ISSN: 2754-6691

Journal of Internal Medicine Research & Reports

SCIENTIFIC Research and Community

Research Article

Open Access

Sexual Dimorphism of Morphometric Parameters of the Vertebral Artery: A Retrospective CT Angiographic Study

Valchkevich Dzmitry* and Tokina Ina

Department of Normal Anatomy, Grodno State Medical University, Grodno, Belarus

ABSTRACT

Background and Objectives: Despite the well-documented clinical significance of the Vertebral Artery (VA) in posterior cerebral circulation, standardised normative data stratified by biological sex remain scarce. The aim of this study was to compare morphometric parameters of the extracranial VA between males and females using Multidetector Computed Tomography Angiography (MDCTA).

Materials and Methods: A retrospective analysis of 120 consecutive MDCTA examinations performed between January 2025 and March 2026 was conducted. Sixty males and 60 females, aged 25-75 years, were included. VA diameters were measured at three standardised levels: V1 (origin), V2 (C4 vertebra), and V3 (suboccipital segment). Dominance pattern, asymmetry index, and the prevalence of VA hypoplasia (diameter <2.0 mm) were assessed. Statistical comparisons used the independent-samples t-test and chi-square test.

Results: Males consistently exhibited larger VA diameters than females at all measured levels ($p<0.001$). The mean right V1 diameter was 4.12±0.68 mm in males versus 3.58±0.61 mm in females. Left VA dominance was predominant in both sexes (56.7% overall). VA hypoplasia was identified in 14 subjects (11.7%), with a higher frequency in females (16.7%) than in males (6.7%), although the difference did not reach statistical significance ($p=0.087$). Right-sided hypoplasia accounted for 71.4% of all cases.

Conclusions: Significant sexual dimorphism exists in VA diameter across all extracranial segments. These findings underscore the necessity of sex-stratified reference values in clinical imaging interpretation and preoperative planning for cervical and posterior cranial interventions.

***Corresponding author**
Valchkevich Dzmitry, Department of Normal Anatomy, Grodno State Medical University, Grodno, Belarus.

Received: March 28, 2026; **Accepted:** April 09, 2026; **Published:** April 13, 2026

Keywords: Vertebral Artery, Morphometry, Sexual Dimorphism, CT Angiography, Hypoplasia, Anatomical Variation

Introduction

The Vertebral Artery (VA), arising from the first portion of the subclavian artery, constitutes one of the principal sources of blood supply to the posterior cerebral circulation, perfusing the brainstem, cerebellum, and portions of the occipital and temporal lobes [1]. Its extracranial course is conventionally divided into four segments (V1-V4), with the V2 and V3 portions traversing the transverse foramina of the cervical vertebrae before entering the cranial cavity through the foramen magnum. This anatomical arrangement renders the artery vulnerable to injury during posterior cervical surgery, atlantoaxial fixation, and endovascular procedures, making precise morphometric knowledge critically important for surgical safety [2,3].

A growing body of evidence highlights the considerable anatomical variability of the VA regarding its origin, calibre, and dominance pattern. Among reported variants, VA hypoplasia – defined as a luminal diameter of less than 2.0 mm at any segment – has attracted particular clinical attention given its proposed association with posterior circulation ischemia, vestibular dysfunction, and vertebrobasilar aneurysm formation [4-6]. However, the majority of published normative datasets have not accounted for biological sex as a variable, despite the well-established principle that vascular calibre correlates with body dimensions, haemodynamic load, and hormonal milieu, all of which differ substantially between sexes [7].

Several recent studies have drawn attention to this gap. Demonstrated statistically significant differences in VA diameters across multiple extracranial levels when data were stratified by sex, and explicitly recommended that future normative studies adopt sex-disaggregated analysis [8]. Similarly, reported that males exhibit consistently larger VA diameters at all measured levels in a Balkan population cohort [7]. Nonetheless, population-specific reference values are lacking for many geographic regions, and the interplay between sex, laterality, and segmental attenuation of VA calibre warrants further investigation.

The present study was therefore designed to quantify sexual dimorphism in VA morphometry using MDCTA in a consecutive hospital-based cohort, providing standardised measurements at three reproducible extracranial levels, and to characterise the sex-specific prevalence of VA dominance patterns and hypoplasia.

Materials and Methods

This retrospective cross-sectional study was conducted at the Department of Radiology of Emergency Medical Hospital and the Department of Normal Anatomy of Grodno State Medical University. The study was performed in accordance with the 1964 Declaration of Helsinki and its later amendments. Informed consent was waived given the retrospective nature of the data collection.

From the institutional MDCTA database, 148 consecutive neck and head angiographic studies performed between January 2025 and March 2026 were screened. After applying inclusion and exclusion criteria, 120 subjects (60 males, 60 females) were enrolled. Inclusion criteria were: age ≥18 years, technically adequate MDCTA with homogeneous arterial enhancement, and complete bilateral visualisation of VA from the subclavian origin to the foramen magnum. Exclusion criteria included: poor image quality or motion artefacts (n=8), history of cervical surgery or trauma (n=7), known arteriovenous malformation or VA occlusion (n=5), and incomplete demographic data (n=8).

All examinations were performed on a 64-slice MDCT scanner (Siemens Somatom Definition AS+, Erlangen, Germany) using a standardised neck-to-vertex protocol. Contrast medium (70 mL of iopromide 370 mg I/mL, Bayer AG) was injected intravenously at 5 mL/s, followed by a 40 mL saline flush. Axial source images were reconstructed at a slice thickness of 0.75 mm and an increment of 0.6 mm using a dedicated vascular kernel. Multiplanar reformatted (MPR) images in the coronal and sagittal planes, as well as maximum intensity projection (MIP) reconstructions, were generated for each case using dedicated post-processing software (Syngo.via, Siemens Healthineers).

VA diameter measurements were performed independently by two observers (a radiologist with 8 years of experience and an anatomist with 15 years of vascular imaging experience) on MPR images, using the electronic caliper tool of the workstation. Measurements were taken perpendicular to the long axis of the vessel. Three standardised measurement levels were defined: (1) V1 – at the origin from the subclavian artery; (2) V2 – at the C4 vertebral level, within the transverse foramen; (3) V3 – 5 mm proximal to the point of dural penetration at the foramen magnum, corresponding to the suboccipital segment. Inter-observer agreement was evaluated using the intraclass correlation coefficient (ICC).

VA dominance was defined as the side with the larger diameter at the V2 level. When the difference between left and right V2 diameters was less than 0.2 mm, the pattern was classified as co-dominant. VA hypoplasia was defined as a diameter of <2.0 mm at any level on either side, consistent with the most widely adopted criterion in the literature [4,9]. The asymmetry index (AI) was calculated as: AI (%) = [(D_left – D_right) / D_left] × 100; AI values >30% were considered to indicate significant asymmetry [8].

Data were entered into Statistica v.10.0. Continuous variables are presented as mean ± Standard Deviation (SD) and were compared between sexes using the independent-samples t-test after confirming normality with the Shapiro-Wilk test. Categorical variables are presented as absolute numbers and percentages, and were compared using Pearson's chi-square test or Fisher's exact test as appropriate. Left-right diameter differences within each sex were assessed with the paired-samples t-test. A p-value of <0.05 was considered statistically significant.

Results

Demographic Characteristics

The study cohort comprised 60 males (mean age 51.3±12.4 years; range 27-74) and 60 females (mean age 49.8±13.1 years; range 25-75). The two groups were comparable regarding age (p=0.512) and body mass index (p=0.238). The main clinical indication was stroke workup (65.8% of all cases). Detailed demographic data are presented in Table 1.

Table 1: Demographic and Clinical Characteristics of the Study Cohort

Parameter	Males (n=60)	Females (n=60)	p-value
Age (years), mean ± SD	51.3±12.4	49.8±13.1	0.512
Age range (years)	27-74	25-75	–
BMI (kg/m²), mean ± SD	26.8±4.1	25.9±3.9	0.238
Hypertension, n (%)	18 (30%)	16 (26.7%)	0.681
Diabetes mellitus, n (%)	9 (15%)	7 (11.7%)	0.599
Main indication: stroke workup, n (%)	38 (63%)	41 (68.3%)	0.563

SD-Standard Deviation.

Vertebral Artery Diameters

Inter-observer agreement was excellent for all diameter measurements (ICC 0.91-0.96, p<0.001). Males exhibited significantly larger VA diameters compared with females at all three measured levels and on both sides (all p<0.001). The mean V1 origin diameter was 4.12±0.68 mm (right) and 4.31±0.71 mm (left) in males, compared with 3.58±0.61 mm (right) and 3.74±0.65 mm (left) in females, representing a difference of approximately 13.2% at the V1 level. At V3, the sex difference remained prominent: 3.54±0.59 mm vs. 2.97±0.52 mm on the right side, and 3.61±0.57 mm vs. 3.08±0.54 mm on the left. In both sexes, VA diameters decreased progressively from V1 to V3 (p<0.001 for all intra-individual level comparisons).

Left VA diameters were consistently larger than right VA diameters within both sexes, though this intra-individual asymmetry reached statistical significance only at the V1 level in males (p=0.041). Full diameter data are presented in Table 2.

Table 2: Mean VA Diameters (mm) at three Standardised levels, Stratified by Sex and Side

Segment	Males Right (mm)	Males Left (mm)	Females Right (mm)	Females Left (mm)	p (sex)*	p (side)*
V1 (origin)	4.12±0.68	4.31±0.71	3.58±0.61	3.74±0.65	<0.001	0.041
V2 (C4 level)	3.87±0.62	3.94±0.65	3.32±0.55	3.41±0.59	<0.001	0.387
V3 (suboccipital)	3.54±0.59	3.61±0.57	2.97±0.52	3.08±0.54	<0.001	0.312

Values are mean ± SD. *p-value for sex comparison at the respective level (independent-samples t-test); p-value for side comparison (paired-samples t-test). Bold values indicate p<0.05

Dominance Pattern, Asymmetry, and Hypoplasia

Left VA dominance was the most frequent pattern in the overall cohort (56.7%, n=68), followed by right dominance (25.8%, n=31) and co-dominance (17.5%, n=21). The distribution of dominance patterns did not differ significantly between males and females (p>0.4 for all comparisons). Significant VA asymmetry (AI >30%) was detected in 50 subjects (41.7%), with a non-significant trend towards higher frequency in females (46.7%) compared with males (36.7%; p=0.258).

VA hypoplasia was identified in 14 patients (11.7%). Although the difference between males (6.7%, n=4) and females (16.7%, n=10) did not reach statistical significance (p=0.087), the magnitude of the observed difference suggests a clinically meaningful trend, consistent with findings reported in larger MRI-based studies [10]. Right-sided hypoplasia predominated, accounting for 71.4% (n=10) of all hypoplastic arteries. No bilateral hypoplasia was recorded. Summary data for dominance and hypoplasia are presented in Table 3.

Table 3: Vertebral Artery Dominance Patterns, Asymmetry, and Hypoplasia by Sex

Parameter	Males n (%)	Females n (%)	Total n (%) / p-value
Left dominance	36 (60.0%)	32 (53.3%)	68 (56.7%) / 0.464
Right dominance	15 (25.0%)	16 (26.7%)	31 (25.8%) / 0.835
Co-dominance	9 (15.0%)	12 (20.0%)	21 (17.5%) / 0.452
VA hypoplasia (diameter <2.0 mm)	**4 (6.7%)**	**10 (16.7%)**	**14 (11.7%) / 0.087**
– right-sided hypoplasia	3 (5.0%)	7 (11.7%)	10 / 71.4% of all VAH
– left-sided hypoplasia	1 (1.7%)	3 (5.0%)	4 / 28.6% of all VAH
Asymmetry Index >30%	22 (36.7%)	28 (46.7%)	50 (41.7%) / 0.258

VA – Vertebral Artery; VAH – Vertebral Artery Hypoplasia. Chi-square test or Fisher's exact test as appropriate

Discussion

The principal finding of the present study is that biological sex exerts a significant and consistent influence on VA calibre across all extracranial segments. Males exhibited larger diameters than females by approximately 13-16% depending on the level, a magnitude that is both statistically robust and clinically meaningful when interpreting angiographic images or planning instrumented cervical procedures. These findings corroborate and extend the seminal data of, who reported analogous sex differences in a Balkan cohort of 91 patients, and of who specifically called for sex-disaggregated analysis in future normative studies [7,8].

The mechanisms underlying sexual dimorphism in arterial calibre are multifactorial. Differences in body size and cardiac output between males and females account for a portion of the observed variation, as vessel diameter scales with the haemodynamic requirements of the perfused territory. Hormonal factors, in particular, oestrogens, are known to influence vascular smooth muscle tone, endothelial function, and arterial remodelling, potentially contributing to the relatively smaller calibre observed in females, especially in the post-menopausal period [7,8].

The progressive reduction in VA diameter from V1 to V3 observed in both sexes in our cohort aligns with previously reported data [7,11] and likely reflects the diminishing haemodynamic cross-section as the artery traverses progressively narrower osseous channels within the cervical transverse foramina. The left VA was consistently wider than the right at all levels, consistent with the well-documented dominance of the left posterior circulation in the majority of individuals. reported left VA dominance in their cohort of 223 subjects undergoing CTA, with left-sided preponderance in the majority of anatomical variants-findings that mirror our observed dominance distribution of 56.7% [11].

VA hypoplasia was detected in 11.7% of our cohort, which falls within the wide prevalence range of 5-26% reported across different populations and imaging modalities [5,12,13]. The higher frequency of hypoplasia in females (16.7% vs. 6.7% in males), although not statistically significant at our sample size (p=0.087), is biologically plausible given the smaller baseline diameter in females and has been noted in prior MRI-based studies [10]. Demonstrated haemodynamic consequences of VA hypoplasia in the form of regional hypoperfusion in the dependent posterior inferior cerebellar artery territory [4] and identified VAH as an independent risk factor for posterior circulation atherosclerosis and ischaemic stroke [5]. Collectively, these observations underscore the importance of routinely reporting VA hypoplasia and its side when present.

The right-sided predominance of hypoplasia (71.4% in our series) is a consistent finding in the literature and has been attributed to the inherently smaller baseline calibre of the right VA [4,7,14]. The clinical relevance of this asymmetry is further amplified in the context of posterior cranial base surgery: detailed preoperative knowledge of VA hypoplasia and dominant side is essential to avoid inadvertent injury of the dominant vessel, which could result in catastrophic vertebrobasilar ischaemia [3,6].

Several limitations of this study merit discussion. First, the retrospective single-centre design inherently introduces selection bias, as the study population consisted of patients referred for stroke workup rather than healthy volunteers. Second, the relatively modest sample size (n=120) may have been insufficient to detect a statistically significant sex difference in the prevalence of VA hypoplasia, despite the clinically relevant effect size. Third, although inter-observer reproducibility was excellent, the absence of an intraclass correlation comparison with a third independent rater represents a methodological limitation. Fourth, body surface area, which is a more precise normalisation factor for vascular dimensions than sex alone, was not available for all patients. Future studies with larger, population-representative cohorts and prospective design are needed to establish definitive sex- and age-stratified reference ranges.

Conclusions

The present CT angiographic study demonstrates statistically significant sexual dimorphism in the extracranial vertebral artery, with males exhibiting consistently larger diameters at the V1,

V2, and V3 levels compared with females. Left VA dominance was the most frequent pattern in both sexes. VA hypoplasia, predominantly right-sided, was found in approximately 11.7% of the cohort, with a non-significant trend towards higher prevalence in females. These findings support the incorporation of sex-specific reference intervals into clinical radiology reporting guidelines and into preoperative anatomical assessment protocols for posterior cervical and skull base approaches.

Conflicts of interest

The authors declare no conflicts of interest.

Funding

This research received no external funding.

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