approximately midway between the origin of the ophthalmic artery and the ICA bifurcation.[1,3] In the embryo the PComA is continuous with the PCA, but in the adult the latter artery is seen to be included by the basilar system. When the PComA remains the major origin of the PCA the configuration is said to be fetal. If the PComA is normal or small in size, it courses posteromedially to join the PCA but if it is a fetal type it courses further laterally above or lateral to the occulomotor nerve i.e., if it is normal it is medial to the occulomotor nerve, if it is fetal type it is lateral to the occulomotor nerve. The caliber of the PComA is highly variable. Dilenge in 1962 found the PComA diameter to be greater than 2 mm in 38.7%, between 1-2 mm in 41.2% and less than 1 mm in 18.9%.[1] De Vriese (1905) and Paget (1944) suggest that the mean caliber of PComA in children is larger and is seen to decrease with advancing age.[1] Hypoplasia, aplasia, duplication of the PComA, fenestration etc. have all been reported.[1] In our series hypoplasia of the PComA was seen in eight cases. However, no duplication or aplasia was noted. An average of eight, ranging from 4-14 perforating branches arise from the PComA, mostly from the superior and lateral surfaces.[4] In our series a mean of 7.8 branches on the right side and 5.7 on the left were seen to arise from the superolateral surface of PComA. Hence it is advisable while dissecting the PComA to remain on the medial aspect of the artery in order to avoid injury to these perforators. These perforators are generally divided into the anterior group and the posterior group.[1,2,4] These branches are also quite variable in size and may originate as large stem branches with ramifications or small thin branches. Even when the PComA is small, the perforators may be seen to be stout and large. The mamillary bodies too are supplied by the branches from the PComA or by the branches from the proximal PCA i.e., P1.[1]

Conclusion

Microsurgical anatomy of the posterior circulation is extremely complex and variable. It is important for the microneurosurgeon to have a working knowledge of the microsurgical anatomy of the vascular structures as well as the neural structures in this area in order to tackle the various pathologies in this region safely and confidently. The authors have made an attempt to document the various anomalies as well as the differences of the vascular anatomy in this area in the Indian population as compared to the Western literature.

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Accepted on 16-11-2006
Source of Support: Nil, **Conflict of Interest:** None declared.