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Original Article

Anatomy Section

Prevalence of Morphological Variations of Posterior Communicating Artery and its Association with Age, Sex, and Laterality using Magnetic Resonance Angiography: A Cross-sectional Study

ASHISH KUMAR[1], PRIYANKA SHARMA[2], NEHA VIJAY[3], MANOJ KULKARNI[4], HETAL VAISHNANI[5], ASHUTOSH PATEL[6], PARTH CHANDUBHAISAVALIYA[7], KINJAL JETHVA[8]

ABSTRACT

Introduction: The Posterior Communicating Artery (PCoA) is a vital component of the circle of Willis, providing collateral circulation between the anterior and posterior cerebral circulations. Morphological variations such as hypoplasia, aplasia, foetal-type configuration, and duplication may influence cerebral haemodynamics and predispose individuals to neurovascular disorders. Magnetic Resonance Angiography (MRA) allows accurate non-invasive assessment of these variations.

Aim: To determine the prevalence of PCoA morphological variations and assess their association with age, sex, and laterality using Time-Of-Flight Magnetic Resonance Angiography (TOF-MRA).

Materials and Methods: The present cross-sectional study included 150 patients who underwent brain MRA between May 2024 and August 2025 in department of Radiology, Dhiraj hospital, BK Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth Deemed to be University, Vadodara, Gujarat, India and excluded those with cerebrovascular abnormalities confirmed by clinical evaluation and imaging review. High-resolution 1.5T TOF-MRA images were analysed for PCoA morphology and classified into normal, hypoplasia (<1 mm), aplasia (non-visualisation), foetal-type configuration, and duplication. Two Radiologists independently assessed the images, with consensus in case of disagreement. Chi-square/Fisher exact tests were used to evaluate associations between variations and demographic factors such as age and sex.

Results: Among 300 arteries examined, hypoplasia was the most common variation type in 122 (40.66%) cases, and duplication was present in 5 (1.66%) cases. No statistically significant associations were noted between PCoA morphology and age and sex. However, laterality showed significant differences.

Conclusion: Hypoplasia emerged as the predominant PCoA variation in this cohort. PCoA morphology demonstrates significant laterality-related differences at the aggregate level. In contrast, PCoA morphology shows no statistically significant association with sex or age. Observed absolute differences, particularly in aplastic configurations, may be anatomically and clinically relevant and warrant further investigation in larger, adequately powered studies. Routine MRA evaluation of PCoA morphology is essential for understanding individual cerebrovascular risk and for planning neurosurgical and endovascular interventions.

Keywords: Aplasia, Duplication, Foetal, Hypoplasia, Ischaemia, Stenosis

INTRODUCTION

The vessels supplying the brain and neck can be effectively evaluated using routine imaging techniques, including Computed Tomography (CT), MRA, and Digital Subtraction Angiography (DSA). Anatomical information obtained from these modalities plays a critical role in guiding clinical and surgical decisions [1,2].

The polygonal arterial network at the base of the brain functions as an important collateral pathway, maintaining cerebral perfusion during arterial obstruction [3]. The PCoA, arising from the internal carotid artery, links the anterior and posterior cerebral circulations [4]. It courses posteromedially to join the Posterior Cerebral Artery (PCA) at the junction of its pre-communicating (P1) and post-communicating (P2) segments and supplies the ventrolateral and dorsomedial thalamic nuclei, tuber cinereum, mammillary bodies, and cerebral peduncles [5,6]. Embryologically, the posterior division of the ICA initially forms a primitive PCA continuous with the PCoA, supplying the occipital lobe and brainstem. As the vertebrobasilar system develops, the PCoA typically regresses to a small segment connecting the ICA to P1-PCA. Failure of regression results in a foetal-type PCoA, whereas excessive regression or failed canalisation leads to hypoplasia or aplasia [4,7,8].

The PCoA exhibits several morphological variations with clinical significance including hypoplasia aplasia, duplication, and foetal-type configurations, all recognised as structural variants of the Circle of Willis [9]. Hypoplasia, a narrowed or underdeveloped PCoA, occurs in 6-35% of individuals, while aplasia, representing complete absence, occurs in 3-6% [10,11]. Foetal-type PCoA, with absence or underdevelopment of the P1 segment and persistence of the PCoA as the main supply to the PCA, occurs in 4-29% and has implications for open and endovascular procedures [12]. Duplication, the presence of two separate arterial branches, is extremely rare (~0.04%), emphasising the role of high-resolution MRA in accurate detection [13,14]. These variants are risk factors for hemispheric low-blood flow infarcts in patients with carotid occlusive disease [15].

A narrowed or absent PCoA can significantly impair cerebral blood flow, increasing ischemic stroke risk. Hypoplastic or aplastic PCoAs further elevate infarction risk when the internal carotid artery is obstructed [15]. Foetal-type PCoA shifts posterior circulation dependence to the anterior circulation, affecting stroke patterns and complicating surgery [12]. Bilateral hypoplasia or aplasia further increases risk, especially when additional vascular anomalies are

present [9,15]. Completeness of the circle of willis, including PCoA patency, is crucial for endovascular planning, as it enhances collateral flow, thrombectomy success, and clinical outcomes, whereas incomplete configurations may require alternative strategies [16].

Recent advances in MRA have improved non-invasive visualisation of vascular variations, enabling detailed morphological assessment and risk stratification, which are essential for neurosurgical and endovascular planning and understanding individual susceptibility to cerebrovascular disease [15]. Although previous anatomical and imaging studies have reported PCoA variations, most focused on overall Circle of Willis configurations using cadaveric studies, CTA or DSA with wide variability in prevalence [9-11]. Systematic evaluation of isolated PCoA morphology and its associations with age, sex, and laterality using high-resolution MRA remains limited. The present cross-sectional study aimed to address this gap by analysing PCoA variations using MRA, highlighting their demographic patterns and clinical relevance in cerebrovascular risk assessment and therapeutic planning.

MATERIALS AND METHODS

The present cross-sectional study was conducted in 150 patients at the department of Radiology, Dhiraj Hospital, BK Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth Deemed to be University, Vadodara, Gujarat, India, between May 2024 and August 2025. The study was conducted following the principles of the Institutional Ethical Committee, which approved the study (approval no. SVIEC/ON/ASLP/PhD/April/24/22/2024).

Inclusion and Exclusion criteria: Patients aged 18-90 years of both sexes, with good quality of MRA scans, and no evidence of cerebrovascular abnormalities in the circle of Willis who underwent brain MRA screening at the Radiology department, were included in the study. The exclusion criteria were the presence of CNS tumours, cerebrovascular abnormalities, aneurysms, any accidental head injury, and incomplete MRA brain scans.

Study Procedure

The study included a convenience sample of 150 patients who met the inclusion criteria and had high-quality MRA available for analysis.

The TOF-MRA technique was used, and the study was conducted and analysed in the Departments of Radiology and Anatomy. The patients underwent non-contrast three- dimensional time-of-flight MRA of the circle of Willis using a 1.5T MR system. The imaging parameters were 40/ 6.5; TR/ TE (time of repetition/time of echo), 20° flip angle, 200 × 150 mm field of view for the circle area, 225× 512 matrix, 0.67 × 0.39 mm pixel resolution, three signals acquired, and 1.4 mm section thickness. The Three-dimensional (3D) TOF-MRA sequence required four minutes 30s [17].

The MRA images were transferred to a dedicated workstation and MRA DICOM images were analysed using RadiAnt DICOM Viewer for PCoA diameter measurements and 3D visualisation. The MRA images were analysed to detect hypoplastic, aplastic, foetal-type and duplication PCoAs. Diameters were measured with electronic calipers on source images with reference to MIP reconstructions at the mid-segment of the PCoA [17,18]. Hypoplasia of the PCoA was defined as a PCoA diameter of < 1 mm [19]. Aplasia was defined as complete non-visualisation on both source and MIP images despite adequate imaging quality, in accordance with recent MRA variant classification protocols [20]. The PCoA occasionally continues as PCA, called as foetal PCA (f-PCA) with a complete absence/hypoplastic of P1 segment of PCA [21]. PCoA duplication is characterised by two separate arteries originating independently from the supraclinoid Internal Carotid Artery (ICA), with a short distance between them, and running parallel before merging with the PCA and pseudo-duplication with early common trunk [14]. All suspected variations were verified using Multiplanar Reconstruction (MPR) and Maximum Intensity Projection (MIP) [14]. To minimise errors related to vessel tortuosity, measurements were preferentially performed on source images rather than MIP alone [22]. All images were reviewed by two qualified Radiologists. Both were blinded to the patient demographic and clinical details to minimise observer bias. In the case of disagreement, a consensus was reached after a joint review. Demographic and clinical data were extracted from hospital electronic medical records.

STATISTICAL ANALYSIS

Data were analysed using Statistical Package for Social Sciences (SPSS) software (version 31.0; IBM Corp., Armonk, NY, USA). Continuous variables (age) were expressed as mean±Standard Deviation (SD), and categorical variables (sex, laterality, and PCoA morphology- hypoplasia, aplasia, and foetal type) were presented as frequencies and percentages. Participants were categorised into two age groups: ≤40 years and >40 years. Associations between PCoA morphological variations and demographic variables (age group, sex, and laterality) were evaluated using the Chi-square test or Fisher's exact test, as appropriate. A p-value <0.05 was considered statistically significant.

RESULTS

Total of 150 patients undergoing brain MRA were included in the final analysis. The mean age of the study population was 47.77±15.77 years (range: 18-81 years). Males constituted 66% (n=99) of participants, while females accounted for 34% (n=51). Based on age, 32% (n= 48) of participants were ≤40 years and 68% (n=102) were >40 years [Table/Fig-1].

Variables	Category	Frequency (n=150)	Percentage (%)
Age group (Years)	≤40	48	32%
	>40	102	68%
Sex	Male	99	66%
	Female	51	34%
Mean age±SD (years)	–	–	47.77±15.77

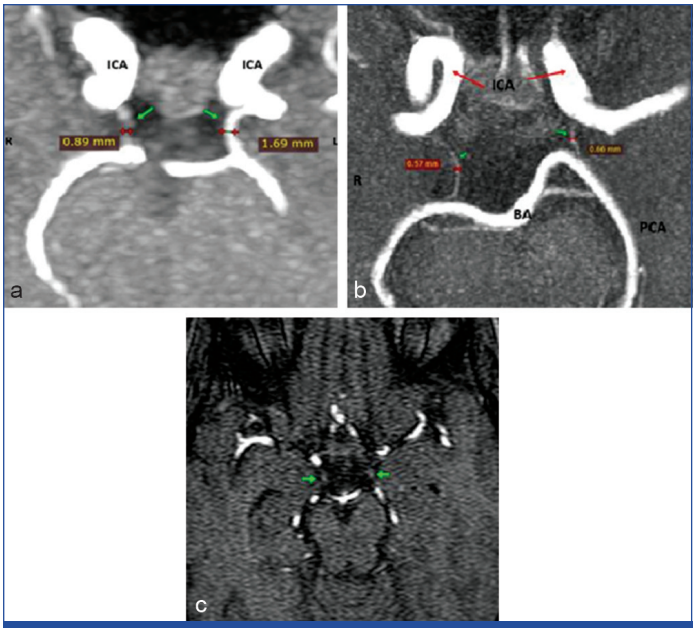
[Table/Fig-1]: Demographic characteristics of the participants.
This table presents the distribution of participants according to age, sex, and mean age (±SD).

Evaluation of 300 PCoAs demonstrated [Table/Fig-2] that hypoplasia was the most frequent morphological variation [Table/Fig-3], followed by aplasia [Table/Fig-4], normal configuration [Table/Fig-5], foetal-type configuration [Table/Fig-6], and duplication [Table/Fig-7]. Side-wise analysis revealed a statistically significant right-left asymmetry (χ^2=10.23, p=0.037). Aplasia was more common on the left-side, whereas normal morphology was more frequently observed on the right. Hypoplasia and foetal-type configurations showed nearly symmetrical distribution between sides, while duplication was rare and predominantly left-sided.

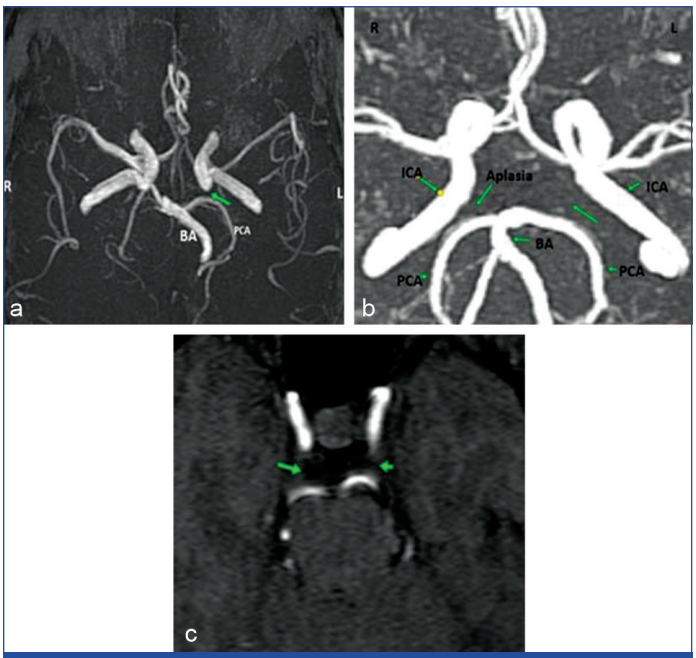
Sex-based analysis showed that hypoplasia was the predominant morphology in both males and females, followed by aplasia and

PCoA morphology	Right-side arteries 150 (%)	Left-side arteries 150 (%)	Total arteries (300)	Chi-square value	p-value
Normal	39 (26%)	22 (14.66%)	61 (20.33%)	10.23	0.037
Hypoplasia	62 (41.3 %)	60 (40%)	122 (40.66%)		
Aplasia	27 (18%)	43 (28.66%)	70 (23.33%)		
Foetal type	21 (14%)	21 (14%)	42 (14%)		
Duplication	1 (0.66%)	4 (2.66%)	5 (1.66%)		

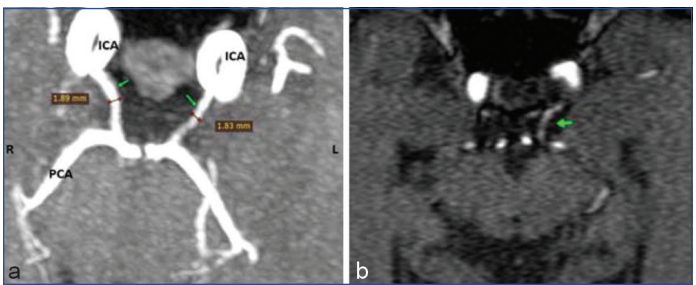
[Table/Fig-2]: Distribution of Posterior Communicating Artery (PCoA) morphological variations according to side-wise
Chi-square test; p<0.05 was considered significant.



[Table/Fig-3]: Axial and MIP view of MRA images showing: a) Right-side hypoplasia of PCoA; b) Hypoplasia of bilateral PCoA; c) Bilateral hypoplasia in axial view (green arrow).
(BA: Basilar artery; ICA: Internal carotid artery; PCA: Posterior cerebral artery; PCoA: Posterior communicating artery)

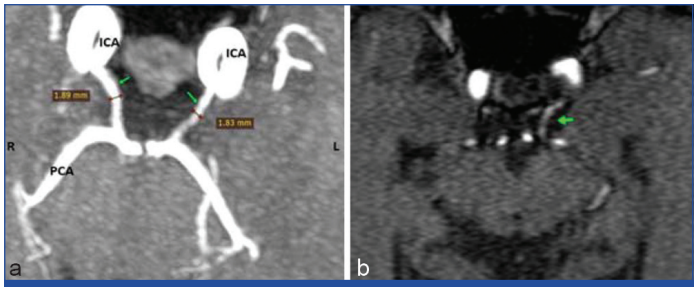


[Table/Fig-4]: 3D TOF MRA images showing: a) Left-side Aplasia of PCoA; b) Aplasia of bilateral PCoA; c) Axial view showing bilateral aplasia of PCoA. (green arrow).
(BA: Basilar artery; ICA; Internal carotid artery; PCA: Posterior cerebral artery; PCoA: Posterior communicating artery)

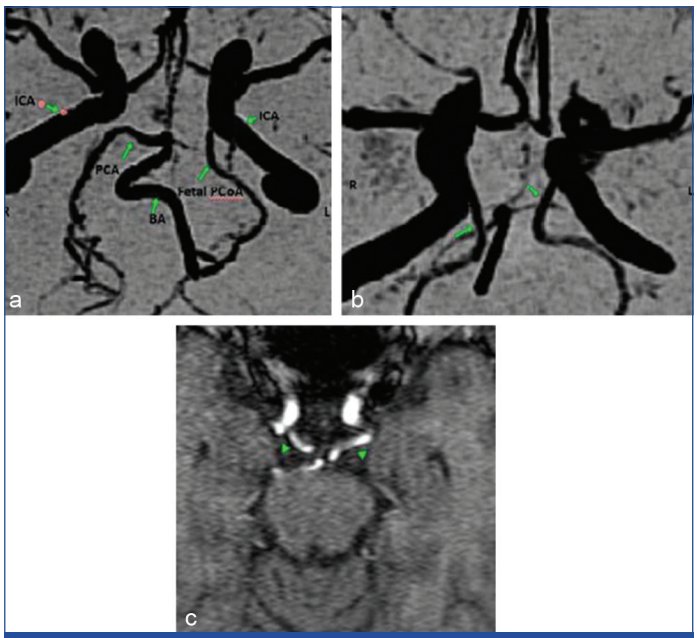


[Table/Fig-5]: Axial and MIP view of MRA images showing bilateral typical type of PCoA (green arrow); b) Unilateral normal type PCoA.
(BA: Basilar artery; ICA: Internal carotid artery; PCA: Posterior cerebral artery; PCoA: Posterior communicating artery)

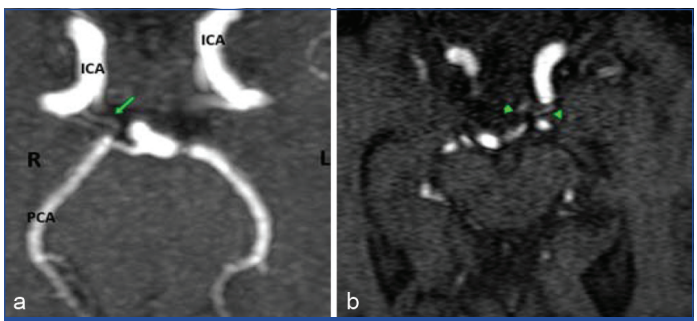
normal configuration. Although minor differences were observed in the distribution of individual variants between sexes, statistical analysis demonstrated no significant association between PCoA morphology and sex (χ^2=2.51, p=0.642) [Table/Fig-8].



[Table/Fig-5]: Axial and MIP view of MRA images showing bilateral typical type of PCoA (green arrow); b) Unilateral normal type PCoA.
(BA: Basilar artery; ICA: Internal carotid artery; PCA: Posterior cerebral artery; PCoA: Posterior communicating artery)



[Table/Fig-6]: MRA images showing: a) Left-side foetal-type PCoAl b) bilateral PCoA foetal-type; c) Bilateral foetal type (green arrow).
(ICA: Internal carotid artery; PCA: Posterior cerebral artery; PCoA: Posterior communicating artery, BA: Basilar artery) (green arrow)



[Table/Fig-7]: MRA image showing right-side: a) Unilateral Duplication of PCoA; b) Axial view of MRA showing unilateral duplication (green arrow).
(BA: Basilar artery; ICA: Internal carotid artery; PCA: posterior cerebral artery; PCoA: Posterior communicating artery)

Similarly, age-based analysis revealed that hypoplasia remained the most common variant in both age groups. Aplasia was relatively more frequent in individuals aged ≤40 years, while foetal-type configuration was more commonly observed in those aged >40 years. However, these differences did not reach statistical significance, and no significant association was found between PCoA morphology and age group (χ^2=7.39, p=0.117).

Overall, although statistically significant laterality-related differences were observed, associations with sex and age were not statistically significant. These non-significant findings should be interpreted as insufficient evidence to demonstrate a difference rather than confirmation of morphological uniformity, and may reflect limited power to detect moderate but clinically relevant variations.

Morphology	Male (n=198)	Female (n=102)	χ^2	p-value	≤40 years (n=96)	>40 years (n=204)	χ^2	p-value
Normal	38 (19.19%)	23 (22.54%)	2.51	0.642	18 (18.75%)	43 (21.07%)	7.39	0.117
Hypoplasia	82 (41.41%)	40 (39.21%)			38 (39.58%)	84 (41.17%)		
Aplasia	49 (24.74%)	21 (20.58%)			30 (31.25%)	40 (19.60%)		
Foetal type	27 (13.63%)	15 (14.70%)			8 (8.33%)	34 (16.66%)		
Duplication	2 (1.01%)	3 (2.94%)			2 (2.08%)	3 (1.47%)		

[Table/Fig-8]: Association of Posterior Communicating Artery (PCoA) morphology with sex and age group.
Chi-square (χ^2) test; p-value <0.05 was considered statistically significant.

DISCUSSION

The principal findings were that hypoplasia was the most common variation (40.66%), followed by aplasia (23.33%), while foetal-type configuration was observed in 14% of arteries and duplication in 1.66%. No statistically significant association was observed between PCoA morphology and age or sex, whereas a significant association with laterality was identified.

In the present study, combined prevalence of hypoplasia and aplasia was higher than the global pooled prevalence reported in the meta-analysis by Jones JD et al., which estimated unilateral and bilateral PCoA hypoplasia/aplasia at approximately 19.45% and 22.83%, respectively [11]. Similarly, in a clinical MRI cohort from Iran, Haghighimorad M et al., reported an even higher overall prevalence of PCoA hypoplasia/aplasia at 77.5%, indicating that clinical or patient-based populations may exhibit greater variant frequencies [23]. In a large healthy adult MRA cohort, Gaigalaite V et al., documented absence or hypoplasia of both PCoAs in ~47.9% of subjects [24], while cadaveric anatomical studies by Eftekhar B et al., reported hypoplasia in 25.3% and aplasia in 3.5% of cases [25].

In the present study, no statistically significant association was found between PCoA morphology and age or sex. Although hypoplasia was slightly more common in males (41.41%) than females (39.21%), this difference was not statistically significant. Earlier anatomical study by Gunnal SA et al., similarly failed to demonstrate strong sex-based differences, though they often reported lower rates of aplasia and higher rates of hypoplasia compared with our findings [9]. However, a recent meta-analysis by Ophelders MEH et al., found that bilateral hypoplasia or aplasia of the posterior communicating arteries was more frequent in males, which aligns with the present study's observation that morphological variations tended to be more common in males [26], which is consistent with the current study's observation that all morphological variations were numerically more common in males. A 3-Tesla MRA study by Bhanu SP et al., from the Andhra population reported hypoplastic PCoA in 27.3% of cases, with a significantly higher incidence in males and on the right-side [10], supporting this study finding of a significant association with laterality. Similar studies for comparison of PCoA hypoplasia and aplasia are tabulated in [Table/Fig-9] [10,11,23-26].

In the present study, foetal-type PCoA configuration occurred in 14% of arteries, aligning with recent South Asian MRA reports showing 5-25% prevalence. This rate matches Gunasekaran D et al., (20%0 in Tamil Nadu MRI cohorts and Bhanu SP et al., (5.6% f-PCA) in Andhra 3T-MRA, reflecting regional embryological patterns distinct from Western CTA data (15-30%) [10,27]. "In the Turkish MRA study by Kızılgöz V et al., foetal-type PCoA configuration was observed in approximately 13% of arteries, which aligns with our reported findings [28]. Gaigalaite V et al., reported a foetal-type PCA configuration in 15.9% of subjects in a large MRA cohort of healthy Eastern European adults [24].

In the present study, PCoA duplication was observed in 1.66% of arteries, aligning with the rare prevalence range of 0.2-2% across imaging and cadaveric literature. Indian studies report 0.5-1.3%: Kapoor K et al., documented 0.7-1% duplication/fenestration in North Indian cadavers, while Bhanu SP et al., noted 0.5% true PCoA duplication in an Andhra 3T-MRA cohort this study slightly higher rate reflects enhanced 1.5T TOF-MRA sensitivity for parallel-origin variants via rigorous source+MPR verification [10,29]. Some studies show rates remain consistently low: Kizilgöz V et al., reported 0.4%, Gaigalaite V et al., found 0.8%, and Uchino et al. confirmed 1-2% MRA cases-positioning this study finding at the validated upper limit while distinguishing true duplication from pseudo-forms [14,24,28]. Comparison of foetal-type PCoA and duplication across studies has been done in [Table/Fig-10] [10,14,24,27-29].

Such discrepancies between the present study and earlier reports can be largely attributed to methodological differences. MRA, as used in the present study, evaluates functional patency and flow dynamics and may overestimate hypoplasia due to signal loss in low-velocity vessels, particularly at 1.5-Tesla field strength, Previous studies have demonstrated that TOF-MRA at 1.5-T may result in apparent hypoplasia or non-visualisation of small-caliber arteries in approximately 10-30% of cases, reflecting flow-related limitations rather than true anatomical absence (Krabbe-Hartkamp MJ et al.,

S. No.	Author's name and year	Place of study	Sample size	Parameters assessed	Conclusion
1	Present study (2025)	India (tertiary care hospital)	150	Hypoplasia: 40.66%Aplasia: 23.33%	Hypoplasia was the most common variant, followed by aplasia. No significant association with age or sex; significant association with laterality.
2	Jones JD et al., 2020 [11]	Meta-analysis (global)	NA	Unilateral hypoplasia/aplasia: 19.45%Bilateral hypoplasia/ aplasia: 22.83%	Global pooled prevalence lower than present study, indicating methodological differences and population variability.
3	Haghighimorad Met al., 2017 [23]	Iran (clinical MRI cohort)	250	Combined hypoplasia/aplasia: 77.5%	Clinical population shows higher variant prevalence, reflecting patient selection bias.
4	Gaigalaite V et al., 2019 [24]	Lithuania / Eastern Europe	923	Absence/hypoplasia both PCoA: 47.9%	Large healthy adult MRA cohort; prevalence higher than global pooled estimate but lower than clinical populations.
5	Eftekhar B et al., 2006 [25]	Iran (cadaveric)	100	Hypoplasia: 25.3%Aplasia: 3.5%	Cadaveric study shows lower aplasia rate and moderate hypoplasia prevalence compared with present study.
6	Bhanu SP et al., 2020 [10]	Andhra Pradesh, India	231	Hypoplasia: 27.3%	Moderate prevalence; higher incidence in males and right side; supports present study's laterality findings.
7	Ophelders MEH et al., 2016 [26]	Europe (meta-analysis)	NA	Bilateral hypoplasia/aplasia more frequent in males	Confirms that sex may influence bilateral variants, aligning with the observation that morphological variations were numerically more common in males.

[Table/Fig-9]: Comparison of PCoA hypoplasia and aplasia across studies [10,11,23-26].

S. No.	Author's name and year	Place of study	Sample size	Parameters assessed	Conclusion
1	Present study (2025)	India	150	Foetal-type PCoA: 14%Duplication: 1.66%	Foetal-type configuration moderately common; duplication rare. Findings align with previously reported prevalence ranges.
2	Gunasekaran D et al., 2020 [27]	Tamil Nadu, India	700	Foetal-type PCoA: 20%	South Indian MRI cohort; foetal-type prevalence consistent with regional embryological patterns.
3	Bhanu SP et al., 2020 [10]	Andhra Pradesh, India	231	Foetal-type PCoA: 5.6%Duplication: 0.5%	Low prevalence of foetal-type and duplication; supports laterality and sex association in present study.
4	Kızılgöz V et al., 2017 [28]	Turkey	200	Foetal-type PCoA: 13%Duplication: 0.4%	Foetal-type prevalence similar to present study; duplication rare.
5	Gaigalaite V et al., 2019 [24]	Lithuania / Eastern Europe	923	Foetal-type PCoA: 15.9%Duplication: 0.8%	Large healthy adult MRA cohort; duplication rare, foetal-type consistent with South Asian studies.
6	Kapoor K et al., 2008 [29]	North India (cadaveric)	100	Duplication/fenestration: 0.7-1%	Cadaveric study confirms duplication is a rare variant.
7	Uchino A et al., 2006 [14]	Japan	200	Duplication: 1-2%	MRA studies confirm low prevalence of duplication; highlights importance of careful imaging to distinguish true duplication from pseudo-forms.

[Table/Fig-10]: Comparison of foetal-type PCoA and duplication across studies [10,14,24,27-29].

Stock kw et al.,) [30,31]. In contrast, CTA provides superior spatial resolution (approximately 0.4 mm) for direct luminal visualisation but may still fail to detect subtle aplasia in the absence of optimal three-dimensional reconstruction (Villablanca JP et al., Varga A et al.,) [32,33]. These technical differences strongly influence the reported prevalence of PCoA variants across studies (Villablanca JP et al., Varga A et al.,) [32,33]. Furthermore, a recent meta-analysis of anatomical studies by Jones JD et al., reported that PCoA hypoplasia or aplasia is present in approximately 68% of cases overall, with substantial between-study heterogeneity driven by differences in imaging modality, diameter thresholds, and definitional criteria, reinforcing the role of technique in determining reported prevalence [11]. Supporting this observation, emerging evidence from ultra-high-field 7.0-Tesla MRA by Krabbe-Hartkamp MJ et al., Conijnb MM et al., has demonstrated substantially lower rates of apparent PCoA absence compared with conventional 1.5-Tesla imaging, attributable to improved visualisation of small-caliber vessels and perforators. This suggests that lower-field MRA may systematically underreport small but patent arteries rather than true anatomical absence [30,34].

Similar methodological influences are evident in studies evaluating foetal-type PCoA configuration. This MRA-based approach detects functional patency but may underrepresent foetal dominance in low-flow states when compared with CTA-based studies, such as the Turkish cohort by Karataş A et al., reporting a prevalence of 17%, or cadaveric studies that reflect broader embryological persistence [35].

Regarding PCoA duplication, the consistently low prevalence observed in the present study mirrors that reported in prior radiological and cadaveric literature. These low rates suggest methodological robustness; however, MRA may slightly underdetect duplication because of flow overlap when compared with CTA's superior spatial precision or cadaveric anatomical detail. This emphasises the importance of multiplanar imaging in accurate variant characterisation (Sahin H et al.,) [36]. In the present study, duplication was defined as the presence of two distinct vessels originating from different embryological sources. Care must be taken to avoid misinterpretation caused by pseudo-duplications, where branches of the anterior choroidal artery may retain embryological vascular territory, mimicking true PCoA duplication (Uchino A et al.,) [14].

Overall, differences between the present study and previous literature are best explained by variation in imaging modality, magnetic field strength, spatial resolution, flow sensitivity, and definitional thresholds, rather than true population-based anatomical disparity. These methodological factors significantly influence the detection and classification of PCoA variants.

The clinical importance of PCoA morphology has been well documented. Chuang YM et al., identified PCoA hypoplasia as a significant risk factor for ischemic stroke involving thalamic perforator territories [15]. Underdeveloped or absent PCoA can result in reduced collateral circulation between the anterior and posterior cerebral systems, increasing vulnerability to ischaemic events, particularly within the thalamic and vertebrobasilar territories. PCoA hypoplasia has been associated with an increased risk of ischemic stroke even in the absence of carotid artery disease and is linked to diminished collateral capacity during acute cerebrovascular events [15,37]. Variants such as foetal-type PCoA and duplication may further modify cerebral haemodynamics and influence the risk of aneurysm formation or infarction. Clinically, occlusion or reduced patency of a foetal-type PCoA- such as during aneurysmal rupture or transient embolic events- can lead to significant neurological deficits, including impaired occipital lobe perfusion or infarction of PCoA-dependent perforators [38]. Although foetal-type PCoA may serve a compensatory role in certain Circle of Willis configurations, it warrants closer evaluation because of its association with altered cerebral haemodynamics and increased susceptibility to posterior circulation ischaemia [39]. From a clinical perspective, duplicated PCoAs may influence aneurysm formation, collateral pathways, and interventional planning, underscoring the need for careful pre-procedural evaluation [40]. Therefore, accurate identification of PCoA morphology through non-invasive imaging modalities such as MRA is essential for risk stratification, surgical and endovascular planning, and individualised patient management, reinforcing the clinical relevance of routine morphological assessment in cerebrovascular evaluation [41].

Larger multicentre studies using higher-resolution imaging (3T/7T) and correlating vascular variations with clinical outcomes are needed. Advanced techniques such as perfusion imaging and computational flow analysis may further clarify the haemodynamic significance of PCoA variants. Future studies could benefit from integrating machine-learning–based vascular segmentation and classification tools to automate Circle of Willis and PCoA variant analysis. Automated pipelines using convolutional neural networks or transformer-based models on TOF-MRA data may enhance reproducibility, reduce observer bias, and allow large-scale quantitative assessment of vessel calibers, branching patterns, and collateral scores. Prospective work should compare MRA findings with CTA and DSA to validate PCoA and PCA morphological classifications. Multimodal correlation will help confirm true variants, identify flow-dependent artefacts, and define the strengths and limitations of non-contrast TOF-MRA in routine practice.

Limitation(s)

The study was limited by a single-center sample, modest size, and the use of 1.5 T time-of-flight MRA, with its limited spatial resolution and signal-to-noise ratio, may reduce visualisation of small-caliber intracranial arteries, leading to underdetection of hypoplastic, particularly when a <1 mm diameter threshold approaches the effective resolution limits of the technique. Non-visualisation of a

vessel on TOF-MRA does not necessarily indicate true aplasia, as it may reflect a vessel caliber below the spatial resolution threshold rather than anatomical absence. Clinical outcomes were not correlated with PCoA morphology, restricting functional interpretation. Even though two observers independently examined the images, kappa statistics for inter-observer agreement were not calculated, as any discrepancies were resolved through consensus. This method limits the formal assessment of reproducibility.

CONCLUSION(S)

Hypoplasia emerged as the most prevalent PCoA variation, followed by aplasia, normal anatomy, foetal-type PCA, and rare duplication observed in this study. No significant associations existed with age or sex, though laterality showed borderline significance, suggesting these patterns primarily represent anatomical diversity rather than demographic influences. Hypoplastic/aplastic PCoAs reduce compensatory flow during ICA occlusion, increasing posterior territory stroke risk. Foetal-type configurations alter PCA supply, affecting aneurysm coiling and basilar thrombectomy planning. Complete variants predict better endovascular outcomes; incomplete patterns may require balloon-guided catheters or extended reperfusion windows.

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PARTICULARS OF CONTRIBUTORS:
1. PhD Scholar, Department of Anatomy, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth (Deemed to be University), Vadodara, Gujarat, India.
2. Associate Professor, Department of Anatomy, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth (Deemed to be University), Vadodara, Gujarat, India.
3. Associate Professor, Department of Anatomy, Government Medical College, Alwar, Rajasthan, India.
4. Professor, Department of Anatomy, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth (Deemed to be University), Vadodara, Gujarat, India.
5. Professor and Head, Department of Anatomy, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth (Deemed to be University), Vadodara, Gujarat, India.
6. Assistant Professor, Department of Radiology, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth (Deemed to be University), Vadodara, Gujarat, India.
7. Junior Resident, Department of Radiology, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth (Deemed to be University), Vadodara, Gujarat, India.
8. Professor, Department of Anatomy, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth (Deemed to be University), Vadodara, Gujarat, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Ashish Kumar,
76, Vishwakarma Colony, Opposite Saran Petrol Pump, Old Gajner Road, Bikaner, Rajasthan, India.
E-mail: Suthar201532@gmail.com

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