

ANATOMICAL VARIATIONS OF THE CIRCLE OF WILLIS ON MAGNETIC RESONANCE ANGIOGRAPHY: A CROSS-SECTIONAL STUDY OF PREVALENCE AND CLINICAL ASSOCIATIONS

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Abstract

Background: The circle of Willis (CoW) is the principal anastomotic ring at the base of the brain, and its configuration is highly variable. A classic, complete circle is present in only a minority of individuals; hypoplasia, aplasia and fetal-type variants of its component vessels influence collateral capacity and are relevant to stroke risk, aneurysm formation and neurosurgical planning. We described the prevalence of anterior- and posterior-circulation variants on magnetic resonance angiography (MRA) and examined their associations with sex, age and clinical indication.

Methods: In this cross-sectional study, 320 intracranial MRA examinations were reviewed. Overall CoW status, anterior and posterior configurations, vessel-segment diameters, vertebral dominance, and the presence of fetal-type posterior cerebral artery (PCA), fenestration, aneurysm, significant stenosis/occlusion and infarction were recorded. Continuous variables are summarised as mean $\pm$ SD and categorical variables as counts and percentages; associations were tested with the χ^2 test. Reporting follows STROBE.

Results: A variant or incomplete circle was present in 205 examinations (64.1%) and a complete classic circle in 115 (35.9%). Anterior circulation was complete in 221 (69.1%), the commonest anterior variant being a hypoplastic A1 segment (16.6%). Posterior circulation was complete in 167 (52.2%), with a hypoplastic posterior communicating artery (PComA) in 20.3% and a fetal-type PCA in 19.1% (unilateral 16.2%, bilateral 2.8%). Vertebral arteries were codominant in 45.3%. An intracranial aneurysm was detected in 24 (7.5%), significant stenosis/occlusion in 38 (11.9%) and infarction in 39 (12.2%). Variant status was not associated with sex ($p = 0.53$), age group ($p = 0.53$) or aneurysm detection ($p = 1.00$).

Conclusions: In this variant CoW anatomy was the rule rather than the exception, affecting nearly two-thirds of examinations, with hypoplastic PComA and fetal-type PCA the leading posterior variants. Although variant status was not statistically associated with aneurysm in this sample, the high background prevalence of clinically relevant configurations supports routine documentation of CoW anatomy on every intracranial MRA.

Keywords: circle of Willis; magnetic resonance angiography; anatomical variation; fetal posterior cerebral artery; hypoplasia; intracranial aneurysm.

1. Introduction

The circle of Willis is the arterial polygon at the base of the brain that links the anterior (internal carotid) and posterior (vertebrobasilar) circulations through the anterior communicating artery and the paired posterior communicating arteries. When complete and symmetric, it provides a route for collateral flow that can compensate for proximal stenosis or occlusion. In practice, however, a textbook-complete circle is present in a minority of people; hypoplasia or absence of one or more communicating or precommunicating segments, and persistence of the embryonic (fetal-type) posterior cerebral artery, are common.

These variations are not merely anatomical curiosities. The adequacy of collateral flow through the circle influences the size and pattern of infarction after large-vessel occlusion; certain configurations — notably a fetal-type PCA and asymmetries of the anterior communicating complex — have been linked in the literature to altered haemodynamic stress and to the distribution of intracranial aneurysms; and knowledge of an individual's circle is important before carotid cross-clamping, aneurysm treatment and other neurovascular interventions. Time-of-flight and contrast-enhanced MRA allow this anatomy to be mapped non-invasively and without ionising radiation, making population description feasible.

Reported prevalences vary widely with population, imaging modality and, critically, the diameter threshold used to define hypoplasia. There remains value in characterising the spectrum of variants in defined imaging cohorts and in testing whether variant anatomy clusters with demographic factors or with detected vascular pathology.

This cross-sectional study was therefore designed to (i) determine the prevalence of complete versus variant/incomplete circles on intracranial MRA; (ii) describe the specific anterior- and posterior-circulation configurations, vessel-segment calibres and vertebral dominance pattern; (iii) record associated aneurysm, stenosis/occlusion and infarction; and (iv) test whether variant status is associated with sex, age group or clinical indication. We hypothesised that variant anatomy would predominate and that its distribution would be largely independent of sex and age.

2. Materials and Methods

2.1 Study design and setting

This was a single-centre, cross-sectional, observational study conducted jointly by the Departments of Anatomy, Sri Lakshmi Narayana Institute of Medical Sciences. The unit of observation was one intracranial MRA examination. Reporting follows the STROBE statement for cross-sectional studies.

2.2 Participants and eligibility

Consecutive intracranial MRA examinations performed for headache, stroke/TIA workup, vertigo/syncope, aneurysm screening or follow-up, preoperative vascular mapping, or incidental indications during the study period were screened. Examinations of diagnostic quality permitting evaluation of the circle of Willis were included. Studies with non-diagnostic image quality, gross motion degradation, or extensive vascular pathology precluding assessment of the native anatomy were excluded.

2.3 Imaging technique

Most examinations used three-dimensional time-of-flight (3D TOF) MRA; contrast-enhanced MRA and combined protocols were used in a minority [state sequences, parameters, and post-processing — MIP and source-image review]. Examinations were reviewed independently by [n] radiologists/anatomists blinded to clinical details, with discrepancies resolved by consensus.

2.4 Variables and definitions

The circle was classified overall as a complete classic circle or a variant/incomplete circle. The anterior configuration was categorised as complete, hypoplastic A1 segment, absent A1 segment, anterior communicating artery (AComA) not visualised, or fenestrated AComA; the posterior configuration as complete, hypoplastic PComA, absent PComA, or unilateral/bilateral fetal-type PCA. A1, PComA, P1 and basilar diameters were measured on source images; a segment was deemed hypoplastic below a pre-specified threshold [state the exact millimetre threshold used, e.g., <1 mm for communicating arteries] and aplastic when not visualised. Vertebral dominance, fenestration, intracranial aneurysm (with location), significant stenosis/occlusion (with location) and acute/chronic infarction on companion MRI were recorded.

2.5 Sample size

The analysed sample comprised 320 examinations. [Provide the a priori justification: to estimate a variant prevalence near 60% with a 95% CI half-width of ~5.5%, approximately 300 examinations are required; state assumptions for any comparative analyses.]

2.6 Statistical analysis

Continuous variables were summarised as mean $\pm$ SD (median [IQR] where skewed) and categorical variables as frequencies and percentages. Associations between variant status and sex, age group, indication and aneurysm detection were tested with the χ^2 test (Fisher's exact test for sparse cells). A two-sided $p < 0.05$ was considered significant. Analyses were performed in [software and version].

3. Results

3.1 Sample and imaging characteristics

Of 320 examinations, 162 (50.6%) were from women and 158 (49.4%) from men; mean age was 49.6 ± 20.0 years (range 18–85), distributed across the 18–39 (35.6%), 40–59 (28.4%) and ≥ 60

(35.9%) year groups. The commonest indication was stroke/TIA workup (89; 27.8%), followed by headache evaluation (69; 21.6%) and incidental/other (61; 19.1%). Most studies used 3D TOF MRA (246; 76.9%) and were of good diagnostic quality (235; 73.4%) (Table 1).

Characteristic	Value
Examinations, n	320
Age, years (mean $\pm$ SD; range)	49.6 $\pm$ 20.0 (18–85)
Sex — Female / Male, n (%)	162 (50.6) / 158 (49.4)
Age group — 18–39 / 40–59 / $\geq$ 60, n (%)	114 (35.6) / 91 (28.4) / 115 (35.9)
Indication — Stroke/TIA / Headache / Incidental, n (%)	89 (27.8) / 69 (21.6) / 61 (19.1)
Indication — Aneurysm / Vertigo / Preop, n (%)	43 (13.4) / 34 (10.6) / 24 (7.5)
Technique — 3D TOF / CE-MRA / Both, n (%)	246 (76.9) / 58 (18.1) / 16 (5.0)
Image quality — Good / Acceptable / Limited, n (%)	235 (73.4) / 78 (24.4) / 7 (2.2)

Table 1. Demographic and imaging profile of the study sample ($n = 320$).

3.2 Overall circle status and configurations

A variant or incomplete circle was present in 205 examinations (64.1%), and a complete classic circle in 115 (35.9%). In the anterior circulation, a complete configuration was seen in 221 (69.1%); the leading variants were a hypoplastic A1 segment (53; 16.6%), a non-visualised AComA (20; 6.2%), an absent A1 segment (18; 5.6%) and a fenestrated AComA (8; 2.5%). In the posterior circulation, a complete configuration was seen in 167 (52.2%), with a hypoplastic PComA in 65 (20.3%), a unilateral fetal-type PCA in 52 (16.2%), an absent PComA in 27 (8.4%) and a bilateral fetal-type PCA in 9 (2.8%) — a fetal-type PCA of either type in 61 (19.1%) (Table 2).

Circulation	Configuration	n (%)
Overall circle	Variant / incomplete	205 (64.1)
	Complete classic	115 (35.9)
Anterior	Complete	221 (69.1)
	Hypoplastic A1 segment	53 (16.6)
	AComA not visualised	20 (6.2)
	Absent A1 segment	18 (5.6)
	Fenestrated AComA	8 (2.5)
Posterior	Complete	167 (52.2)
	Hypoplastic PComA	65 (20.3)
	Unilateral fetal-type PCA	52 (16.2)
	Absent PComA	27 (8.4)
	Bilateral fetal-type PCA	9 (2.8)

Table 2. Overall status and anterior/posterior configurations of the circle of Willis ($n = 320$).

3.3 Vessel calibres and vertebral dominance

Mean segment diameters were: right A1 1.78 ± 0.73 mm, left A1 1.97 ± 0.59 mm; right PComA 1.40 ± 0.72 mm, left PComA 1.39 ± 0.70 mm; right P1 1.86 ± 0.65 mm, left P1 1.80 ± 0.62 mm; and basilar artery 3.55 ± 0.76 mm. A hypoplastic segment (any) was present in 161 (50.3%) and an aplastic/absent segment in 63 (19.7%). The vertebral arteries were codominant in 145 (45.3%), left-dominant in 114 (35.6%) and right-dominant in 61 (19.1%); fenestration was seen in 11 (3.4%) (Table 3).

Segment / feature	Value (mean $\pm$ SD or n (%))
Right A1, mm	1.78 ± 0.73
Left A1, mm	1.97 ± 0.59
Right PComA, mm	1.40 ± 0.72
Left PComA, mm	1.39 ± 0.70
Right P1, mm	1.86 ± 0.65
Left P1, mm	1.80 ± 0.62
Basilar artery, mm	3.55 ± 0.76
Hypoplastic segment present	161 (50.3)
Aplastic / absent segment present	63 (19.7)
Vertebral dominance — Codominant / Left / Right	145 (45.3) / 114 (35.6) / 61 (19.1)
Fenestration present	11 (3.4)

Table 3. Vessel-segment calibres and vertebrobasilar features ($n = 320$).

3.4 Associated vascular pathology

An intracranial aneurysm was detected in 24 examinations (7.5%); the commonest sites were the middle cerebral artery bifurcation (9; 2.8%) and the internal carotid terminus / PComA origin (5; 1.6%), with AComA and basilar-tip aneurysms in 3 each (0.9%). Significant stenosis or occlusion was present in 38 (11.9%) and an acute or chronic infarct on companion MRI in 39 (12.2%). Overall, a variant and/or vascular-pathology flag was raised in 226 examinations (70.6%) (Table 4).

Finding	n (%)
Intracranial aneurysm detected	24 (7.5)
— MCA bifurcation	9 (2.8)
— ICA terminus / PComA	5 (1.6)
— AComA	3 (0.9)
— Basilar tip	3 (0.9)
— Other	4 (1.2)
Significant stenosis / occlusion	38 (11.9)
Acute or chronic infarct on MRI	39 (12.2)
Variant and/or vascular-pathology flag	226 (70.6)

Table 4. Associated aneurysm, stenosis/occlusion and infarction ($n = 320$).

3.5 Associations with demographics and pathology

Variant/incomplete circle status did not differ significantly by sex (women 66.0% vs men 62.0% variant; χ^2 , $p = 0.53$), by age group (18–39, 63.2%; 40–59, 60.4%; ≥ 60 , 67.8%; $p = 0.53$), or by aneurysm detection (variant circles harboured aneurysms at a similar rate to complete circles; $p = 1.00$). These null associations, in the presence of a high overall variant prevalence, indicate that variant anatomy in this sample was broadly distributed rather than concentrated in any demographic or pathological subgroup (Table 5).

Comparison	Result	χ^2 p
Variant status by sex (F vs M)	66.0% vs 62.0% variant	0.53
Variant status by age group (18–39/40–59/ ≥ 60)	63.2% / 60.4% / 67.8% variant	0.53
Aneurysm by circle status (variant vs complete)	similar rates	1.00

Table 5. Association of variant circle status with sex, age and aneurysm detection

4. Discussion

In this cross-sectional MRA study of 320 examinations, a variant or incomplete circle of Willis was the predominant finding, present in almost two-thirds of cases, while a textbook-complete circle was seen in only about a third. The posterior circulation contributed most of the variability, with hypoplasia of the posterior communicating artery and fetal-type posterior cerebral arteries together accounting for the majority of variant configurations.

The high prevalence of a fetal-type PCA (about one in five examinations) is clinically salient because, in this configuration, the occipital lobe is supplied predominantly from the carotid rather than the vertebrobasilar system; this alters the expected territory of infarction in both anterior- and posterior-circulation ischaemia and is relevant when planning endovascular access.

Variant status was not associated with sex, age group or aneurysm detection in this sample. The absence of a demographic association is compatible with the view that circle configuration is largely established in development and is not strongly modified by later demographic factors.

The practical message is that variant anatomy is common enough to be expected on any given MRA, and that structured reporting of the anterior and posterior configurations, communicating-segment status and vertebral dominance adds value for downstream stroke and neurosurgical care.

4.2 Implications and future directions

The findings support routine, structured documentation of circle-of-Willis anatomy on intracranial MRA. Future work should pre-specify hypoplasia thresholds, use contrast-enhanced or combined MRA to reduce flow-related artefact, model specific configurations against aneurysm location and infarct pattern, and, where feasible, link anatomy to clinical outcomes in a prospective design.

5. Conclusion

Within the limits of variant or incomplete circle-of-Willis anatomy affected nearly two-thirds of MRA examinations, driven mainly by posterior-circulation variants (hypoplastic PComA and fetal-type PCA), while aneurysm, stenosis and infarction were each detected in a clinically meaningful minority. Variant status was independent of sex, age and aneurysm detection in this sample.

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