The Parieto-Occipital Artery Revisited: A Microsurgical Anatomic Study

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BACKGROUND: **The parieto-occipital artery (PoA) is the terminal posterior cerebral artery branch, which typically runs in the parieto-occipital sulcus. Previous studies have highlighted variation in the PoA origin and branching pattern and their clinical implications. Nevertheless, PoA anastomoses have not been systematically investigated. The present study aimed to assess whether putative variation in PoA origin and its branching as well as anastomotic pattern is associated with differences in demographic/anthropometric variables.**

METHODS: **In 15 cadaveric heads, PoA anatomic features were quantified and assessed in relation to demographic/anthropometric variables.**

RESULTS: **The mean distance of PoA origin from the posterior limit of the splenium and the occipital pole (OP) is 3.1 and 53.1 mm, respectively. The latter is significantly longer in taller individuals. The PoA supplies a mean of 10.5 and 9.1 branches to the precuneus and cuneus, respectively. PoA anastomoses primarily involve the precuneal artery complex (PAc) and the calcarine artery. The analysis indicated significant, positive correlations between the distance of PoA origin from the OP and the number of PoA anastomoses and between the number of PoA precuneal and cuneal branches.**

CONCLUSIONS: **Although the PoA invariably supplies the precuneus and almost always the cuneus, its direct contribution to the former seems inferior to PAc. Nevertheless, the PoA frequently shows putative collateral supply networks to the precuneus and cuneus via anastomoses with the PAc and calcarine artery, respectively. The distance between PoA origin and OP varies with an individual's height; the frequency of intrahemispheric PoA anastomoses varies with its site of origin.**

INTRODUCTION

The parieto-occipital artery (PoA) is the terminal branch of the posterior cerebral artery (PCA), which typically runs in the parieto-occipital sulcus (Pos) at the medial border of the cuneus and precuneus.[1-9]

The origin of the PoA in relation to segmentation patterns of the PCA, as well as its branching pattern, has been investigated by several previous anatomic studies. Despite differences in the PCA segmentation schemes followed by previous studies,[7-9] findings in several cadaveric cohorts provide evidence for considerable variation in the origin of the PoA.[1-6,8,9] Moreover, anomalous origins of the PoA have been highlighted by previous case reports based on angiographic methods.[10-14] The branching pattern of the predominantly single PoA[1,4,9] within areas such as the cuneus, precuneus, and visual cortex also shows considerable variation, as indicated by previous findings.[1,3,4,9,15]

The present cadaveric study focusing on the PoA aims to provide a detailed anatomic description of its origin, course, and

Key words
- Anastomoses
- Calcarine artery
- Cuneus
- Parieto-occipital artery
- Parieto-occipital sulcus
- Posterior cerebral artery
- Precuneus

Abbreviations and Acronyms
ACA: Anterior cerebral artery
AVM: Arteriovenous malformation
BMI: Body mass index
CA: Calcarine artery
CPOIA: Contralateral parieto-occipital interhemispheric approach
OIA: Occipital interhemispheric approach
OP: Occipital pole
PAc: Precuneal artery complex
PCA: Posterior cerebral artery
PoA: Parieto-occipital artery
POIA: Parieto-occipital interhemispheric approach
Pos: Parieto-occipital sulcus

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branching pattern. By systematically assessing putative anastomoses and the quantification of branches within common supply areas, we also aimed to provide novel insights into the anatomic features of this vessel. Moreover, we tested the hypothesis that variation in several anatomic characteristics of the PoA (origin and branching pattern) supported by previous studies is associated with differences in demographic and/or anthropometric variables. In addition, we assessed the relationship between the PoA and distinct anatomic landmarks that can be used in surgical approaches and effective treatment of associated diseases.

METHODS

Fifteen formalin-fixed, colored latex-injected human cadaveric heads (9 male and 6 female) preserved in a solution of ethyl alcohol (10%) were studied. The mean values ±standard deviation of the height, weight, and body mass index (BMI, calculated as weight in kilograms divided by the square of height in meters) of the sample were 167.98 ± 10.81 cm, 70.49 ± 21.04 kg, and 25.01 ± 7.21 kg/m^2, respectively. Microsurgical instruments and the operating microscope (OPMI pico, Carl Zeiss Meditec AG, Oberkochen, Germany) were used during the dissection process.

After an occipital craniotomy, the occipital lobes were exposed and after their lateral displacement, the PoA distribution was studied, bilaterally. Then, the cerebrum was removed from the cranial vault to investigate the PoA branching pattern. Moreover, putative interhemispheric anastomoses of the PoA were investigated.

After sagittal sectioning of the corpus callosum and brainstem, allowing separation of the cerebral hemispheres, the origin of PoA in each hemisphere was identified. Its course in relation to the calcarine artery (CA) and Pos and the PoA branching pattern was also recorded. We measured the distance from the PoA origin to the posterior edge of the corpus callosum (splenium) and to the posterior border of the occipital pole (OP). After subpial dissection, the PoA branching pattern was identified and the number of branches supplying the precuneal lobule, cuneus, and additional areas irrigated by the artery were recorded. We examined putative intrahemispheric anastomoses of the PoA. We followed the PCA segmentation scheme described by Rhoton.[7]

Statistical Analysis

The measured PoA anatomic variables were assessed for statistically significant differences between hemispheres (right vs. left), genders (male vs. female), age-groups (<78 years vs. ≥78 years), height groups (<170 cm vs. >170 cm), weight groups (<70 kg vs. >70 kg), and BMI groups (<26 kg/m^2 vs. >26 kg/m^2). Normally distributed variables were expressed as mean value ±standard deviation; variables with skewed distribution were expressed as median value (interquartile range). If the normality assumption was satisfied for the comparison of means between 2 groups, a Student *t* test was used. Mann-Whitney rank sum tests were carried out if data were not normally distributed (Shapiro-Wilk normality test). The Spearman correlation coefficient was used to explore the association of 2 continuous variables. All reported *P* values were 2-tailed and statistical significance was set at $P < 0.05$. Analysis was carried out using SigmaStat statistical analysis software.

RESULTS

Microsurgical Study

The exposure of the occipital lobes after craniotomy provided adequate access to the superior and lateral occipital cortical areas supplied by the PoA. Lateral traction of the occipital lobe was necessary to show the PoA branches at the medial surface of each hemisphere. The PoA origin was not easily identifiable microsurgically, primarily because of the long distance of the location of the artery from the posterior surface of the occipital lobe. Hence, in most heads studied, the PoA origin could only be identified after dissection of the PCA, within the ambient cistern.

Microanatomic Study

Origin of the PoA. The PoA was present in all specimens as a PCA branch. Its emersion from the P4 segment (origin at the anterior end of the calcarine sulcus) (Figure 1) was detected in 75%, from P2 (origin from the posterior communicating artery to the posterior edge of the midbrain) in 21.43% (17.86% from the

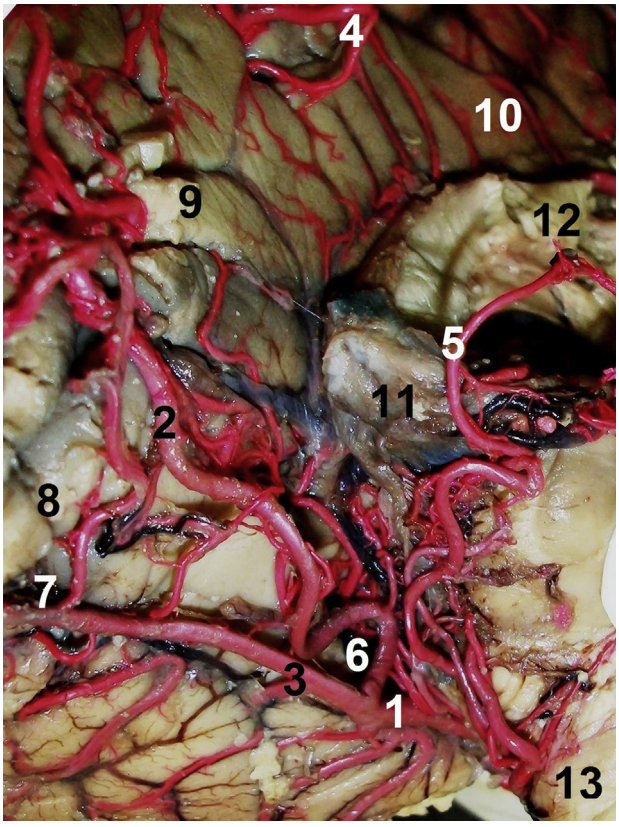

Figure 1. Midsagittal section of human brain, left hemisphere (after removal of the cerebellum), medial surface, zoom in the perisplenial area. (*1*) Posterior cerebral artery (transition of P3 segment to P4); (*2*) parieto-occipital artery; (*3*) calcarine artery; (*4*) precuneal artery complex; (*5*) medial posterior choroidal artery; (*6*) parieto-occipital sulcus; (*7*) calcarine sulcus; (*8*) cuneus; (*9*) precuneus; (*10*) cingulate gyrus; (*11*) splenium of the corpus callosum; (*12*) body of corpus callosum; and (*13*) brainstem.

posterior P2 and 3.57% from the anterior P2), and from P3 (between P2 and P4) in 3.57% (a single hemisphere). In one third of cadaveric heads, the PoA origin differed between the 2 hemispheres (i.e., P3 vs. P4, or P2 anterior vs. P4, or P2 posterior vs. P4). In 80% of the cadaveric heads (4 of 5) showing this type of interhemispheric variation in PoA origin, the left PoA emerged more posteriorly than the right PoA. As shown in Table 1, the mean distance of the PoA origin from the

Table 1. Results of the Studied Anatomic Parameters Regarding the Parieto-Occipital Artery and Relative Morphometric Data

	Morphometric Data						Studied Parameters					
Number	Gender	Age (years)	Height (cm)	Weight (kg)	Body Mass Index (kg/m^2)	Side	a1 (N)	a2 (N)	b1 (n)	b2 (n)	d1 (mm)	d2 (mm)
1	M	91	170.18	68.04	23.49	L	1	3	24	9	5	52
2						R		6	7	7	−38	95
3	M	88	165.10	76.66	28.12	L	0	2	7	13	7	42
4						R		5	7	16	13	42
5	M	92	172.72	49.90	16.72	L	0	2	6	3	16	45
6						R		4	6	5	4	67
7	M	82	185.42	108.86	31.66	L	0	4	9	12	11	46
8						R		5	11	4	−4	62
9	M	67	182.88	81.65	24.41	L	0	2	3	9	6	56
10						R		1	4	*	*	*
11	M	55	182.88	83.91	25.09	L	0	1	12	2	6	48
12						R		1	14	4	8	52
13	F	96	149.86	45.36	20.20	L	0	2	8	3	14	35
14						R		3	12	6	4	43
15	F	56	154.94	65.77	27.39	L	0	0	3	2	5	46
16						R		3	5	3	−26	60
17	M	83	172.72	40.82	13.68	L	0	4	14	30	16	45
18						R		0	21	22	18	43
19	F	59	165.10	101.60	37.27	L	0	2	24	16	11	42
20						R		5	17	12	−27	80
21	M	79	175.26	58.97	19.20	L	0	3	9	18	−18	70
22						R		7	6	6	−3	66
23	F	78	162.56	81.65	30.89	L	0	1	7	10	17	42
24						R		2	8	6	8	52
25	F	60	154.94	84.82	35.33	L	0	4	7	2	−13	75
26						R		3	9	7	15	44
27	F	84	160.02	70.31	27.45	L	0	3	12	7	4	41
28						R		3	14	0	13	47
29	M	57	165.10	39.01	14.31	L	0	2	20	17	9	48
30						R		4	10	14	8	54
Mean value		75.13	167.98	70.49	25.01		0.07	2.90	10.53	9.14	3.07	53.10
Standard deviation		14.65	10.81	21.04	7.21		0.26	1.69	5.81	6.95	14.28	13.78

a1, number of interhemispheric PoA (parieto-occipital artery) anastomoses; a2, number of intrahemispheric PoA anastomoses; b1, number of PoA branches supplying the precuneus; b2, number of PoA branches supplying the cuneus; d1, distance of the PoA origin from the posterior limit of the corpus callosum; d2, distance of the PoA origin from the occipital pole; M, male; L, left; R, right; F, female; N, anastomoses; n, branches.

*Not identifiable parameter (because of specimens' limitations).

posterior border of the splenium and the OP was 3.1 ± 14.3 mm (range, −38 to 18) and 53.1 ± 13.8 mm (range, 35–95), respectively. In 24.14% of hemispheres, the PoA origin was located anterior to the posterior splenial border.

Course of the PoA. In 90% of specimens, the PoA emerged as a single artery. In 96.67% of the hemispheres, the PoA coursed superiorly to the CA and in all hemispheres, it was detected along the Pos at variable depths, usually more than 1 cm deep (Figure 2). A notable variation of the PoA course was detected in a single hemisphere in which the main stem of the PoA ran within the calcarine sulcus.

Branching Pattern of the PoA. Table 2 summarizes the observed frequencies of arterial supply by PoA branches. In all specimens, the PoA supplied branches to the precuneal lobule and in all but one to the cuneus (Figures 2 and 3). A splenial branch of PoA supplying the corpus callosum and retrosplenial area (Figure 3) was found in 30% of the hemispheres (Table 2). In 2 hemispheres, the calcarine and splenial branches of the PoA were unilaterally duplicated. In addition, a duplicate thalamogeniculate branch was observed in a single hemisphere and quadruplication of the hippocampal branch was detected in another hemisphere.

The mean number of PoA branches supplying the precuneal lobule was 10.53 ± 5.81 (range, 3–24); it was 9.14 ± 6.95 (range, 0–30) for the cuneus (Table 1). Table 3 summarizes the mean number of additional PoA branches supplying other brain areas.

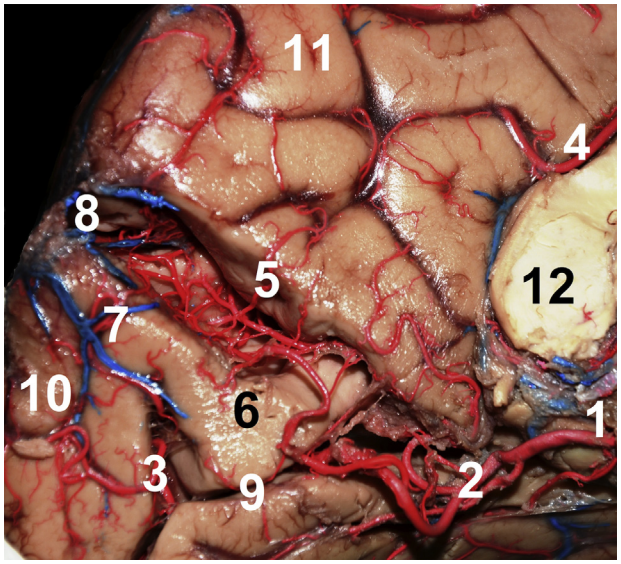

Figure 2. Midsagittal section of human brain, left hemisphere (after removal of the cerebellum), medial surface, zoom in the parieto-occipital sulcus (which is opened). (*1*) Posterior cerebral artery (P3 segment); (*2*) parieto-occipital artery; (*3*) calcarine artery; (*4*) precuneal artery complex; (*5*) precuneal branch of the parieto-occipital artery; (*6*) cuneal branches of parieto-occipital artery; (*7*) anastomosis between the parieto-occipital artery and the calcarine artery; (*8*) parieto-occipital sulcus (opened); (*9*) calcarine sulcus; (*10*) cuneus; (*11*) precuneus; and (*12*) splenium of the corpus callosum.

Table 2. Observed Frequencies of Arterial Supply by Parieto-Occipital Artery Branches in the Present Study

Branches	Frequency (%)
Precuneal	100.00
Cuneal	96.55
Callosal/(retro)splenial	30.00
Calcarine*	27.59
Lateral occipital	20.69
Hippocampal/parahippocampal	13.33
Superior parietal	6.67
Paracentral	6.67
Thalamic/thalamogeniculate	6.67
Lateral ventricular	6.67
Third ventricular	6.67
Caudal cingulate	3.33
Anterior temporal	3.33
Medial temporal	3.33
Posterior temporal	3.33
Midbrain	3.33
Medial posterior choroidal	0
Lateral posterior choroidal	0

*Parieto-occipital artery branch to the calcarine sulcus, different from the calcarine artery.

The PoA supplied the brainstem through 6 distinct branches in a single hemisphere.

Anastomoses. Interhemispheric anastomoses originating from the PoA were rare (Table 1). In a single case, the left PoA anastomosed with the right precuneal artery complex (PAc)[16] (Figure 4). In contrast, intrahemispheric anastomoses of the PoA were commonly observed (93.33% of the PoAs; Figures 2, 3, and 5), with a mean number of 2.90 ± 1.69 anastomoses per hemisphere (range, 0–7; Table 1). The observed anastomoses occasionally forming clumps involved the PAc in 68.97% and CA in 51.72% (Figure 2). Moreover, the PoA showed an average of 1.76 ± 1.70 anastomoses (range, 0–7) with the PAc and 0.93 ± 1.07 anastomoses (range, 0–3) with the CA.

The PoA-PAc anastomoses were detected at the medial surface of the posterior precuneal lobule, within the supraplenial area and the superior margin of the precuneal lobule (Figure 5). In 2 cases showing no PoA-PAc anastomoses, a distinct P4 branch, emerging proximal to the PoA (posterior pericallosal artery), anastomosed with the PAc. In 6.90% of the studied hemispheres the PoA anastomosed with branches of the middle cerebral artery (range, 0–2 anastomoses) at the lateral hemispheric surface (Figure 6).

PoA Duplication. The PoA was rarely duplicated (3.33% of the hemispheres). In cases of PoA duplication, a hypoplastic CA coexisted originating from a loop of the posterior segment of PoA.

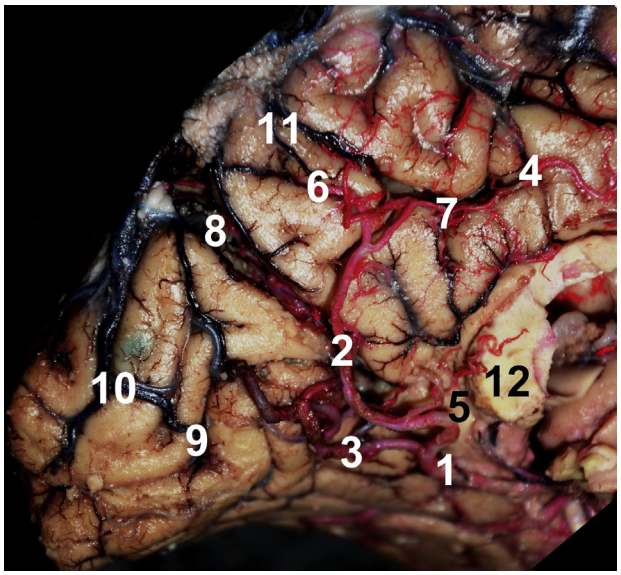

Figure 3. Midsagittal section of human brain, left hemisphere (after removal of the cerebellum), medial surface, zoom in the parieto-occipital sulcus. (*1*) Posterior cerebral artery (P4 segment); (*2*) parieto-occipital artery; (*3*) calcarine artery; (*4*) precuneal artery complex; (*5*) splenial branch of the parieto-occipital artery; (*6*) precuneal branch of the parieto-occipital artery; (*7*) anastomosis between the parieto-occipital artery and the precuneal artery complex; (*8*) parieto-occipital sulcus; (*9*) calcarine sulcus; (*10*) cuneus; (*11*) precuneus; and (*12*) splenium of corpus callosum.

PoA divisions in 2 branches of equal size originating from a common stem within the Pos detected in 6.67% of hemispheres were not characterized as arterial duplications.

Table 3. Additional Cortical and Subcortical Regions Receiving a Relatively Small Number of Parieto-Occipital Artery Branches

	Branches	
Brain Area	Mean Value ± Standard Deviation	Range
Lateral occipital cortex	0.38 ± 0.90	0–4
Corpus callosum*	0.30 ± 0.60	0–2
Lateral ventricle	0.23 ± 0.90	0–4
Midbrain	0.20 ± 1.10	0–6
Caudal parahippocampal gyrus	0.17 ± 0.59	0–3
Superior parietal lobule	0.13 ± 0.57	0–3
Thalamus	0.13 ± 0.51	0–2
Retrosplenial area*	0.10 ±0.31	0–1
Third ventricle	0.07 ± 0.25	0–1
Paracentral lobule	0.07 ± 0.25	0–1
Caudal cingulate gyrus	0.03 ± 0.18	0–1

*Supplied by the splenial branches of parieto-occipital artery origin.

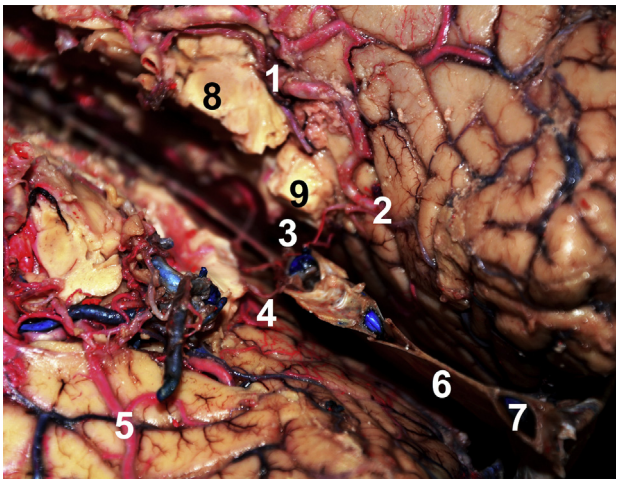

Figure 4. Midsagittal section of human brain (after incision of the falx cerebri and removal of the cerebellum and lower brainstem), inferior surface, zoom in perisplenial area. (*1*) Left posterior cerebral artery (within the ambient cistern); (*2*) left parieto-occipital artery; (*3*) interhemispheric branch of the left parieto-occipital artery; (*4*) right precuneal artery complex; (*5*) right posterior temporal artery; (*6*) falx cerebri; (*7*) superior sagittal sinus; (*8*) midbrain (transverse section); and (*9*) splenium of corpus callosum.

Anatomic Parameters of the PoA in Relation to Gender, Age, Side, Height, Weight, and BMI. No statistically significant differences were found when the measured parameters of the PoA (number of anastomotic branches, number of branches to the cuneus or precuneus, and distance between PoA origin and the OP) were assessed in relation to gender, age, hemisphere side, weight, and BMI. A statistically significant difference was found when the present results

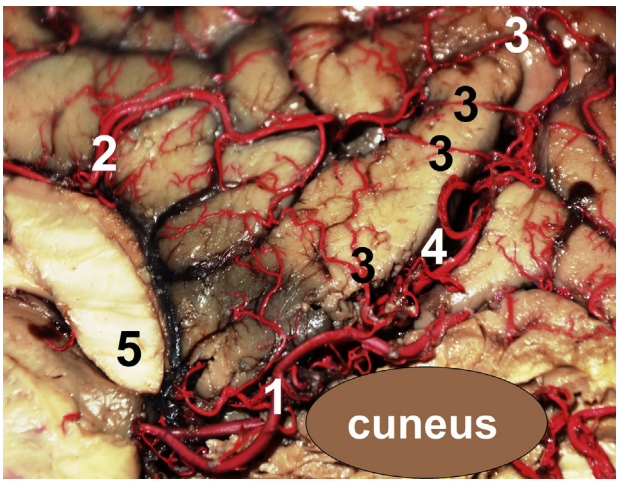

Figure 5. Midsagittal section of human brain, right hemisphere, medial surface, zoom in the parieto-occipital sulcus. (*1*) Parieto-occipital artery; (*2*) precuneal artery complex; (*3*) branch of the parieto-occipital artery anastomosing with the precuneal artery complex; (*4*) parieto-occipital sulcus; and (*5*) splenium of corpus callosum.

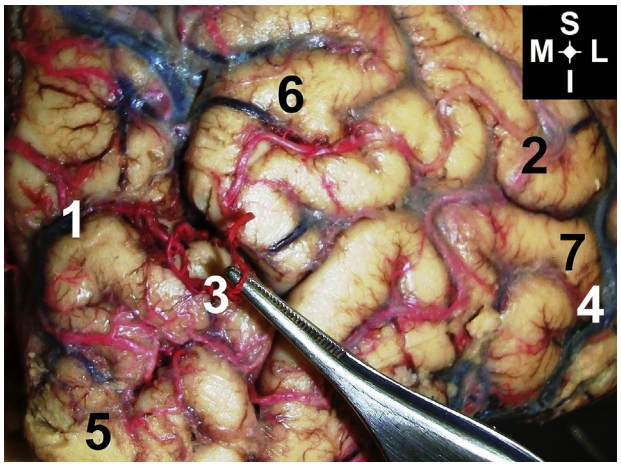

Figure 6. Lateral view, right hemisphere, posterior surface, zoom in the occipital lobe. (*1*) Parieto-occipital artery; (*2*) cortical branches of the middle cerebral artery; (*3*) anastomosis between the parieto-occipital artery and the middle cerebral artery; (*4*) vein of Labbé; (*5*) occipital pole; (*6*) parietal lobe; and (*7*) temporal lobe; I, inferior; L, lateral; M, medial; S, superior.

were dichotomized according to height (i.e., the average distance of the PoA origin from the OP was nearly 8 mm longer in taller individuals [cutoff height, 170 cm; distance, 57.46 ± 14.59 mm vs. 49.56 ± 12.43 mm; P = 0.048]). Compared with PoAs with an origin posterior to the posterior splenial border, those with an anterior origin showed a significantly higher mean number of intrahemispheric anastomoses (4.71 ± 1.5 vs. 2.41 ± 1.33; P = 0.0006).

Correlations Between Anatomic Parameters of the PoA. Only 2 significant correlations between the measured parameters were found. These were a highly significant (r = 0.596; P = 0.01) positive correlation between the distance of PoA origin from the OP and the number of intrahemispheric anastomoses of the PoA and a significant (r = 0.416; P = 0.025) positive correlation between the number of cuneal and precuneal PoA branches (i.e., the longer the distance of the PoA origin from the OP, the higher the number of intrahemispheric PoA anastomoses, and the higher the number of PoA branches to the precuneus, the higher the number of PoA branches to the cuneus).

DISCUSSION

Microanatomic Study

The origin of the PoA in relation to segmentation patterns of the PCA has been examined in several previous cadaveric studies[7,9] (Table 4). These results indicate considerable variation in PoA origin within and between cadaveric cohorts. Nevertheless, the following trends are apparent. In line with the present findings, the more distal P4 (calcarine) and P3 (quadrigeminal) segments represent the most frequent sites of PoA origin, whereas PoA origin at the more proximal P2 anterior segment is rare (Table 4).

Despite previous evidence for atypical/anomalous PoA origins directly from the internal carotid or basilar arteries,[10-14] none of these was apparent in the present study. The present findings indicated that the average distance of the PoA origin from the OP was significantly longer (by nearly 8 mm; P = 0.048) in taller individuals (height >170 cm). Although this result seems consistent with previous findings indicating positive correlations between height and brain volume, including visual cortex volume,[17-19] it should nevertheless be interpreted cautiously and thus warrants confirmation in studies with larger cohorts.

Asymmetries in the origin of proximal PCA segments have been reported previously[20]; nevertheless, no previous cadaveric study has focused on terminal PCA branches. Our findings indicate that asymmetry in PoA origin is relatively common (5 of 15 heads, 33.3%). Moreover, in 4 of 5 heads (80%) in our study, the left PoA emerged more distally than the right. Asymmetric PoA origin may be a significant consideration in the context of procedures requiring bilateral interpretation, such as neuroradiologic interventions.[21] Rare cases of asymmetries caused by an anomalous origin of PoA have been highlighted by previous angiographic studies.[10-14]

Course

Our findings on PoA course indicated that in all except one of the examined hemispheres, the main stem of the vessel entered the

Table 4. Frequency of Parieto-Occipital Artery Origin in Cadaveric Cohorts

	Reference							
	Margolis et al.[3]	Zeal and Rhoton[9]	Marinkovic et al.[4]	Milisavljevic et al.[5]	Parraga et al.[6]	Cilliers and Page[1]	Uz[8]	Present Study
Number of hemispheres	40	50	62	74	70	20	40	30
PoA origin in P2 anterior	—	10	—	—	—	13.6	—	3.57
PoA origin in P2 posterior	38	40	15	15.7	1.4	18.2	—	17.86
PoA origin in P3	22	46	18.3	18.6	71.4	54.6	100	13.57
PoA origin in P4	40	—	66.7	65.7	27.1	9.1		65

Values are % except where indicated otherwise.
PoA, parieto-occipital artery.

Table 5. Frequency of Irrigation (Descriptive or Numeric) by Parieto-Occipital Artery Branches in Various Brain Regions Reported in the Literature Compared with the Present Findings

	Reference						
Parieto-Occipital Artery Supply/Branches	**Margolis et al.[3]**	**Zeal and Rhoton[9]**	**Marinkovic et al.[4]**	**Milisavljevic et al.[5]**	**Parraga et al.[6]**	**Cilliers et al.[1]**	**Present Study**
Precuneus	Consistently	Consistently	Consistently	*	Consistently	*	100%
Cuneus (including calcarine branches)	Consistently	Consistently	Consistently	*	Consistently	*	96.55%
Parasaggital region	*	Consistently	*	*	Consistently	*	*
Lateral occipital gyrus	*	Consistently	23.3%	*	*	*	20.69%
Precentral region	*	Rarely	*	*	*	*	6.67%
Superior parietal lobule	*	Rarely	23.3%	*	Occasionally	*	6.67%
Caudal cingulate gyrus	*	*	Occasionally	*	*	*	3.33%
Callosal (splenium)	*	62%	48.3%	*	*	50%	30%
Midbrain	*	Those with proximal origin	*	*	Rarely	*	*
Thalamus, pulvinar, geniculate bodies	Those with P2P origin (38%)	Those with proximal origin	15%	Those with proximal origin (15.7%)	Rarely	*	6.67%
Choroid plexus (lateral and third ventricle)	*	24% (mainly those with proximal origin)	*	*	*	*	13.34%
Hippocampus	Those with P2P origin (38%)	*	3.3%	*	*	*	13.33%
Parahippocampal gyrus (caudal part)	*	*	Occasionally	*	*	*	
Temporal arteries (anterior, mid, posterior)	*	*	8.3% (3.3%, 1.7%, 3.3%)	*	*	0%	6.66%
Posterior choroidal arteries (medial/lateral)	Those with P2P origin (38%)	23% (10%/13%)	28.3% (5%/23.3%)	*	*	*	*
Calcarine artery	16%	10%	*	*	*	4%	27.59%

Asterisks denotes branches/areas that were not examined or detected.
P2P, posterior P2 (segment).

Pos and ran along it, at variable lengths, usually deeper than 1 cm from its surface. These findings are consistent with previous anatomic descriptions.[3,4,8,9] Moreover, in line with previous findings,[3,8] the PoA was shown to run superiorly to the CA. A relatively rare variation of putative clinical significance has been reported by Milisavljevic et al.,[5] with the PoA arising from the P2 posterior segment and forming an enlarged loop; its apex enters the temporal horn of the lateral ventricle. In the present study, we detected another variation with the main stem of the PoA running within the calcarine sulcus in a single hemisphere.

Duplication

On the basis of previous cadaveric findings, duplication of the PoA is a rare phenomenon; its frequency ranges between 1.7% and 10%.[1,4,9] In the present study, a double origin of the PoA was identified in 3.33% of hemispheres. Despite common misuse of the term,[22] arterial duplication denotes the vascular variant with an artery having 2 separate distinct origins and no distal arterial convergence.[23,24] Duplications are considered variants of developmental abnormalities possibly resulting from incomplete involution of fetal vessels[22,25,26]; these may be distinct arteries or an arterial network.[25] Fusion of primitive vessels usually occurs from distal to proximal.[25,27] In this regard, PoA division in 2 branches of equal size originating from a common stem within the Pos was not characterized as arterial duplication.[22,23,27]

Branches

Findings on the branching pattern and supply areas of the PoA derive from several cadaveric studies (Table 5). Given that most of the aforementioned studies did not focus on the PoA, the associated descriptions are of limited detail, often lacking rates of irrigation. Expectedly and in line with the present findings, PoA branches have been found to invariably supply the precuneus and cuneus. Nevertheless, a single case showing only precuneal PoA supply, possibly indicating a rare anatomic variation, was highlighted by the present findings. In the current study, quantification of precuneal and cuneal branches indicated a mean number of 10.5 and 9.14, respectively. Considering our previous findings on the irrigation of the precuneus by the PAc (mean number of 19 branches; range,

4–55),[16] it is apparent that although the PoA consistently supplies this region, its direct contribution (i.e., number of PoA branches in the medial surface) seems to be nearly 50% less than that of the PAc, the main precuneal supplier.

A significant positive correlation between the number of precuneal and cuneal PoA branches was identified by the present results (i.e., the higher the number of PoA branches to the precuneus, the higher the number of PoA branches to the cuneus). The extent to which this finding reflects a distinct developmental process is a hypothesis that warrants investigation.

Considering additional irrigation areas, the PoA has been shown to frequently supply the posterior parasagittal region and the lateral occipital gyrus; occasionally, the superior parietal lobule and the splenium of corpus callosum; and rarely, the precentral and parahippocampal gyrus, the retrosplenial area, and the most caudal part of the cingulate gyrus (Table 5). With the exception of posterior choroidal branches, PoA branches were identified to all aforementioned regions (Tables 2, 3, and 5). Moreover, a well-defined calcarine branch (different from the CA) was identified at a relatively high frequency by the present study (in 27.59% of hemispheres). Calcarine branches arising from the PoA within the Pos were frequently identified in the present study; veins coursing within the Pos, close to the PoA and reaching the superior sagittal sinus, were also occasionally observed.

Anastomoses

To the best of our knowledge, this is the first cadaveric study systematically assessing PoA anastomoses. The present findings indicate that intrahemispheric PoA anastomoses are relatively frequent and primarily involve the PAc and to a lesser extent the CA (rates of 68.97% and 51.72%, respectively; mean number of anastomoses per hemisphere was 1.76 and 0.93, respectively). Nevertheless, an interhemispheric anastomosis (left PoA–right PAc) was also detected. These results are consistent with our previous findings indicating ipsilateral PAc-PoA anastomoses at comparable rates[16]; collectively, they indicate a significant contribution of the PoA to the supply of both the precuneus and cuneus via collateral networks. In addition to the aforementioned anterior cerebral artery (ACA)–PCA and PCA-PCA collateral pathways the present findings provide support for rarer PoA anastomoses with middle cerebral artery branches (in 6.9% of hemispheres).

Correlations

The present results also indicated a highly significant positive correlation between the distance of the PoA origin from the OP and the total number of intrahemispheric anastomoses of the PoA. In addition, compared with PoA with origin posterior to the splenial border, those with an anterior origin showed a higher mean number of intrahemispheric PoA anastomoses. This result seems consistent with the higher frequency and number of identified ACA-PoA anastomoses; these can be hypothesized to result from PoA branches of more proximal origin. In this context, anastomoses between splenial branches and pericallosal arteries have been previously detected at high frequencies.[1,3,5,9,28]

Surgical and Clinical Considerations

Surgical Approaches. Surgical approaches involving the PoA and several of its supply areas (Table 5) are the parieto-occipital interhemispheric approach (POIA), the contralateral POIA (CPOIA), and the occipital interhemispheric approach (OIA). The POIA and CPOIA are mainly used for neoplastic and vascular lesions in the trigonal and peritrigonal areas. The OIA uses a path at the medial surface of the cuneus; because of the more horizontal angle, the OIA is indicated for approaching more distal areas. The POIA allows adequate access to the lateral ventricle trigone (atrium) and the peritrigonal area, to the medial surfaces of the parietal and occipital lobes, to the splenium and parasplenial area, with preservation of the optic radiations.[29] The Pos, PoA, and splenium are the main landmarks for this procedure. In the present study, the origin of PoA was at a mean distance of nearly 3 mm posterior to the posterior splenial border. In approximately 24% of the hemispheres, the PoA origin was located anterior to the posterior splenial border. In cases of proximal PoA origin, PoA branches to eloquent areas, such as the brainstem and thalamus, have been shown to be present (Table 5); thus, these must be clearly recognized and preserved. Moreover, as suggested previously, when approaching intraventricular lesions, care must be taken for a possible intraventricular course of the PoA main stem to avoid bleeding as a result of arterial injury.[5]

CPOIA allows access to the same areas as the POIA, working from the contralateral side after transection of the falx.[30–32] This approach offers a wider surgical angle compared with the POIA and may reduce retraction by accessing lesions located more laterally or deep within the Pos. A prerequisite for both POIA and CPOIA is the identification of the Pos. In this context, the variability and complexity of Pos anatomy must be taken into consideration.[33]

As indicated by the present findings, the PoA in its natural position is in contrast to its depiction in classic anatomic atlases, typically not visible at the medial hemispheric surface as it courses along the Pos at variable depths, usually >1 cm deep. Moreover, although rare, duplications and atypical origins of the PoA have been highlighted by the present and previous studies. It therefore seems safer to approach the Pos from proximal to distal (anterior to posterior at the medial surface and subsequently medial to lateral at the prepared segment) after recognition of the posterior border of the splenium, the PCA, and the PoA origin. Thus, notwithstanding technical difficulties associated with working depth, the presence of the aforementioned landmarks can assist approaches to diseases deep within the Pos, especially its proximal part.

Preservation of Anastomotic Networks. Considering the present findings on PoA anastomoses, a PoA-PAc network seems to offer the most frequent collateral supply to the areas irrigated by the PoA, mainly the precuneus followed by a PoA-CA network offering a direct collateral supply to the cuneus/visual area. Approaches involving the medial hemispheric surfaces in the parieto-occipital region should ideally respect these 2 networks. We therefore suggest preoperative three-dimensional computed tomography angiography, minimal intraoperative retraction, and if possible, no use of electrocautery in the medial hemispheric surface at the

posterior precuneal lobule, specifically at its superior margin and the suprasplenial area, as well as deep within the Pos.

Previous findings indicating postoperative return of full visual fields after CA ligation seem consistent with a significant contribution of the PoA to the visual area.[34] Moreover, in patients with PCA stroke, the neurologic deficits and the final ischemic area are usually less than expected regarding the territory of the occluded artery.[34] The robust collateral vascular network at distal PCA areas has been postulated to decrease symptoms caused by vasospasm after subarachnoid hemorrhage, thereby improving outcome.[35] Although rare, the presence of interhemispheric PoA anastomoses detected in the present study is another parameter that should be taken into consideration before and during surgery.

Disorders and Management

Aneurysms and Arteriovenous Malformations. Distal PCA aneurysms (P3 and P4 segments), although relatively rare, have been reported in several previous studies focusing on their characteristics and treatment.[35-37,38-44] Nevertheless, aneurysms distinctly involving the terminal PCA bifurcation and the 2 terminal PCA branches (PoA or CA) have been highlighted by only a few case reports. Thus, Yamahata et al.[45] reported a case of a saccular aneurysm located at the PCA terminal bifurcation, presenting with subarachnoid hemorrhage within the Pos, clipped via an OIA. Ishibashi and Onuma[46] reported a case of a saccular PoA aneurysm that presented with intracerebral hematoma in the occipital lobe, intraventricular hemorrhage in the ipsilateral lateral ventricle, and subdural hematoma in the interhemispheric fissure. This aneurysm was also clipped using an OIA. A third case was reported by Ramakrishnamurthy et al.[47]: a fusiform CA aneurysm presenting with subarachnoid hemorrhage and a small hematoma in the occipital lobe, clipped via OIA. The OIA performed in the 3 aforementioned cases is likely to allow adequate access to the far distally located diseases; however, it seems inappropriate for approaching more proximal areas and definitive/accurate detection of the PoA origin if it is located more proximally. Moreover, the dome of the aneurysm may partially obscure the operative field and the proximal part of the parent artery may not be visible because of its location behind the aneurysm. Therefore, the POIA and the CPOIA are likely to be more appropriate for this purpose, allowing an adequate proximal vision and access caused by a more vertical angle.

Distal PCA aneurysms compared with proximal ones are more often fusiform[38,40,43] (i.e., the vessel is diseased in its entirety); consequently, to avoid a nidus for recurrence, parent artery sacrifice may be necessary. Consistent with the present anatomic findings, evidence from previous clinical series supports the notion that occlusion of the PCA does not result in clinical deficits because of the highly anastomotic vascular network of the region with collateral supply from terminal ACA and middle cerebral artery branches.[40] Bypassing the PoA seems to be associated with high morbidity,[40] possibly caused by insufficient blood flow if donor and recipient vessel have very small calibers.[39] Despite associated risks, Goehre et al.[42] recommend that reconstructive procedures should be discussed for cases with a positive balloon occlusion. Relatively recent endovascular techniques, such as coiling combined with stenting or flow-diverting devices, have been reported to have better outcomes in aneurysm occlusion with parent artery preservation.[38]

Four subtypes of arteriovenous malformations (AVMs) associated with the Pos have been described previously.[48] The deep medial AVMs are principally located in the peritrigonal area and their arterial supply involves the PoA.[48] In cases of deep medial Pos AVM that extend more than 2 cm off the midline, the CPOIA may offer a safer alternative to POIA because the latter creates a deep perpendicular perspective with limited access to the lateral margins of the lesion.[33]

CONCLUSIONS

The present study provides further insights into the anatomy of the PoA. Although this artery invariably supplies the precuneus and almost always the cuneus, its direct contribution to the arterial supply of the former seems inferior to PAc, the main precuneal arterial supplier. Nevertheless, the PoA shows frequent intrahemispheric anastomoses with PAc and to a lesser extent with the CA, thus forming additional collateral supply networks to both the precuneus and cuneus. The distance between the PoA origin and the OP seems to vary with an individual's height; the number of intrahemispheric PoA anastomoses varies with the site of origin of this vessel. The highlighted anatomic characteristics of PoA and its anastomotic networks and variants can be of significance in the planning and performance of surgical approaches to this vessel and supply areas.

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