# Cadaveric study of variations in the posterior cerebral and superior cerebellar arteries

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## SUMMARY

Anatomical variations of arteries at the base of the brain may predispose to clinical conditions such as stroke, leading to cognitive and sensorimotor deficits. The aim of this study was to report variant patterns of the vessels at the cerebral arterial circle. In a random sample of 35 fixed human brain dissections, variations of the posterior cerebral artery (PCA) and superior cerebellar artery (SCA) were observed. Variations observed included: unilateral hypoplastic pre-communicating (P1) segment of PCA, bilateral persistent fetal PCA with hypoplasia of its P1 segment (posterior communicating artery contributing to the formation of PCA's post-communicating (P2) segment), and origination of the PCA in common with the superior cerebellar artery, the latter finding being less common than previously reported variations of the cerebral arterial circle. Hypoplasia was assessed, grossly followed by measurement of the vessels' diameters using a Dial Caliper, and ultimately by calculation of the statistical significance of the diameter in comparison to normal variants. Our findings suggest that vascular variations at the base of the brain are not uncommon. Ischemic stroke, aneurysms and the potential for compromised collateral blood flow, especially in cases of hypoplasia, are among the clinical implications associated with variations of the arterial network at the base of the brain. Therefore, we recommend paying extra attention to these possibilities when developing overall guidelines for diagnosis and treatment of cerebrovascular pathologies.

**Key words:** Posterior cerebral artery – Fetal pattern of posterior cerebral artery (FPCA) – Superior cerebellar artery – Cerebral arterial circle – Anatomical variations

## INTRODUCTION

The PCA, normally observed as the terminal branch of the posterior circulation, is divided into several segments, termed P1-5 in a proximodistal distribution. The part of the PCA that extends from the basilar artery to the posterior communicating artery (PCom) is P1; and the segment of PCA from the posterior communicating artery to the posterior edge of the midbrain is called P2. The P3 segment continues from P2 to the calcarine sulcus, and the latter indicates the beginning of the P4 segment. The division between P4 and P5 is indistinct, as the artery extends beyond the cuneus of the occipital lobe (Krayenbühl and Yaşargil, 1968; Kaya et al., 2010; Uz, 2019). Typically, the left and right posterior cerebral arteries (PCAs) are formed by the bifurcation of basilar artery near the interpeduncular fossa of the ventral midbrain and thus considered terminal branches of the basilar artery. The PCA is responsible for

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**Table 1.** Prevalence of p-FPCA in relation to side and sex (n=5).

| Gender | Unilateral | | Bilateral |
|---|---|---|---|
| | Right | Left | p-FPCA |
| Male | 1 (20%) | 1 (20%) | 1 (20%) |
| Female | 1 (20%) | 1(20%) | - |

**Table 2.** Prevalence of variation in origin of SCA in relation to side and sex (n=3).

| Gender | Unilateral | | Bilateral |
|---|---|---|---|
| | Right | Left | |
| Male | 1 (33.33%) | 2 (66.66%) | - |
| Female | - | - | - |

the blood supply of portions of the midbrain, the caudal diencephalon, and the posterior/lateral aspects of the cerebral cortex. The pre-communicating segment (P1) of PCA is connected to the posterior communicating artery (PCom), thereby constituting the posterior component of the cerebral arterial circle, an anastomotic connection between the internal carotid (anterior) and the vertebrobasilar (posterior) circulations of the brain.

However, this classic pattern, well-known from textbook illustrations (Carpenter, 1991), is not totally ubiquitous, as evidenced by in vivo imaging and cadaveric dissection observations. Completely missing or hypoplastic P1 variants have been identified as the various forms of fetal type PCA. The fetal variant, known as fetal pattern of the posterior cerebral artery (FPCA), being transitory in embryologic development, is considered full fetal type if the P1 segment is missing, partial (p-FPCA) when P1 is smaller than Pcom, or intermediate when P1 is equal in size to the corresponding Pcom (Van Raamt et al., 2006; Shaban et al., 2013).

According to previously published data, these variants may coincide with other anatomical variations of the cerebral arterial circle (He and Wan, 2018) and may also be associated with alterations in hemodynamics (Lochner et al. 2011), transient Neurologic deficit signs (Tocco et al., 2011), aneurysm formation (Ilbay et al., 2012; He and Wan, 2018) and occipital cortical area strokes paradoxically stemming from carotid artery stenosis (Lambert et al., 2016). However, basilar tip aneurysms were found to be significantly less common in cases with fetal type PCA in clinical populations (Diogo et al., 2017).

The superior cerebellar artery (SCA) is a branch of the distal basilar artery (BA) that passes in a posterolateral direction. Its course is divided into four segments: anterior ponto-mesencephalic, lateral ponto-mesencephalic, cerebello-mesencephalic, and cortical. SCA supplies the pons, the cerebral peduncles, the upper part of the cerebellum, and the cerebellar peduncles (Kim et al., 2019). SCA typically originates as a single vessel from the distal part of BA, and shortly after its origin and near its maximal caudal descent, SCA bifurcates into two major trunks: rostral and caudal (Hardy et al., 1980). Nonetheless, SCA was infrequently reported to originate from the PCA or by a common trunk with PCA from BA. Variations related to SCA such as duplication, triplication, fenestration, origin from the internal carotid artery, and variations related to its course have also been reported (Malicki et al., 2023).

The current study was conducted to investigate the occurrence of PCA anatomical variants in an unbiased sampling of human cadavers, originally donated for educational purposes. The study also aimed to determine whether the potential PCA variants might coexist with other unusual findings in the cerebral arterial circle, and whether a relationship between the occurrence of variant vessels and the reported cause of death or clinical diagnosis existed.

## MATERIALS AND METHODS

The study was carried out at William Carey Uni-

versity, College of Osteopathic Medicine, using cadavers provided by the University of South Alabama, Anatomical Gifts Program. Human brains with attached blood vessels were obtained from a sample of a total of 35 cadavers, where the brains had been fixed and vascular beds perfused. The donors were completely anonymous; only the age, sex and cause of death (if known) were made available to the authors. Arteries at the base of the brain were carefully observed and photographed using a Sony a6300 camera with a Sony SEL30M35 30mm f/3.5 macro lens. The diameters of vessels were measured by a Chicago Brand 150mm Premium Dial Caliper, where three sets of measurements were taken along the course of a vessel, then averaged for statistical comparisons with the diameter of the normal variants.

The study was conducted according to the guidelines of the Declaration of Helsinki.

## RESULTS

In the present study, all cases that exhibited a FPCA were of the partial variant (p-FPCA). From the general lot of 35 cadaveric brain specimens, five cases with p-FPCA (14.28%) were recognized; and, of those cases, three were male (60%) and two were female (40%) (Table 1). From the 35 brain specimens, three cases (8.57%) with variation in origin of SCA were recorded, all of which (100%) were male (Table 2).

In 4/5 cases (80%) the p-FPCA was unilateral, 2/4 cases (50%) of p-FPCA were on the right side, and 2/4 (50%) cases on the left side. In one other case (20%) p-FPCA was found to be bilateral (Table 1). In 3/3 cases (100%) variation in origin of SCA was unilateral, with 2/3 cases (66.66%) on the left side and 1/3 cases (33.33%) on the right (Table 2).

The typical adult pattern of the cW and its branches was seen in Fig. 1. Quadrigeminal arteries were seen arising from the P1 segment. The posterior communicating artery gives off many fine, scarcely visible, perforating branches, the largest branch of which is called the pre-mammillary or anterior thalamoperforating artery, which was seen branching from left Pcom to supply the cerebral peduncle. In the general lot, unilateral p-FPCAs were seen in four cases (4/35, 11.42%): two males (Figs. 4 and 6) and two females (Figs. 5 and 7). Bilateral partial p-FPCAs were seen in one male case (1/35, 2.85%) (Fig. 2). The SCA exhibited variation in origin in three cases (3/35, 8.57%), in which it was seen to arise from PCA in one male case (Fig. 3) and by a common stem with PCA in two male cases (Figs. 2 and 4). Furthermore, hypoplasia of right SCA and right anterior choroidal arteries (Fig. 3), and duplication and hypoplasia of left SCA (Fig. 6) were additional recorded findings.

By using SPSS version 27.0 software, Student's t-test was used for statistical analysis and a p-value $< 0.05$ was considered statistically significant. There were no statistically significant differences regarding the incidence of unilateral p-FPCA in relation to sex ($p=0.500$) nor side ($p = 0.500$). However, the prevalence of variation in origin of SCA was significantly higher in male in comparison to female ($p = 0.000$) but showed no statistical significance ($p = 0.193$) in relation to side.

In terms of hypoplasia, the mean ± SD for the outer diameters of the normal variants of the posterior cerebral and superior cerebellar arteries were 2.4 ± 0.5 mm and 1.12 ± 0.31 mm respectively. By using SPSS version 27.0 software, two-sample Welch's t-test was used to determine the statistical significance. An outer vessel diameter of a p-value $< 0.05$ was considered statistically significant and the vessel was considered hypoplastic. In Fig. 2, the mean ± SD for the three measurements of the outer diameter of the P1 segment of PCA was 0.7933 ± 0.0058 and 0.791 ± 0.022 mm for the right and left segments respectively, which showed a statistical significance difference of $p = 0.0028$ and $p =0.0027$ respectively. In Fig. 3, the mean ± SD of the SCA diameters was 0.4 ± 0.036 ($p = 0.027$). In Fig. 4, the mean ± SD for the three measurements of the outer diameter of the P1 segment was 0.7833±0.015 ($p = 0.0025$). In Fig. 5, the mean ± SD for the three measurements of the outer diameter of P1 segment was 0.818 ± 0.01 mm ($p = 0.0032$). In Fig. 6, the mean ± SD for the three measurements of the outer diameter of P1 segment was 0.89 ± 0.02 ($p = 0.0048$) and for the three measurements of SCA it was 0.4 ± 0.01 mm ($p = 0.026$). In Fig. 7, the mean ± SD for the three measurements of the outer diameter of P1 segment was 0.85 ± 0.056 ($p = 0.0044$).

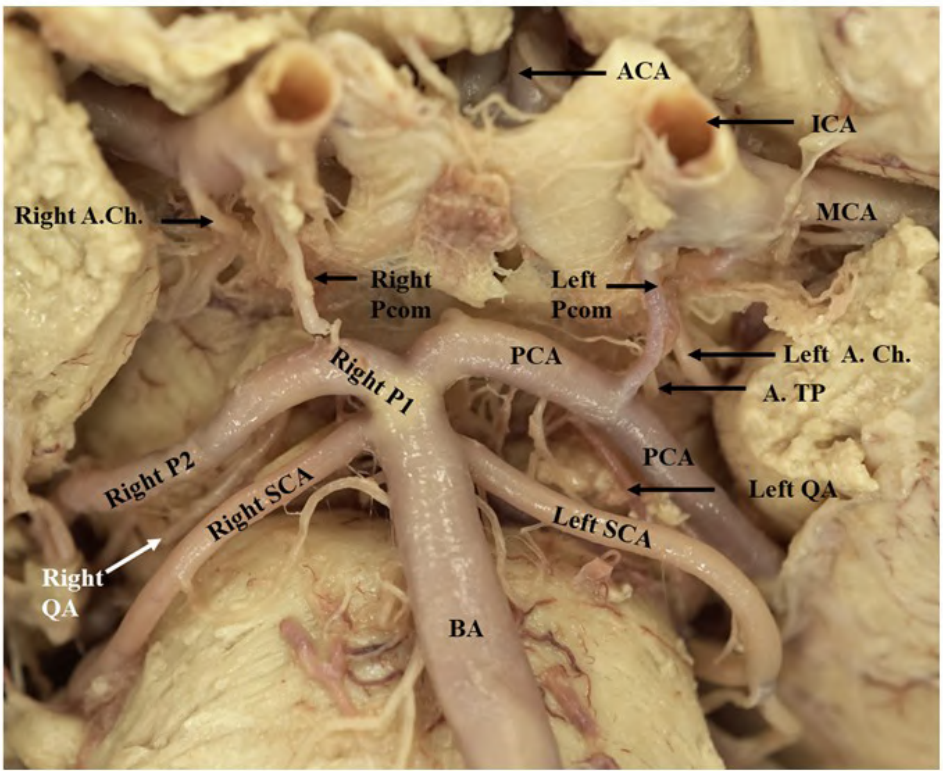


**Fig. 1.-** Ventral view of the brain with associated neurovascular structures showing typical adult pattern of the cerebral arterial circle. ACA: anterior cerebral artery; A.Ch.: anterior choroidal artery; A.TP: anterior thalamoperforating artery; BA: basilar artery; ICA: internal carotid artery; MCA: middle cerebral artery; P1 and P2: P1 and P2 segments of posterior cerebral artery; PCA: posterior cerebral artery; Pcom: posterior communicating artery; QA: quadrigeminal artery; SCA: superior cerebellar artery.

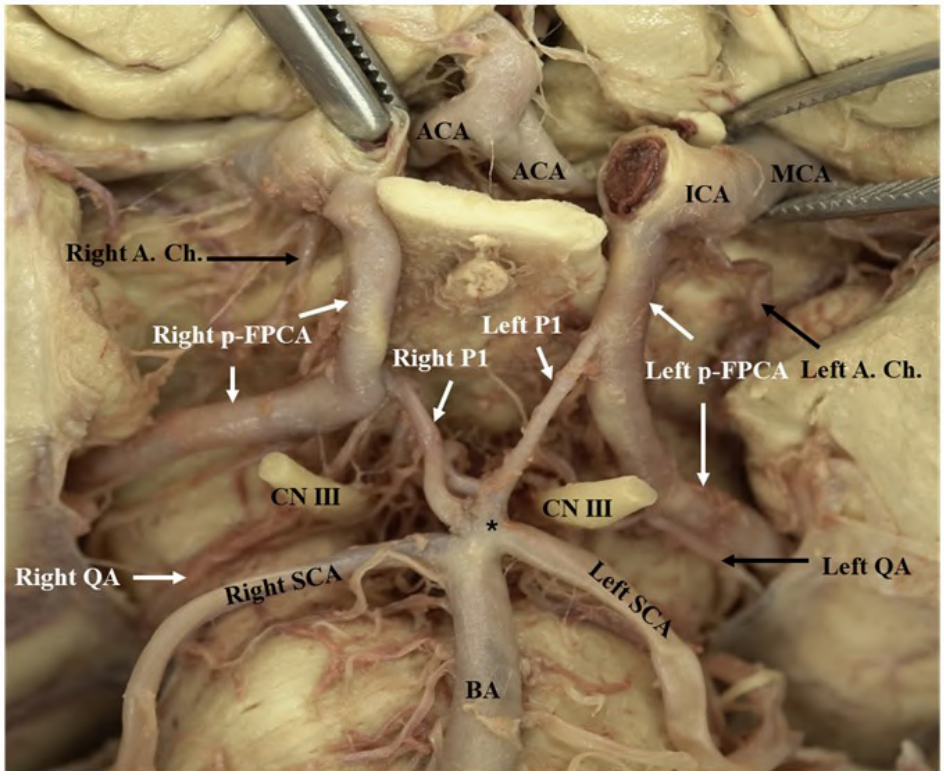


**Fig. 2.-** Bilateral partial fetal PCA (p-FPCA), bilateral hypoplasia of P1 segments, and a common stem for PCA and SCA on the left side (asterisk). ACA: anterior cerebral artery; A.Ch.: anterior choroidal artery; BA: basilar artery; CN III: cranial nerve III (oculomotor nerve); ICA: internal carotid artery; MCA: middle cerebral artery; P1: P1 segment of posterior cerebral artery; QA: quadrigeminal artery; SCA: superior cerebellar artery.

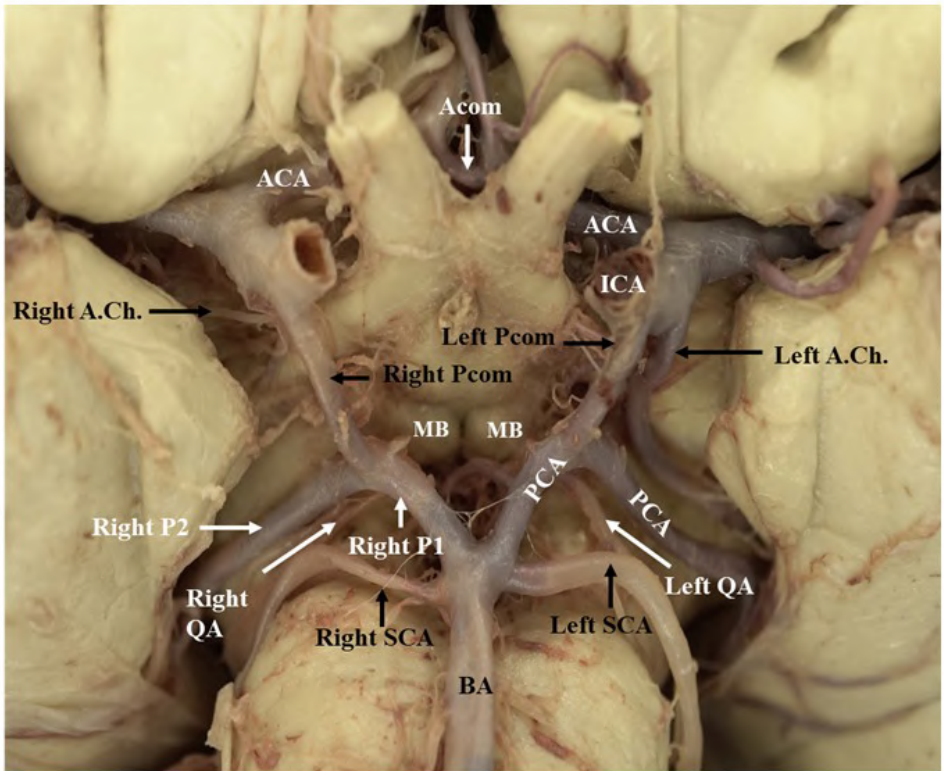


**Fig. 3.-** Superior cerebellar artery arises from P1segment of the posterior cerebral artery on the left side. Note the hypoplasia of right superior cerebellar and right anterior choroidal arteries. ACA: anterior cerebral artery; A.Ch.: anterior choroidal artery; Acom: anterior communicating artery; BA: basilar artery; ICA: internal carotid artery; MB: mamillary bodies; P1 and P2: P1 and P2 segments of posterior cerebral artery; PCA: posterior cerebral artery; Pcom: posterior communicating artery; QA: quadrigeminal artery; SCA: superior cerebellar artery.

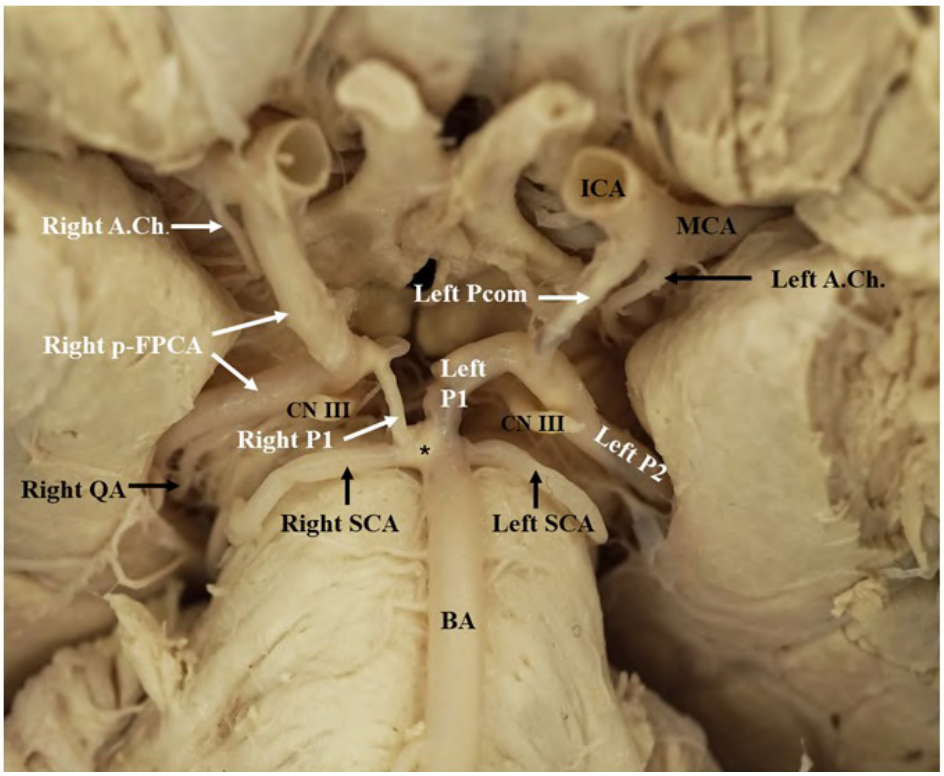


**Fig. 4.-** Right unilateral partial fetal PCA (p-FPCA), hypoplasia of right P1 segment and a common stem for PCA and SCA on the right side (asterisk). A.Ch.: anterior choroidal artery; BA: basilar artery; CN III: cranial nerve III (oculomotor nerve); ICA: internal carotid artery; MCA: middle cerebral artery; P1 and P2: P1 and P2 segments of posterior cerebral artery; Pcom: posterior communicating artery; QA: quadrigeminal artery; SCA: superior cerebellar artery.

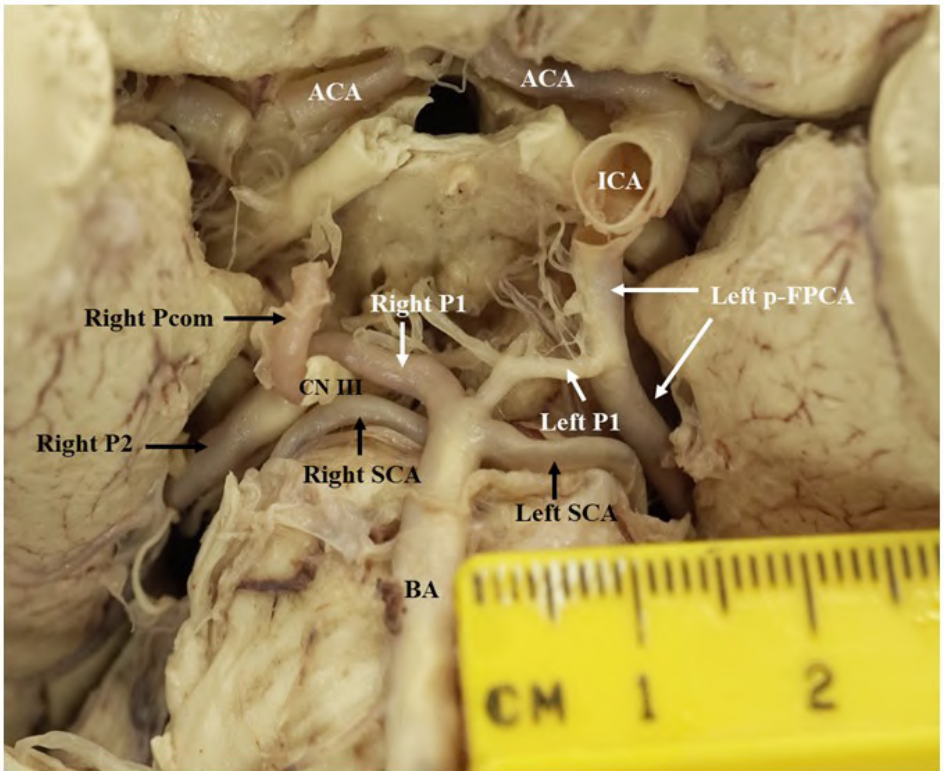


**Fig. 5.-** Left unilateral partial fetal PCA (p-FPCA) with hypoplasia of left P1 segment. ACA: anterior cerebral artery; BA: basilar artery; CN III: cranial nerve III (oculomotor nerve); ICA: internal carotid artery; P1 and P2: P1 and P2 segments of posterior cerebral artery; Pcom: posterior communicating artery; SCA: superior cerebellar artery.

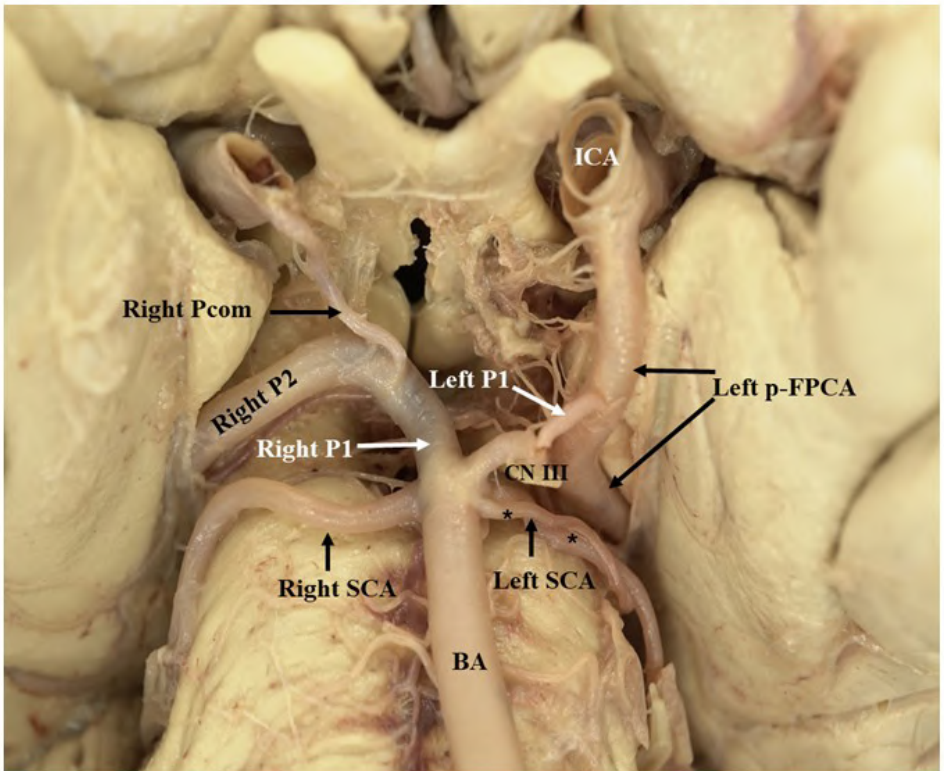


**Fig. 6.-** Left unilateral partial fetal PCA (p-FPCA) with hypoplasia of P1 segment. Duplication (asterisk) and hypoplasia of left SCA are also seen. BA: basilar artery; CN III: cranial nerve III (oculomotor nerve); ICA: internal carotid artery; P1 and P2: P1 and P2 segments of posterior cerebral artery; Pcom: posterior communicating artery; SCA: superior cerebellar artery.

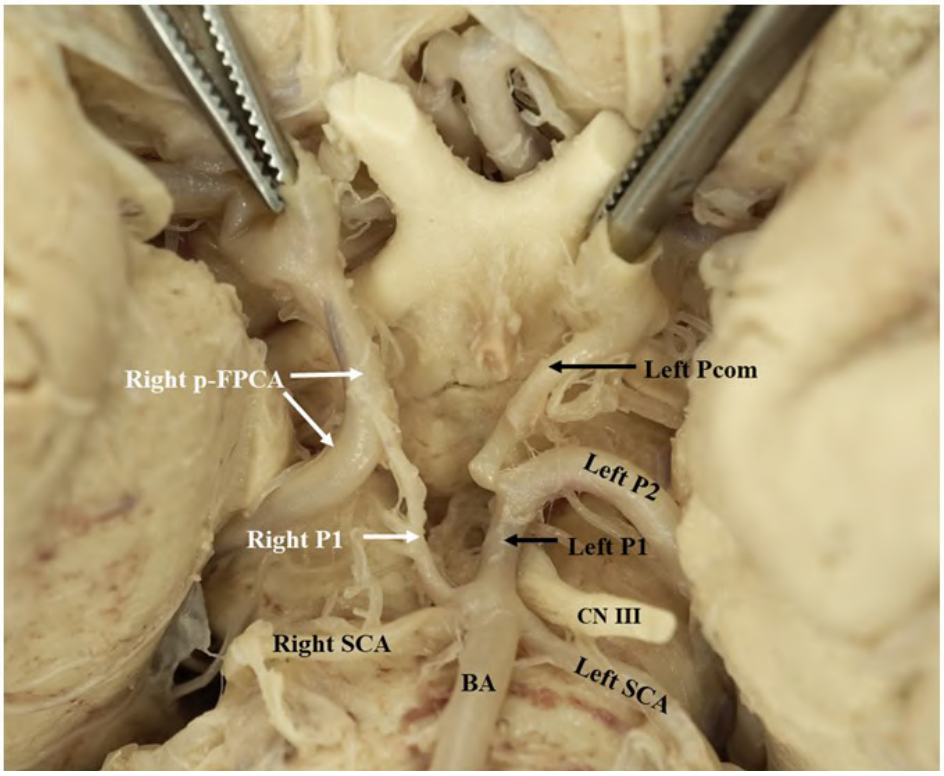


**Fig. 7.-** Right unilateral partial fetal PCA (p-FPCA) with hypoplasia of P1 segment. BA: basilar artery; CN III: cranial nerve III (oculomotor nerve); P1 and P2: P1 and P2 segments of posterior cerebral artery; Pcom: posterior communicating artery; SCA: superior cerebellar artery.

## DISCUSSION

The vertebrobasilar arterial system is also known as the posterior circulation of the brain, being responsible for the supply of the brainstem, cerebellum, parts of the diencephalon and thalamus, the inferomedial temporal lobe area, and most of the occipital lobe. Among the vessels of this arterial system, the posterior cerebral artery (PCA) is highly relevant, as it supplies not only the mesencephalic-diencephalic junction, but also thalamus and caudal regions of cerebral cortex. Therefore, ischemic events of PCA in the occipital lobe often result in homonymous hemianopia, quadrantanopia or sectoranopia, whereas those of the inferomedial temporal and occipital regions result in prosopagnosia, visual agnosia, color agnosia or alexia without agraphia. The latter is seen in ischemia involving the left occipital lobe, and features patients with a preserved ability to write, but with an inability to read, even words they had previously written (Wityk, 2017). Cognitive and behavioral dysfunction affecting memory and consciousness, aggressive behavior and hallucinations may also be seen in PCA-related vascular accidents (Abdalkader et al., 2021).

It is important to recognize that the development of the occipital and temporal lobes occurs later than that of the frontal lobe. Therefore, the PCAs' development appears to follow the timeline for the lobes' development. Of the branches that are recognized as part of the posterior circulation, the PCA is the last to form (Puchades-Orts et al., 1976).

In 28-to-30-day-old embryos, the cranial and caudal divisions of the primitive internal carotid artery (ICA) are formed. The longitudinal neural arteries form the BA, with which the caudal divisions of the ICA will anastomose. The primitive PCom and the stem of the PCA arise from the caudal primitive ICA. The primitive PCom normally regresses in size, as the final form of the vertebrobasilar system becomes established. If the primitive PCom fails to regress, the main supply of the PCA will be provided from the ICA via the PCom, making the fetal pattern of the posterior cerebral artery (FPCA) permanent (Okahara et al., 2002).

FPCA occlusion may resemble MCA syndromes

and thus could be overlooked. It may present with hemiparesis, hemisensory loss, hemispatial neglect and aphasia. The simultaneous FPCA occlusion and ICA or MCA occlusion can be catastrophic, and may explain the deterioration of patients despite treatment. This satisfaction of search (SOS) error, where the detection of one target makes detection of subsequent targets less likely, may add to the diagnostic challenge of FPCA occlusion. In FPCA occlusion, examination of the computed tomography angiogram (CTA) of the brain reveals the "hyperdense PCOM/PCA sign" (Abdalkader et al., 2021).

In accordance with our results, Uz( 2019) reported the average diameter of PCA's P1 segment as 2.21 mm, and in accordance with the results of Davidoiu et al. (2023), our results showed no statistically significant association between p-FPCA and sex. In contrast, Horikoshi et al. (2002) reported that FPCA is significantly more common in females. In the present study, there was no statistically significant difference in p-FPCA relative to side. However, Frid et al. (2022) found that unilateral FPCA was significantly more frequent on the right than on the left side.

The superior cerebellar artery is often described as the most consistent artery of the arteries at the base of the brain. In agreement with the results of our study, Tian et al. (2024) found that the mean diameter of SCA was 1.11 ± 0.22 mm. Some variations related to SCA were reported in the literature, notably in the proximal part of the artery, such as duplication, triplication, and unusual origin (Dagcinar et al., 2007).

On the 28th or 29th day of embryonic life, the distal primitive internal carotid artery (ICA) bifurcates into cranial and caudal branches. The former is the olfactory artery, which supplies the forebrain and later becomes the anterior cerebral artery (ACA), while the latter becomes the posterior communicating artery (PCom) and supplies the mesencephalon. The hindbrain is supplied by bilateral ventral longitudinal neural arteries (LNAs) that feature transient carotid-vertebrobasilar anastomoses. The caudal branch of the ICA then extends posteriorly to fuse with the LNAs, forming the PComs, whereas midline fusion of the LNAs gives rise to the basilar artery. On the 32nd day, the vertebral arteries (VAs) begin to form through union of the longitudinal anastomoses of the cervical intersegmental arteries at the C1 to C7 levels, with regression of the vestigial carotid-vertebrobasilar anastomoses now complete, and the appearance of superior cerebellar artery (SCA) from the cranial end of BA over the rhombencephalon. The embryologic arrangement of blood supply to the brain stem and cerebellum resembles that of the spinal cord. It entails longitudinal anterior (BA and anterior spinal artery) and posterior (lateral medullary PICAs and posterior spinal arteries) arteries that provide perforators (basilar perforators and sulcocomissural arteries) and transverse arteries (transverse pontine arteries, coronary arteries). Fusion of transverse arteries results in formation of the SCA, AICA, and PICA, which connect through longitudinal posterior artery anastomoses. This description offers an understanding of the formation of all observed anatomic variations of the posterior fossa arteries, including duplications (Klostranec and Krings, 2022).

The origin of SCA from the PCA or by a common trunk with PCA from BA have been reported in literature (Malicki et al., 2023). The first variant was seen in 1.88-15%, with bilateral occurrence in 1.2–5% of cases (Kalaiyarasi and Chitra, 2018), whereas the second variant was observed in 1–5.93%, with bilateral occurrence in 0.7–1% of cases (Krzyżewski et al., 2014). In the present study, both variants were seen, where the SCA was found to unilaterally originate by a common stem with the PCA in two cases. Caruso et al. (1991) reported a common trunk between P 1 and SCA as a pattern never reported in the literature before. We also found a case where of unilateral origin of SCA from the P1 segment of PCA.

Unilateral duplication of the SCA was seen in one of our cases. According to Krzyżewski et al. (2014), duplication incidence of SCA varies approximately from 3% to 30% where the frequency of the left and right duplication was similar. In agreement with the results of the present study, Caruso et al. (1991) found the duplication of the SCA in examined brains to be always unilateral.

The superior cerebellar artery (SCA) is related to the oculomotor, trochlear, and trigeminal nerves

and has a role in trigeminal neuralgia. In cases of anatomical variability, SCA may also lead to other neurovascular compression (NVC) disorders, including hemifacial spasm, oculomotor nerve palsy, and ocular neuromyotonia. Furthermore, SCA may be associated with ischemic syndromes and aneurysm development, emphasizing its clinical significance (Malicki et al., 2023).

## CONCLUSIONS AND RECOMMENDATIONS

In the present study, unilateral partial FPCA was the most frequently found variation in a random sample of cadaveric brains, where the cause of death was not stated as a cerebrovascular accident. Anatomical evaluations of the cerebral arterial circle in general and of the PCA and SCA in specific should be performed on a case-by-case basis, as their variations are unpredictable and not uncommon and one anatomical variation could neither predict nor exclude other anatomical variations of the cerebral arterial circle. Future research should emphasize the size and branching pattern of PCA. Possible sex, age and population variability may also exist. Preoperative identification of vascular variations at the cerebral arterial circle is important for avoiding complications during surgery and/or other interventional procedures.

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