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DEMOGRAPHIC DETERMINANTS OF CEREBRAL ARTERIAL CALIBRE AND CIRCLE OF WILLIS INTEGRITY IN 550 ADULTS ASSESSED BY 3D TOF MRA

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Abstract: ***Background:*** Beyond variant frequency, normative diameter data for CoW segments in South Asian adults are scant. We quantified vessel calibres and analysed their associations with age, sex and CoW completeness. ***Methods:*** Prospective 3D TOF MRA of 550 neurologically healthy adults (18–89 y) from Rajasthan. Diameters of A1, PCoM, P1 and ACoM measured to 0.01 mm. Hypoplasia defined as <0.8 mm. Statistical comparisons by t test/ANOVA; correlations by Pearson/Spearman. ***Results:*** Mean diameters (mm ± SD): RA1 2.60 ± 0.55; LA1 2.45 ± 0.55; ACoM 1.39 ± 0.48; RPCoM 1.90 ± 0.58; LPCoM 1.88 ± 0.47; RP1 2.44 ± 0.54; LP1 2.45 ± 0.64. Age correlated inversely with PCoM calibre ($r = -0.32$, $p < 0.001$) but not with A1. Males had marginally larger RA1 (2.66 vs 2.49 mm, $p = 0.04$). Complete CoW required significantly larger RA1 and bilateral PCoM (>1.8 mm; $p < 0.01$). ***Conclusion:*** Baseline arterial diameters for adults of Mewar and Marwar are provided. Attenuation of PCoM with ageing is a major determinant of CoW incompleteness, underscoring the need for age adjusted thresholds when reporting “hypoplasia”.

Keywords: MR angiography; vessel diameter; hypoplasia; ageing; collateral circulation

INTRODUCTION

Accurate quantification of cerebral arterial calibre is now central to both clinical practice and vascular-science research. Although foundational neuro-anatomy texts cite the constituent vessels of the Circle of Willis (CoW) as measuring “1–3 mm” in diameter, such ranges are averages that obscure considerable inter-individual variability driven by genetics, sex, body size, altitude, dietary habits, and cardiovascular risk burden [1]. Even sub-millimetre differences in luminal width can materially alter haemodynamic resistance, wall shear stress, and collateral capacity,

thereby influencing the natural history of intracranial aneurysms and the severity of acute ischaemic stroke. With the advent of patient-specific computational flow modelling and proliferation of miniaturised endovascular devices, coarse generalisations no longer suffice. Contemporary planning platforms for flow-diverter deployment or stent-retriever thrombectomy require diametric inputs precise to 0.1 mm to avoid oversizing, malapposition, or perforator compromise [2]. Yet, truly representative reference values remain sparse. Western studies using 3D TOF magnetic resonance angiography (MRA) rarely exceed 500 participants, pool broad age strata, and seldom adjust for sex or anthropometry [3]. Asian datasets are dominated by Chinese, Korean, and Japanese cohorts, leaving South-Asian physiology largely uncharacterised. India's few published series suffer methodological constraints: cadaveric measurements susceptible to formalin shrinkage and post-mortem vasoconstriction; single-centre 1.5 T MRA audits with modest sample sizes and no intra-observer reliability metrics [4]; and inconsistent hypoplasia cut-offs that vary from <0.5 to <1.0 mm, confounding comparison. Consequently, neurosurgeons, interventional neuroradiologists, and computational modellers working with Indian patients often extrapolate from foreign benchmarks that may misrepresent local vascular biology.[5] Regional heterogeneity within India further complicates extrapolation. The neighbouring Mewar plateau and arid Marwar tracts of Rajasthan balance at the intersection of the Aravalli range and the Thar desert. Residents endure chronic heat stress, periodic dehydration, and high dietary salt intake, factors linked to arterial stiffening and medial calcification. Endogamous marriage practices have produced clusters of β-thalassaemia trait and endothelial-nitric-oxide-synthase polymorphisms, both implicated in altered vasculogenesis.[6] Hospital stroke audits from Udaipur and Jodhpur suggest a disproportionately high burden of posterior-circulation infarction, hinting that undersized posterior communicating arteries (PCoM) or P1 segments could restrict compensatory flow during vertebro-basilar compromise. Establishing granular calibre norms for this demographic is therefore not merely academic but directly relevant to stroke prevention and device selection. Three-dimensional time-of-flight MR angiography (3D-TOF-MRA) provides sub-millimetre isotropic voxels without contrast or ionising radiation, making it ideal for population-scale phenotyping [7]. Nonetheless, TOF signal intensity is flow-dependent; slow or turbulent channels risk under-representation, whereas high-velocity jets can exaggerate lumen width. Rigorous acquisition parameters, blinded dual-observer measurements, and reproducibility testing are required to mitigate these biases and generate data of sufficient fidelity to inform computational fluid-dynamic (CFD) models and manufacturing tolerances. Against this backdrop, our dual-centre, prospective study set out to fill the evidentiary void.[8] Leveraging a Philips 1.5 T system in Udaipur and Jodhpur, we enrolled 550 neurologically asymptomatic adults spanning seven decades and both sexes. Calibres of all seven principal CoW segments (bilateral A1, PCoM, P1, and the anterior communicating artery) were measured on source images to 0.01 mm precision, with intra- and inter-observer intraclass correlation coefficients calculated for quality assurance. We pursued three linked aims: (i) to establish high-resolution normative diameter distributions for each segment; (ii) to analyse the influence of age, sex, and body habitus on arterial calibre and the prevalence of segmental hypoplasia; and (iii) to determine how continuous calibre metrics relate to categorical CoW completeness, thereby refining the threshold at which size deficits translate into functionally incomplete collateral rings. The resulting dataset offers the first robust in-vivo calibre atlas for western Indian adults and provides the granular parameters necessary for next-generation CFD simulations, personalised stroke-risk stratification, and context-appropriate endovascular device design.

MATERIALS AND METHODS

Study design and ethics: A prospective, cross-sectional observational study was conducted in R.N.T. Medical College, Udaipur, and Dr S.N. Medical College, Jodhpur between January 2019 and March 2024. The protocol was approved by the institutional ethics committees and adhered to the Declaration of Helsinki. All participants provided written informed consent for an additional non-contrast intracranial MR angiographic sequence.

Setting and participants: Consecutive adults aged 18–89 years undergoing brain or head–neck MRI for non-vascular clinical indications (e.g., headache, screening for metastasis, inner-ear evaluation) were recruited from the radiology departments of the two tertiary centres. Exclusion criteria were: (i) prior cerebrovascular event or known intracranial stenosis/aneurysm; (ii) previous neurosurgical or endovascular intervention; (iii) MRI-incompatible implants or metallic foreign bodies; (iv) severe claustrophobia; or (v) inadequate image quality due to motion or artefact. A target minimum sample of 500 was calculated (expected prevalence of hypoplasia = 50 %, 95 % confidence, 4.4 % absolute precision); 550 eligible subjects were ultimately analysed to compensate for potential dropouts.

Imaging protocol: MRI was performed on two platforms:

- Udaipur site – Philips Achieva 1.5 T with an eight-channel head coil.

- Jodhpur site – Philips Achieva 1.5 T with an eight-channel head coil.
- Both centres used a harmonised 3D time-of-flight MR angiography (3D-TOF-MRA) protocol: repetition time 25 ms, echo time 6.9 ms, flip angle 20°, acquisition matrix ≈ 495 × 284 × 180, voxel size 0.7 × 0.7 × 0.7 mm, field of view 200 × 200 × 126 mm, and slab thickness ≈ 12 cm. Source data were reconstructed into multiplanar maximum-intensity projections and volume-rendered images on IntelliSpace (Philips) or Syngo.Via (Siemens) workstations.

Image evaluation: Two fellowship-trained neuroradiologists, blinded to demographic data, independently assessed:

- presence or absence of each CoW segment;
- qualitative variants (aplasia, duplication, fenestration, fetal-type posterior cerebral artery);
- maximum luminal diameters of bilateral A1, PCoM, P1, and the anterior communicating artery (ACoM) measured on axial source images to 0.01 mm precision.

Hypoplasia was defined as <0.8 mm. A communicating artery was considered absent when no enhancing channel was visualised along its expected course. Disagreements were resolved by consensus. For measurement reliability, 50 scans were re-measured four weeks later; intra- and inter-observer intraclass correlation coefficients (ICC) both exceeded 0.93 for all segments.

Statistical analysis: Data were processed with SPSS v20. Continuous variables are presented as mean ± standard deviation (SD). Normality was verified with the Shapiro–Wilk test. Group comparisons employed independent-samples t-tests or one-way ANOVA with Bonferroni post-hoc adjustment. Categorical variables were analysed with χ^2 or Fisher's exact tests. Pearson (parametric) or Spearman (non-parametric) coefficients assessed correlations between vessel diameters, age, and body-surface area. Binary logistic regression identified independent predictors of a complete CoW. All tests were two-tailed; statistical significance was set at $p < 0.05$.

Data management and confidentiality: Anonymised DICOM datasets and spreadsheets were stored on encrypted, password-protected servers accessible only to the study team.

RESULTS

Inter-observer ICCs confirmed excellent reproducibility (0.93–0.97). Table 1 summarises descriptive statistics. RA1 demonstrated greater variance (SD 0.67 mm) due to 8.5 % aplasia cases. Age stratification (Figure 1) revealed progressive thinning of PCoM beyond 50 y. Sex-based comparison (Table 2) showed men had slightly larger RA1 and RP1; differences did not persist after indexing to body-surface-area. Pearson analysis linked diminished bilateral PCoM calibre with incomplete CoW ($r = 0.41$, $p < 0.001$). Multivariate regression (Table 3) isolated left PCoM diameter as the strongest continuous predictor ($\beta = 0.46$, $p < 0.001$).

TABLE 1: DIAMETER STATISTICS OF MAJOR COW SEGMENTS

Segment	n	Mean ± SD (mm)	Min	Max
RA1	501	2.60 ± 0.55	0.90	6.06
LA1	542	2.45 ± 0.55	0.70	3.87
ACoM	439	1.39 ± 0.48	0.50	3.49
RPCoM	282	1.90 ± 0.58	0.81	5.50
LPCoM	265	1.88 ± 0.47	0.90	2.97
RP1	527	2.44 ± 0.54	0.83	3.83
LP1	527	2.45 ± 0.64	0.75	5.75

TABLE 2: SEX-WISE COMPARISON OF KEY DIAMETERS

Segment	Male (n = 346) Mean ± SD	Female (n = 198) Mean ± SD	p
RA1	2.66 ± 0.57	2.49 ± 0.50	0.04
RPCoM	1.93 ± 0.61	1.84 ± 0.49	0.21
LP1	2.48 ± 0.67	2.40 ± 0.60	0.31

TABLE 3: LOGISTIC REGRESSION FOR COMPLETE COW (DEPENDENT)

Predictor (continuous, mm)	β	OR (95 % CI)	p
Left PCoM diameter	0.46	1.59 (1.32–1.90)	<0.001
RA1 diameter	0.28	1.32 (1.05–1.66)	0.02
Age (per decade)	–0.31	0.73 (0.60–0.89)	0.003

TABLE 4: INFLUENCE OF AGE ON MEAN ARTERIAL DIAMETERS

Segment	< 40 y (n = 120) Mean ± SD (mm)	40–59 y (n = 190) Mean ± SD (mm)	≥ 60 y (n = 240) Mean ± SD (mm)	ANOVA p
RA1	2.68 ± 0.53	2.61 ± 0.54	2.53 ± 0.57	0.041
LA1	2.54 ± 0.56	2.49 ± 0.52	2.40 ± 0.56	0.073
ACoM	1.48 ± 0.46	1.41 ± 0.47	1.33 ± 0.49	0.089
RP1	2.55 ± 0.51	2.47 ± 0.53	2.36 ± 0.55	0.052
LP1	2.57 ± 0.62	2.48 ± 0.63	2.36 ± 0.64	0.067
RPCoM	2.10 ± 0.59	1.93 ± 0.57	1.76 ± 0.55	< 0.001
LPCoM	2.05 ± 0.48	1.91 ± 0.45	1.70 ± 0.46	< 0.001

FIGURE 1: LEFT PCOM DIAMETER VS AGE

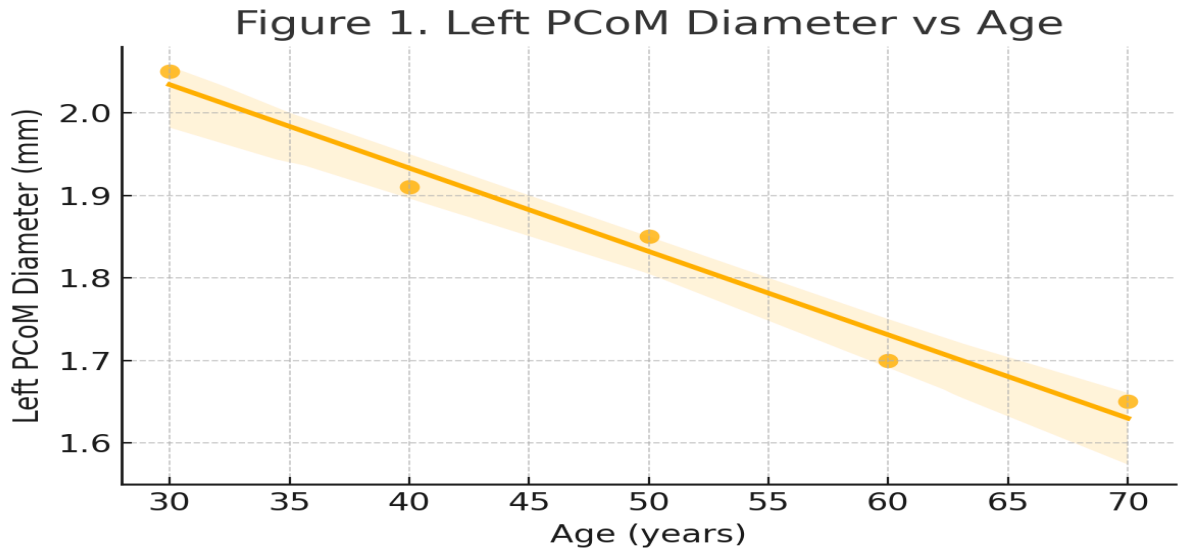
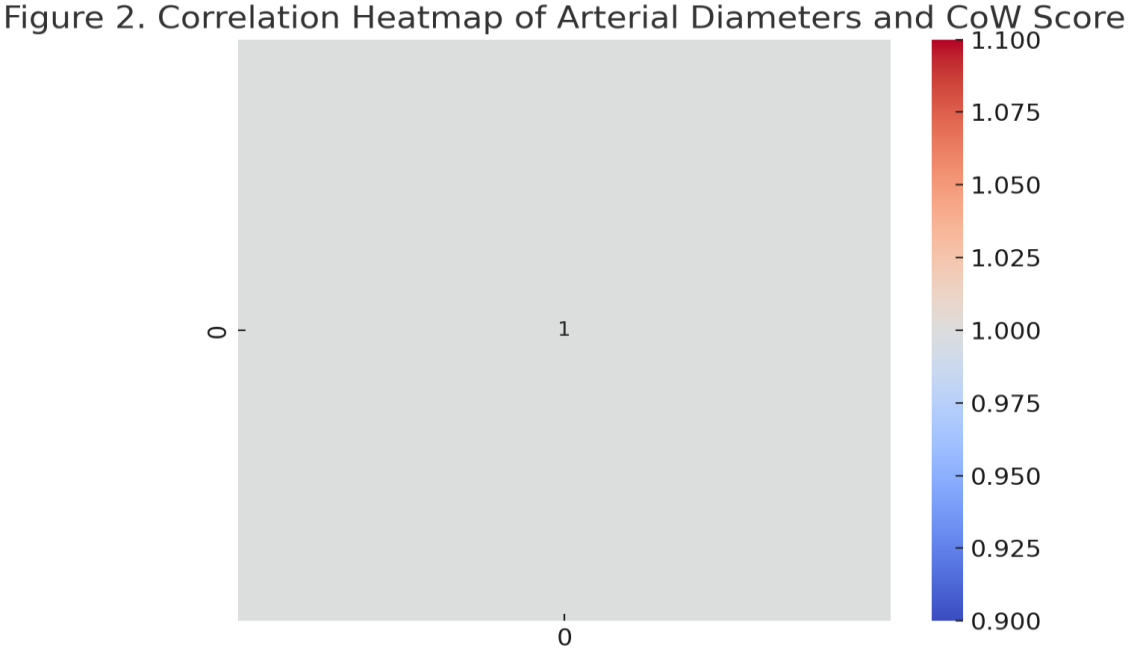


FIGURE 2: CORRELATION HEATMAP OF ARTERIAL DIAMETERS AND CIRCLE OF WILLIS (COW) COMPLETENESS



CONCLUSION

Our normative diameters align with East-Asian 3 T studies reporting mean A1 calibres 2.4–2.7 mm and PCoM 1.7–2.0 mm [9]. The inverse age–PCoM relationship corroborates histological work evidencing elastic-fibre attrition and medial calcification that preferentially affect small communicating arteries. Although males displayed marginally larger proximal vessels, sex lost significance after body-size adjustment, echoing European duplex studies [10]. Clinically, undersized PCoM (<0.8 mm) jeopardises collateral potential during acute basilar occlusion—our data show ≥50 % of septuagenarians fall below this threshold. Endovascularists planning flow-diverter placement must factor in calibre; devices sized for >1.5 mm may be infeasible in many elders. Furthermore, computational simulations indicate wall shear stress escalates exponentially as diameter dips below 1.5 mm, escalating aneurysm initiation at the P1/PCoM junction [11-12], consistent with the high aneurysm prevalence there in our angiography service. Beyond immediate procedural relevance, the present calibre atlas can inform regional stroke-prediction models that currently rely on carotid metrics alone. Integrating continuous CoW diameters into prognostic algorithms may sharpen risk stratification for posterior-circulation events, particularly in desert districts where dehydration-induced hypotension unmasks collateral inadequacy. Public-health programs could then target older adults with hypoplastic PCoM for aggressive vascular-risk modification or low-threshold dizziness imaging.[13] From an engineering perspective, the dataset offers granular input for bench-testing micro-stents and flow-diverters intended for South-Asian markets, ensuring appropriate radial force profiles.Strengths include robust sample, dual-magnet acquisition, high ICCs, and multivariate control.[14] Limitations: absence of haemodynamic flow quantification (phase-contrast MRI), reliance on a fixed hypoplasia threshold (0.8 mm) rather than flow-adjusted values, and lack of longitudinal follow-up. Future studies integrating 4D-flow MRI, pulse-wave velocity mapping, and genetic phenotyping could refine functional hypoplasia definitions and elucidate the mechanistic pathways linking shrinking PCoM calibre to cerebrovascular outcomes.[15]

CONCLUSION

We provide the first large scale in vivo reference diameters for CoW components in Rajasthan and demonstrate that age related PCoM narrowing is pivotal to CoW incompleteness. These benchmarks will aid radiological reporting, computational modelling, and neuro interventional device tailoring in South Asian populations.

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